Title

Assessing Current Site Conditions and Vulnerabilities to Sea-Level Rise and Saltwater Intrusion: Lower Carneros Creek, Elkhorn Slough

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Abstract:

Sea-level rise will have extreme impacts on coastal estuaries, including freshwater sources like rivers and creeks. Though freshwater linkages are critical to overall estuarine health, few studies have explicitly considered how sea-level rise and saltwater intrusion will impact riparian vegetation composition or community health in freshwater creeks adjacent to tidally influenced systems. Our study sought to identify the historical and current conditions as well as projected vulnerabilities for the lower section of Carneros Creek, the main freshwater source for the Elkhorn Slough, in Monterey County, California. To describe historical and current conditions of Lower Carneros Creek, we assessed historical maps, surveyed riparian vegetation using the rapid assessment method, and evaluated drinking water well data for evidence of existing saltwater intrusion. To assess future sea-level rise impacts for Lower Carneros Creek, we mapped previously modeled groundwater rise and saltwater intrusion footprints under a 0.25m sea-level rise scenario. We found that the Western lower section of Lower Carneros Creek is currently characterized by the presence of halophytic, tidal wetland species while the Eastern upper section is dominated by freshwater, riparian species. Our results also showed that even with tidal controls, sea-level rise induced groundwater rise and saltwater intrusion will impact Lower Carneros Creek's hydrology and likely alter riparian vegetation composition. In response to these findings, we presented management considerations for Lower Carneros Creek that account for historical conditions, broader estuary-wide conservation goals, and public health concerns for communities living in the floodplain.

Introduction

The Elkhorn Slough is a 3.25 kilometers-squared (km^2) tidal wetland system located in Monterey County of Central California that drains into Monterey Bay (Gee et al., 2010). The slough consists of a main channel and a network of connected waterways where freshwater flows mix with saltwater brought upstream by tidal exchange. The main slough channel and its side channels have average depths of 6.5m and 2.5m, respectively (Gee et al., 2010). Tidal exchanges are the primary hydrological drivers of water exchange in the Elkhorn Slough. Tidal flows can extend as far as 6km into the Slough from its mouth connected to Monterey Bay and approximately 50-75% of the volume of the Slough is exchanged with each tidal cycle (Gee et al., 2010).

The Elkhorn Slough contains the largest tidal marsh habitat in California south of the San Francisco Bay and is jointly managed by the Elkhorn Slough National Estuarine Research Reserve (ESNERR), administered by the National Oceanic and Atmospheric Administration and the California Department of Fish and Wildlife, and the Elkhorn Slough Foundation (ESF), a non-profit land trust partner. Together, these entities are charged with conserving, restoring, and stewarding the Slough’s tidal marshes and surrounding watershed while also planning for future climate change impacts. While the majority of the Elkhorn Slough watershed is conserved, some parcels abutting the slough remain under private ownership.

Carneros Creek has been the primary source of freshwater and sediment for the Elkhorn Slough since the mouth of the Salinas River was diverted southward away from Elkhorn Slough to a separate mouth directly into Monterey Bay in 1909. Historically, the slough was connected to other regional freshwater bodies like the Salinas and Pajaro rivers, as well as an inland network of freshwater lakes (Figure 1). The creek originates east of the Slough in the Gabilan

Range and the water flows through agricultural, natural, and built lands, eventually passing through the freshwater-brackish Blohm-Porter Marsh complex and the tidal gate that controls the rate at which the water flows into the main slough channel (Figure 2; Figure 6). Carneros Creek is seasonal and has a flow range of 0.0-3.8m3/s that varies as a function of yearly rainfall (Caffrey et al., 2007). Researchers consider the creek to be degraded due to poor water quality caused by nutrient loading and eutrophication (D. Dunkell, personal communication, October 2023; ESNERR & Elkhorn Slough Foundation, 2023).

In this study, we focus our investigation on a portion of the creek, hereafter referred to as Lower Carneros Creek (LCC), which lies in between Blohm Road and an unnamed road north of Triple M Ranch and is located directly east of the Blohm-Porter marsh (Figure 7). The earliest map depicting pre-channelized LCC was developed by US surveyors in 1867 (Figure 3). As Figure 3 shows, LCC is located just upstream of the “head of tidal lands,” where surveyors marked a shift from tidal lands in blue. Surveyors noted the green area surrounding LCC as “overflowed land” which suggests that the brackish-freshwater marsh surrounding LCC was regularly inundated by surface flows (A. Woolfolk, personal communication, November 2023). During winter storm flows, however, water levels likely extended beyond the marked area.

In 1869, landowners built Elkhorn Road and bisected the main slough channel from present day Blohm-Porter marsh. In 1872, the Southern Pacific Railroad built a railroad embankment and bridge adjacent to the road (Peichel et al., 2007). As settlers arrived in the region, they “reclaimed” tidal wetland acreage for agriculture and grazing by diking and draining the saltwater areas across the greater slough (Figure 4). These activities drastically altered the hydrology of the area. Widespread groundwater pumping for irrigation caused water tables to decline. As a result, freshwater springs that were dependent on high water tables dried up, leading to a decline in surface flow from smaller spring-fed creeks into LCC. This extensive groundwater pumping also caused subsidence in diked areas (Peichel et al., 2007).

Interventions in the mid-20th century further disrupted the natural hydrology of LCC and the upper slough. In the 1940s, landowners constructed a large earthen dam at Elkhorn Road to restrict tidal inundation and retain freshwater, creating the artificial, freshwater-brackish Blohm-Porter Marsh complex (Figure 2). In 1947, when the Harbor District built the Moss Landing Harbor, engineers diverted the mouth of the main slough channel to the south and dredged the slough to be greater than five times its natural depth to accommodate maritime activities (Van Dyke and Wasson, 2005). As a result, the slough was exposed to “stronger tidal flow, greater tidal reach, and a mismatch between the larger opening and the estuary's shallow, meandering channels and creeks [that] abruptly transformed the slough into a highly erosional system” (Van Dyke and Wasson, 2005). These man-made alterations led to increased tidal flows to the Blohm-Porter Marsh complex and LCC which further impacted the upper slough’s hydrology (Peichel et al., 2007). In 1951, tidal gates were installed to only permit downstream flow from LCC into the main slough channel.

To understand how climate change will impact the Elkhorn Slough, ESNERR has conducted research on tidal marsh vegetation dynamics, tidal marsh restoration methods, and sea-level rise (SLR) resilience over the past three decades. Since the early 2000s, researchers have been monitoring Elkhorn Slough tidal wetlands to develop a strategic plan to thwart the impacts of SLR and improve overall estuarine health. Elkhorn Slough has lost over 50% of its salt marsh in the last 88 years and modeling suggests 90% of the current marsh will be lost with 1m of SLR (Fountain et al., 2020).

Though Lower Carneros Creek is a key component of the estuarine system, its ecological and public health significance is relatively understudied. To date, ESNERR and ESF have not characterized fine-scale vegetation communities along Carneros Creek or analyzed how sea-level rise will result in associated groundwater rise (GWR) and saltwater intrusion (SWI), which will impact riparian habitats and residents living in the floodplain. Though rising seas may be stopped by tidal gates, the increased downward pressure from higher sea-levels can push saltwater deeper into the ground, resulting in saltwater shoving itself beneath fresh groundwater thus pushing the fresh groundwater towards the surface (USGS, 2023; Figure 5). Given the importance of longitudinal connectivity for the ecological health of estuarine systems, understanding freshwater conditions and vulnerabilities to climate change impacts will be critical for effective conservation planning and stewardship at the Elkhorn Slough (Keeley et al., 2022).

To fill this identified gap and support stewardship planning in the upper slough, this report assessed current site conditions and vulnerabilities to sea-level rise for LCC (Figure 7). Specifically, we developed a preliminary historical ecology of LCC, documented and analyzed vegetation communities along LCC, and mapped and contextualized GWR and SWI under a 0.25m SLR scenario. Lastly, we investigated the saltwater content of water monitoring wells in the Carneros Creek floodplain to assess potential public health risks for nearby residents. To conclude, we presented management considerations for ESNERR and ESF.

Study Approach and Methods

Historical Ecology

Historical ecology is an interdisciplinary field that seeks to describe past landscape conditions and human land use (Rhemtulla and Mladenhoff, 2007). To develop a preliminary historical ecology for LCC, we retrieved archival maps of the Elkhorn Slough, accessed archival newspapers, and conducted informal interviews with ESNERR staff (Woolfolk, n.d.).

Vegetation Rapid Assessment

To describe the vegetation along Carneros Creek, we used the vegetation rapid assessment protocol co-developed by the California Department of Fish and Wildlife and the California Native Plant Society (CNPS, 2022). CDFW-CNPS rapid assessment sampling is based on a visually estimated area within a representative portion of a vegetative stand. Over the course of three days in October 2023, we completed assessments every 100 meters along the LCC extent where access was possible (Figure 8). We used a visual estimation of 3-meters length by 1-meter width on each side of the creek. At each sampling site, we noted latitude, longitude, and elevation. We identified plant species present and noted vegetative cover using the Daubenmire method, which employs six cover-class categories: 1, 2, 3, 4, 5, 6, that correspond to 5%, 6-25%, 26-50%, 51-75%, 76-95%, and 95-100%, respectively (Coulloudon et al., 1999). We also took upstream, downstream, and cross-stream photographs at each site to provide a visual reference (Appendix: *Sites*). In addition to handwritten surveys, we used Avenza, a cartographic tool that can be downloaded onto a cellular device, to orient ourselves to the location of our sites and to georeference photos (Avenza Systems, 2023).

In total, we sampled 12 sites across LCC in two primary sections of the creek: the western, downstream portion just east of Blohm Road and the eastern, upstream portion just west of Triple M Ranch road (Figure 8). The middle section of LCC had thick, brambly vegetation that made approximately ⅓ of the intended study area inaccessible for sampling (Figure 8). For each of the 12 sampling sites, we calculated summary statistics including the Shannon-Wiener index, totals for salinity-tolerant halophytic species, and totals for native and non-native species (Ortiz-Burgos, 2016; Table 1). We then developed descriptive graphs showing estimated cover for species (Appendix: *Sites*). All data analysis was conducted in RStudio (version 2021.09.2; RStudio Team).

Spatial Analysis: Projected Exposures of SLR and SWI

We completed spatial analyses to assess risks related to sea-level rise induced groundwater rise and saltwater intrusion along Lower Carneros Creek using ArcGIS Pro (Figure 9; Esri Inc., 2023). Sea-level rise models were downloaded from Bay Conservation and Development Commission's Adapting to Rising Tides 2017 (BCDC, 2017).

To determine if parts of the creek would be inundated under a 0.25m sea-level rise scenario, we aggregated modeled groundwater rise and SWI footprint projections developed by Befus et al. using the modular groundwater flow softwares MODFLOW and MODPATH developed by USGS (Befus et al., 2020; ESF 2023). The models incorporated an array of observed physical data including in-situ groundwater recharge rates, high resolution spatial data, local geology, coastal topography, hydraulic conductivity (K), tidal datums, and more (Befus et al. 2020). Befus et al. modeled multiple K values (0.1, 1.0, and 10.0m/d) and two different tidal datums (local mean sea-level (LMSL) and mean high high water (MHHW)) for groundwater rise and saltwater intrusion across California.

For our study, we used a K value of 0.1m/d, which represents the least permeable soil and is the most conservative conductivity estimate. We chose to use projections based on the MHHW tidal datum because this tidal datum represents the average highest high water height and therefore provides a representation of the most severe projection of flooding potential under the

0.25m sea-level rise scenario. To ascertain what hydrologic conductivity measure would be appropriate, we analyzed surficial geology maps of Carneros Creek developed by the Elkhorn Slough Foundation to determine the geologic makeup of the creek and surrounding floodplain (Figure 11). From this, we inferred the soil type permeability based on pre-existing research that identified the K values of different soil types (Advances in Agronomy, 1997). We overlaid this layer with the saltwater wedge in a 0.25m sea-level rise scenario with the same tidal datum and hydraulic conductivity parameters. Finally, to identify wet season inundation depth in the floodplain, we created 0.5m contours of the previously described 0.25m sea-level rise scenario for groundwater for Carneros Creek.

Spatial Analysis: Saltwater Intrusion and Long-term Monitoring Wells

To determine if there is a history of saltwater intrusion in LCC, we evaluated longitudinal monitoring well data in the study area. We used data from the California State Resources Water Quality Control Board's Groundwater Ambient Monitoring Assessment Program (GAMA). GAMA was developed to improve a statewide groundwater monitoring system and provide public data on periodic water sampling and better protect communities from hazardous groundwater exposures. The dataset includes data for well location, sampling date, sampled compound, sampling result, and occasionally well depth. Identifying the well locations and type of well allowed us to make inferences about the historic and future risk of drinking salinated waters.

To evaluate spatial relationships between halophytic species presence, wells, and saltwater intrusion, we used ArcGIS Pro (version 2.9.3; ESRI) geoprocessing tools to identify where well points and survey points with halophytes were overlapping the saltwater wedge under a 0.25m sea-level rise scenario. Once identified, we visualized the locations of wells and color-coded sites with halophytes present (Figure 9). With the selected wells, we produced a scatterplot in RStudio (version 2021.09.2; RStudio Team) to visualize the quantity of chloride observed in well sampling (Supplemental Figure 1). Chloride is commonly used as a proxy for saltwater and therefore can be used to identify evidence of saltwater intrusion (Dugan et al., 2017).

Results

Historical Ecology of LCC

The restriction of tidal exchange has resulted in documented impacts on ecological health across the Elkhorn Slough system. By only permitting downstream flow, the water control structures have limited tidal flushing in the Blohm-Porter Marsh complex. As agricultural run-off has intensified over the last 60 years, the upper estuary has been characterized by extremely poor water quality with high nutrient levels (Hughes et al., 2010; ESNERR and ESF, 2023). In addition to poor water quality, the combined loss of natural hydrological flows and agricultural pumping has resulted in severe subsidence in the Blohm-Porter Marsh plain (Van Dyke and Wasson, 2005).

Despite concerted efforts to keep saltwater flows out of Blohm-Porter Marsh and LCC, the tidal gates have routinely failed since their initial construction (A. Woolfolk, personal communication, November 2023). The tidal gate was destroyed in the major 1989 Loma Prieta earthquake, which allowed for the natural flow of tides until the tidal gate was reconstructed in 1995 (Figure 6; Peichel et al., 2007). Tidal gate breaching due to mechanical failures has continued over the last 20 years (D. Dunkell, personal communication, October 2023). For this reason, the Blohm-Porter Marsh complex remains brackish and is dominated by halophytic species. To address current poor water quality in the upper marsh, ESNERR researchers are interested in restoring tidal flow to the diked marshes, including Blohm-Porter Marsh. However, private landowners in the watershed have expressed concern about the risks of drinking well salinization and voiced opposition to altering what they perceive to be a naturally-freshwater system (K. Wasson, personal communication, October 2023).

Lower Carneros Creek Vegetation Survey

The extent of LCC that we sampled ranged in elevation from 1.04m to 4.1m and was 1.6km long. We observed evidence of subsidence at the downstream sites 1-6, where the bank channels were extremely recessed relative to the adjacent floodplain. We were unable to identify a visible channel at sites 5-7 due to dense non-native marsh vegetation. At sites 8-12, the channel was identifiable, but dry due to the seasonal conditions at time of sampling.

Riparian vegetation composition varied across the LCC extent. The downstream sites (1-6) were characterized by the consistent presence of halophytic species, such as *Salicornia pacifica* and *Atriplex prostrata* which are also dominant in adjacent Blohm-Porter Marsh (Figure 2, Figure 6). Site 7 had the vegetative composition that characterizes a freshwater marsh and was dominated by *Schoenoplectus spp*. Upstream sites (8-12) were characterized by freshwater riparian species such *Salix spp.*, *Rubus ursinus*, and *Persicaria sp.* Detailed descriptions of species and percent cover for each site are included in the supplemental material of this report (Appendix: *Sites*). There was no identifiable trend of varying species diversity or native versus non-native species presence along the downstream- upstream gradient for LCC (Table 1; Figure 12). Most notably, halophytic species were present across sites 1-6 (Figure 10; Figure 12).

Analysis of Saltwater Intrusion, Soils, and Wells

Within the saltwater intrusion footprint (also referred to as the saltwater wedge), there are 207 observations for the wells in the GAMA dataset. Of those 207, seven observations were for chloride and those measurement dates range from 1970 to 2021. The range of chloride in these wells is 40.95mg/L-88.79mg/L (Supplemental Figure 1).

We found that the soils in the study area just east of Blohm Road are composed of alluvial deposits (clay, silt, gravel) for the majority of the lower portion of the marsh with colluvium (accumulated material at the edge of steeper slopes) on the southern side of the marsh (Figure 6). Landslide deposits are present at the foot of the southern hillside slope as well. At several study area sites, we ribboned the topsoil and found it to be primarily composed of sand or loamy sand. The Blohm-Porter Marsh Complex, which sits just west of our study area, is considered “paludal” or occurring in a marshy habitat, similar to what is seen west of the tidal gate that connects the Slough to Porter Marsh.

Water must contain more than 19,400mg/L of chloride to be considered seawater and at least 500mg/L for it to be considered brackish (Tansel & Zhang, 2022). None of the well observations in the LCC floodplain are in concentrations greater than 90mg/L and therefore cannot be considered saline or brackish (Supplemental Figure 1). Specific conductivity and total dissolved solids were monitored in some of these wells and were notably elevated, so it is possible the elevated chloride levels could be artifacts of the geology or agricultural practices in the region. That said, these wells may be identifying evidence of saltwater intrusion and the area should be explicitly monitored for chloride concentrations to avoid health and infrastructural ramifications (Shammi et al., 2019, Tansel and Zhang, 2022).

The sand and gravel that make up alluvial deposits are extremely permeable, therefore allowing for saltwater to push through the soils as sea-levels rise (Basack et al., 2021). In this study, we used a hydraulic conductivity (K) of 0.1m/d, therefore we chose the most conservative form of permeability for this soil type. If we had chosen a higher hydraulic conductivity, as would be reflective of a sandy environment, we may have found the saltwater wedge to creep even further up the creek and spread out to a greater extent across the floodplain.

Sea-Level Rise and Groundwater Rise Projections for Carneros Creek and Blohm-Porter Marsh Complex

At 0.25m SLR scenario with MHHW, the groundwater depth just east of Blohm Road is projected to be -1.5m, meaning that the groundwater will inundate the area by 1.5m during the wet time of year. At the easternmost part of our study section, the groundwater is at a depth of 0m meaning that the soil will be consistently saturated during the wet season (Figure 11). This suggests that sea-level rise related saltwater intrusion is pushing groundwater up to the surface and that saltwater will rise higher in the water table. Due to the history of diking and limited tidal exchange, the area has undergone subsidence, which we observed evidence of during our fieldwork (Figure 6). The difference in projected groundwater depths between the western and eastern portions of the LCC reflects this elevation difference.

Discussion and Recommendations

Our results show that sea-level rise induced groundwater rise and saltwater intrusion will impact the LCC and the Blohm-Porter Marsh Complex. The system is currently managed as freshwater-brackish through the use of tidal gates, but historical ecology and current vegetation compositions along LCC show that this system was historically tidally influenced and retains tidal wetland vegetation compositions (Figure 10; Table 1).

The eastern portion of LCC is at a slightly higher elevation than the western portion of the creek. Based on our mapped projections, we observed that the Eastern upper portion will not be inundated under a 0.25m MHHW sea-level rise scenario, however the western portion will be inundated under approximately 1.5m of groundwater that will have been pushed to the surface by intruding saltwater (Figure 11). The western, lower portion of LCC will be flooded with freshwater and has the potential for the saltwater wedge to reach the surface of the marsh too.

These results demonstrate that, even with existing tidal controls, saltwater will intrude underground into the Blohm-Porter Marsh complex and Lower Carneros Creek (Figure 12). These hydrological changes will alter the vegetation composition in the riparian zone, including the extent of our sampling area. As our vegetation data demonstrates, halophytic species are already present in the riparian areas. We can infer that as groundwater rises, the middle and upper segments of Lower Carneros Creek will be inundated for longer portions of the year and potentially exposed to salinized groundwater. These changing physical conditions will likely result in plant composition shifts. Freshwater riparian species like *Salix spp.* have low saltwater tolerances and will likely be imperiled as soil salinity increases. These conditions will support species that can withstand inundation for long periods of time as well as salinized soil conditions (RI Coastal Resources Management Council, 2007).

Beyond impacts to vegetation, our results also suggest that SLR, GWR, and SWI may have serious impacts on human health. As groundwater is pushed to the surface and replaced by the saltwater wedge, there may be health risks for residents who rely on groundwater wells for drinking water. Consuming salty water, even in concentrations that are less than what constitutes saltwater or brackishwater, can lead to the cumulative accumulation of sodium in the body that can increase the drinker's risk of developing sodium-related cardiovascular diseases (Talukder et al., 2016). An additional risk to saltwater intrusion is corrosion of sanitary and drinking water pipes that may run through the floodplain (Tansel and Zhang, 2022). The lifetime of service pipes can be significantly shortened when exposed to dissolved oxygen and chloride, therefore it is essential to maintain and monitor these pipe systems to avoid a sewage spill and contamination of drinking water pipes.

Though Carneros Creek has been treated as a freshwater creek by land managers in relatively recent history, historical ecology maps suggest that the western-most segment was a dynamic area where tidal waters and freshwater flows mixed and overtopped a wide channel into a marshy floodplain. As sea-levels rise and existing tidal control structures are rendered ineffective, ESNERR and ESF may consider avenues for transitioning management of the Blohm-Porter Marsh Complex and LCC away from a diked freshwater-marsh to a fully tidal system to return LCC to a state that more closely resembles its late 19th century reference points.

Though transitioning management of Blohm-Porter Marsh Complex and LCC to a fully tidal system may bring ecological benefits, our results show that this may also pose a public health threat through saltwater intrusion and well contamination. To address health risks that will mount as sea-levels rise, we recommend vigilant monitoring for chloride and dissolved oxygen of domestic drinking wells and pipe systems in the floodplain by either the residents, ESF/ESNERR, or the state. As lands become unsuitable for residential or agricultural use because of sea-level rise induced groundwater salinization, ESF and ESNERR can play a key facilitating role in adaptation land-use transitions. We recommend that ESF and ESNERR use this report's findings to begin collaboratively developing adaptation plans with communities in the LCC floodplain. Through this process, which may involve developing long-term land acquisition/buyout strategies around LCC for tidal wetland restoration to mitigate losses in the lower slough, managers can work to meet the needs of the Elkhorn Slough's ecosystems and communities alike.

Conclusion

This report sought to assess current conditions of Lower Carneros Creek and identify vulnerabilities to sea-level rise and saltwater intrusion to inform estuary-wide stewardship and resilience planning at the Elkhorn Slough. Through our use of historical ecology, vegetation ecology, spatial, and public health analyses, we demonstrated how coastal climate change will alter hydrological conditions, vegetation communities, and drinking water availability in the study area.

As a part of an estuary of conservation importance and a floodplain that houses residences and agriculture, LCC has both ecological and community needs. Decisions related to restoration and land acquisition must include a combination of ecological and physical researchers, land managers, community members, and community liaisons. By incorporating the historical ecology and SLR projections of the region into applied restoration practices, practitioners like ESF and ESNERR (that are well suited to partner with and support landowners and residents) can make informed, long term restoration decisions. Additionally, sharing information about the historical ecology and climate change related risks of the region with community members will communicate the urgency of identifying long-term adaptation solutions for the entirety of Elkhorn Slough.

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Figure Captions and Tables:

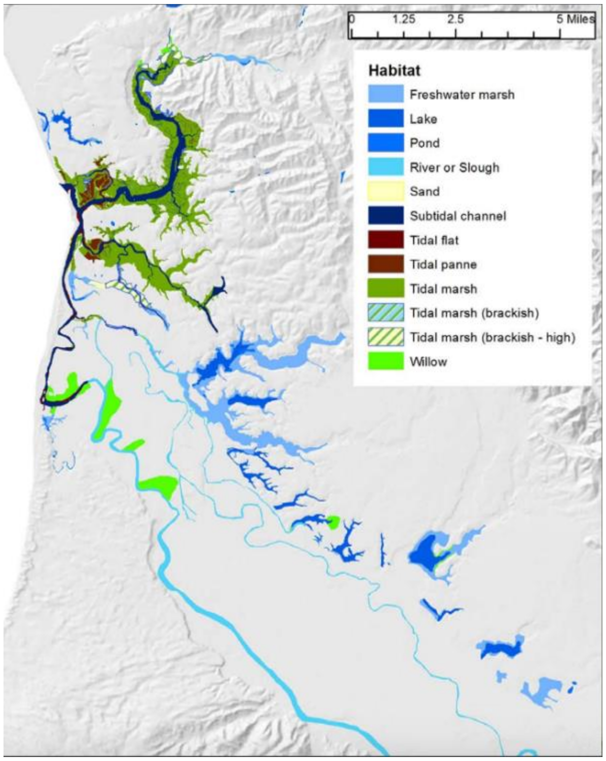


Figure 1. Historical ecology map depicting pre-1800s water bodies in the Monterey Bay region (ESNERR).

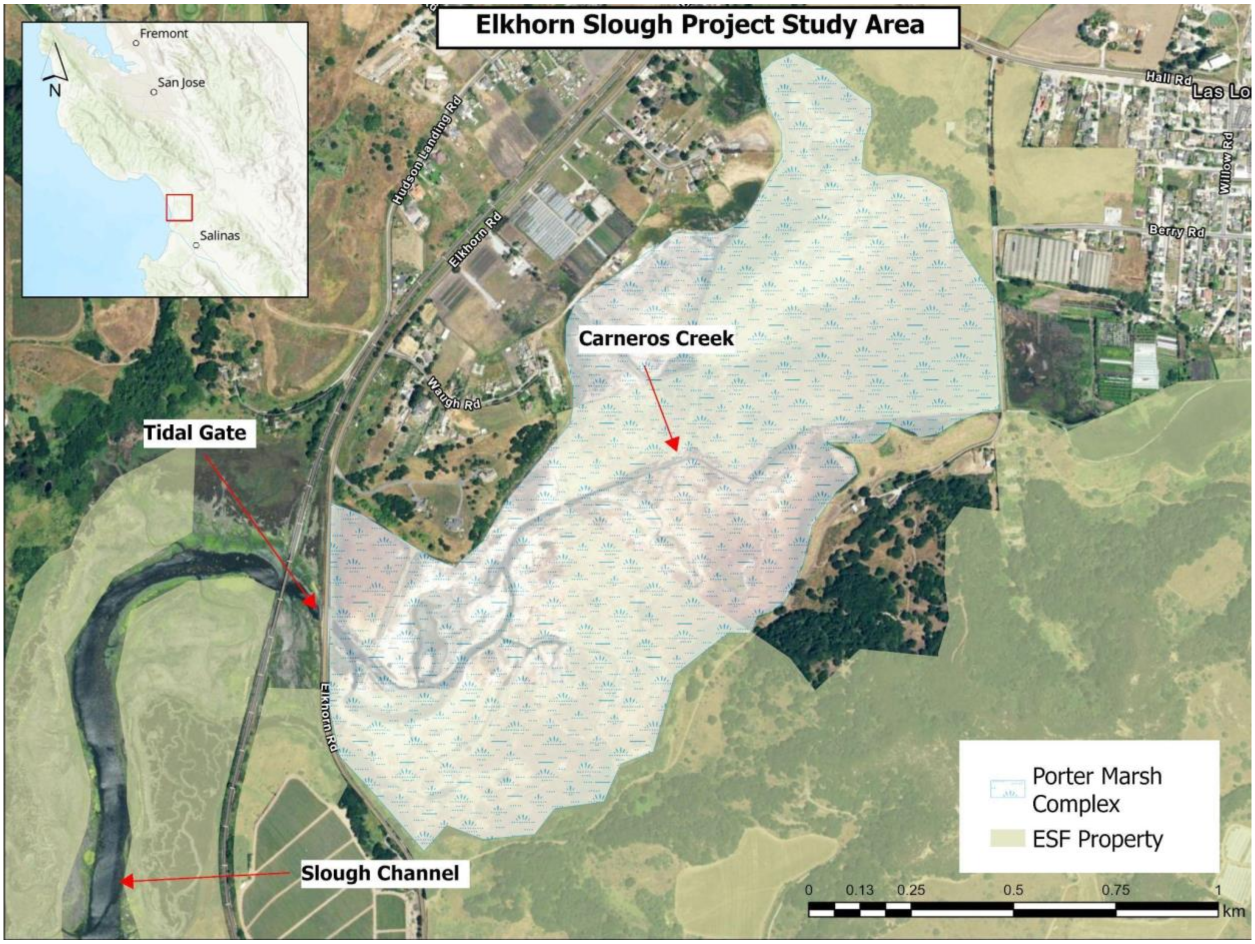


Figure 2. Map showing Elkhorn Slough study area, including hydrological controls, Blohm-Porter Marsh Complex, Lower Carneros Creek, and ESF land ownership.

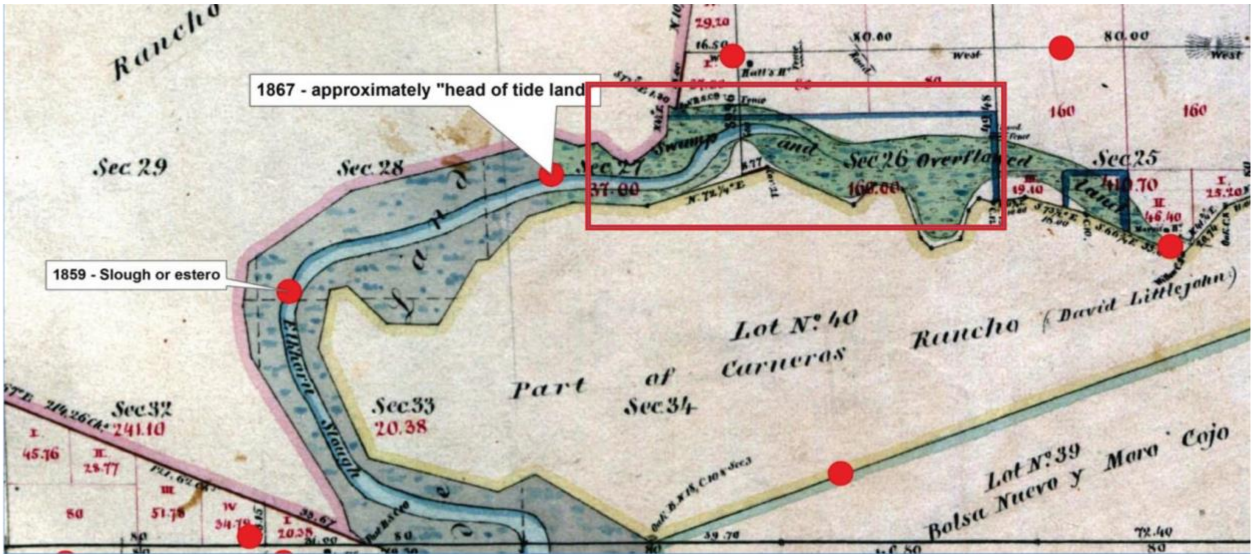


Figure 3. 1867 US Surveyor General Map with approximate LCC extent outlined in the red box, survey points in red, and field notes from land surveys in text boxes (ESNERR)

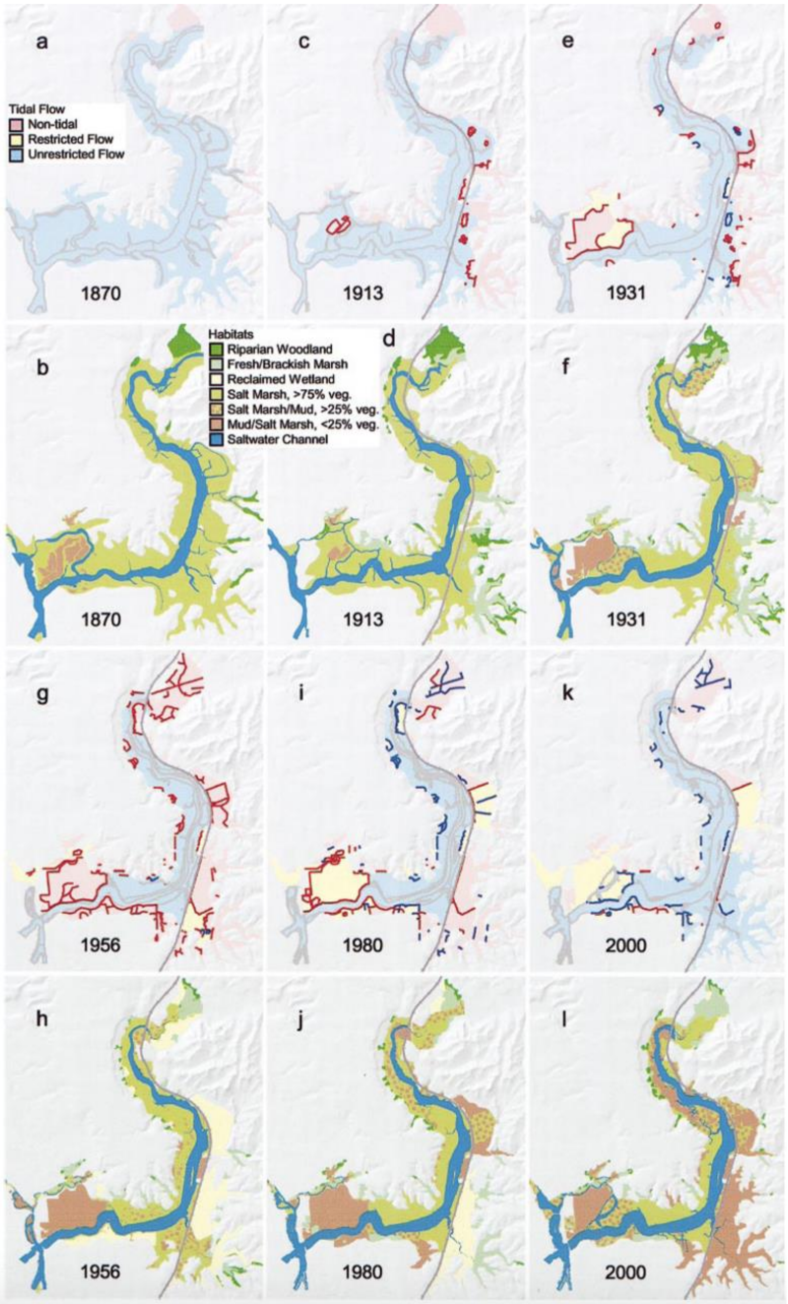


Figure 4. Change in habitat extent and diking in the Elkhorn Slough over time (Van Dyke and Wasson, 2005).

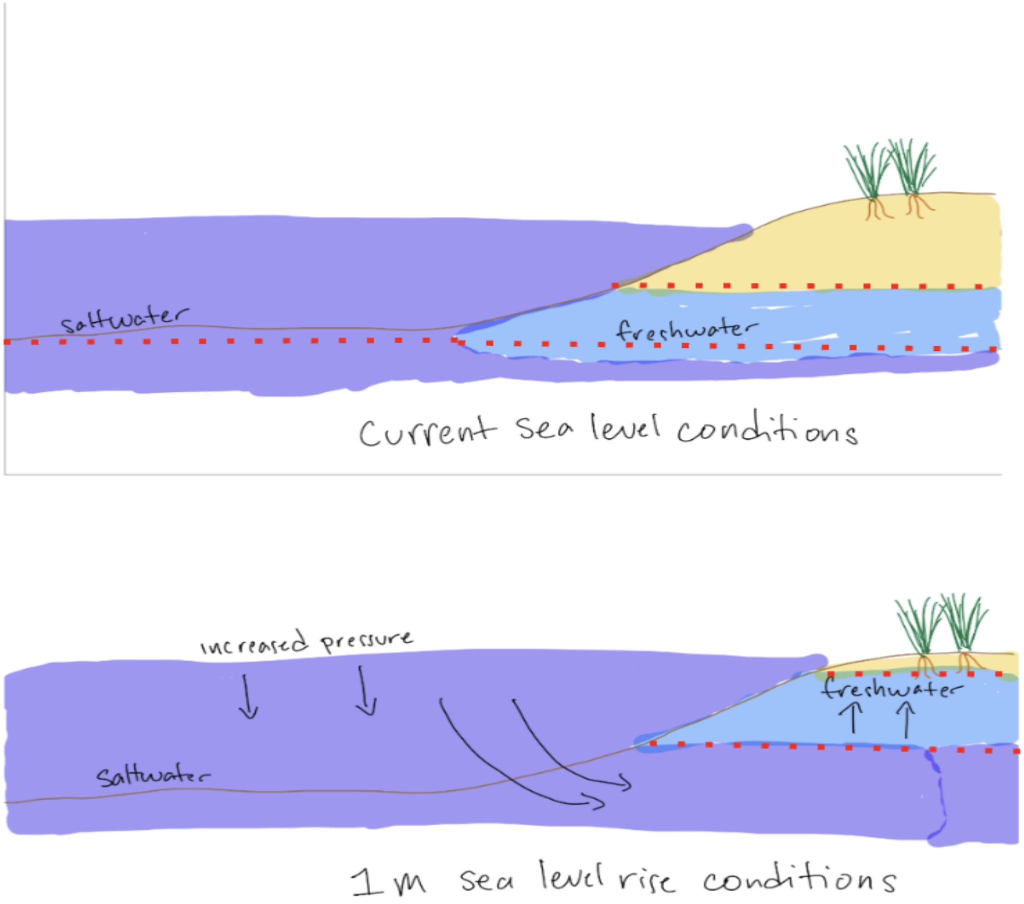


Figure 5. Schematic demonstrating the sea-level rise induced groundwater rise and saltwater intrusion. The red dashed line depicts the fresh and saltwater groundwater boundaries.

Figure 6. Tidal gate at Elkhorn Road separating the Blohm-Porter Marsh Complex from the main Elkhorn Slough channel. The Blohm-Porter Marsh Complex is at a noticeably lower elevation than the land on the other side of the road by the slough channel.

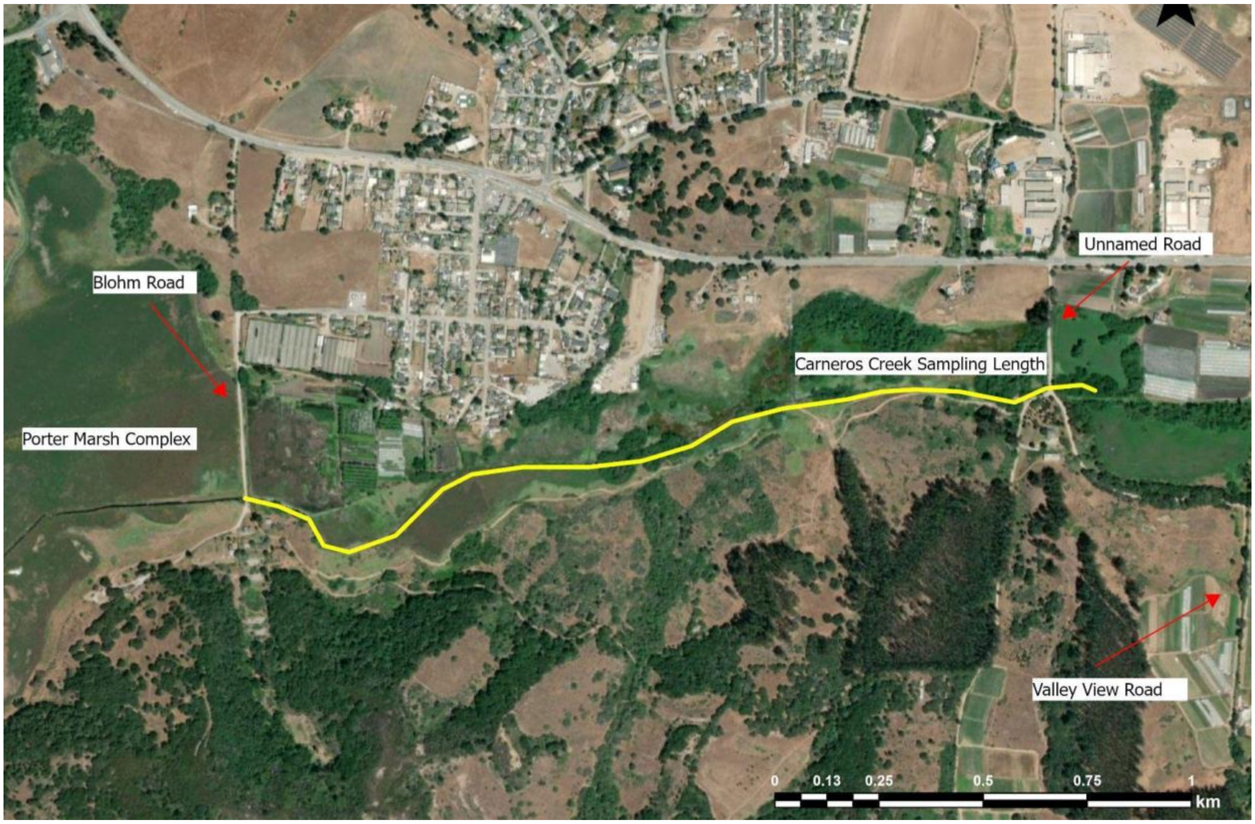


Figure 7. Lower Carneros Creek (LCC) vegetation rapid assessment sampling area east of the Porter Marsh Complex ranging from the eastern side of Blohm Road to the western side of Triple M Ranch road.

Figure 8. Sampling locations along Lower Carneros Creek. There were 12 sampling sites in total and are marked as “CCX” with “CC” signifying Carneros Creek and “X” signifying the sampling number and these sites are marked in blue. The red mark indicates the beginning of the impassable stretch of the creek; this continued until CC7.

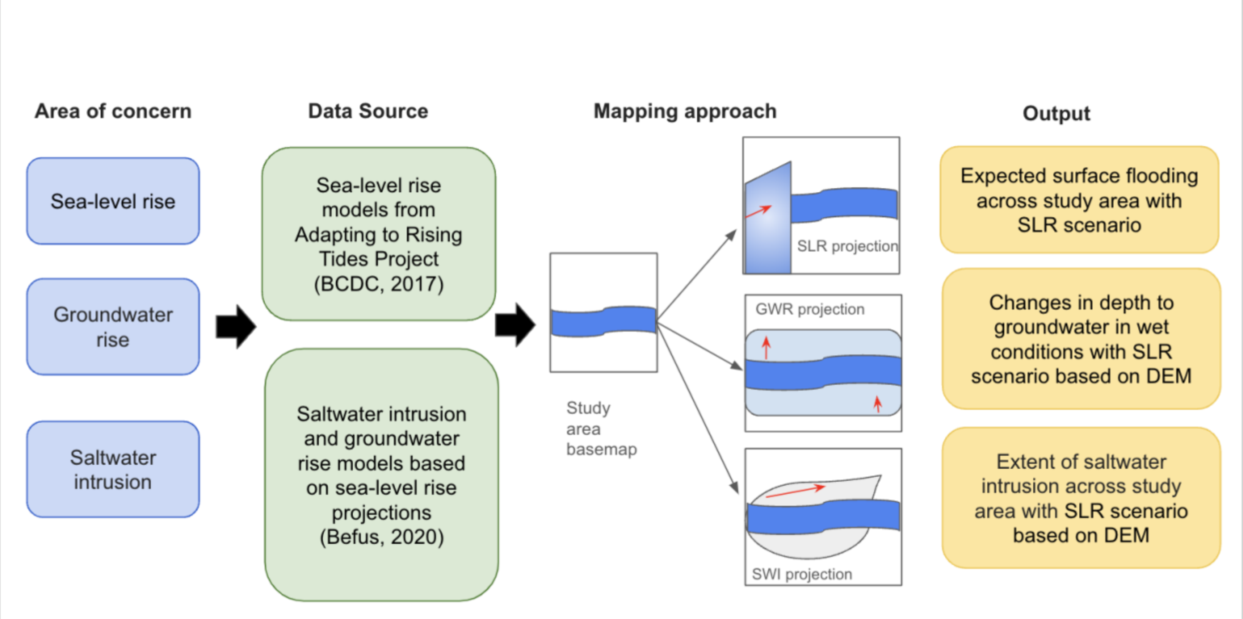


Figure 9. Study approach to evaluate future impacts of sea-level rise, groundwater rise, and saltwater intrusion in Lower Carneros Creek site.

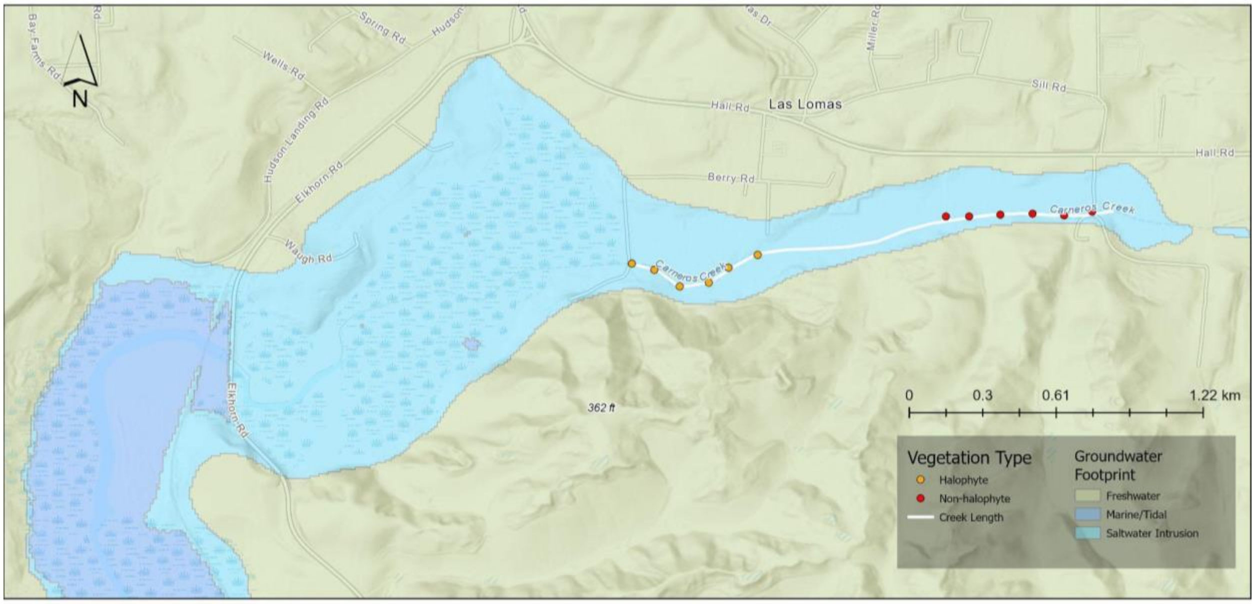


Figure 10. Points of survey sites along Carneros Creek from Blohm Road to the Eastern ranch road with or without halophytic species overlaid onto the groundwater footprint during a .25m sea-level rise scenario with a Kh of 0.1.

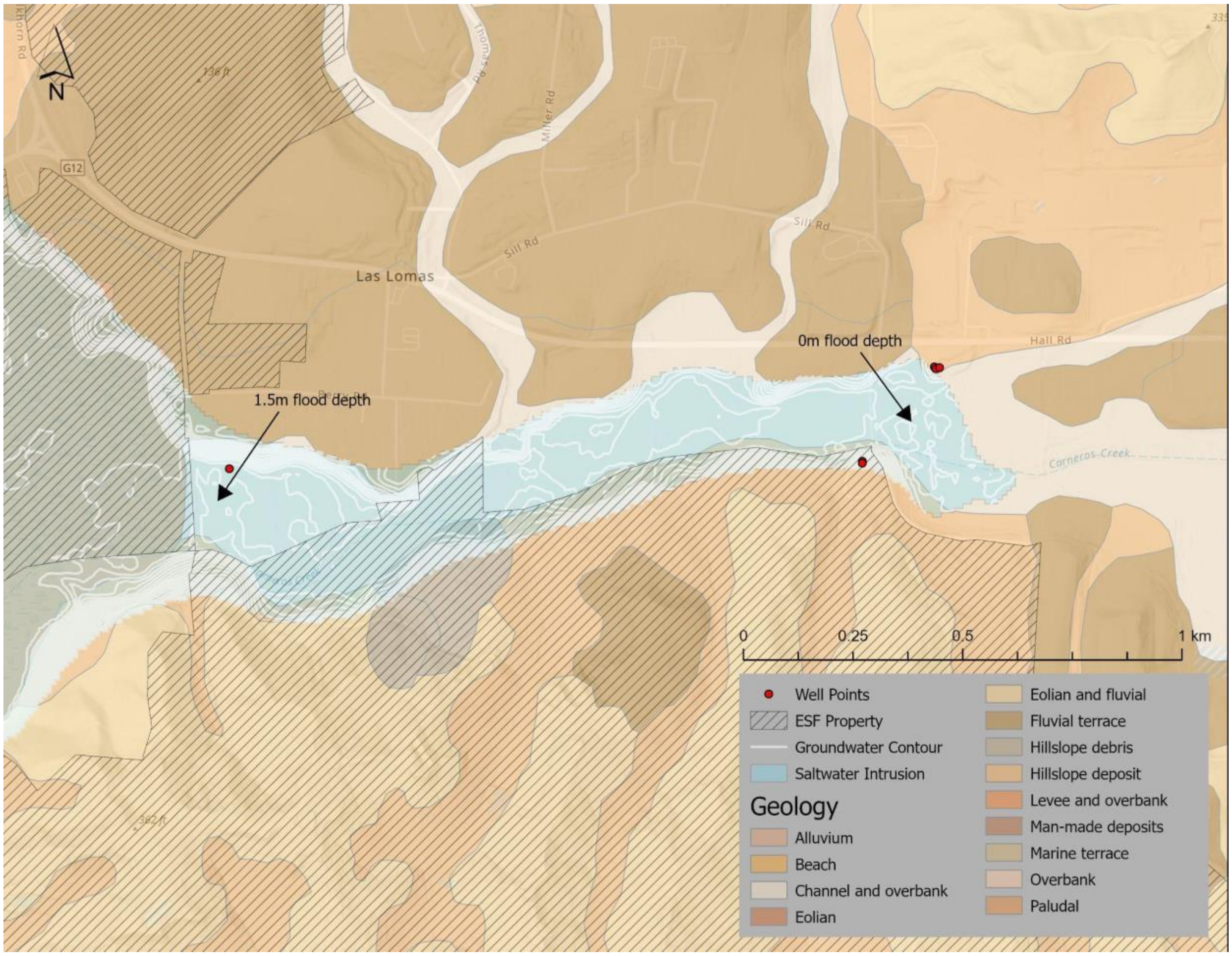


Figure 11. Elkhorn Slough owned land, saltwater intrusion under a 0.25m sea-level rise scenario using a mean high high water datum, the surficial geology, the western inundation depth under a 0.25 sea-level rise scenario, the eastern inundation depth under a 0.25 sea-level rise scenario, and monitoring well points in the study area

Table 1. Summary of species across LCC

Site	**Elevation (m)**	**Shannon-Wiener Index**	**Species Richness**	**Native Species Count**	**Non-Native Species Count**	**Halophytic Species**
1	1.83	2.198826	14	8	6	4
2	3.04	1.884224	8	6	2	1
3	1.59	1.913965	9	5	4	2
4	1.43	2.014623	10	7	3	3
5	1.57	1.56455	7	4	3	2
6	1.31	1.124685	5	2	3	1
7	3.00	1.034452	4	2	2	0
8	3.00	0.872584	5	3	2	0
9	4.10	1.681927	10	5	5	0
10	3.58	1.866002	8	3	5	0
11	4.00	0.888225	3	3	0	0
12	3.97	1.469648	10	6	4	0

Figure 12. Halophytic Species vs Non-Halophytic Species across LCC sampling sites

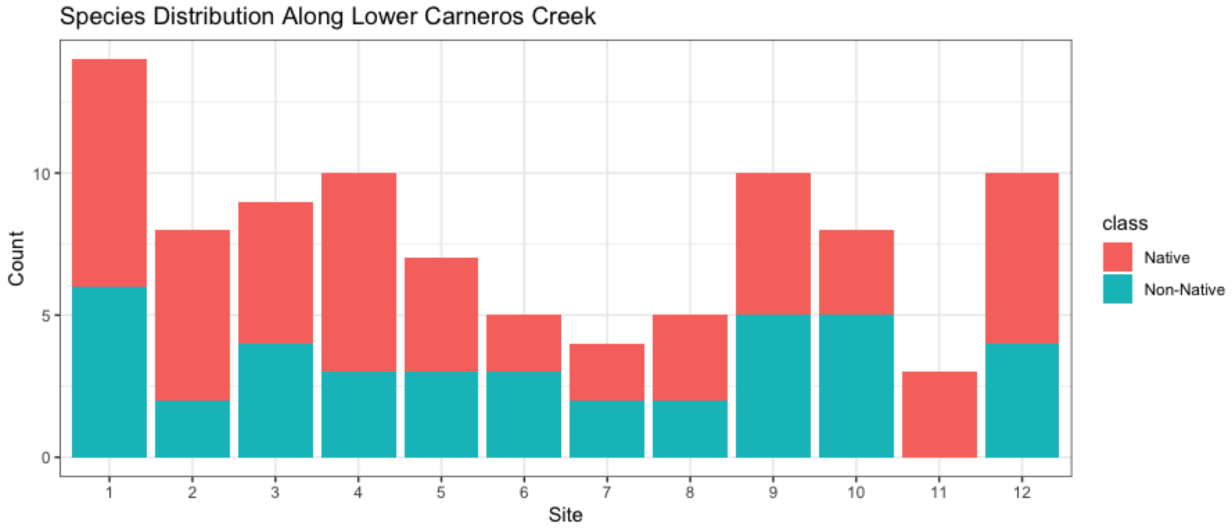
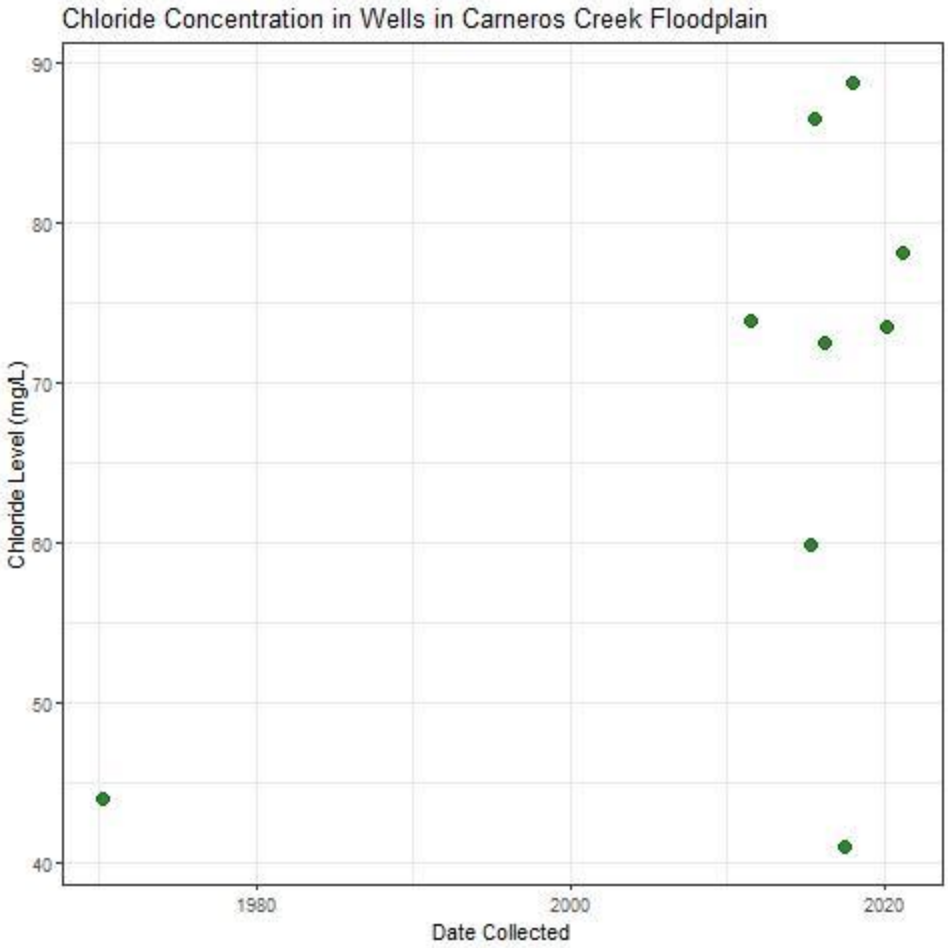


Figure 13. Native Species vs Non-Native Species across LCC sampling sites

Appendix: Chloride levels, Supplemental vegetation sampling photos and graphs

Supplementary figure:



Supplemental Figure 1: Chloride levels for Carneros Creek based on the date they were collected.

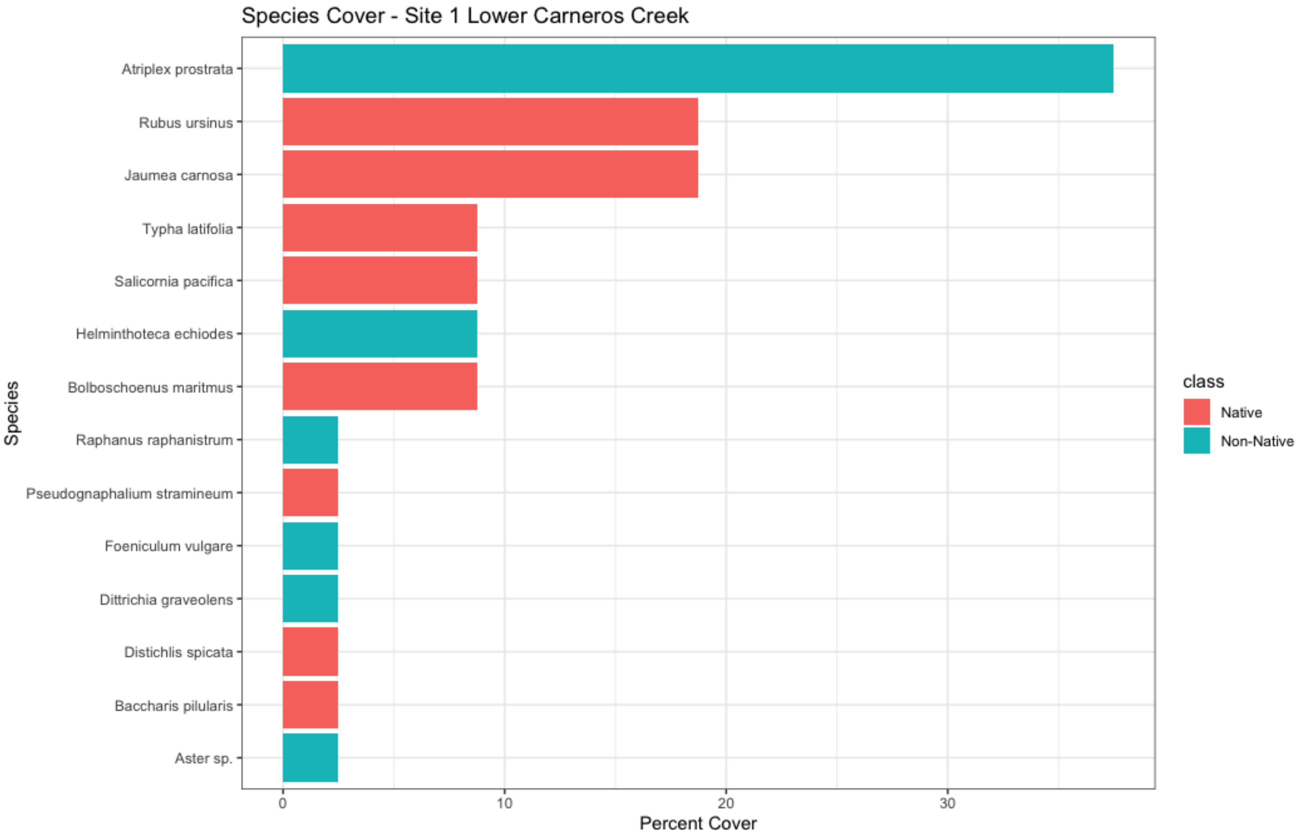
<u>*Sites*</u>

Site 1

Cross-stream

Downstream

Upstream



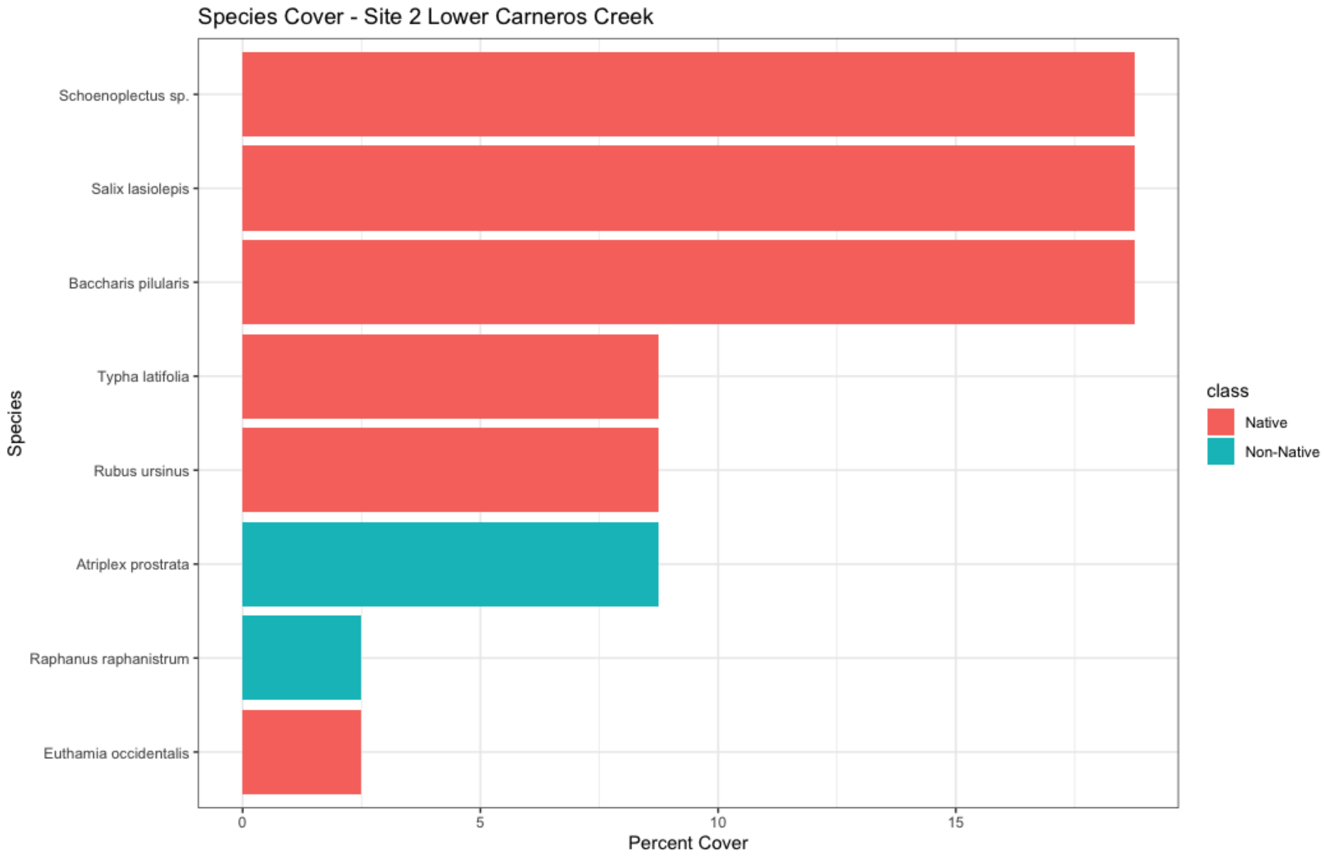
Percent Cover by species at Site 1

Site 2

Cross-stream

Downstream

Upstream



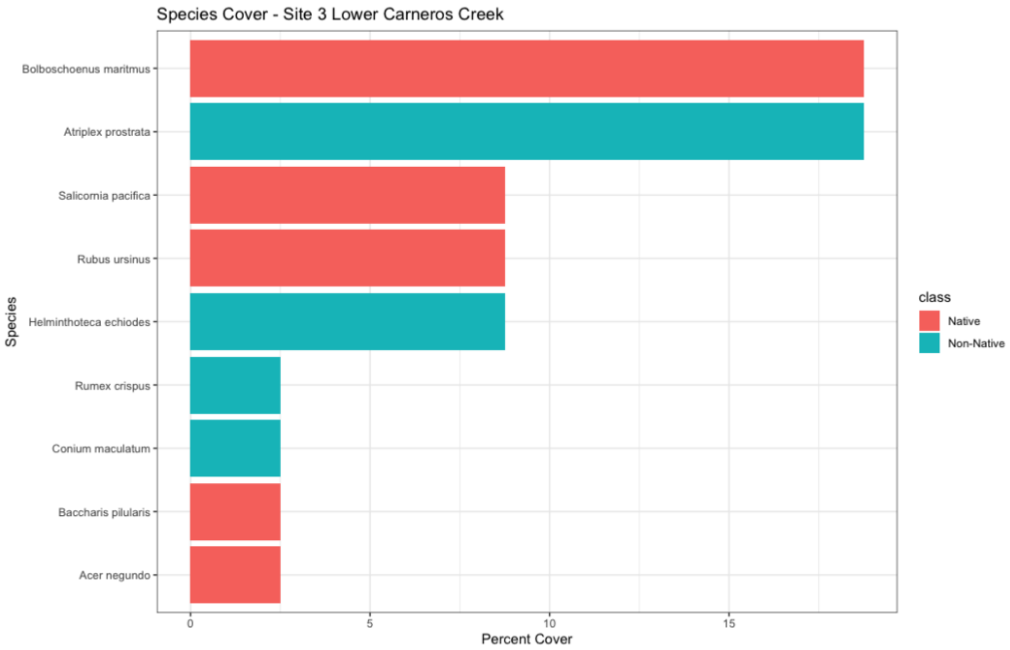
Percent Cover by species at Site 2

Site 3


Cross-stream


Upstream


Downstream



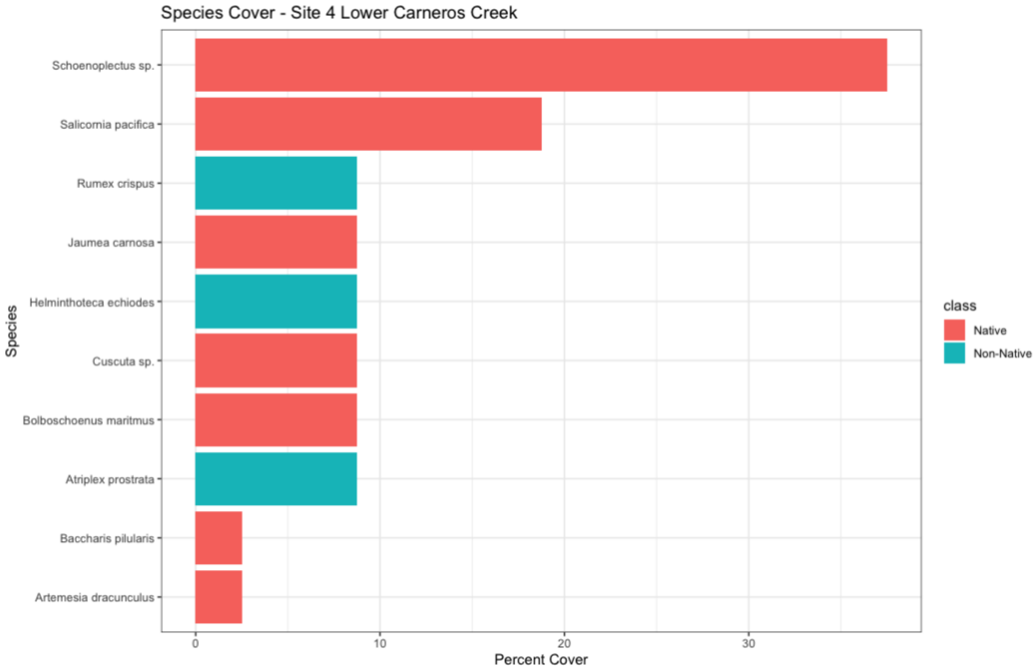
Percent Cover by species at Site 3

Site 4

Cross-stream


Downstream


Upstream



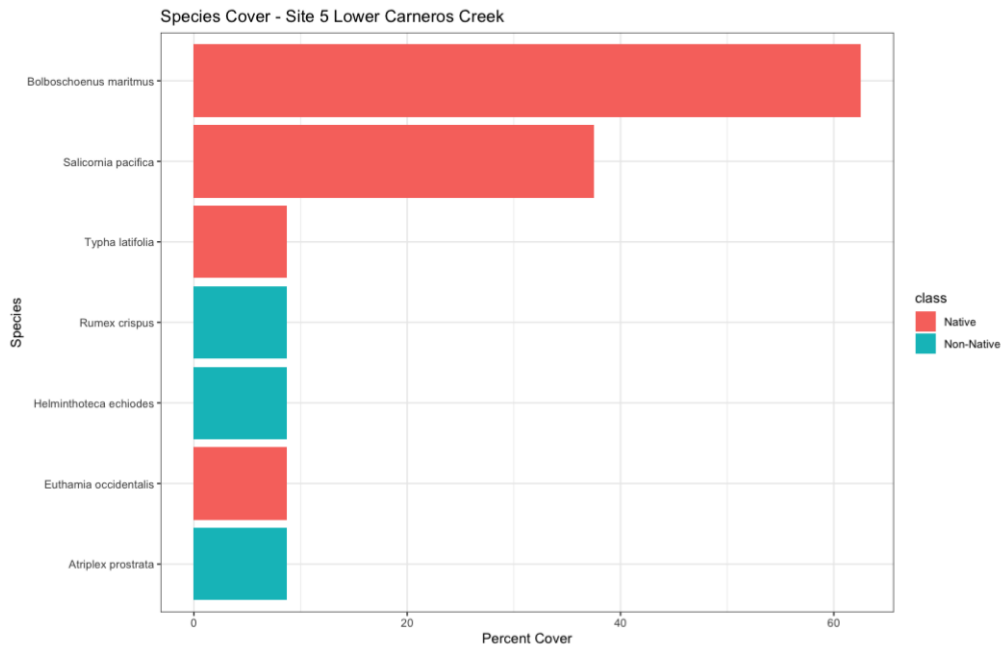
Percent Cover by species at Site 4

Site 5

Cross-stream

Downstream

Upstream



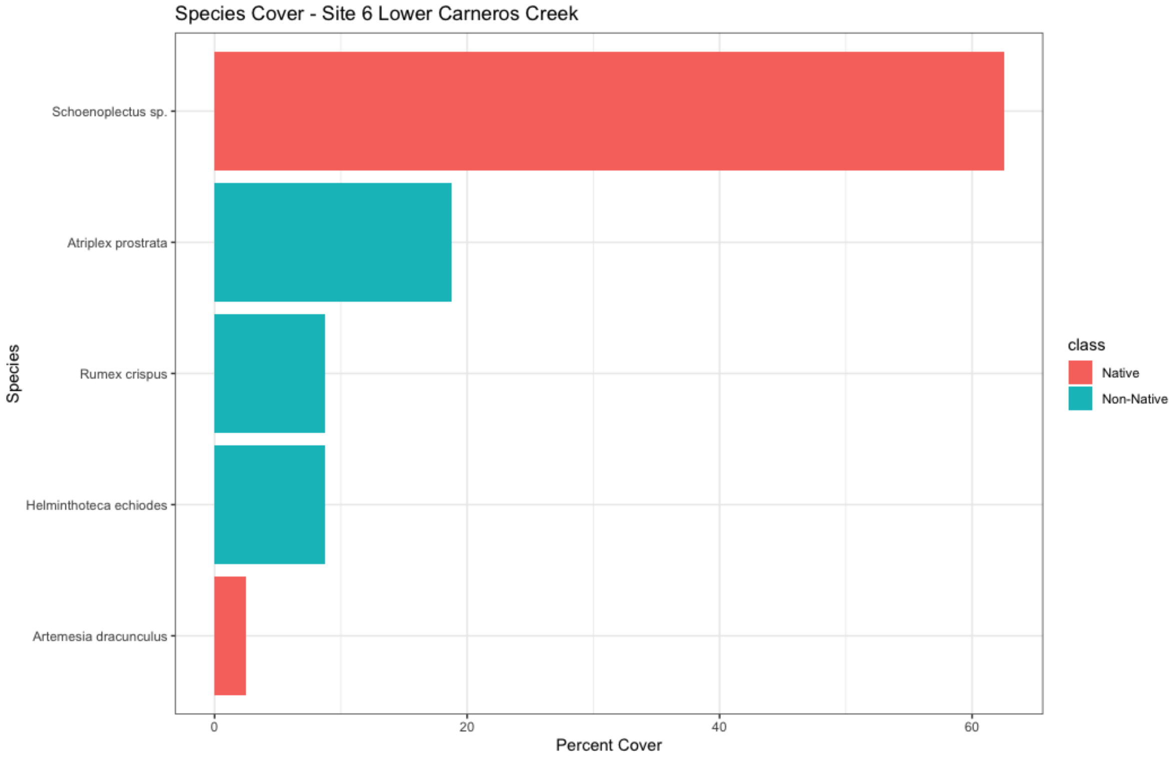
Percent Cover by species at Site 5

Site 6

Cross-stream

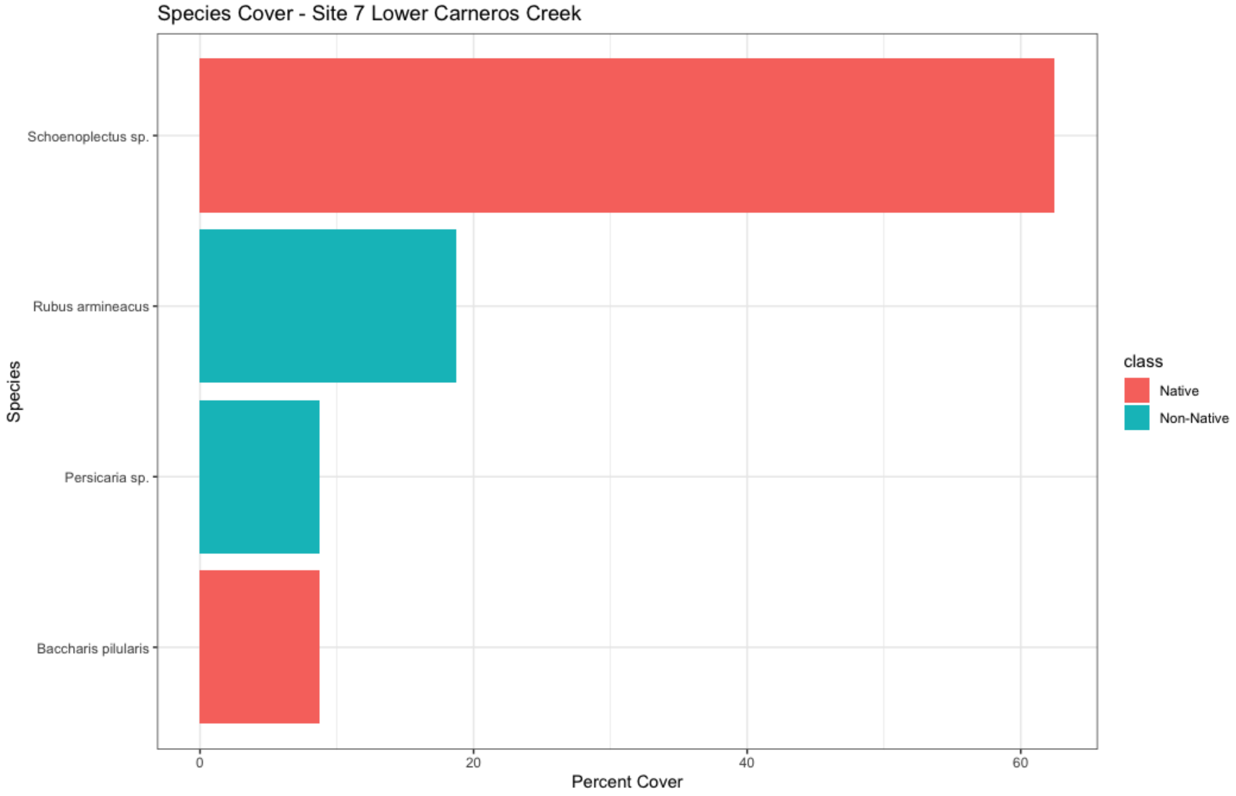
Upstream

Downstream



Percent Cover by species at Site 6

Site 7
Cross-stream

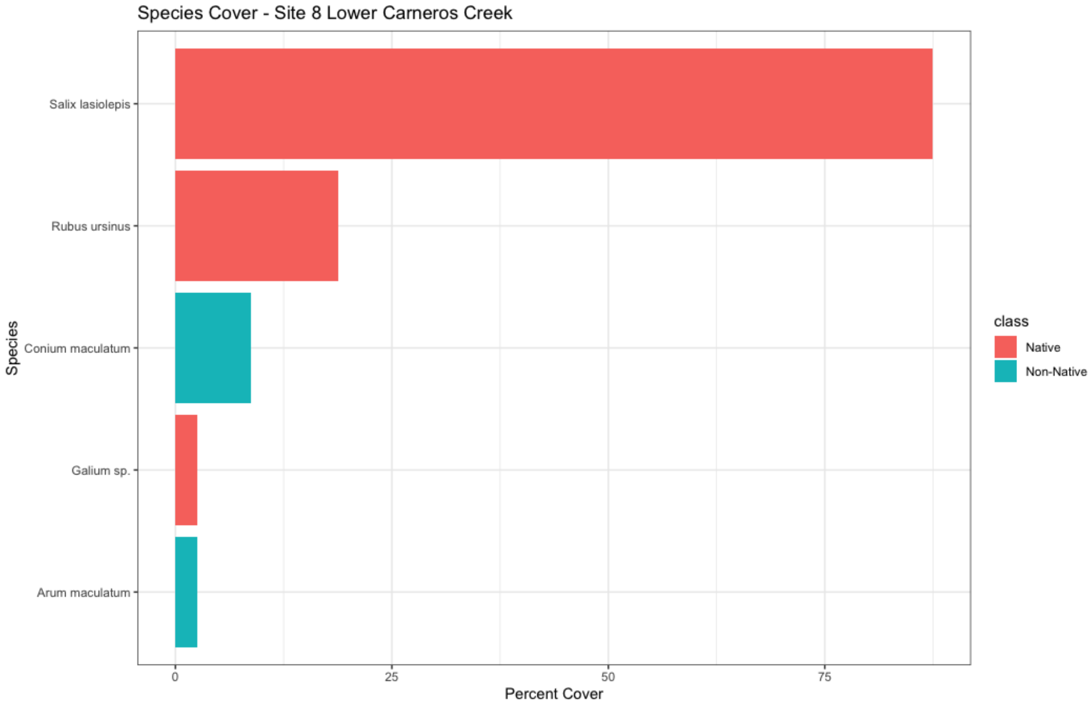


Percent Cover by species at Site 7

Site 8

Cross-stream

Upstream



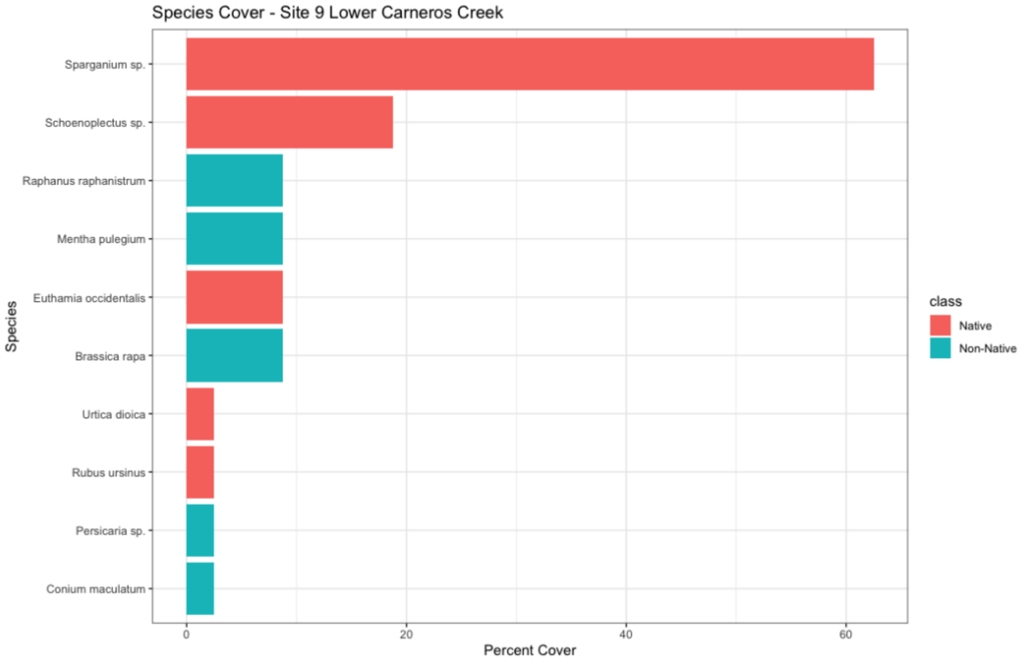
Percent Cover by species at Site 8

Site 9

Cross-stream

Downstream

Upstream



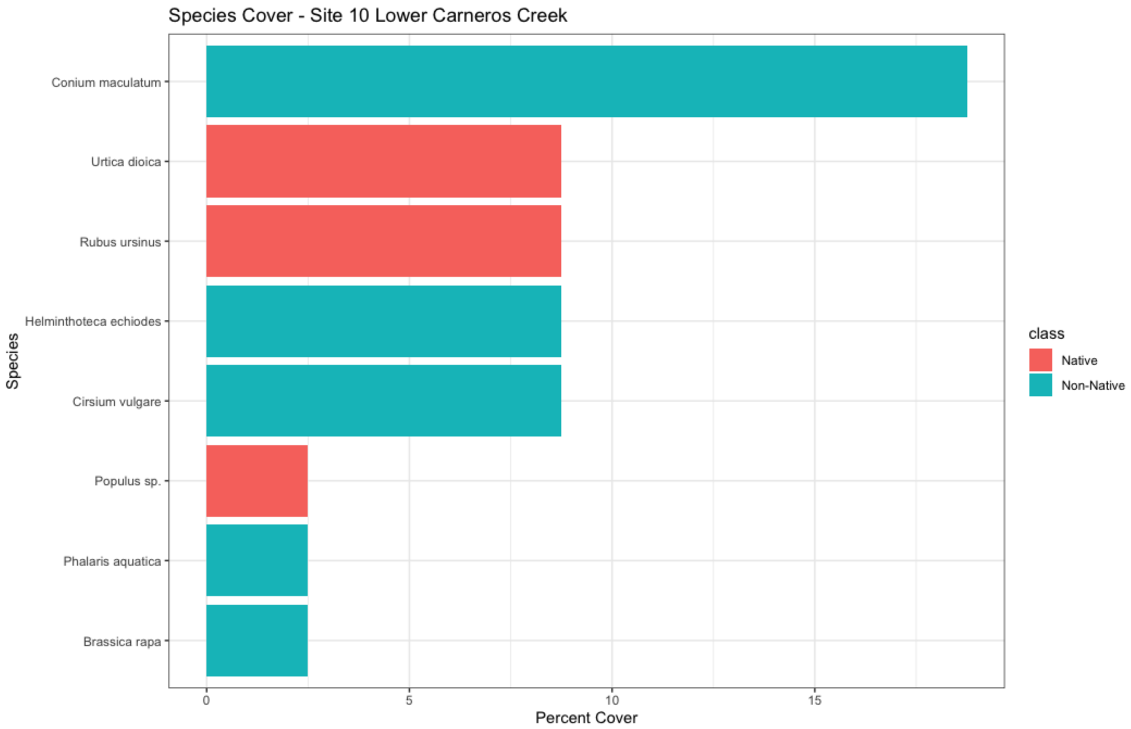
Percent Cover by species at Site 9

Site 10

Cross-section

Upstream

Downstream



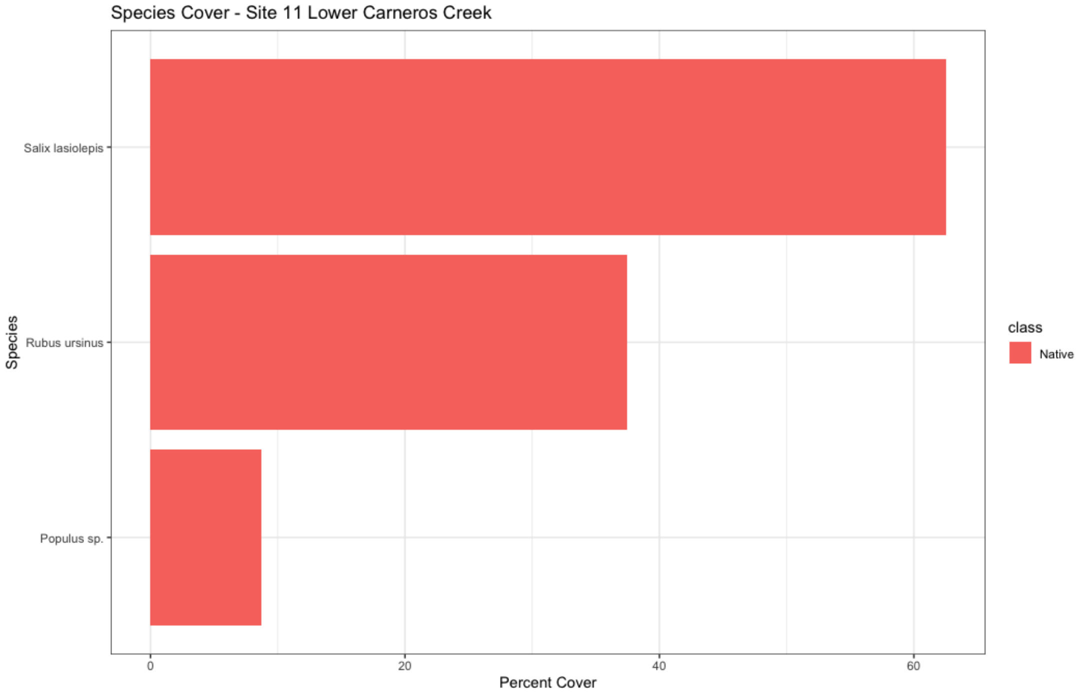
Percent Cover by species at Site 10

Site 11

Cross-stream

Downstream

Upstream



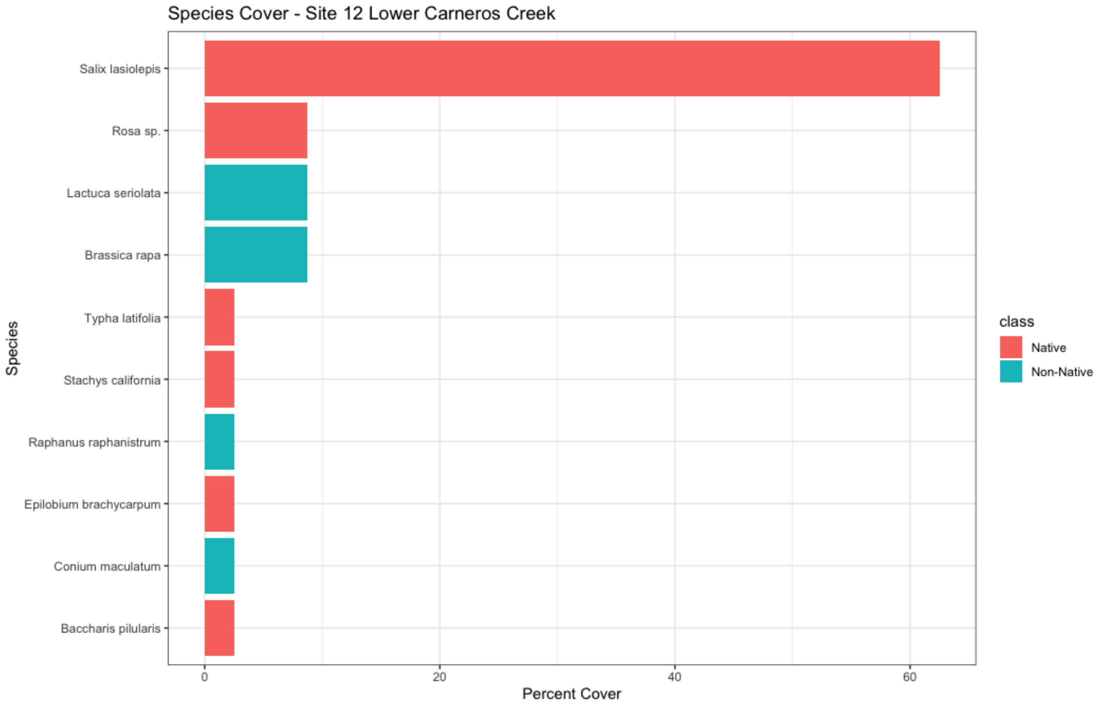
Percent Cover by species at Site 11

Site 12

Cross-stream


Upstream

Downstream



Percent Cover by species at Site 12