Mark West Creek

Environmental Monitoring Report WY2021 & WY2022

MARCH 31, 2023

Prepared for the Wildlife Conservation Board
By: Trout Unlimited and California Sea Grant

Contents

1. Introduction

In April 2020, Trout Unlimited (TU), California Sea Grant's Russian River Salmon and Steelhead Monitoring Program (CSG) and Sonoma Resource Conservation District (SRCD) were awarded a Wildlife Conservation Board (WCB) grant to enhance streamflow in the Mark West Creek watershed through the implementation of ten streamflow enhancement projects and to monitor key watershed characteristics. This report is the second of four annual reports that describes the results of our annual streamflow and environmental monitoring activities.

One objective of this project is to provide baseline data on streamflow, general water quality and late-summer wetted habitat conditions in critical coho salmon and steelhead rearing reaches in order to document potential impacts of low flow on rearing salmonids. Another objective is to demonstrate if and how stream conditions change with the implementation of streamflow enhancement projects. The project overview map (Figure 1) shows the Mark West Creek watershed and the monitored sites, including the wetted habitat survey extent, continuous water quality logger and flow gage locations, and Sonoma Resource Conservation District's potential project sites.

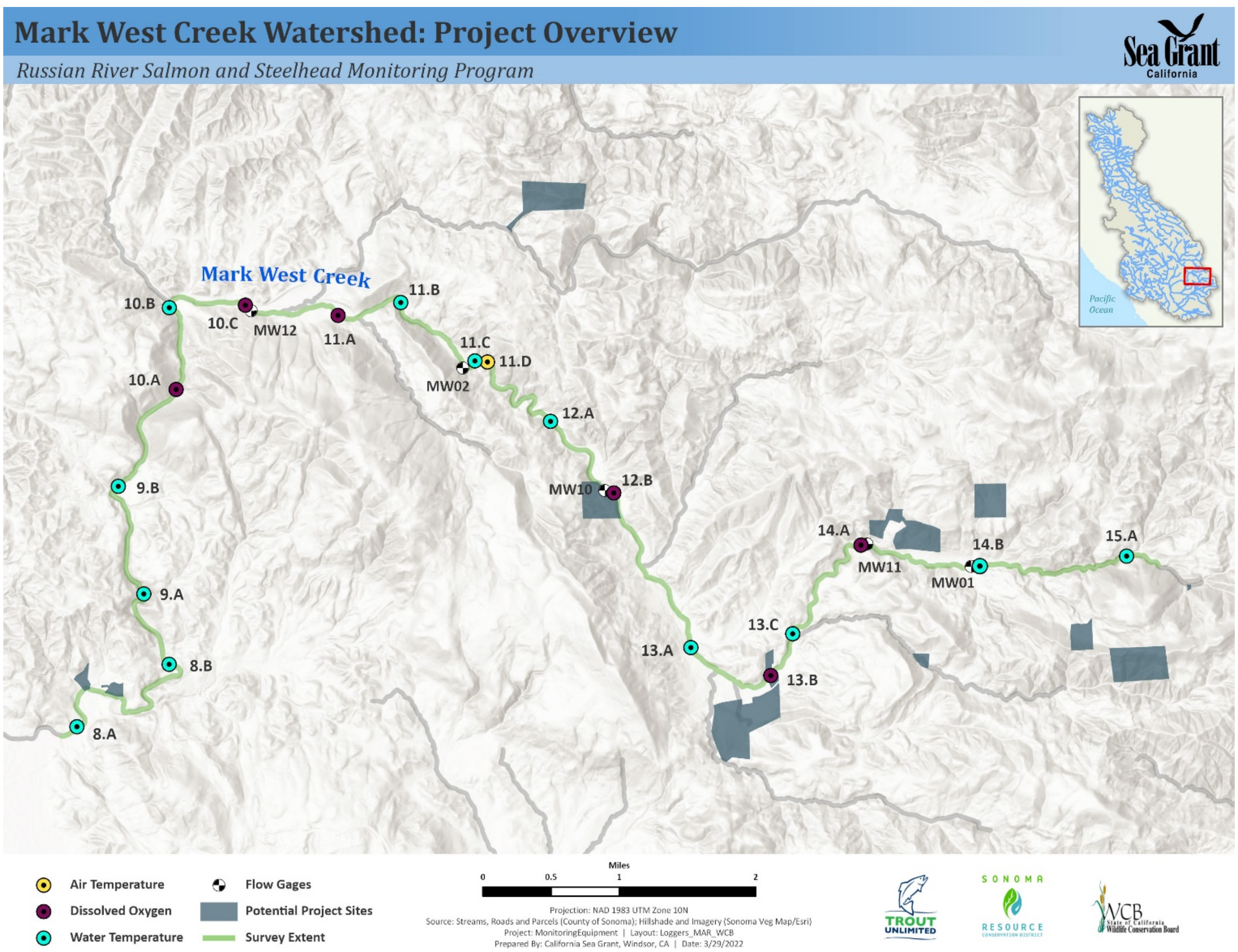

Figure 1. Project overview map, including wetted habitat survey extent, continuous water quality logger and flow gage locations, and Sonoma Resource Conservation District's potential project sites.

2. Fire

The Mark West Creek watershed has experienced two recent wildfires, the Tubbs Fire and the Glass Fire (Figure 2), that had devastating impacts on the landscape. In October 2017, the Tubbs Fire burned nearly 37,000 acres and over 5,600 structures in Sonoma County (https://wildfiretoday.com/tag/tubbs-fire/), including in portions of the middle and upper Mark West Creek watershed. In September 2020, the Glass Fire burned over 67,000 acres and 1,555 structures in Sonoma and Napa counties (https://abc7news.com/glass-fire-napa-bay-area-wildfire-cal-update/6613102/), including in the upper portion of the Mark West Creek watershed. The Tubbs Fire burned approximately 52% of the area of the Mark West Creek watershed defined as the geographic scope of this project, and the Glass Fire burned approximately 35% of the project focus area within the watershed (Figure 2), resulting in a major cumulative impact. The impacts of the fires on streamflow and habitat conditions are largely unknown, and data collected for this series of reports are among the first to examine post-fire conditions.

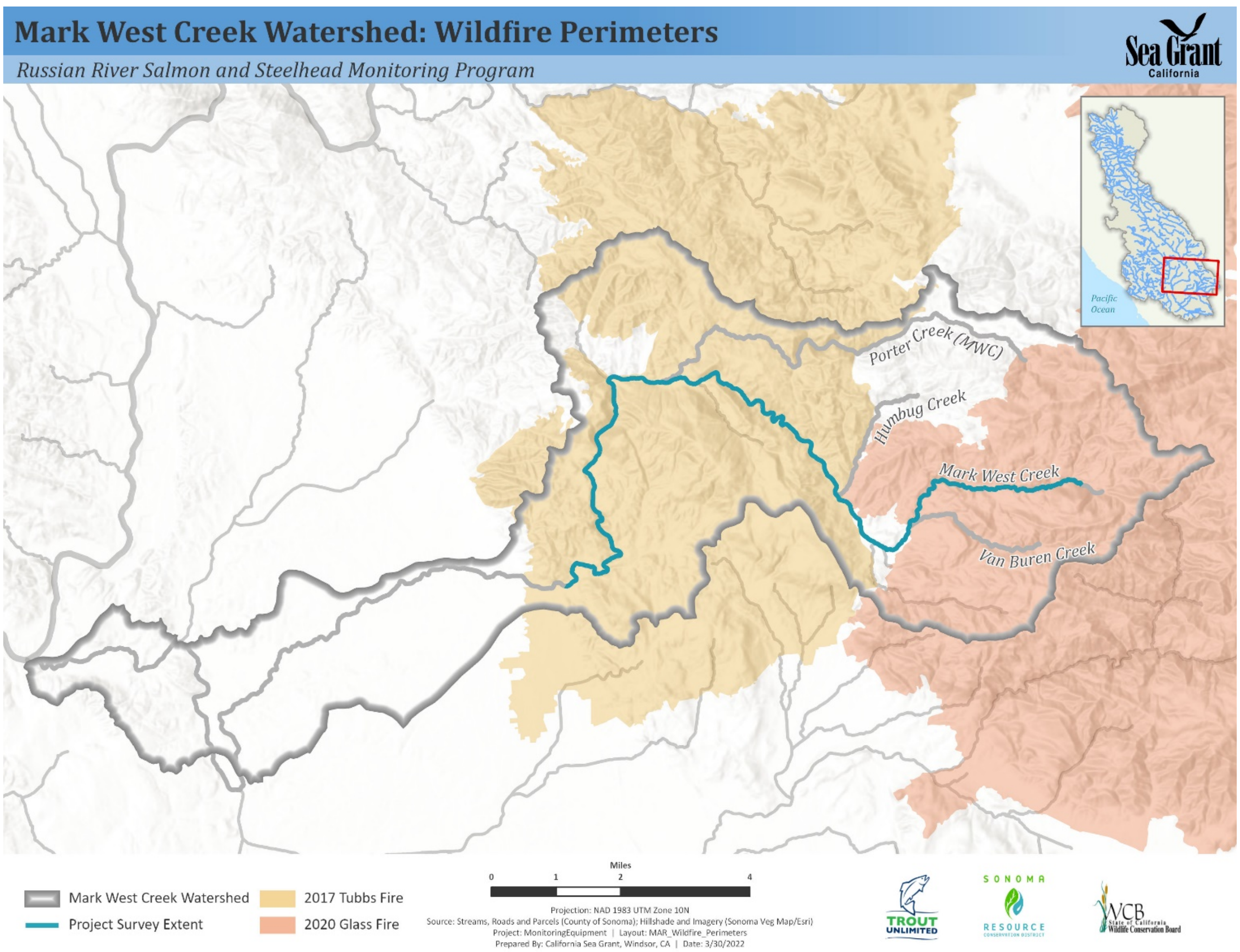

Figure 2. The Tubbs Fire and Glass Fire footprints in relation to the Mark West Creek watershed.

3. Rainfall

Rainfall data were recorded over an 81 water year (WY) period in nearby Healdsburg, CA at National Climatic Data Center (NCDC) Station # 3875 (Healdsburg station, hereafter), median average rainfall at the Healdsburg station is 37.5 inches (Figure 3). Total rainfall in WY2022 was 30.4 inches, 7.1 inches below median average, and 14.5 inches higher than WY2021 (15.91 inches).

Figure 4 shows total monthly rainfall recorded during in water years 2021 and 2022, with the mean average monthly rainfall for the 81-year period of record. WY2022 experienced the highest rainfall over the water year in October (11.7 inches), followed by a storm in December 2021 (9 inches). WY2022 had notably dry winter, with substantially less than average rain in January, no rain in February, little rain in March, and below average rain in April. From a streamflow viewpoint, the water year was saved by a rain event in June (0.64 inches), which boosted early summer streamflow conditions at all gage sites. Overall, the rainfall distribution pattern and the total annual rainfall volume in WY2022 was much more supportive to higher summer streamflow than rainfall conditions in WY2021.

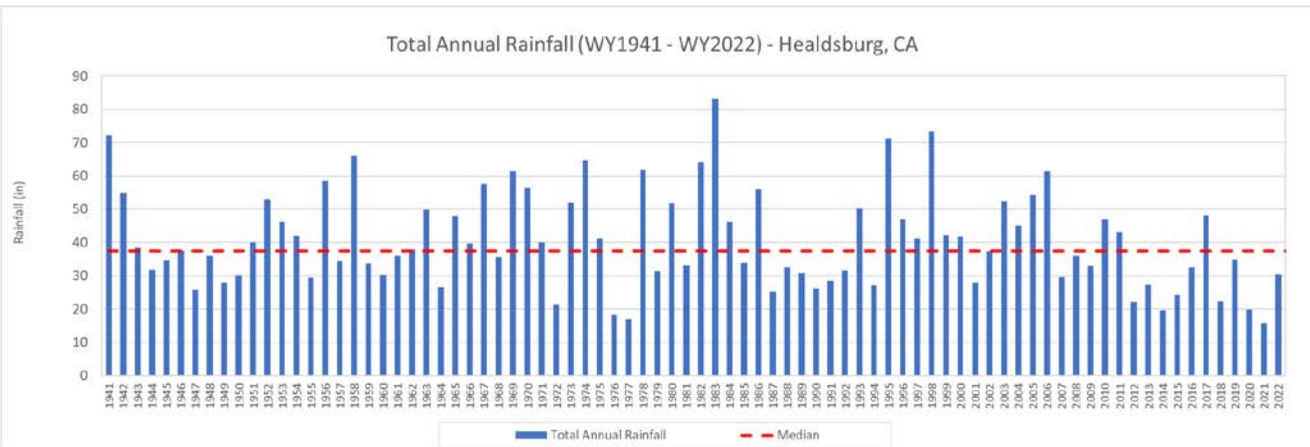

Figure 3. Total and median annual precipitation recorded in Healdsburg, CA (1941-2022) from NCDC station 3875.

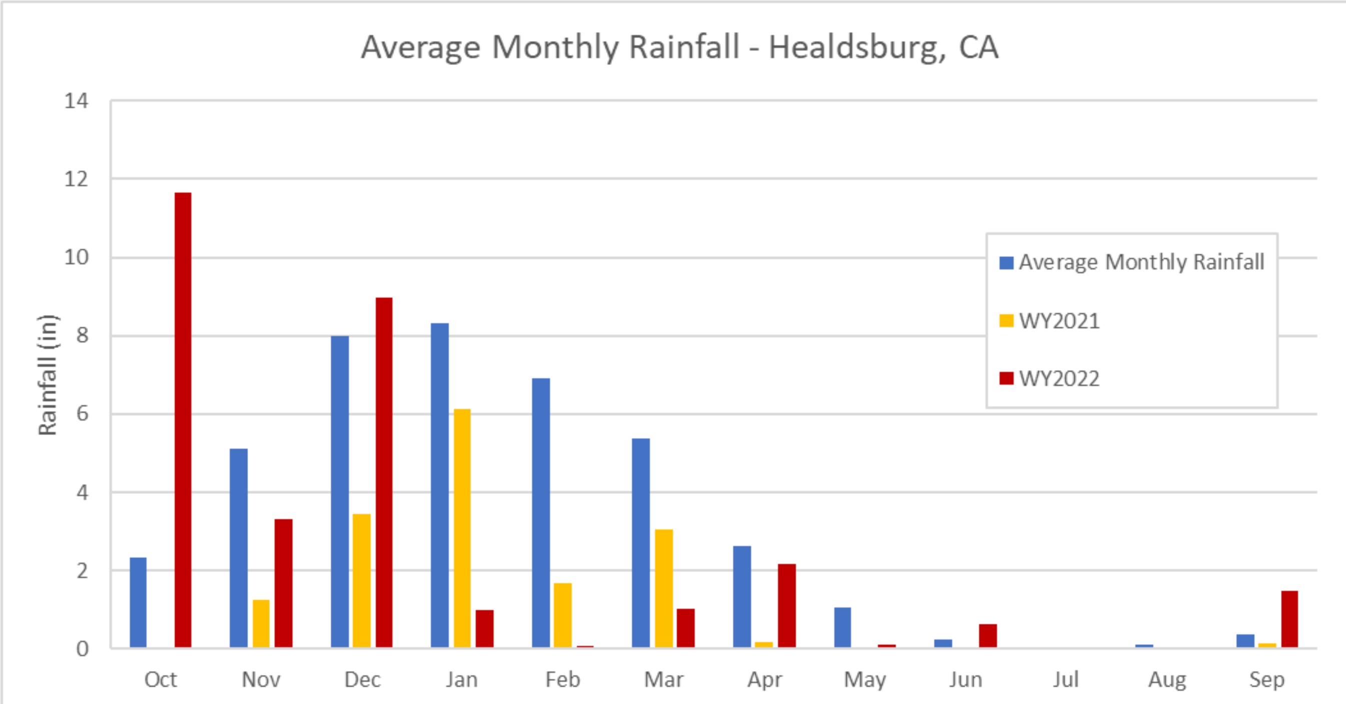

Figure 4. Total monthly precipitation in water years 2021 and 2022 vs monthly average rainfall recorded in Healdsburg, CA from NCDC station 3875.

4. Streamflow

Streamflow was monitored at five sites in Mark West Creek from mid-May through late October in WY2021, and year-round in WY2022 (Figure 1). Adjusted stage data and discrete discharge measurements were used to develop hydrographs for each of the monitored sites for the study period. This section describes stage in WY2022 and streamflow in water years 2021 and 2022 for all gage sites, in order from upstream (MW01) to the farthest downstream (MW12).

(MW01) Mark West Creek below Tarwater Road

At site (MW01) Mark West Creek below Tarwater Road, stage began to rise in response to the first storms of the year in late October 2021 (Figure 5). The two largest storms of the year occurred in October and December. The highest peak flows of the year were observed on October 24, 2021. At its highest level, stage rose to 5.4 feet. Stage began to recede in early January, then rose in response to small storms in April. A low stage of 1.4 feet was reached in September 2022.

Early WY2022 was marked by some of the highest flows on record at this site, which likely is because of the fire events in the watershed. Figure 6 shows streamflow conditions at Mark West Creek below Tarwater Rd in WY2021 and WY2022. Streamflow in May 2021 was just below 0.5 ft^3/sec and in May 2022 it started around 1.1 ft^3/sec and receded to 0.58 ft^3/sec. Streamflow was higher in WY2022 than WY2021 through August, in mid-August 2022 streamflow began to recede at a slightly higher rate than the previous year, and the site reached its lowest flow of 0.087 ft^3/sec in late-August. The lower flows in late summer 2022 could be the results of the vegetation regrowth happening in the watershed post fire and an increase in groundwater and surface water diversions to meet increased human water demands. The gage data from WY2022 shows several potential surface water diversions signals throughout the summer, on the order of 0.02-0.07 ft^3/sec.

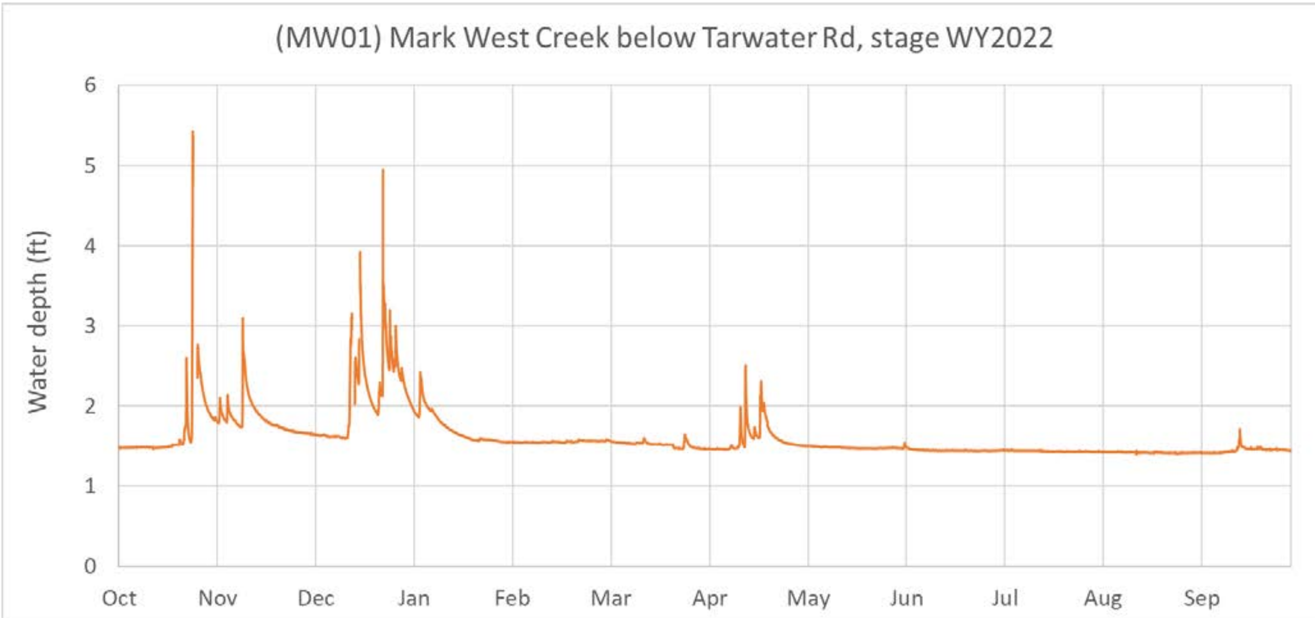

Figure 5. Stage at Mark West Creek below Tarwater Road, WY2022.

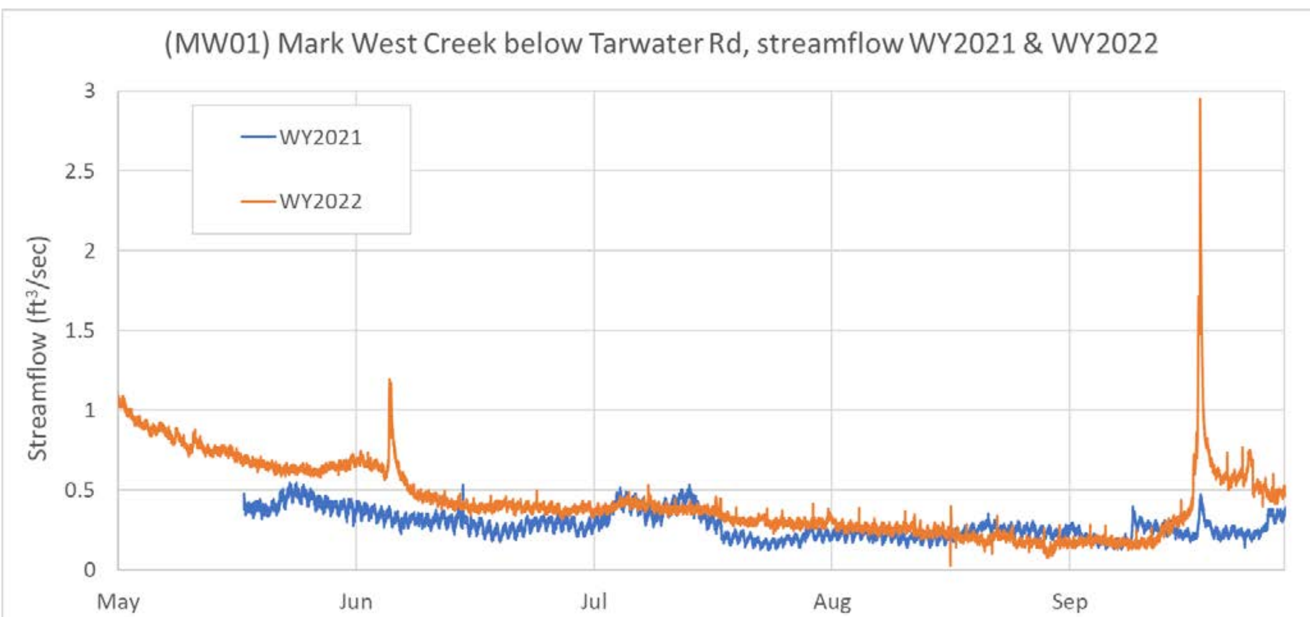

Figure 6. Streamflow at Mark West Creek below Tarwater Road, WY2021 and WY2022.

(MW11) Mark West Creek above Van Buren Creek

The flow gage at (MW11) Mark West Creek above Van Buren Creek was not able to be operated year-round in 2021 due to ongoing erosion at the site. TU reinstalled the gage in May 2022, at stage at the time of installation was 2.03 ft. (Figure 7) shows stage at MW11 rising with a rain event in June and slowly decreasing from mid-June through July. Stage leveled out in late July and remained low through mid-September. Stage spiked in mid-September with the onset of a small rain event.

Figure 8 shows streamflow at at Mark West Creek above Van Buren Creek in WY2021 and WY2022. Streamflow in May 2021 started around 0.69 ft^3/sec (at the time of the gage installation) and receded to 0.12 ft^3/sec, and in May 2022 started around 2.2 ft^3/sec (at the time of the gage installation) and receded to 1.4 ft^3/sec. Due to technical difficulties, there is a gape in streamflow data in WY2021 from late-August through mid-September. Based on the data available, streamflow was higher in WY2022 than WY2021 through most of the summer, with the exception of mid-August when streamflow conditions in both years were near equal. Dips in streamflow on the order of 0.32 ft^3/sec are detected occasionally throughout the summer, likely associated with a surface water diversion.

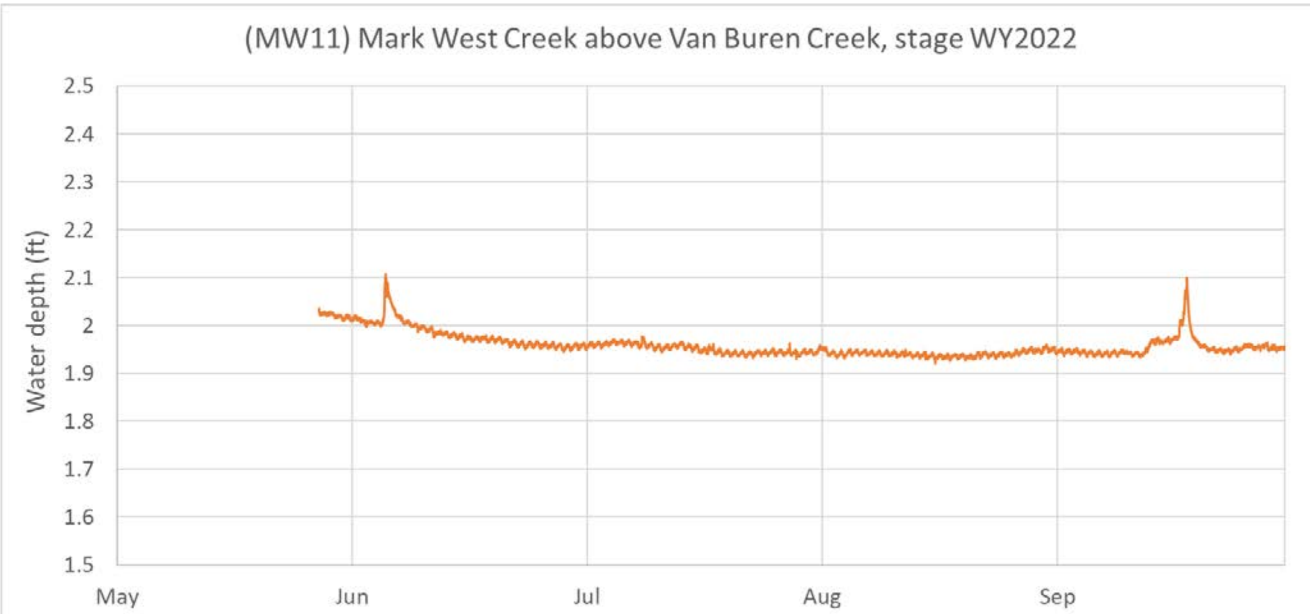

Figure 7. Stage at Mark West Creek below Humbug Creek, WY2022.

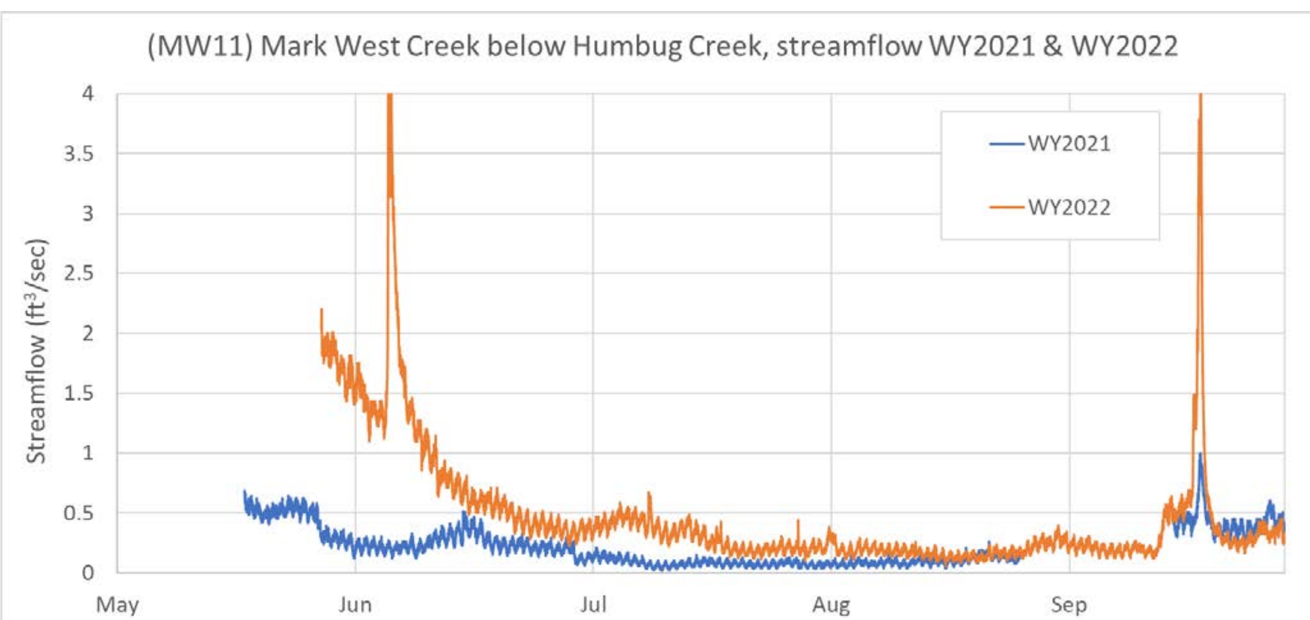

Figure 8. Streamflow at Mark West Creek below Humbug Creek, WY2021 and WY2022.

(MW10) Mark West Creek below Humbug Creek

As with other sites, stage at site (MW10) Mark West Creek below Humbug Creek began to rise in response to the first storms of the year in late October 2021 (Figure 9). The highest peak flows of the year were observed on October 24, 2021, when stage rose to 10.6 feet. Stage began to recede in early January, then rose in response to small storms in April. A low stage of 0.27 feet was reached in September 2022.

Figure 10 shows streamflow conditions at Mark West Creek below Humbug Creek in WY2021 and WY2022. Streamflow in May 2021 started around 1.15 ft^3/sec (at the time of the gage installation) and receded to 0.2 ft^3/sec, and in May 2022 started around 1.9 ft^3/sec and receded to 0.74 ft^3/sec. Streamflow was higher in WY2022 than WY2021 through most of the summer, with the exception of mid-September when the stream disconnected for a brief period.

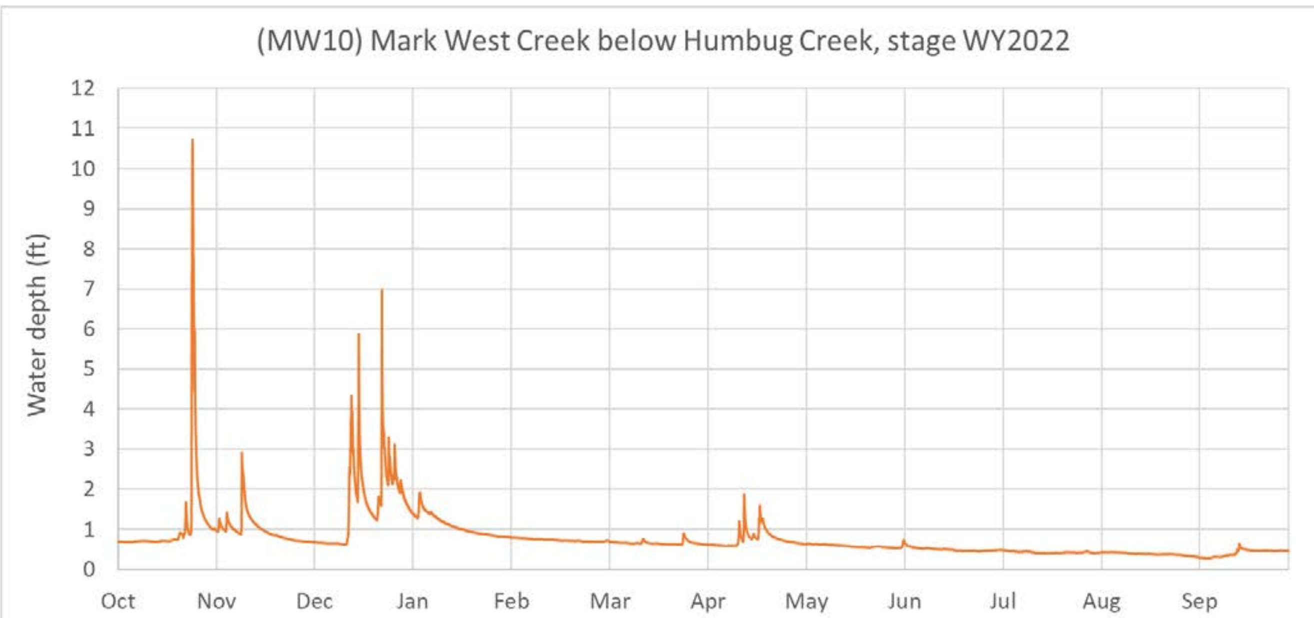

Figure 9. Stage at Mark West Creek below Humbug Creek, WY2022.

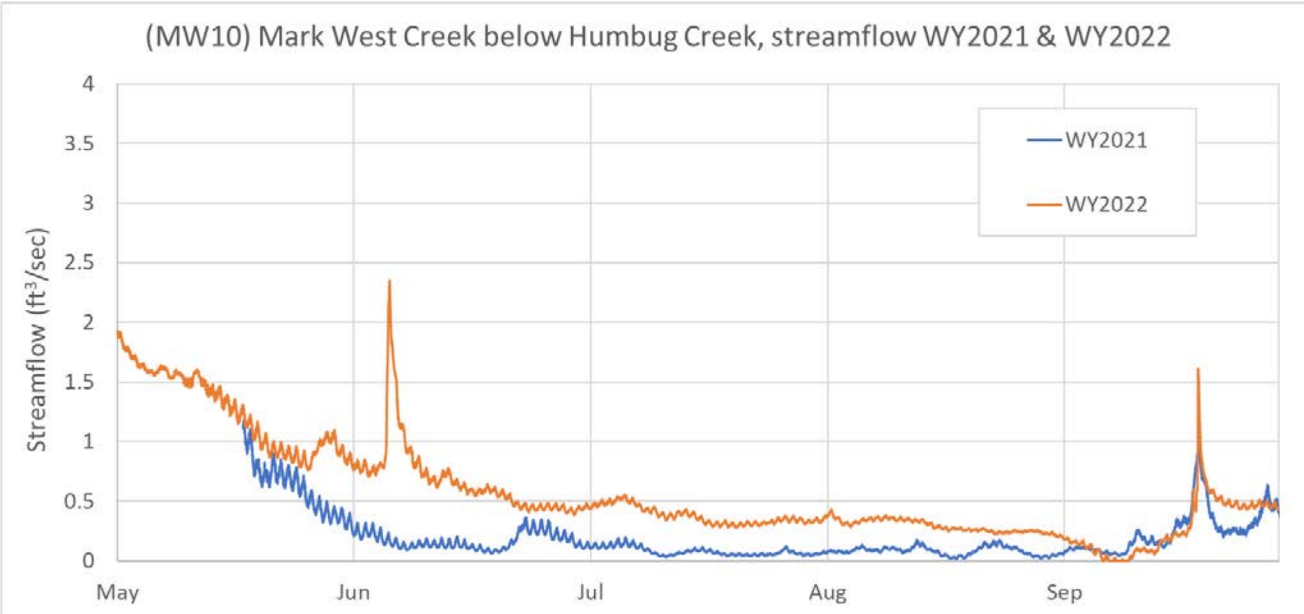

Figure 10. Streamflow at Mark West Creek below Humbug Creek, WY2021 and WY2022.

(MW02) Mark West Creek above Porter Creek

Stage at site (MW02) Mark West Creek above Porter Creek stage began to rise in response to the first storms of the year in late October 2021 (Figure 11). The highest peak flows of the year were observed on October 24, 2021, when stage rose to 11.7 feet. Stage began to recede in early January, then rose in response to small storms in April. A low stage of 1.1 feet was reached in September 2022.

Figure 12 shows streamflow conditions at Mark West Creek above Porter Creek in WY2021 and WY2022. Streamflow in May 2021 was approximately 0.22 ft^3/sec and in May 2022 started around 3.1 ft^3/sec and receded to 0.74 ft^3/sec. Streamflow was higher in WY2022 than WY2021 through the entire summer. Streamflow in WY2022 receded to its lowest flow of 0.02 ft^3/sec in mid-September. The gage data show dips in streamflow potentially caused by surface water pumping in mid-May, at a rate of 0.26 ft^3/sec, and throughout the summer at a rate of 0.1 ft^3/sec.

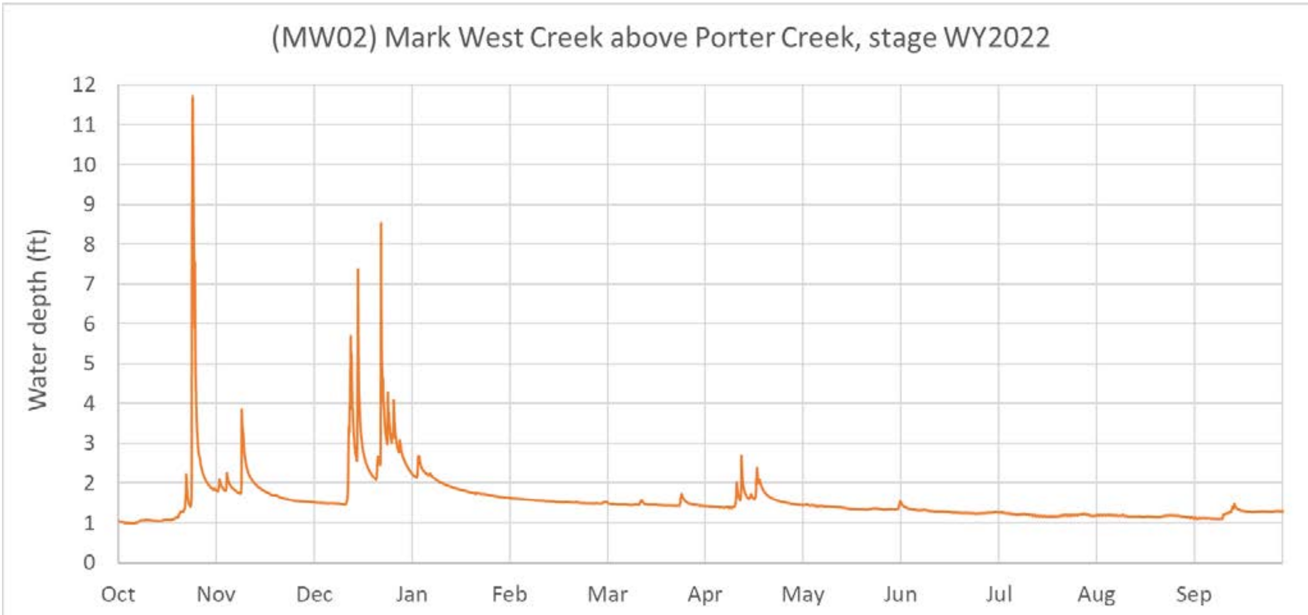

Figure 11. Stage at Mark West Creek above Porter Creek, WY2022.

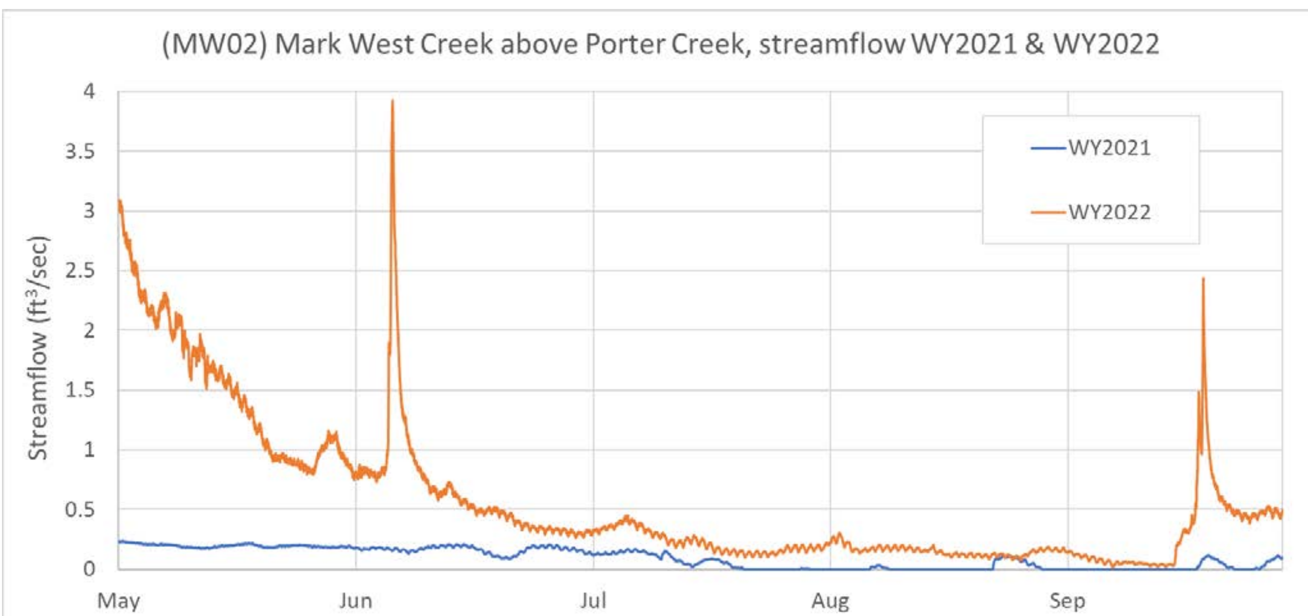

Figure 12. Streamflow at Mark West Creek above Porter Creek, WY2021 and WY2022.

(MW12) Mark West Creek below Porter Creek

Stage (MW12) Mark West Creek below Porter Creek (Figure 13) is similar to stage patterns at the upstream site MW02. Due to technical difficulties, there is a gap in data at MW12 from late November through mid-December. The highest peak flows of the year were observed on October 24, 2021, when stage rose to 11.4

feet. Stage began to recede in early January, then rose in response to small storms in April. A low stage of 2 feet was reached in September 2022.

Streamflow at Mark West Creek above Porter Creek was lower than the upstream site MW02, for later portion of the summer. Figure 14 shows streamflow conditions at Mark West Creek below Porter Creek in WY2021 and WY2022. Streamflow in May 2021 was approximately 0.45 ft^3/sec (at the time of installation) and in May 2022 started around 5 ft^3/sec and receded to 1.48 ft^3/sec. Streamflow was higher in WY2022 than WY2021 through mid-August. By mid-August 2022, streamflow reached a very low baseflow of approximately 0.02-0.01 ft^3/sec.

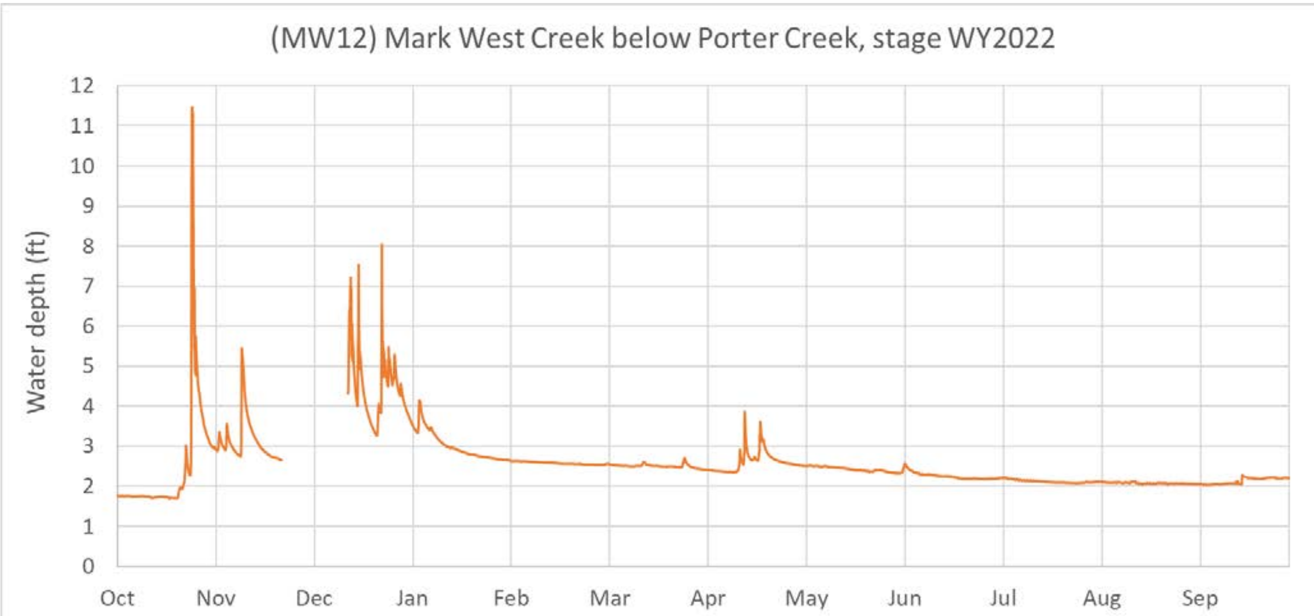

Figure 13. Stage at Mark West Creek below Porter Creek, WY2021.

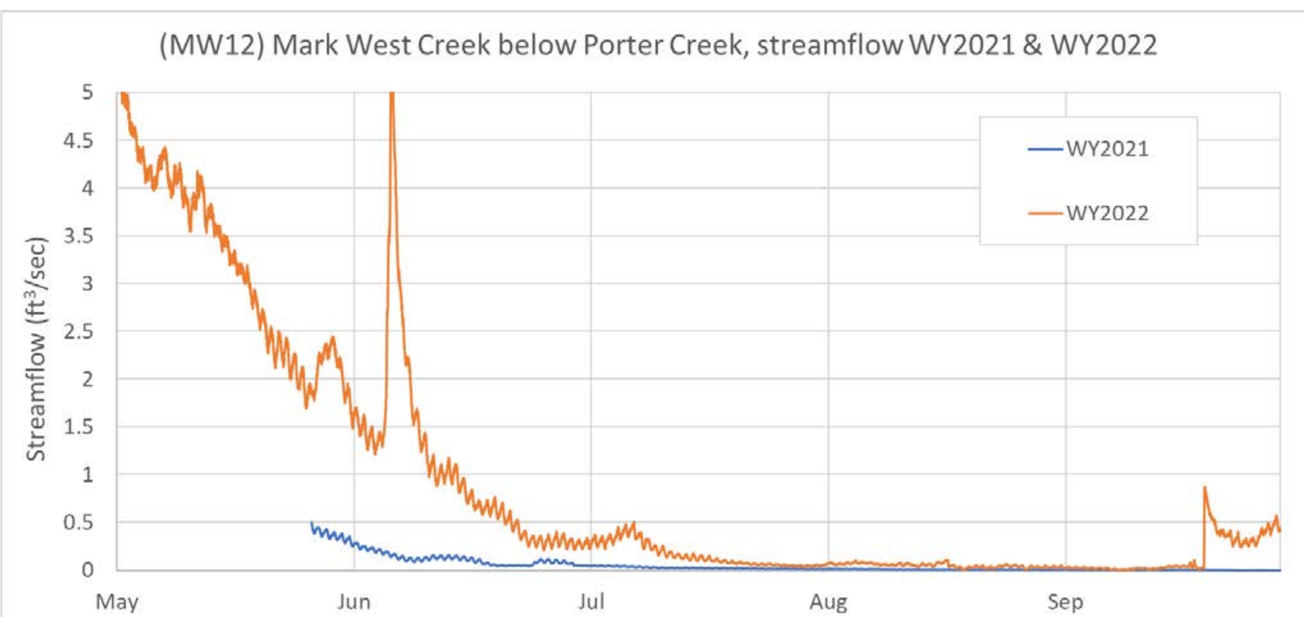

Figure 14. Streamflow at Mark West Creek below Porter Creek, WY2021 and WY2022.

Figures 15a and 15b shows summer streamflow conditions at all gages sites plotted together for each water year. Figure 15a shows streamflow from May through September in WY2021, at all sites in the Mark West Creek watershed. In May, streamflow was very low at all sites (below 1.2 ft^3/sec). Out of all the gage sites, (MW02) Mark West Creek above Porter Creek had the lowest streamflow. Flow slowly decreased and became intermittent at this site, as well as at (MW12) Mark West Creek below Porter Creek. Other sites remained connected at a low summer baseflow. By September, flows began to rebound and the stream reconnected by late October due to the storm.

Figure 15b shows streamflow from May through September in WY2022, at all sites in the Mark West Creek watershed. In May, streamflow was significantly higher at all sites than the previous year, and streamflow increased from the most upstream gage site to the farthest downstream site (as you would expect with the increase in drainage area), with the exception of MW11 which had higher flow than the downstream sites. This streamflow patterned shifted in mid-June and by late summer, (MW02) Mark West Creek above Porter Creek had the lowest streamflow. Flows at all sites rebounded with the mid-September rain event.

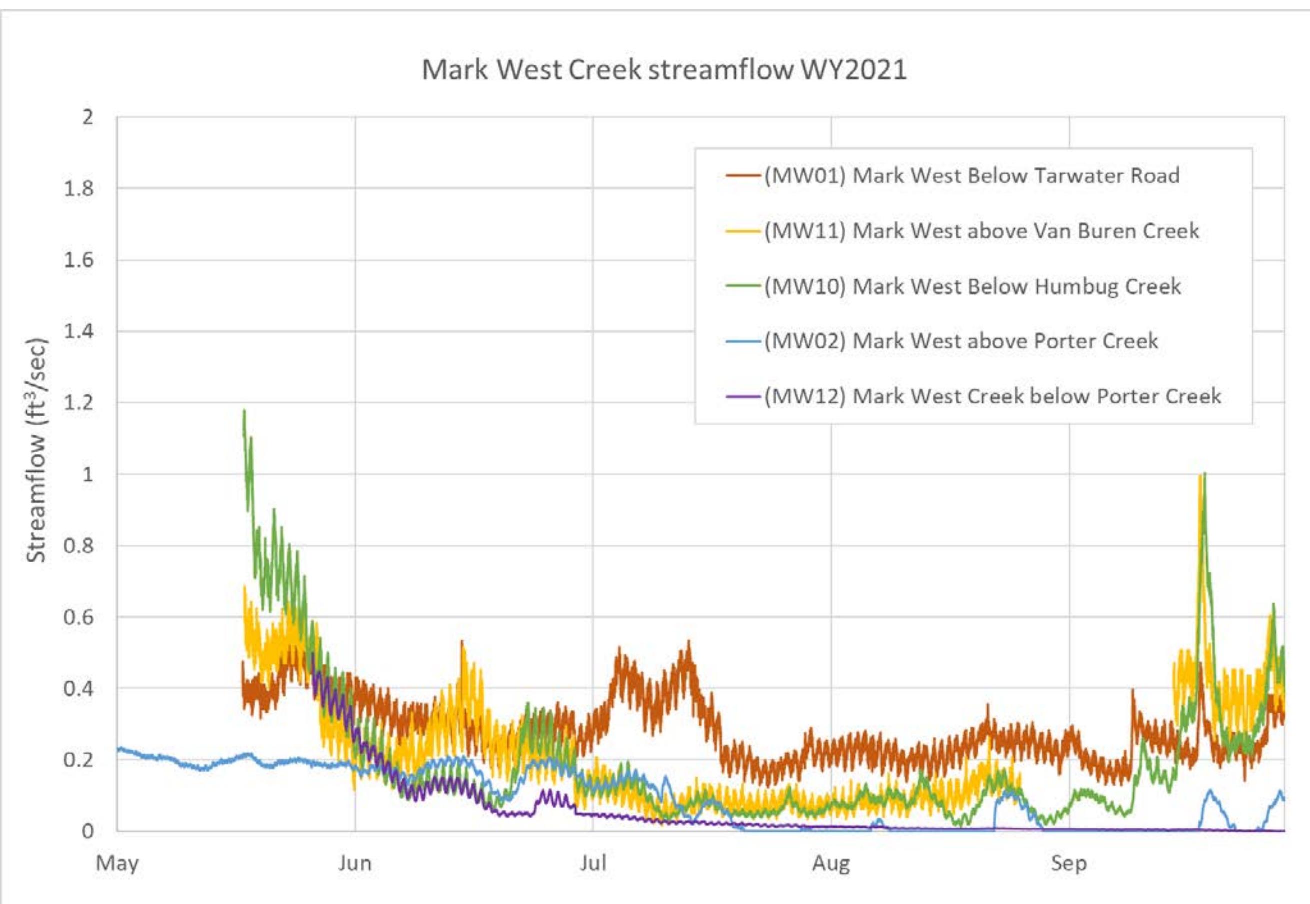

Figure 15a. Streamflow at all Mark West Creek sites, WY2021.

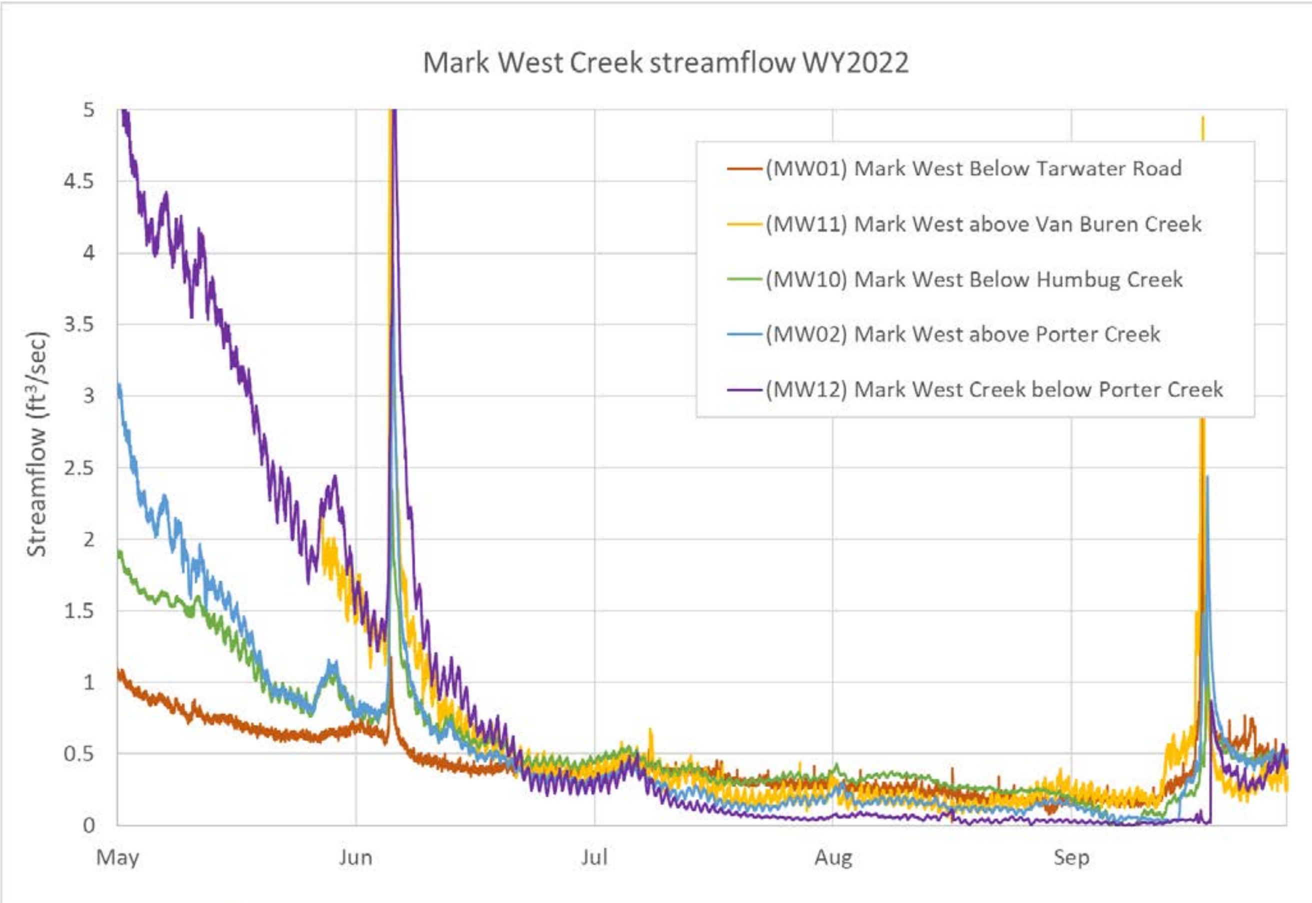

Figure 16b. Streamflow at all Mark West Creek sites, WY2022.

5. Wetted habitat

Mark West Creek stream channel conditions were surveyed approximately each month over the summers of 2021 and 2022 (Table 1) using a protocol developed by CSG to document wetted habitat available to fish. Wetted habitat surveys, also referred to as wet/dry mapping, were performed by walking the stream channel and recording wet and dry sections of stream length as lines on a GPS unit. The spatial data were then processed using a geospatial tool in ArcGIS, where the condition of "intermittent" was assigned to sections of stream with alternating short lengths (<50 feet) of wet and dry lines. Water temperature and dissolved oxygen (DO) concentrations were measured in wet pools at approximately 5-minute intervals. The full field protocol is available online (California Sea Grant 2021b), and data processing procedures are described in the WCB contract report *Flow and survival studies to support endangered coho recovery in flow-impaired tributaries of the Russian River Basin* (California Sea Grant 2019).

The surveyed extent for this project began near Wikiup Bridge Way and extended approximately 23.5 km upstream to Tarwater Road in 2021, and slightly further to approximately 24.5 km upstream, almost to Neal Creek Road, in 2022. The variation in survey extent between years reflects changes in landowner access permissions. The full length of stream surveyed correspond to the California Coastal Monitoring Program (CMP) reach designations of Mark West 8-15 (MAR 8-MAR 15). Monthly surveys were planned for both seasons, but dates were adjusted around weather events, staffing availability, and other project needs (Table 1).

In September 2021, additional wetted habitat surveys were conducted by Sonoma Water in tributaries to Mark West Creek in Porter, Humbug, Weeks and Van Buren creeks, where landowner access permitted, in order to document wet/dry conditions during the driest point of the season. Tributaries were not surveyed in 2022.

Maps displaying results from wetted habitat surveys were used to visualize changes in stream channel conditions over time as it relates to available habitat for fish (Figure 16-Figure 24). The wetted habitat maps and discrete water quality measurement data for these surveys can be viewed on CSG's online dashboard, which includes all wetted habitat surveys completed by CSG and Sonoma Water between 2012 and 2022.

In 2021, the entirety of the surveyed extent of Mark West Creek was wet in early June, the first sample of the season (Figure 16). During the mid-July survey, surface flow disconnection was documented at 30 locations (Figure 17). The most extensive drying was recorded just upstream of the confluence with Porter Creek, where nearly 400 m of stream channel was classified as either dry or intermittent. Overall, 2% of the stream was dry, 1% was intermittent, and 97% was wet and connected. By mid-August, 5% was dry, 2% intermittent, and 93% was wet and connected (Figure 18). In mid-September, 5% of the stream was classified as dry, 3% as intermittent, and 92% remained wet and connected (Figure 19).

On October 24, 2021, Santa Rosa received nearly eight inches of rain in 24 hours—the highest 24-hour rainfall ever recorded for the city (https://www.pressdemocrat.com/article/news/rain-on-the-way-to-sonoma-county/). This tremendous amount of rainfall, which caused localized flooding, resulted in streamflows that were too high to safely wade. On October 26, an informal survey was conducted to verify that the entirety of the stream within the study area was reconnected and wet following an atmospheric river event.

During the summer of 2022, a single disconnection point was documented just upstream of the confluence with Porter Creek during the late-June survey, when the rest of the surveyed extent of Mark West Creek was wet and connected (Figure 20). A full 99% of the stream was still wet and connected during the July 26-August 3 survey, with <1% dry, and <1% intermittent (Figure 21). By mid-August, approximately 2% of the stream was intermittent and 98% was wet and connected (Figure 22), and in mid-September, 3% of the surveyed extent was dry, 2% was intermittent, and 95% remained wet and connected (Figure 23). In October 2022, the surveyed extent of stream was, again, fully wet and connected (Figure 24).

In general, the relatively small amount of stream disconnection and drying that occurred in Mark West Creek had a later onset in 2022 than in 2021 (Figure 25-Figure 26). In both years, the driest sample—the survey with the least amount of habitat classified as wet—was in September and the majority of the intermittency occurred near the confluence with Porter Creek (Figure 19, Figure 23). Stream disconnection and drying in the vicinity of the Porter Creek confluence was more extensive in 2021, when nearly a kilometer of stream channel there was dry and only a few isolated pools remained (Figure 27). By late October of both sample years, Mark West Creek had completely rewetted (Figure 25-Figure 27). The stream was reconnected by an atmospheric river event in October 2021. In 2022, the Santa Rosa earthquake and a minor rain event in mid-September

bolstered streamflow before the usual environmental changes that accompany the seasonal shift to fall, which cause an increase in stream depth and flow due to reduced evapotranspiration.
During the driest September surveys, there was 3% more wet habitat available to rearing fish in 2022 than in 2021 (Figure 25-Figure 26); however, the 2022 surveys included an additional kilometer of primarily wet channel at the upstream end and data were not trimmed for an exact spatial comparison (Figure 19, Figure 23). Overall, particularly when the difference in survey extents are taken into consideration, the amount and locations of late-summer habitat available to rearing salmonids in the upper Mark West Creek survey reaches remained relatively consistent between the two study years.

At the driest conditions of 2015-2018 (no surveys were conducted in 2019 or 2020), patterns were generally consistent in that most drying was observed around the confluence of Porter Creek. Some additional disconnection points in the middle section were observed in dry water years, as well as at the very upper extent of the reach surveyed in 2022. Overall, the driest conditions in 2021 were most similar to those at the peak of the previous drought in 2015 for the extent of stream where data overlapped. Because survey locations and distance of stream length surveyed varied significantly between years sampled prior to 2021, further comparisons were not possible.

There was high variability in end-of-season habitat condition among Mark West Creek tributaries surveyed in 2021 (Figure 28). The entire surveyed length of Weeks Creek and nearly all of Porter Creek were dry or intermittent, while most of the surveyed portions of Humbug and Van Buren creeks remained wet. Stream disconnection was greatest in the downstream reaches of Humbug and Van Buren creeks, near the confluences with Mark West Creek (Figure 19).

Table 1. Mark West Creek wetted habitat survey dates, summers 2021 and 2022. An October 2021 survey was not possible due to high flows, but habitat conditions were verified from the streambank.

Year	Sample number				
	1	**2**	**3**	**4**	**5**
2021	June 1-4	July 12-13	August 16-18	September 13-16	October 26
2022	June 21-24	July 21-28, August 2-3*	August 16-18	September 13-15	October 17-20

**Sample was completed over more days due to other field work needs.*

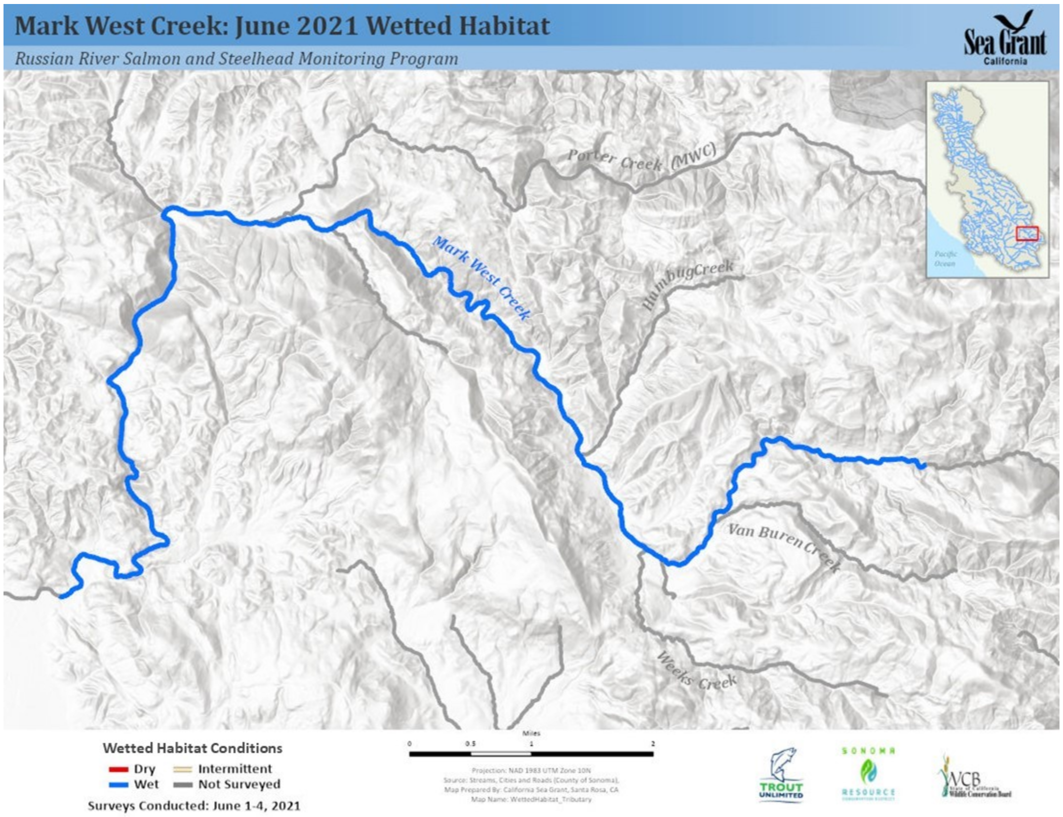

Figure 17. Wetted habitat conditions on Mark West Creek, June 1-4, 2021.

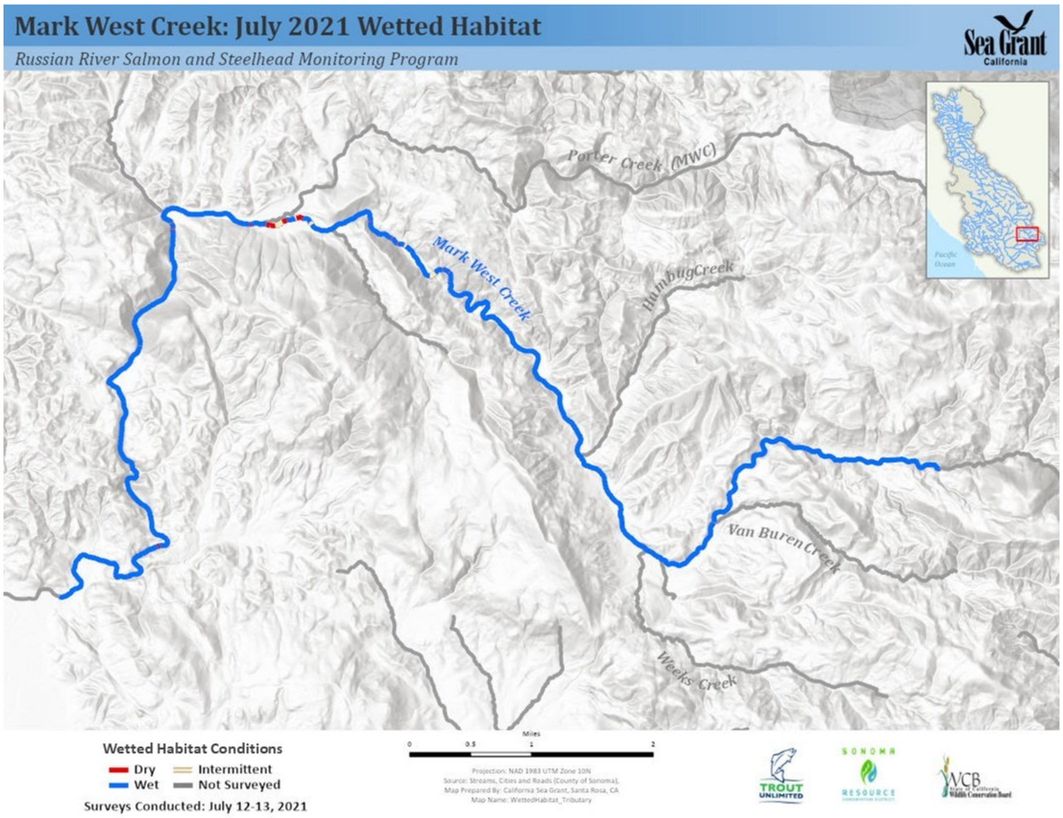

Figure 18. Wetted habitat conditions on Mark West Creek, July 12-13, 2021.

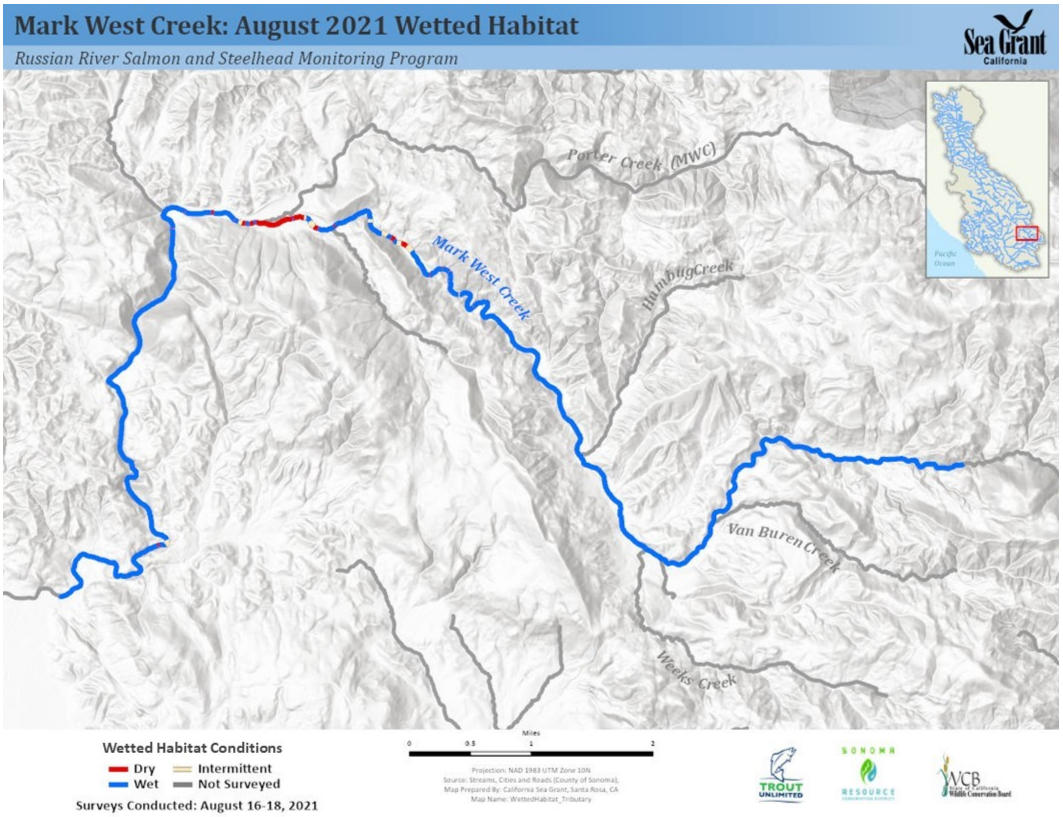

Figure 19. Wetted habitat conditions on Mark West Creek, August 16-18, 2021.

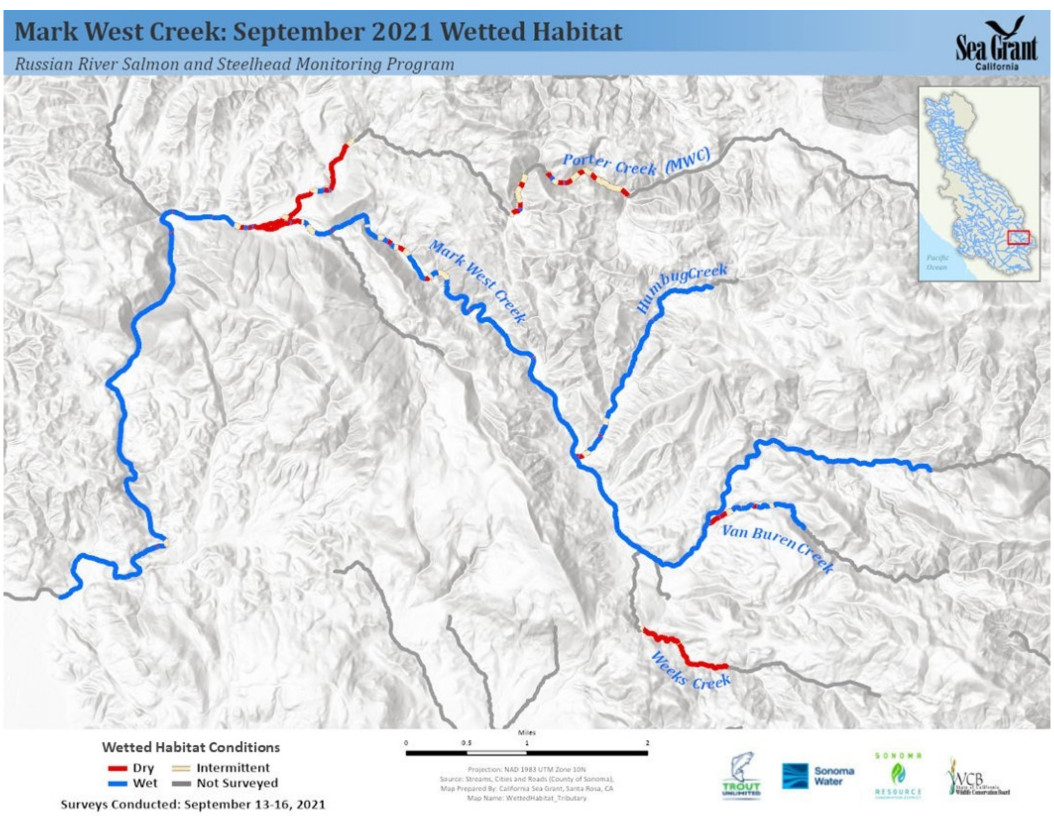

Figure 20. Wetted habitat conditions on Mark West Creek and tributary streams Porter, Humbug, Weeks and Van Buren creeks, September 13-16, 2021.

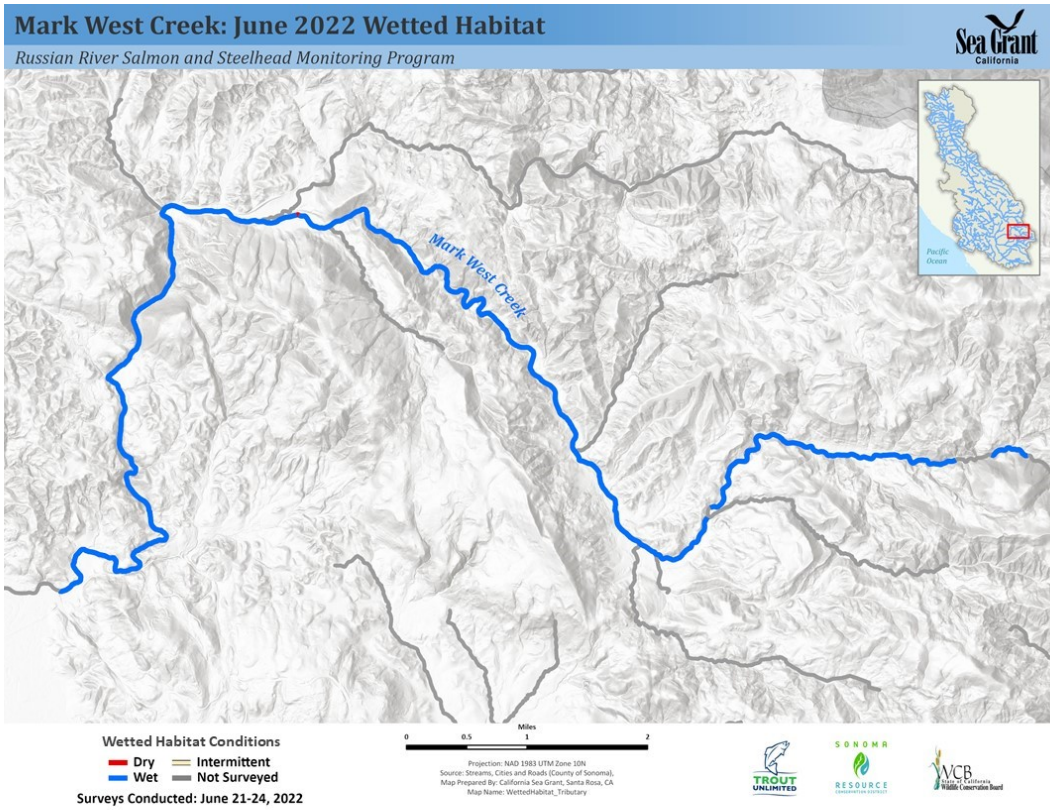

Figure 21. Wetted habitat conditions on Mark West Creek, June 21-24, 2022.

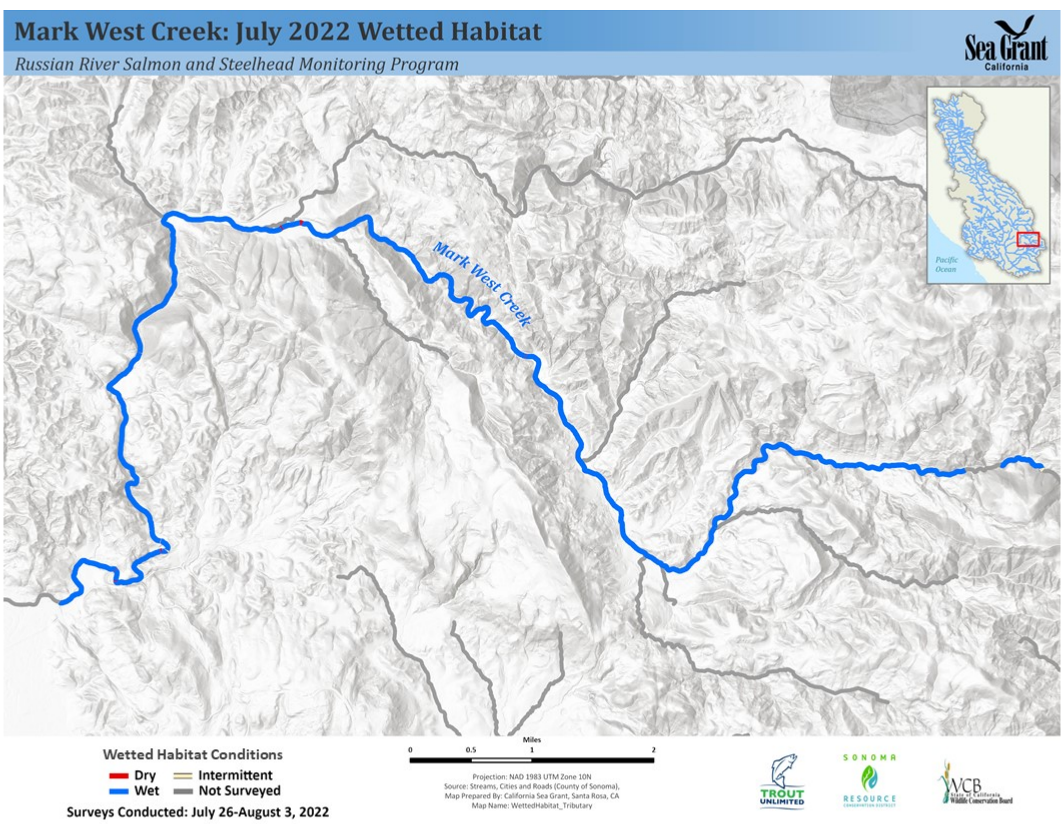

Figure 22. Wetted habitat conditions on Mark West Creek, July 26-August 3, 2022.

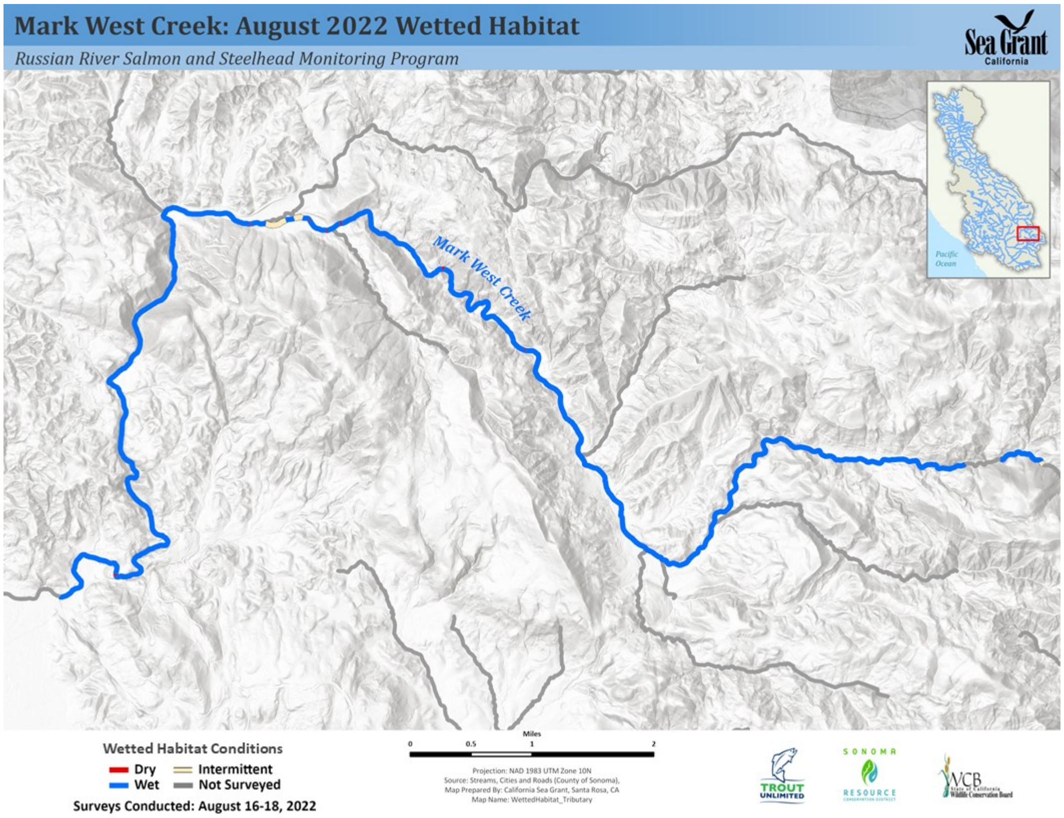

Figure 23. Wetted habitat conditions on Mark West Creek, August 16-18, 2022.

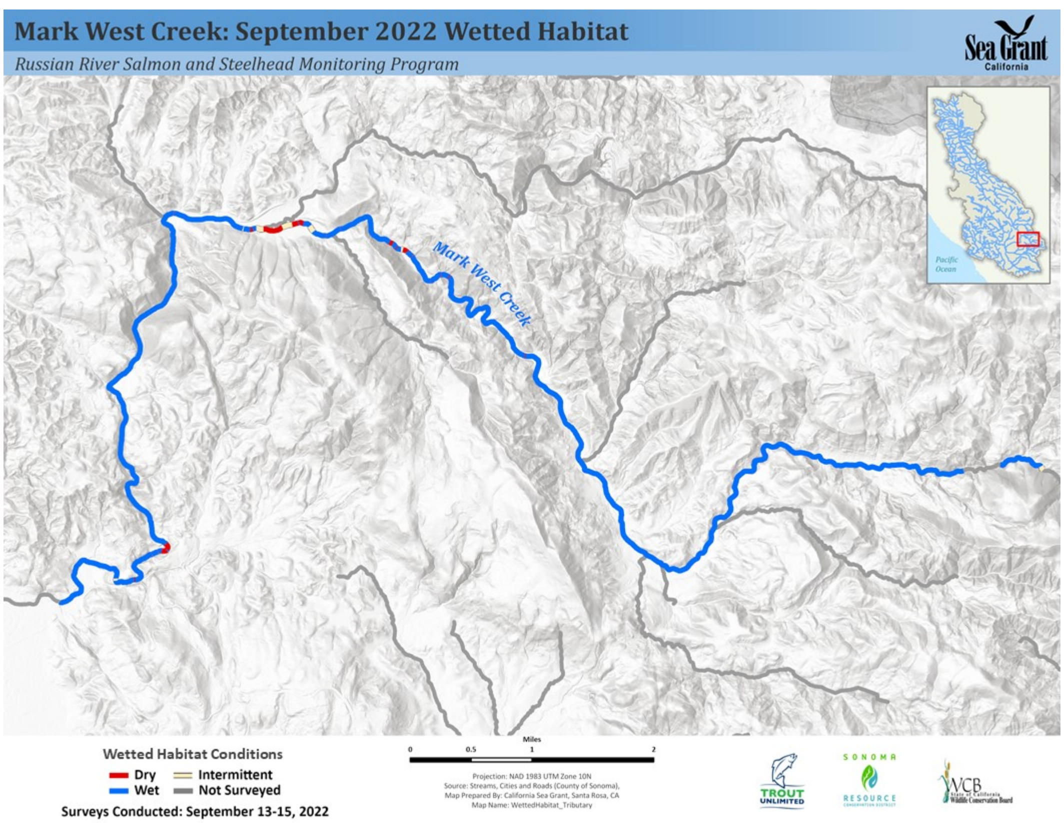

Figure 24. Wetted habitat conditions on Mark West Creek, September 13-15, 2022.

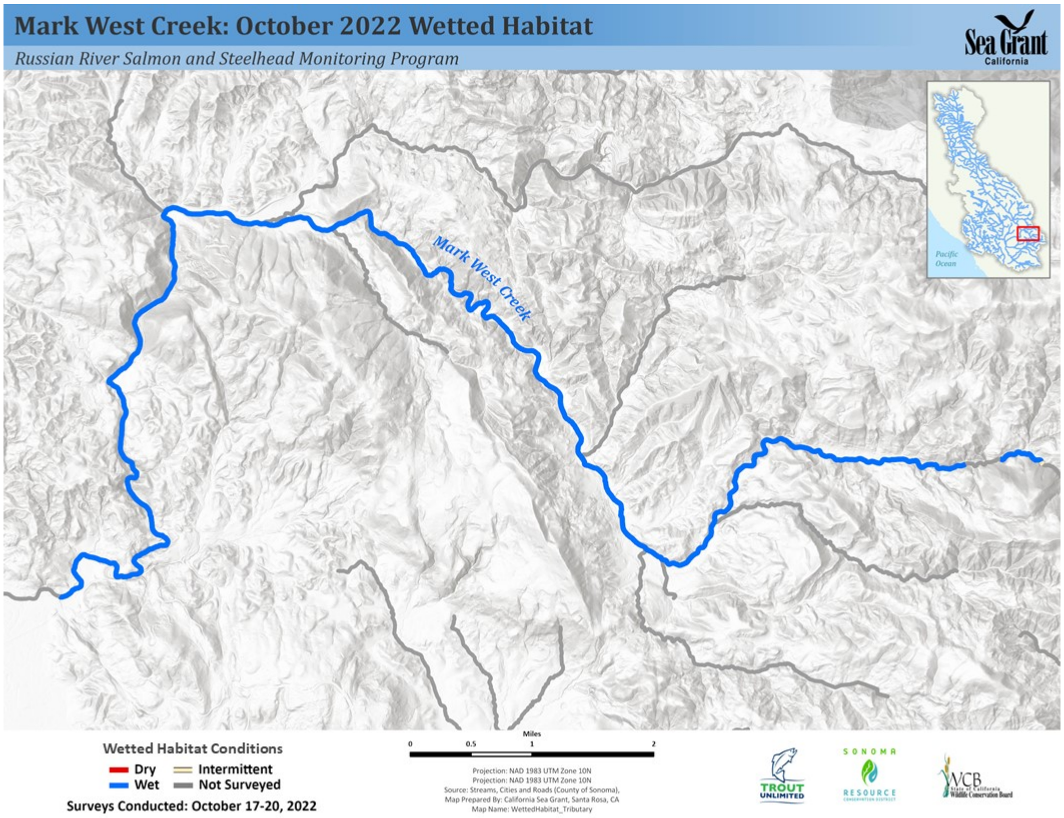

Figure 25. Wetted habitat conditions on Mark West Creek, October 17-20, 2022.

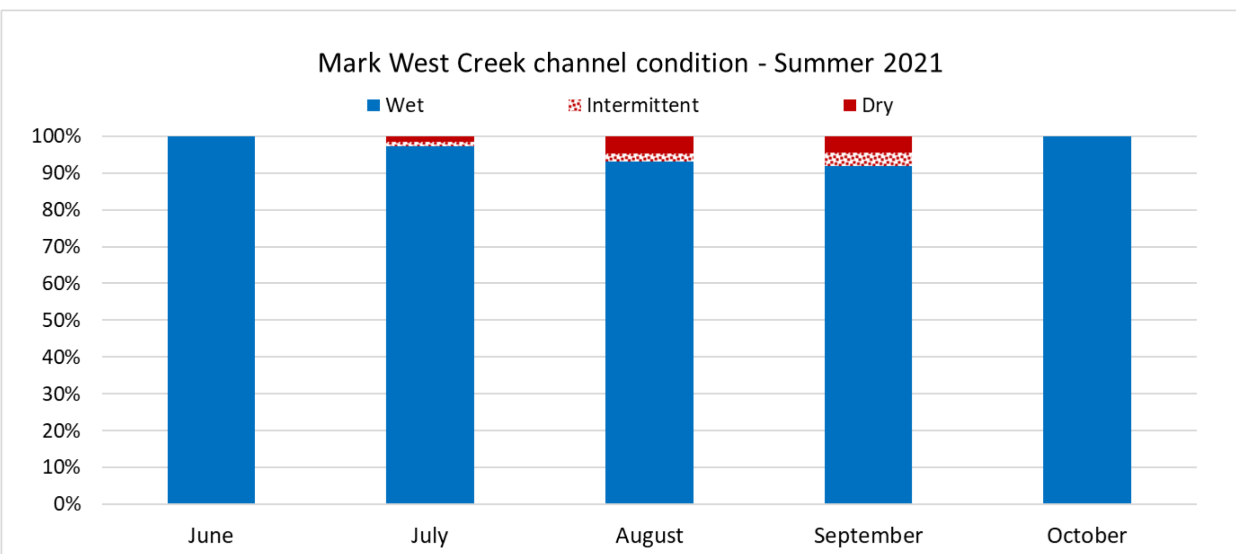

Figure 26. Total proportion of wet, dry and intermittent habitat present in Mark West Creek on June 1-4, July 12-13, August 16-18, September 13-16, and October 26, 2021. While an October 2021 survey was not completed due to high flows, stream condition was verified as entirely wet and reconnected.

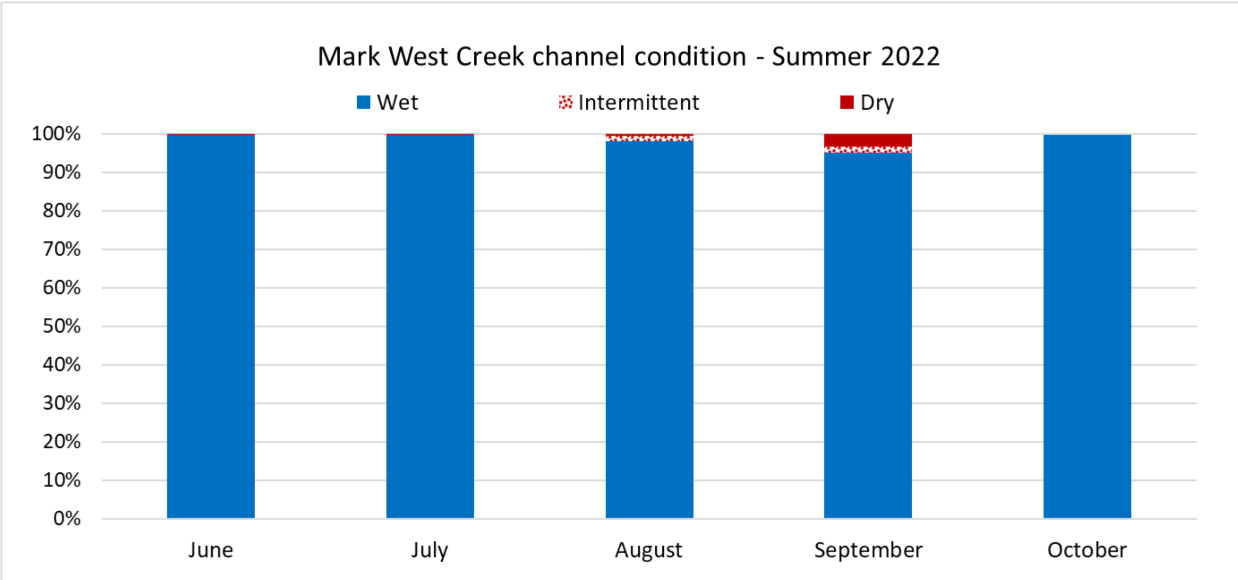

Figure 27. Total proportion of wet, dry and intermittent habitat present in Mark West Creek on June 21-24, July 26-August 3 ("July"), August 16-18, September 13-15, and October 17-20, 2022.

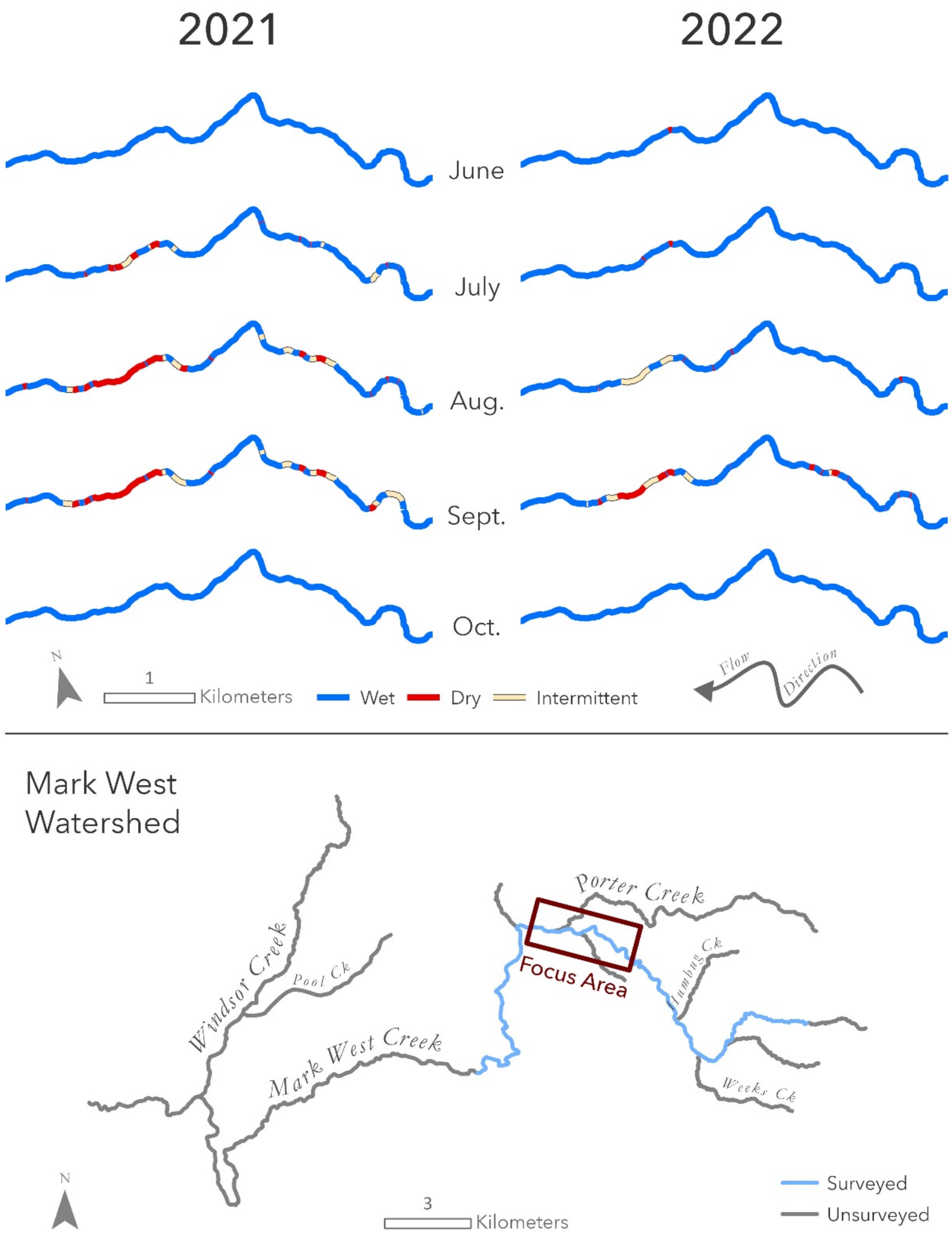

Figure 28. Mark West Creek wetted habitat conditions near the confluence of Porter Creek, summers 2021 and 2022.

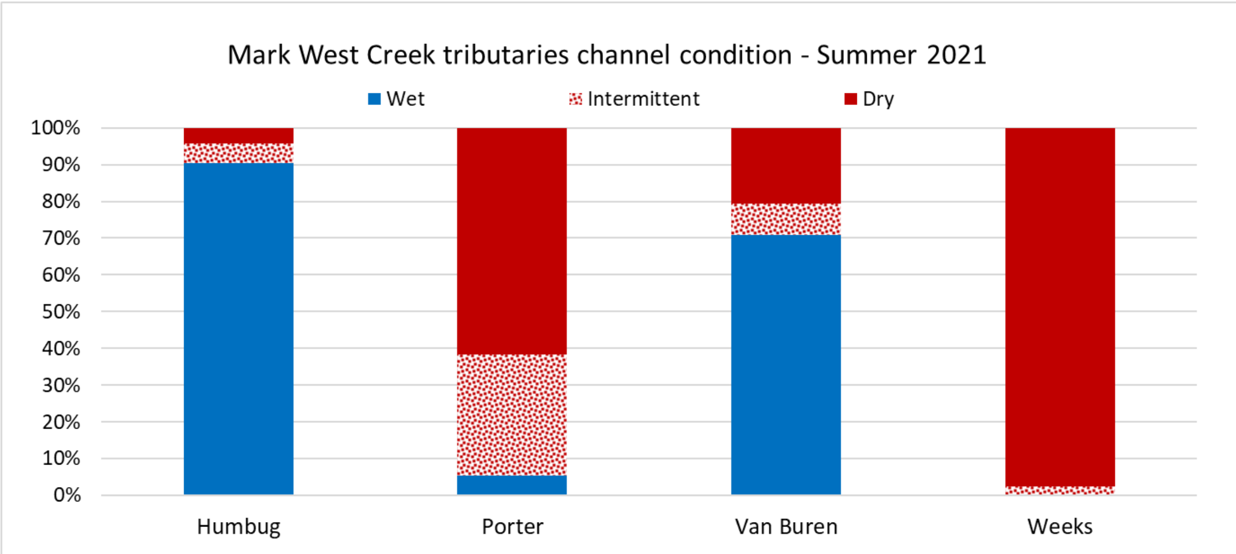

Figure 29. Total proportion of wet, dry and intermittent habitat present in surveyed reaches Humbug, Porter, Van Buren and Weeks creeks on September 13-16, 2021.

6. Salmonid distribution in relation to wetted habitat

Salmonid redds

During the winters of 2020/21 and 2021/22, spawner surveys were conducted in Mark West Creek by CSG and Sonoma Water for CMP efforts, with financial support from the California Department of Fish and Wildlife. Survey methods followed procedures outlined in *Russian River Coho Salmon and Steelhead Monitoring Report: Winter 2020/21* and *Russian River Coho Salmon and Steelhead Monitoring Report: Winter 2021/22*, and detailed outcomes can be found in those reports (California Sea Grant 2021a, California Sea Grant, 2022b). No spawner surveys were conducted in tributaries to Mark West Creek in winter 2020/21, with the exception of one reach of Porter Creek in 2021/22.

The redd distribution data from spawner efforts were spatially joined with the wetted habitat data from the September sample of each year—the sample with the least amount of habitat classified as wet. Overlaying these data helps us to evaluate available juvenile habitat distribution in relation to where adult fish spawning occurs, but it should be noted that late-summer wetted habitat conditions in relation to early-summer young-of--year (yoy) observations is a more useful metric for understanding the direct impacts of low streamflow on rearing salmonids.

A total of 37 salmonid redds were observed in the project reaches of Mark West Creek where spawner surveys occurred in the winter of 2020/21 *and* wetted habitat surveys were completed the following summer (California Sea Grant 2021a). Of these redds, two were identified as coho salmon, six as unknown salmonids, and 29 as steelhead. Approximately one quarter of the redds were downstream of the confluence with Porter Creek (Figure 29). Of the 37 redds observed in the wetted habitat survey extent, 32 (89%) were in locations that remained wet through the 2021 dry season (Figure 31). One steelhead redd (3%) was in an area that became intermittent and four redds (8%), three steelhead redds and one unknown salmonid redd, were in locations that dried completely.

During the winter of 2021/22, 13 redds were observed in the project reaches, including nine coho salmon redds, two steelhead redds, and two unknown salmonid redds (California Sea Grant 2022b). No redds were documented on the surveyed reach of Porter Creek. The majority of the redds were observed above the confluence with Porter Creek (Figure 30). When compared to September 2022 wetted habitat results, 12 redds (92%) were in areas that remained wet through the summer and one steelhead redd (8%), a short distance upstream of the confluence with Porter Creek, was in a location that dried (Figure 31).

It should be noted that, in both winters, spawner surveys were not conducted on all of the CMP reaches where wetted habitat surveys occurred, so 2.9 km was excluded from this comparison in 2021 (Figure 29), and 5.9 km was excluded in 2022 (Figure 30). Also note that two additional steelhead redds were observed in Mark West Creek during the winter of 2020/21, for a total of 39 salmonid redds stream-wide (California Sea Grant 2021a), but they were outside of this project study area so were not included in the calcluations (Figure 31).

In both years, the vast majority of spawning activity was documented in locations that remained wet and connected through the dry season. A slightly higher proportion of redds were observed in locations that remained wet through the summer of 2022 than in 2021; 92% and 89%, respectively (Figure 31).

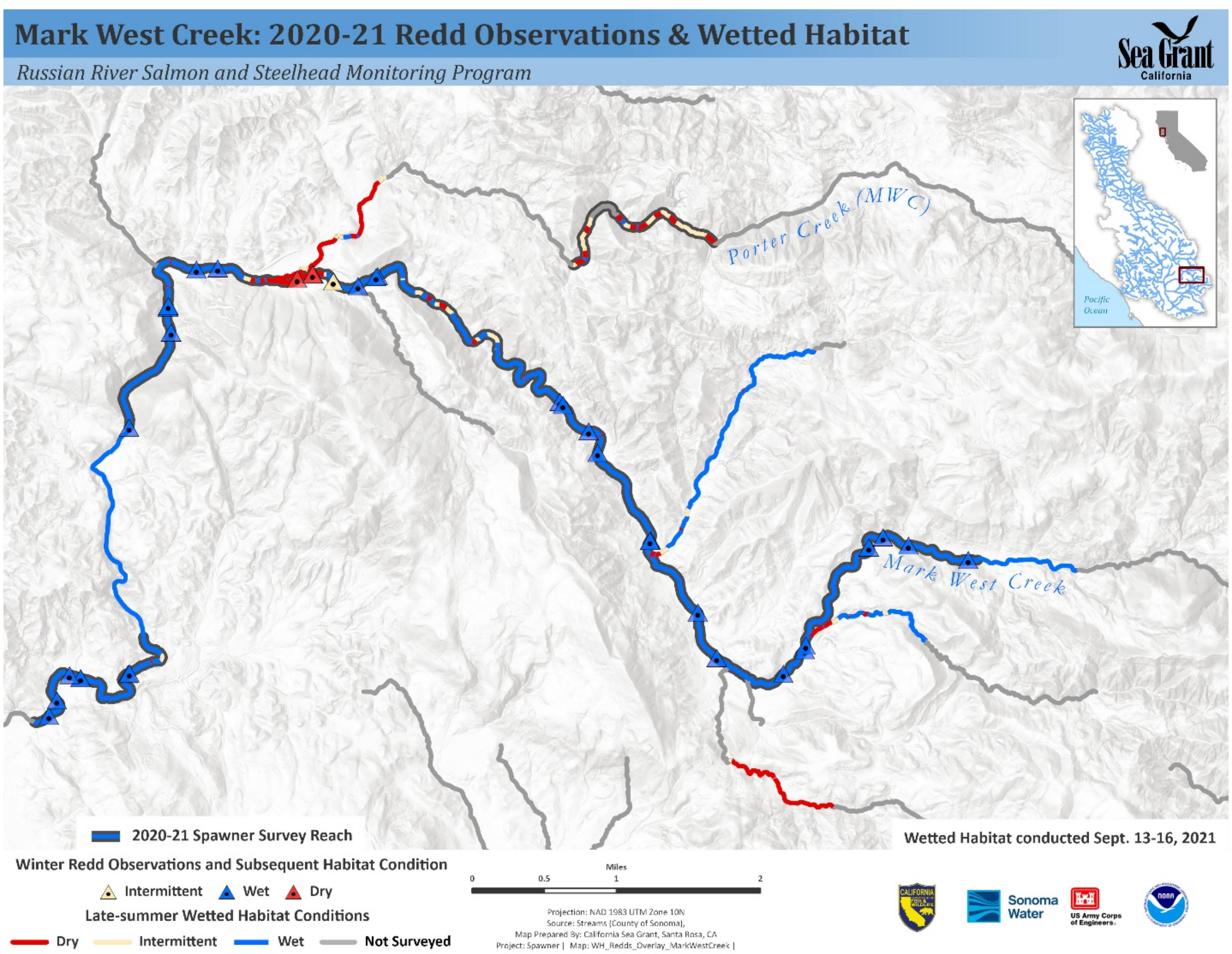

Figure 30. Winter 2020/21 Mark West Creek redd locations in relation to late-summer 2021 wetted habitat conditions. Sections of stream surveyed for both spawner surveys and wetted habitat surveys are outlined in grey, while those that only received wetted habitat surveys are shown as a thin line.

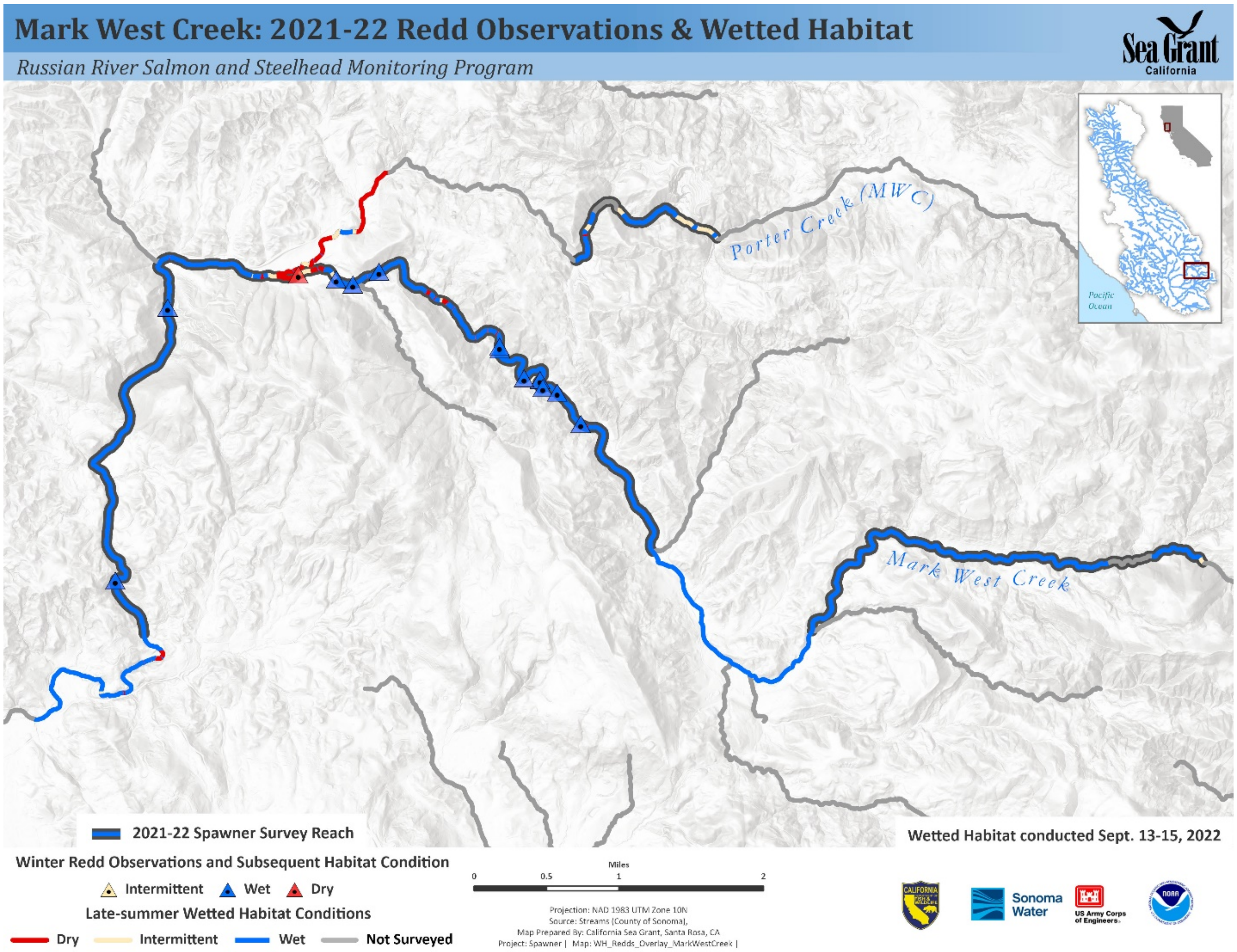

Figure 31. Winter 2021/22 Mark West Creek redd locations in relation to late-summer 2022 wetted habitat conditions. Sections of stream surveyed for both spawner surveys and wetted habitat surveys are outlined in grey, while those that only received wetted habitat surveys are shown as a thin line.

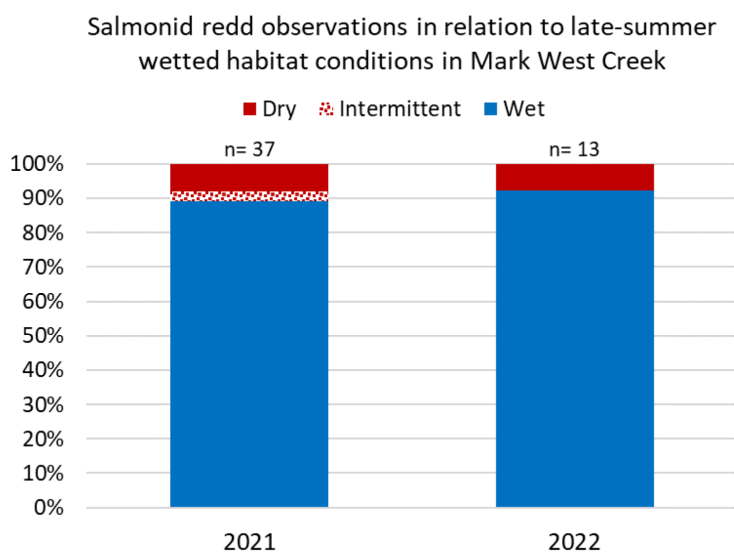

Figure 32. Proportion of salmonid redds observed (coho salmon, steelhead, and unknown salmonids) in relation to driest annual wetted habitat conditions (September) in Mark West Creek, summers 2021 and 2022. Note that two

additional steelhead redds were observed outside of the project study area during the winter of 2020/21.

Juvenile salmonids

In July and August of both seasons, snorkeling surveys were conducted by CSG and Sonoma Water to document the relative abundance and spatial distribution of coho salmon and steelhead yoy in Mark West Creek. Most of the survey reaches in the wetted habitat survey extent were snorkeled for CMP efforts, and the remaining reaches were surveyed to support this project. Coho salmon and steelhead yoy were counted in every second pool using methods outlined in *Coho Salmon and Steelhead Monitoring Report: Summer 2021* and *Coho Salmon* and *Steelhead Monitoring Report: Summer 2022*, and detailed outcomes can be found in those reports (California Sea Grant 2022a, California Sea Grant 2023). No snorkeling surveys were conducted in tributaries to Mark West Creek in summer 2021, though one reach of Porter Creek was snorkeled in 2022.

Comparing summer juvenile salmonid distribution to the driest stream habitat conditions documented later in the same summer—September of each study year in this case—offers useful insight into limiting factors experienced by rearing fish during the lowest streamflows of the dry season. Though it can vary based on site-specific conditions, habitat connected by surface flow is generally most likely to support rearing fish and maintaining pool connectivity has been proven to increase the probability of over-summer survival for juvenile salmonids (Obedzinski et al., 2018).

In 2021, the majority of coho salmon yoy were documented in the lower sections of Mark West Creek, though in very low densities (Figure 32). Twenty-three coho salmon yoy and 203 steelhead yoy were counted in every second pool, and these numbers were used to generate an expanded count of 46 coho salmon and 406 steelhead throughout all the project reaches surveyed (California Sea Grant 2022a).

Juvenile salmonid distribution data from 2021 were spatially joined with the September wetted habitat data (the least wet sample of 2021) and the total proportion of all yoy counted in each habitat condition—wet, dry, and intermittent—was calculated in order to estimate the effect of stream drying and wetted habitat condition on rearing fish. Overall, 92% of all salmon and steelhead yoy observed were seen in pools that stayed wet and connected, with just 8% in locations that became dry or intermittent (Figure 34).

Following a strong coho salmon spawning season over the winter of 2021/22, record-breaking numbers of juvenile coho salmon were observed in tributaries throughout the lower Russian River basin in the summer of 2022. A total of 1,156 juvenile coho salmon were counted in Mark West Creek, as well as 277 steelhead juveniles (California Sea Grant 2023). These numbers were used to generate an expanded count of 2,312 coho salmon and 554 steelhead yoy throughout all reaches surveyed. Juvenile salmonids were distributed fairly evenly throughout the surveyed extent, with the highest densities occurring above the confluence with Porter Creek and in the vicinity of the loggers at sites 11.C, 11.D, and 12.A (Figure 1, Figure 33). Overall, 87% of all coho salmon and steelhead yoy observed were seen in pools that stayed wet and connected, with just 9% in locations that became intermittent, and 4% in locations that dried completely (Figure 34).

In both years, the vast majority of rearing fish were documented in locations that maintained wet and connected habitat. Despite there being slightly more available wetted habitat in the study reaches during the driest sample of 2022 than in 2021 (95% and 92%, respectively), 5% more coho salmon and steelhead yoy were observed in areas that remained wet and connected through the dry season in 2021 (92%) than in 2022 (87%) (Figure 34).

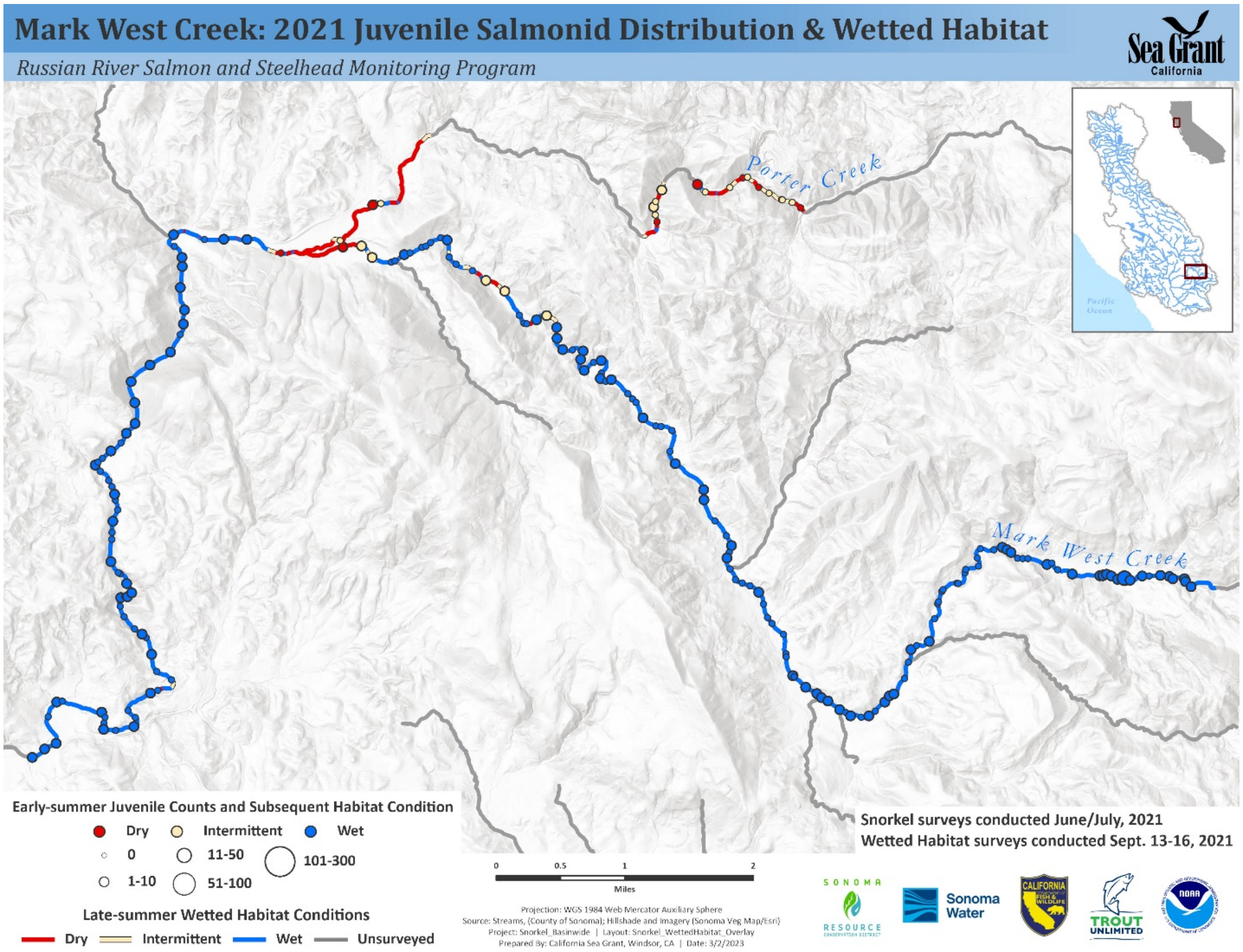

Figure 33. Summer 2021 Mark West Creek salmonid young-of-the-year observations in relation to September 2021 wetted habitat conditions.

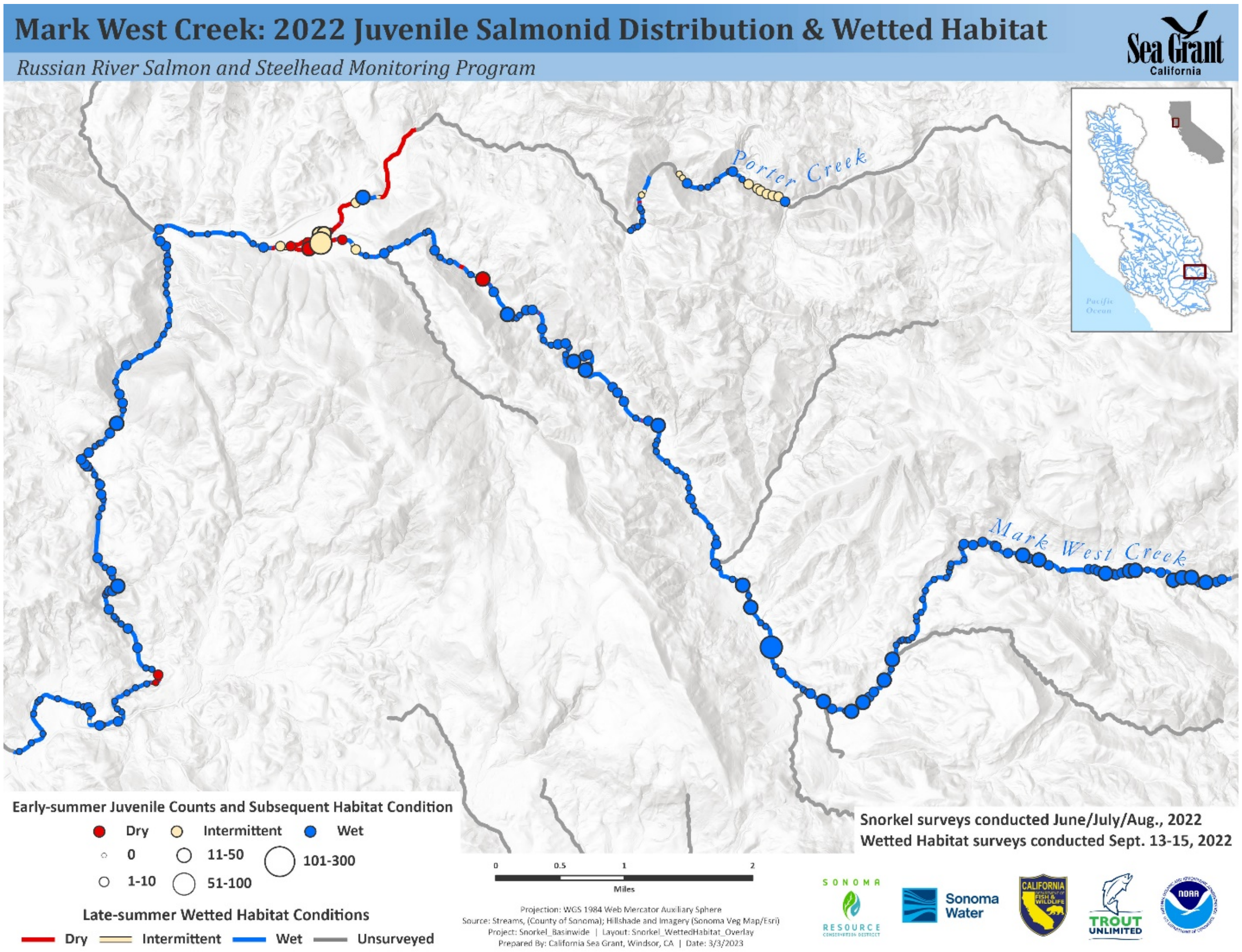

Figure 34. Summer 2022 Mark West Creek salmonid young-of-the-year observations in relation to September 2022 wetted habitat conditions.

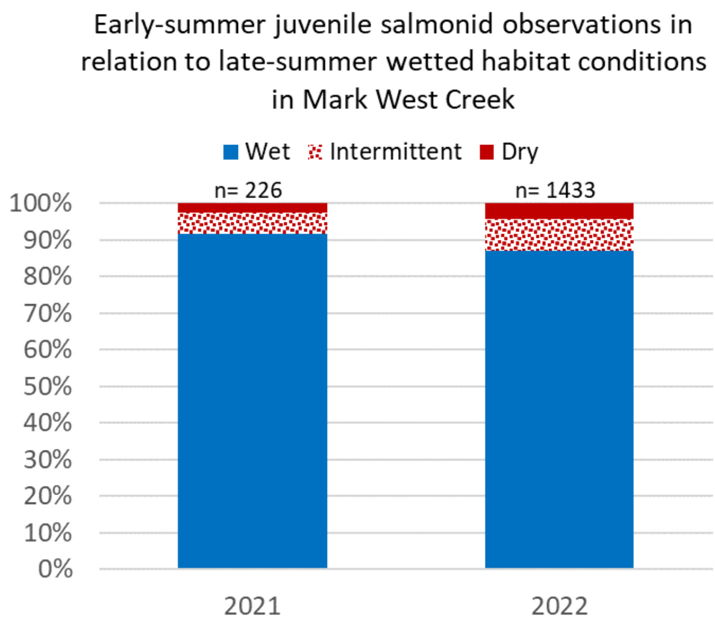

Figure 35. Proportion of minimum counts of juvenile salmonids, both coho salmon and steelhead, in relation to driest wetted habitat conditions (September) in Mark West Creek, summers 2021 and 2022.

7. Water quality

Continuous dissolved oxygen (DO) loggers, which also measure temperature, were deployed in six pools throughout the surveyed extent of Mark West Creek, with locations noted by river km in Table 2. These Onset U26 loggers measured DO concentrations and water temperatures at 15-minute intervals from mid-May through late October. The logger locations were selected to generally represent conditions in the surrounding area, though it should be noted that measurements of DO concentrations are ordinarily site specific, particularly under low flow conditions. Three of the DO loggers were placed in the same locations as TU flow gages to allow comparison of DO to streamflow.

Twelve continuous water temperature loggers were also deployed in the survey reaches (Figure 1, Table 2). Considerations for site selection included data gaps described by O'Connor Environmental Inc. (Kobor et al. 2020), as well as spatial distribution and landowner access permissions. One continuous logger was deployed to measure air temperature near the center of the study area. Data calibration and processing procedures are described in the WCB contract report *Flow and survival studies to support endangered coho recovery in flow-impaired tributaries of the Russian River Basin* (California Sea Grant 2019).

Due to the immense amount of rainfall and subsequent rapid stream level rise that occurred during the atmospheric river event in late October 2021, one DO logger and five temperature loggers were washed out and lost (Table 2). Complete datasets were obtained from all other loggers during 2021, except for the DO logger at site 10.A, which was erroneously set to 5-minute sampling intervals and consequently ran out of battery early in the season. In 2022, complete datasets were obtained for all monitored sites.

Dissolved oxygen

Suitable DO concentrations are essential for fish survival and fitness, and DO may fall below suitable concentrations under low streamflow conditions during the dry season. The North Coast Regional Water Quality Control Board (NCRWQCB) has listed 6.0 mg/L as a daily minimum DO objective for the Russian River Hydrologic Unit (NCRWQCB 2015); decreases in swimming speed and growth rate occur below this concentration (U.S. Environmental Protection Agency 1986). Juvenile salmonids consistently avoid waters with DO concentrations below 5.0 mg/L (Washington State University Department of Ecology 2002). The lower limit to avoid mortality in salmonids is 3.0 mg/L (U.S. Environmental Protection Agency 1986). Continuous DO data from the summer period were compared to the 6.0 mg/L minimum daily objective and the 3.0 mg/L salmonid mortality threshold to evaluate conditions experienced by juvenile salmonids.

Daily minimum DO concentrations in Mark West Creek were above the regional daily minimum objective (6.0 mg/L) at all sites when monitoring was initiated in late May of both study years. DO persisted above that threshold into early June and began to decrease in mid-June or early July, depending on site and year (Figure 35). The declines in daily minimum values across sites were similar in magnitude, but varied slightly in timing between years. Daily minimum DO concentrations dropped below the regional daily minimum objective earlier during 2021 than during 2022, with the exception of site 14.A. This site, the farthest upstream monitored location, experienced oxygen-rich conditions during both years—likely due to an abundance of algae—with only a handful of days where minimum concentrations dropped below the regional objective.

Data from sites 10.C and 12.B illustrate the delayed onset of declining DO concentrations during 2022. At site 10.C, the slope of the downward trend is similar between 2021 and 2022, but the first occurrence of DO dropping below the daily minimum objective was two weeks later in 2022 (Figure 35). Similarly, at site 12.B, DO first fell below the 6.0 mg/L objective on May 31, 2021 and three weeks later in 2022, on June 21. Once DO concentrations dropped below this threshold, they generally remained low for the remainder of the dry season. In 2022, concentrations began increasing at most sites in September except for 10.C and 12.B, where improvements were slower and daily minimum values began meeting the objective again by early October.

We did not detect a trend in DO concentrations that reflected any distinct spatial pattern (i.e., upstream to downstream)(Figure 35). However, there were some comparable patterns observed between sites within a given year. During 2021, a sudden and short-lived drop in daily minimums was observed at sites 10.A, 12.B, and 13B. In 2022, DO trends were also similar between sites 11.A and 10.C.

The proportion of all sample days that met the regional daily minimum objective of 6.0 mg/L was calculated for both study years. In 2021, the only site that had a complete dataset and met the daily minimum DO objective more than half of days sampled was 14.A (Table 3). DO conditions were generally better in 2022, when sites 10.A, 13.B, and 14.A met the daily objective more than 85% of the time. For all sites in which there were complete datasets for both years, a greater proportion of both sites and days met the objective in 2022 than in 2021, ranging from 3% more days at site 14.A to 42% more at site 13.B (site 10.A was excluded from this calculation, due to the disparity in days sampled per year). It should be noted that variability in the number of days sampled was due to lost instruments, scheduling constraints and, in the case of site 10.A in 2021, a deployment error.

DO concentrations typically follow a diurnal pattern, with highest values occurring later in the afternoon after peak photosynthesis by aquatic plants and algae, and lowest values occurring before sunrise, long after photosynthesis pauses and biotic consumption of oxygen continues. It is useful to evaluate continuous data to determine if fish rearing in the vicinity of the loggers experienced sustained low-DO conditions, or if there was relief from those conditions when DO was highest. Two sites with complete continuous datasets were selected for closer examination in this context: 10.C and 12.B. Site 10.C was selected because it was the first DO monitoring site downstream of the section of Mark West Creek that experienced the greatest intermittency, and because the yearly trends diverged after the initial decline in daily minimums (Figure 35). Site 12.B was selected because the trends were relatively similar in both years, though the timing was offset by several weeks in 2022.

At 10.C, 10% of sampled days in 2021 and 31% of the sampled days in 2022 met the regional objective (Table 3). In 2021, DO concentrations fell below 6.0 mg/L in mid-June and even daily maximum values did not surpass the objective for the rest of the season (Figure 36). DO continued to decline, with minimum daily values less than 3.0 mg/L in late July, and by September, the majority of all continuous measurements were below the mortality threshold and eventually reached 0.0 mg/L. Once DO was depleted at this site, concentrations did not recover for the rest of the monitoring season. In 2022, daily DO concentrations fluctuated more than in 2021, and daily maximums were often above the 6.0 mg/L objective, which would have provided rearing fish with relief from the low daily minimum concentrations.

Continuous DO concentrations provided relief for fish in both years at site 12.B. Though the daily minimum objective was met only 29% and 35% of sample days in 2021 and 2022, respectively, daily maximums often exceeded 6.0 mg/L (Table 3, Figure 36). This same pattern, of continuous DO concentrations providing relief from the daily minimums, has been observed in other Russian River tributaries, such as Green Valley and Mill creeks. In both years, continuous concentrations at site 12.B in Mark West Creek began increasing in mid-September and continued to generally increase until the end of the monitoring period.

Water temperature

The optimum summer water temperature range for juvenile coho salmon is 10 to 15 °C (McMahon 1983). At water temperatures greater than 20 °C, significant decreases in swimming speed and increases in mortality due to disease occur, and water temperatures exceeding 25.5 °C have been shown to be lethal to coho salmon (McMahon 1983). In the nearby Mattole River watershed, coho salmon were not present in otherwise suitable rearing habitat when the maximum weekly average temperature (MWAT) exceeded 16.7 °C and maximum weekly maximum temperature (MWMT) exceeded 18 °C (Welsh et al. 2001). We chose to summarize the continuous water temperature in comparison to the 18 °C avoidance threshold described in the Mattole River due to the geographic proximity of that watershed to Mark West Creek.

Daily maximum temperatures in Mark West Creek during summer months (June-August) in 2021 and 2022 were not suitable for juvenile salmonids at any of the monitored sites. Temperatures were rarely below the 18 °C avoidance threshold at all sites in both years (Figure 37). Maximum temperatures were occasionally below the threshold at the beginning of the season and often reached desired cooler temperatures at the end of the season, by October.

Continuous air temperature was recorded at site 11.D. In 2021, high air temperature in June aligned with increased water temperature (Figure 38). In October 2021, there was a large decrease in air temperature as well as the range of daily temperatures, which corresponded to an increase of almost 5 °C in water temperatures. These shifts were caused by the atmospheric river event that occurred in late October.

In 2022, the air temperature logger was deployed in late June, so there are no air temperature data to examine in relation to the high June water temperatures. However, the spike in air temperature in September of that year aligns with increased water temperatures observed at all sites. Near the conclusion of the monitored period, air temperatures began to cool slightly, but the moderate decrease in air temperature does not explain the large decrease observed in water temperatures (Figure 38, Figure 39, Figure 37). It is likely that the small rain event in late September 2022 contributed to this shift (section 4).

Temperatures were slightly cooler in 2021 than in 2022 (Figure 37), and while the number of days sampled varied slightly between years and sites, in 2021 there was a greater proportion of sampled days in which the daily maximum temperature was below 18 °C (Table 4). The average proportion of days that were below the threshold was 38% in 2021 and 20% in 2022. At the majority of sites in both years, the hottest water temperatures occurred in June, though a handful of sites experienced hottest temperatures later in the season. The highest water temperatures recorded for the study period in both years occurred at site 8.B: 27.3 °C on June 18 2021 and 26.9 °C on September 6 2022. Site 8.B had consistently warmer water temperatures than the other sites. Daily maximums at this site were below the 18 °C avoidance threshold only 11% of the monitored days in 2021 and 4% in 2022.

The coolest temperatures in 2021 were observed at site 13.B, which experienced daily maximums below the threshold on 70% of the sampled days. In 2022, site 11.C had the greatest proportion of days in which the daily maximum temperature was below 18 °C, though it was below the objective 40% of the monitored days. Water temperatures were variable by site and year, and no stream-scale spatial trends were apparent (Figure 37).

Overall, water temperatures in the Mark West Creek study pools were too warm for rearing salmonids and daily variability in continuous water temperatures did not appear to provide refuge from excessively high daily maximums. This is illustrated by the data for sites 10.C and 12.B (Figure 39); the same sites used to evaluate continuous DO concentrations above. From July to September, even the coolest temperatures at site 10.C were at or above 18 °C in both years, with daily maximums consistently above 20°C. While maximum temperatures at site 12.B were more or less comparable, daily minimum values dropped below the avoidance threshold more frequently, which may have provided some relief during the warmest period of the summer for fish in that pool. While water temperatures vary somewhat by site, they are generally far more consistent between sites than DO concentrations (Figure 36, Figure 39). It is likely that refuge from excessive temperatures is uncommon throughout the study reaches of Mark West Creek for rearing juvenile salmonids.

Habitat suitability

Juvenile salmonids occupying Mark West Creek experienced a dynamic suite of physical, chemical and hydrological habitat conditions simultaneously. While it is useful to analyze wetted habitat, DO, and temperature data separately, evaluating them collectively in relation to salmon tolerances paints a clearer picture of overall habitat suitability and highlights daily habitat impairment during the summer season. Biologists at CSG developed a framework to characterize habitat suitability at a daily scale in monitored pools. The factors used to characterize daily habitat suitability included the presence of water and whether water quality objectives described above were met; specifically, daily minimum DO was equal to or greater than 6.0 mg/L and maximum daily water temperature was below 18 °C. Pool units were described using the following categories: “suitable” if the pool was wet and met the water quality objectives on a given day, “partially impaired” if the pool was wet but one of the two water quality objectives were not met, “fully impaired” if the pool was wet but neither water quality objective was met, “dry” if the pool was dry, and “no data” if habitat suitability could not be determined due to lack of data. However, none of the monitored sites went dry in Mark West Creek during the study period.

Daily habitat suitability was determined for each site from May 10 to October 20 (166 days), in both 2021 and 2022, to allow for visual comparison between years (Figure 40). The proportions of monitored days per year classified in each category were also calculated (Table 5). The proportion of monitored days classified as suitable ranged from 8-41% in 2021, and 9-34% in 2022. Habitat suitability at sites 10.A and 11.A could not be compared between 2021 and 2022 due to incomplete datasets, but there were more days designated as suitable in 2021 than in 2022 at the remaining four sites; 10.C, 12.B, 13.B, and 14.A. Overall, suitable habitat was present on more days at the beginning and end of each monitoring season for all sites and both years. Site 13.B had suitable habitat intermittently in 2021 and rarely in 2022, but was the only site that met suitability criteria midsummer in both years. It also experienced the highest proportion of days with suitable habitat in both years.

There does appear to be a spatial trend in habitat suitability, with the worst sites in the middle and lower sections of the study area. There is also a strong temporal trend; the onset of partial or complete habitat impairment began in June at all sites, in both years. There was a slight delay in the onset of full impairment in 2022, compared to 2021, by approximately two weeks (Figure 40). This delay was likely caused by a rain event that increased flows in the first week of June, 2022 (section 3 and 4). Generally, once conditions became fully impaired, they remained impaired until the end of the dry season. In all cases, conditions gradually improved as the dry season came to a close and flows began to increase with minor rain events and reduced evapotranspiration demand.

Table 2. Water quality monitoring sites in Mark West Creek, summers 2021 and 2022. Dissolved oxygen loggers also measured water temperature. Grey shading indicates loggers for which data were not retrieved due to loss or damage in 2021. Complete datasets were collected for all sites in 2022.

Site name	Approximate river kilometer	Logger type
8.A	23.61	Temperature
8.B	26.11	Temperature
9.A	27.19	Temperature
9.B	28.70	Temperature
10.A	30.20	Dissolved oxygen, temperature
10.B	31.27	Temperature
10.C	32.26	Dissolved oxygen, temperature
11.A	33.49	Dissolved oxygen, temperature
11.B	34.36	Temperature
11.D	35.81	Temperature (air)
11.C	35.81	Temperature
12.A	37.43	Temperature
12.B	38.56	Dissolved oxygen, temperature
13.A	40.95	Temperature
13.B	42.14	Dissolved oxygen, temperature
13.C	42.74	Temperature
14.A	44.41	Dissolved oxygen, temperature
14.B	45.29	Temperature
15.A	47.91	Temperature

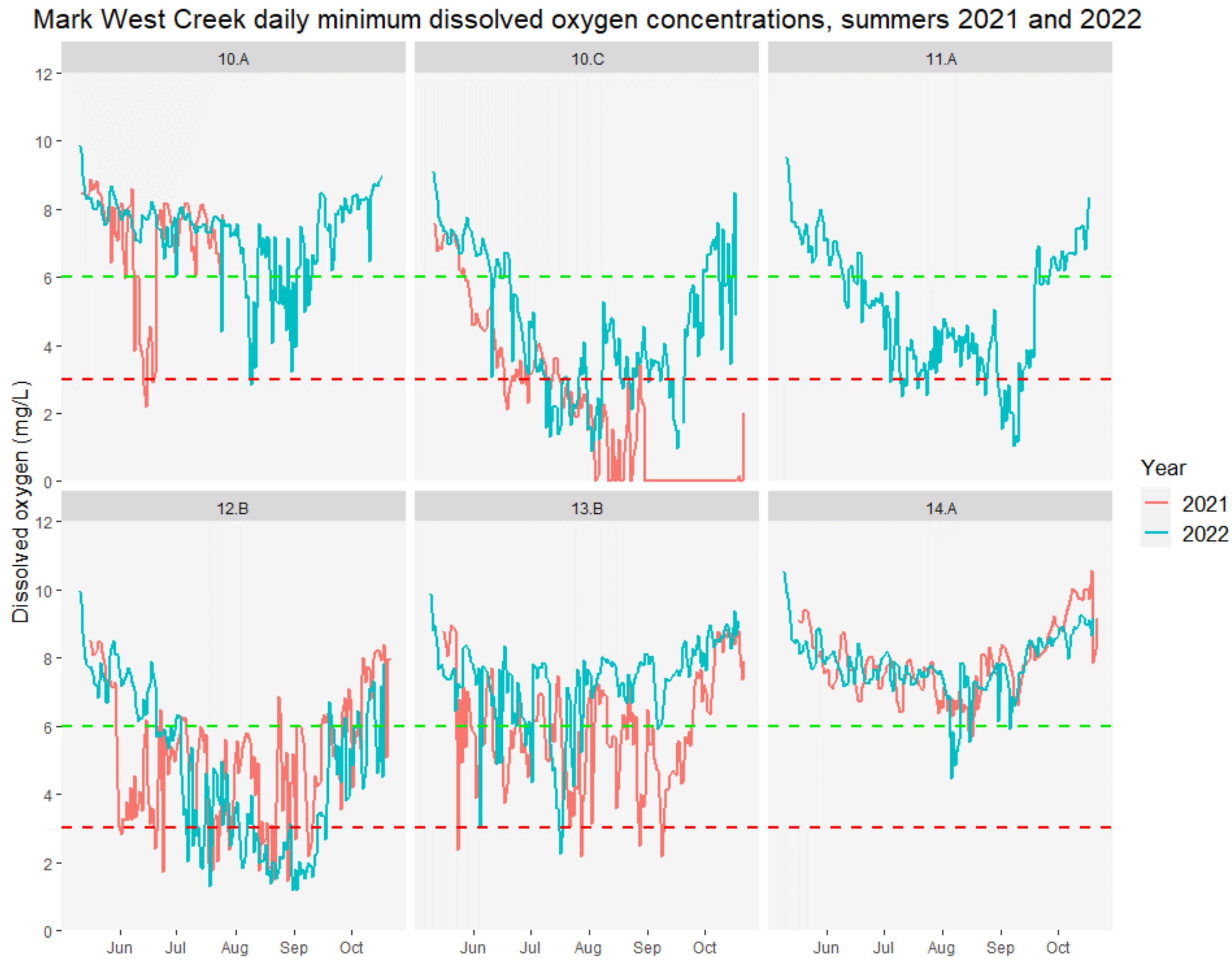

Figure 36. Daily minimum dissolved oxygen by site in Mark West Creek, summers 2021 and 2022. Dashed green line represents the regional daily minimum objective of 6.0 mg/L and the dashed red line represents the mortality threshold of 3.0 mg/L. The dataset for site 10.A in 2021 ends mid-season due to a logger deployment error, and no data were retrieved for 11.A in 2021 due to the loss of the logger during a storm event.

Table 3. Number of days in which DO was continuously sampled at logger sites in Mark West Creek and the proportion of days that met the regional daily minimum objective of 6.0 mg/L, summers 2021 and 2022.

	2021		2022	
Site name	**Days sampled**	**% of days DO objective met**	**Days sampled**	**% of days DO objective met**
10.A	76	86%	161	87%
10.C	164	10%	161	31%
11.A	N/A	N/A	161	37%
12.B	159	29%	162	35%
13.B	159	46%	163	88%
14.A	159	99%	164	96%

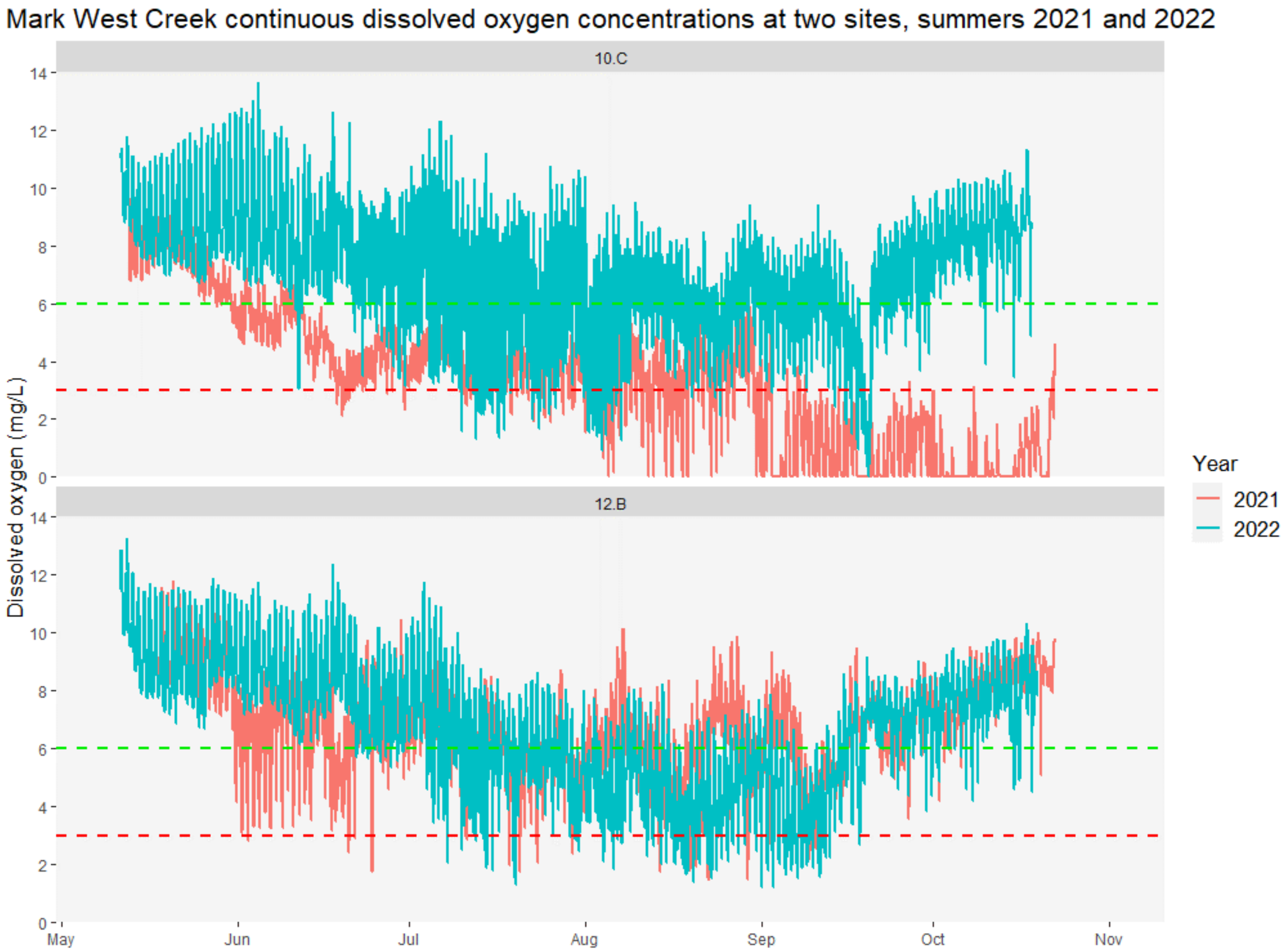

Figure 37. Mark West Creek continuous dissolved oxygen at sites 10.C (top panel) and 12.B (bottom panel), summers 2021 and 2022. Dashed green line represents the regional daily minimum objective of 6.0 mg/L and the dashed red line represents the mortality threshold of 3.0 mg/L.

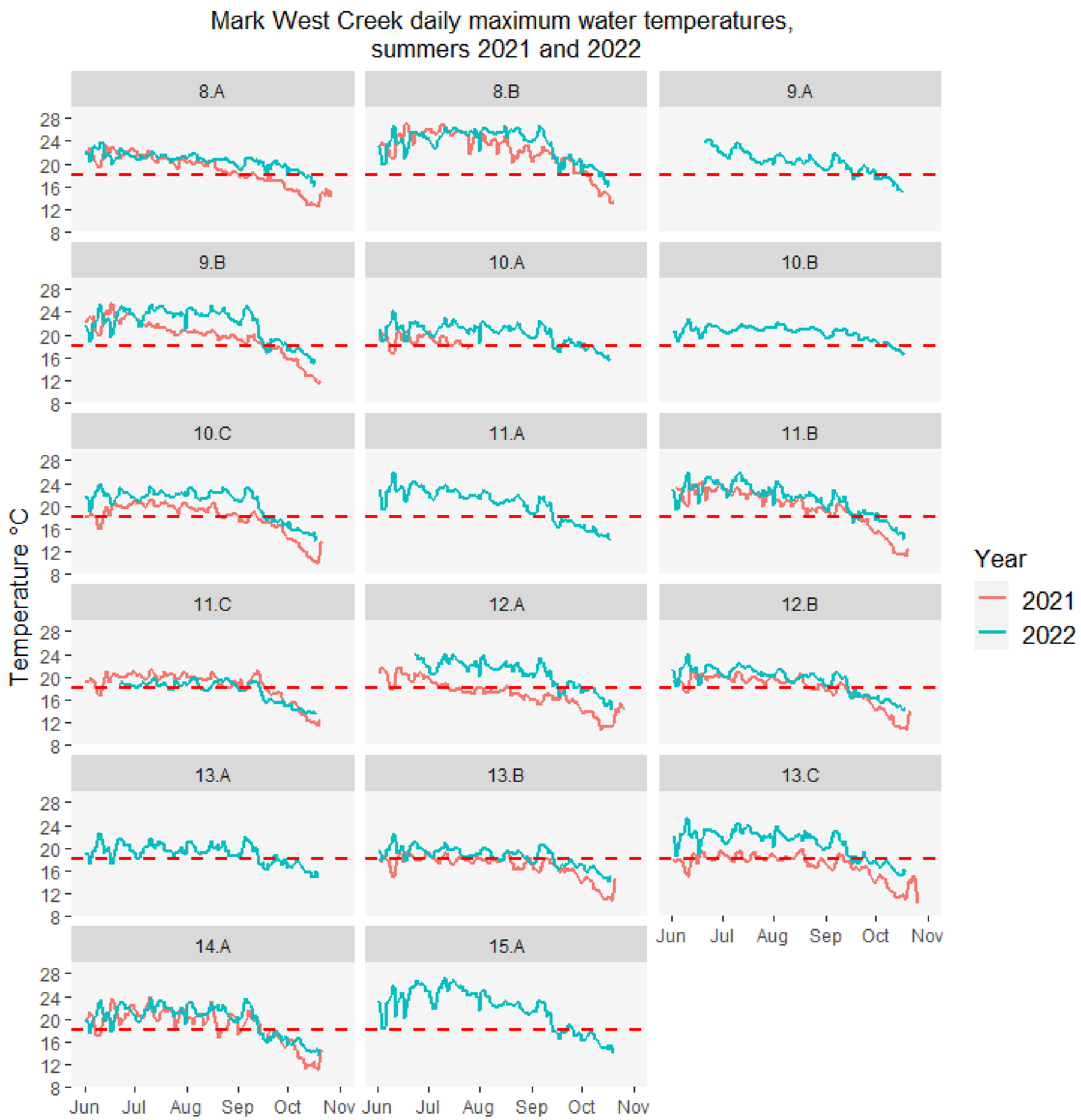

Figure 38. Daily maximum water temperatures by site in Mark West Creek, summers 2021 and 2022. Dashed red line represents 18°C avoidance threshold.

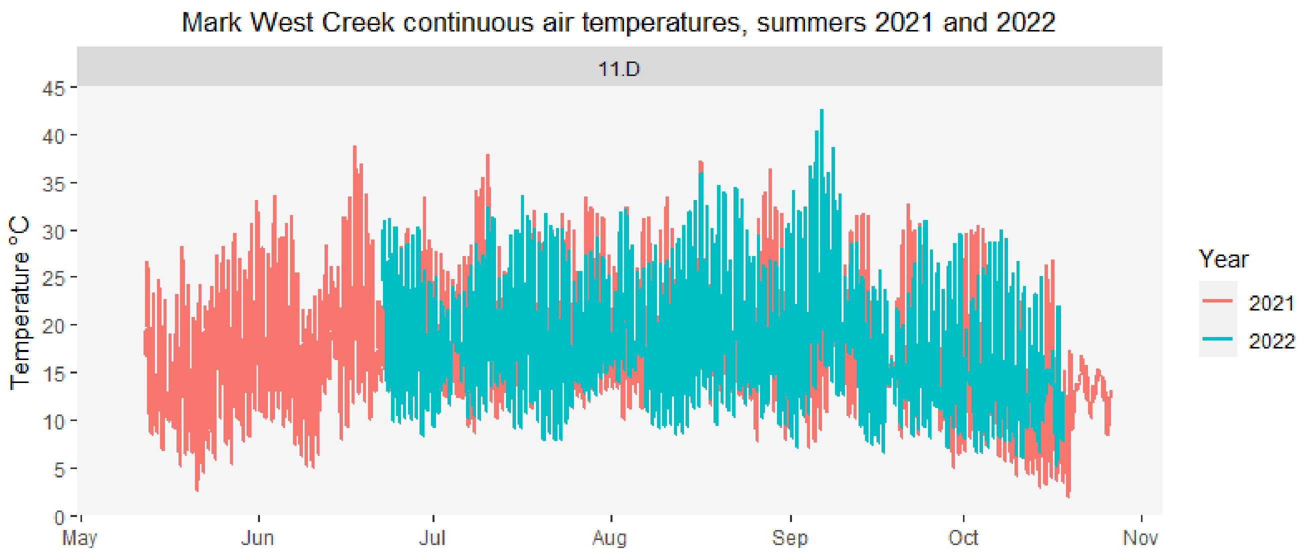

Figure 39. Mark West Creek continuous air temperatures at site 11.D, summers 2021 and 2022.

Table 4. Number of days in which water temperature was continuously sampled at logger sites in Mark West Creek and the proportion of days that the daily maximum temperature was below the avoidance threshold of 18 °C, summers 2021 and 2022.

Site name	2021		2022	
	Days sampled	% of days below threshold	Days sampled	% of days below threshold
8.A	168	31%	160	5%
8.B	158	11%	160	4%
9.A	N/A	N/A	119	15%
9.B	162	22%	160	14%
10.A	76	16%	161	16%
10.B	N/A	N/A	161	7%
10.C	164	44%	161	20%
11.A	N/A	N/A	161	24%
11.B	140	23%	161	14%
11.C	163	34%	119	40%
12.A	169	65%	119	18%
12.B	159	40%	162	24%
13.A	N/A	N/A	163	33%
13.B	159	70%	163	34%
13.C	168	64%	163	20%
14.A	159	35%	164	30%
14.B	N/A	N/A	164	17%
15.A	N/A	N/A	164	21%

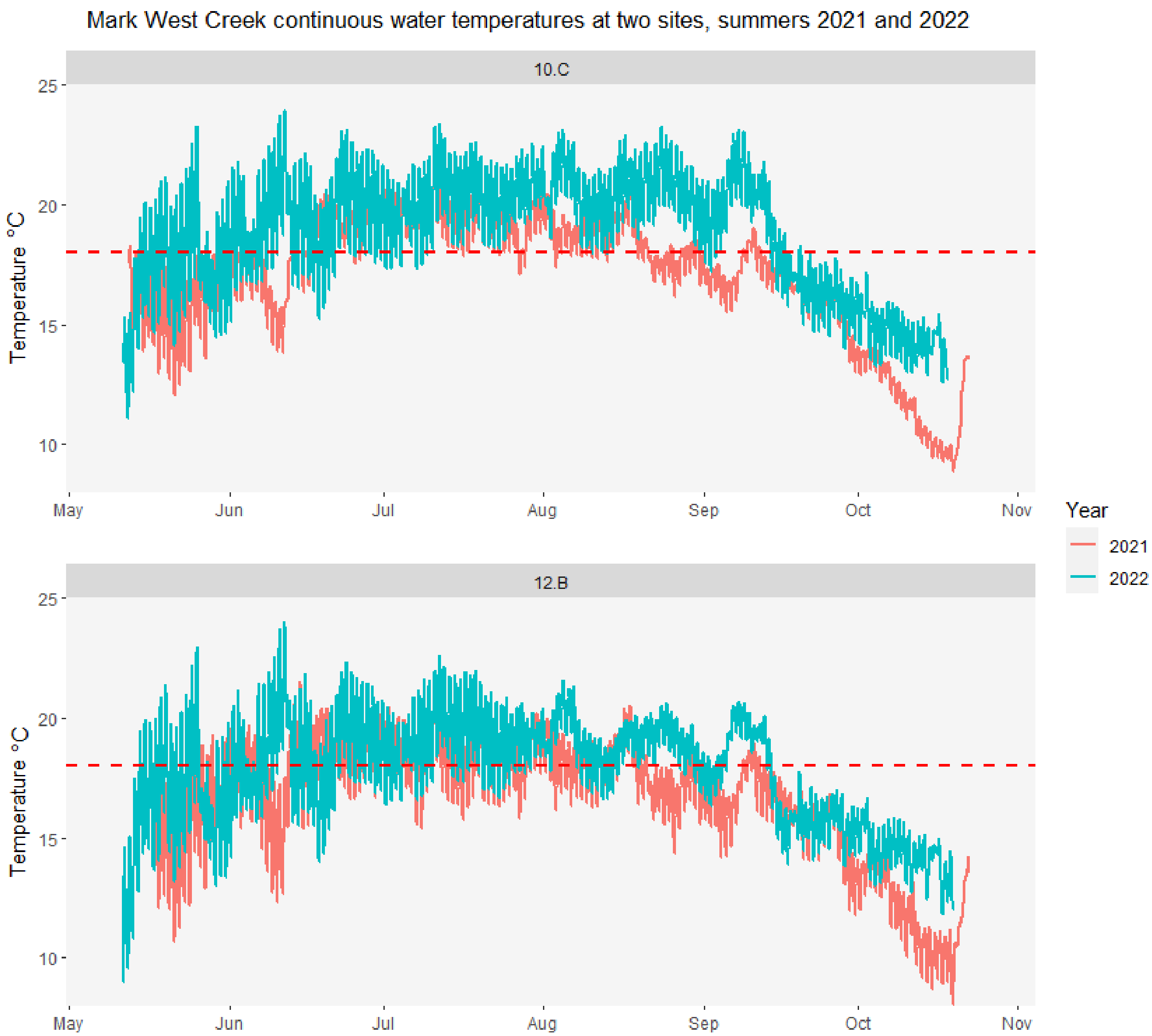

Figure 40. Mark West Creek continuous water temperatures at sites 10.C (top panel) and 12.B (bottom panel), summers 2021 and 2022. Dashed red line represents 18 °C avoidance threshold.

Figure 41. Habitat suitability at logger sites in Mark West Creek from May 10 to October 20, 2021 (top panel) and 2022 (bottom panel). Each tile represents one day, for a total of 166 days per site, per year. The habitat was considered suitable if it was wet and met both the DO and temperature thresholds. Partial impairment describes habitat that is wet but does not meet one of the two water quality thresholds. Full impairment indicates that neither the DO or temperature objectives were met, but the pool retained water. If there was no water in the sample pool, it was designated as dry. Days with no data are shown in grey. The dataset for site 10.A in 2021 ends mid-season due to a logger deployment error, and no data were available for 11.A in 2021 due to the loss of the logger during a storm event.

Table 5. Proportion of monitored days that met each habitat suitability classification, and the number of days monitored at the Mark West Creek DO logger sites, summers 2021 and 2022. In 2021, the logger at site 10.A failed early in the season due to a launch error and the logger at 11.A was lost in a storm, so full-season water quality data were not available, though the sites remained wet all season.

Year	Site	Habitat suitability				*# of days*
		Suitable	**Partially impaired**	**Fully impaired**	**Dry**	
2021	10.A	14%	72%	13%	0%	76
	10.C	8%	38%	54%	0%	164
	11.A	N/A	N/A	N/A	N/A	N/A
	12.B	21%	26%	52%	0%	159
	13.B	41%	34%	25%	0%	159
	14.A	35%	64%	1%	0%	159
2022	10.A	16%	71%	13%	0%	161
	10.C	10%	32%	58%	0%	161
	11.A	17%	27%	57%	0%	161
	12.B	9%	40%	51%	0%	162
	13.B	34%	55%	12%	0%	163
	14.A	30%	65%	4%	0%	164

8. Discussion

In 2021, the Russian River watershed, like much of the western region of the United States, experienced exceptional drought conditions on the heels of the severe drought of 2020 (https://droughtmonitor.unl.edu/Maps/MapArchive.aspx). WY 2021 was the second driest year in state record (California Department of Water Resources 2021) and the driest on record at the Healdsburg station. Overall, streams in the greater Russian River basin were drier than in 2015, when the driest in-stream conditions were previously documented at the peak of the recent historic drought (on average over all streams sampled; CSG unpublished data). Only 50% of the 118 miles of 45 streams where CSG mapped wetted habitat in the lower Russian River basin remained wet and connected through the 2021 dry season, and just 20% of all streams sampled had ≥ 90% wet and connected habitat by late summer (CSG unpublished data). Mark West Creek stood out as one of the rare streams that provided summer flow refugia to fish under exceptional drought conditions. Even at its driest point in 2021, the study area in upper Mark West Creek was still 92% wet and connected, demonstrating a measure of drought resilience that the majority of Russian River tributaries do not exhibit.

The 2022 water year was wetter than 2021 and characterized by severe drought in the Russian River region (https://droughtmonitor.unl.edu/Maps/MapArchive.aspx). Rain fall in WY2022 was 7.1 inches below median average, and 14.5 inches higher than WY2021. Streamflow conditions in Mark West Creek in May 2022 were in general approximately 10 times higher than were the previous year. Of the 121 miles sampled in 42 streams in the lower Russian River watershed, 66% remained wet and connected through the dry season. When *only the 39 streams that were sampled in both years* were compared, there was 18% more late-summer wetted habitat available to fish in 2022 (68%) than in 2021 (50%) (CSG unpublished data). A full 95% of Mark West Creek within the study area remained wet and connected through the 2022 dry season.

While WY2022 was a wetter year than WY2021, streamflow conditions recorded at TU's gage network in Mark West Creek reached similar levels in late summer 2022 as in 2021. This data represents the second year of post-fire data available for the watershed and it is possible it is showing the impacts of vegetation regrowth and human water development in the watershed post fire. Late summer conditions represent a time when evapotranspiration rates are highest, and it's possible that near stream vegetation could be negatively affecting streamflow. Low canopy, near stream vegetation management is recommended to reduce water demand while maintaining the upper canopy, which provides the shade needed to maintain cool water temperatures. Human water demands have also likely increased from WY2021 due to landowners' rebuilding and replanting. Storage and forbearance projects to reduce both surface and groundwater demands would likely improve late-summer flow.

Late-summer low flows were observed at the five streamflow gaging stations in the Mark West Creek watershed, with streamflow at all sites below 0.5 ft^3/sec by mid-July. Streamflow generally increased from the most upstream gage site to the farthest downstream site (as you would expect with the increase in drainage area), except for site (MW11) Mark West above van Buren, which had higher flow than the downstream sites. This streamflow patterned shifted in mid-June and by late summer, Mark West Creek above Porter Creek (MW02, the furthest downstream site) had the lowest streamflow. This reduction in flows from upstream to downstream may be caused by human water demands (both surface and groundwater pumping) as well as an increased evapotranspiration rate from vegetation regrowth post fire.

The most extensive stream drying in both study years occurred in the vicinity of the Porter Creek confluence, in particular immediately upstream of it. The lowest streamflow volume and greatest amount of dry and intermittent channel was documented on the current Regional Parks property in this area during the study years and in all previous years surveyed, while nearly all of Mark West Creek downstream and upstream of that point maintained perennial surface flow, with a handful of short stretches of disconnection or drying downstream of Michele Way (see CSG's annual wetted habitat viewer). The conditions captured during the September 2021 wetted habitat survey (Figure 19) can be considered baseline dry conditions under current surface and groundwater dynamics, given that this survey represents the most extensive sample conducted in the Mark West system under exceptional drought conditions, post- Tubbs and Glass fires, as well as post- Napa and Santa Rosa earthquakes; all natural events that impacted the flow regime.

Drying patterns were extremely variable in the tributaries where September 2021 wetted habitat surveys were conducted. Porter and Weeks creeks were incredibly dry, with just 5% and 0% of wetted habitat remaining in the surveyed extent, respectively, at the end of the season. On the contrary, 90% of Humbug Creek and 71% of Van Buren Creek remained wet. We can conclude that Porter and Weeks creeks are not able to support rearing fish and do not provide substantial hydrological inputs into Mark West Creek, particularly in dry years such as 2021. The main stem of Mark West Creek stayed wet and primarily connected for a good distance downstream of both Van Buren and Humbug creeks; however, both tributaries were dry at the confluence with Mark West Creek, so it is not clear to what extent they contribute flow inputs to the system.

In both study years, the vast majority of spawning activity and juvenile salmonid yoy were observed in locations that remained wet and connected through the dry season; 89% and 92% of redds, and 92% and 87% of coho salmon and steelhead yoy in 2021 and 2022, respectively. The minor difference between the relative proportion of redds and yoy located in areas that stayed wet in both years might be explained by juvenile fish dispersing from locations where they were spawned into wetter or drier areas at different rates. While a number of environmental and intrinsic factors could influence this, movement of juvenile salmonids has not been quantified in Russian River tributaries. In addition, the distribution of redds and juvenile fish in relation to late-summer habitat condition is not a simple reflection of the total amount of available wetted habitat, but of annual variability in spawning distribution and juvenile fish movement, as indicated by the fact that more yoy were seen in locations that dried or became intermittent in 2022, despite there being a higher proportion of wet, connected habitat. Overall, Mark West Creek has sufficient streamflow to support salmonid summer rearing even in the driest years, particularly as compared to the majority of lower Russian River tributaries.

Despite the relatively high amount of wet and connected dry-season habitat available in Mark West Creek, the quality of that habitat is not suitable for rearing juvenile salmonids for the majority of the season. The stream is severely temperature impaired, as shown by data from all 17 spatially-dispersed gaging sites, and continuous data indicate that there is minimal relief from daily maximum water temperatures. At some sites, fish appear to experience some relief from insufficient daily minimum DO concentrations due to diurnal fluctuations.

Water quality data from 2021 and 2022 highlight an atypical relationship between water temperature and DO in this stream. Colder water has a greater capacity to retain dissolved gasses (like DO) than warmer water, in the absence of additional inputs of DO from aeration or photosynthesis. However, in 2021, water temperatures were colder but monitoring sites had lower DO concentrations, while the water temperatures were warmer with higher DO concentrations in 2022. Higher rates of flow are often associated with higher DO, and it is possible that when flows drop below a certain threshold, temperature begins to exert a greater influence over DO concentrations. This lack of the typical inverse temperature-DO relationship implies that there are other, stronger drivers influencing DO during the dry season in Mark West Creek. We observed some comparable patterns between sites in a given year, which suggests that there may be stream- or landscape-scale factors influencing DO in the monitoring pools. Another factor that could likely be affecting DO concentrations is site-specific groundwater intrusion, though that evaluation is beyond the scope of this project.

When wetted habitat, DO, and temperature data were evaluated collectively in relation to salmon DO objectives and temperature tolerances, the monitored pools were classified as suitable only 25% of the time in 2021, on average across all sites. In 2022, the average proportion of days that were classified as suitable was just 19%. Increasing the number of days in which habitat is suitable for rearing fish by increasing DO concentrations and reducing water temperatures should be a priority for salmonid recovery in this system.

Site 13.B had the greatest proportion of days in which the habitat was classified as suitable in both years, and was the only site that had suitable habitat for any amount of time in midsummer. We have observed that sites like this, that teeter on the edge of water quality impairment, tend to respond quickly and positively to increases in streamflow (California Sea Grant 2019). It would be valuable to collect another year of water quality data at this site specifically, though continued monitoring of all sites is recommended to better understand the complex factors shaping habitat suitability for juvenile salmonids in Mark West Creek.

The primary take-away from the first two years of monitoring is that Mark West Creek provides valuable and relatively rare flow refugia for rearing juvenile coho salmon and steelhead in the Russian River basin, even under severe to exceptional drought conditions, though water quality conditions are in need of improvement. The relationship between streamflow and water quality is not yet clear, but appears to be different than that observed in nearby study streams, such as Green Valley Creek, where surface flow connectivity and increases in streamflow of as little as ≤0.1 ft^3/s have been shown to correspond with improvements in water quality (California Sea Grant 2020). A third year of data collection in a wetter water year may yield more conclusive data in regard to the ability of water quality impairment to be remediated through additional summer streamflow.

Moving into the 2023 sample year, with the change in project partners, we plan to continue the full extent of streamflow monitoring and water quality data collection, along with wetted habitat surveys at a reduced interval (due to unforeseen changes in the capacity of project partners)in order to fill remaining data gaps, establish patterns and trends over the three-year project period, document changes after streamflow project implementation, and investigate how streamflow and other measured parameters are influencing water quality conditions.

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