The Fall Midwater Trawl Survey

Season Report: 2023

California Department of Fish and Wildlife

Bay Delta Region (Stockton)

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Interagency Ecological Program

Cooperative Ecological Investigations Since 1970

Contents

Introduction

The Fall Midwater Trawl (FMWT) is an ecological monitoring survey that has been conducted by the California Department of Fish and Wildlife (CDFW) annually since 1967. Due to the creation of the federal and state water projects, concern over ecological impacts on the San Francisco Estuary (estuary) and its fisheries drove the creation of this survey. At its inception, the FMWT was focused primarily on determining relative abundance and distribution of age-0 Striped Bass (*Morone saxatilis*) (Stevens 1977) due to the popularity of the sport fishery in the state. The survey proved to be adept at monitoring pelagic fishes as well as recording associated environmental parameters. As such, it became an integral piece to the framework of compliance monitoring necessary to determine impacts from water exports, habitat degradation, and ecological shifts in the largest estuarine habitat in western North America.

The original sampling range and station placement of the survey occurred from San Pablo Bay upstream to the Lower Sacramento River and the Lower San Joaquin River, respectively. Station Placement and range effectively covered the estuary, which was a known nursery habitat for young Striped Bass (Turner and Chadwick 1972). This spatial and temporal coverage allowed for a more accurate calculation of young-of-the-year (age-0) Striped Bass relative abundance indices. FMWT also developed abundance and distribution information for other pelagic fishes that utilize part, or all of the estuary. These species include Delta Smelt (*Hypomesus transpacificus*), Longfin Smelt (*Spirinchus thaleichthys*), Splittail (*Pogonichthys macrolepidotus*), American Shad (*Alosa sapidissima*), and Threadfin Shad (*Dorosoma petenense).* The anadromous, and estuarine life histories of these species make them excellent indicators of watershed health due to their integration throughout the system. Low outflow conditions led to the creation of “non-index” stations in upstream areas of the Delta in the early 1990s, as well as an expansion into the north Delta in 2009 to increase Osmerid habitat sampling. Subsequent station additions were created in 2021 and 2023 to further broaden FMWT spatial sampling coverage in upstream habitats. This upstream station expansion has facilitated increased detection of pelagic fishes (White and Baxter 2022). Currently, FMWT samples 130 stations monthly from September through December (Figure 1). Sampling ranges from San Pablo Bay upstream to West Sacramento in the Sacramento River Deep Water Ship Channel (DWSC), and south to Stockton on the San Joaquin River. Since 2009, the survey has also conducted meso- and macro-zooplankton sampling at a subset of stations to track food web dynamics integral to recruitment of young fishes. This additional sampling helps to inform if reduced or altered prey abundance is a contributing factor in fish population declines.

The FMWT has been sampling annually for over half a century. The data collected has been fundamental in creating a baseline for fish abundance and distribution within the estuary and continues to be a key asset for understanding changes within this highly dynamic system. The FMWT is one of many long-term monitoring surveys conducted within the estuary (Tempel et al 2021), and is a monitoring element of the Interagency Ecological Program (IEP; see: Interagency Ecological Program 2023 Annual Work Plan). The work done by this survey has been central in determining water exports for one of the largest agricultural operations in the country, as well as for municipal use for over 25 million residents of California. Long term monitoring studies like the FMWT are important in recognizing and quantifying changes in the environment, linking biological patterns to environmental variability, and informing anthropogenic impacts on ecosystems (McGowan 1990; Cody and Smallwood 1996; Ducklow et al. 2009; Clutton-Brock and Sheldon 2010; Magurran et al. 2010; Nelson et al. 2011; Likens 2012; Lindenmayer et al. 2012; Hofmann et al. 2013; Hughes et al. 2017). For example, FMWT data has helped highlight a striking and sweeping decline in fish populations throughout the estuary (Sommer et al. 2007; Baxter et al. 2010; Mac Nally et al. 2010; Thomson et al. 2010), as well as underscoring resilience abilities of fish communities to long term drought cycles in the estuary (Mahardja et al. 2021). The FMWT also collaborates with other agency efforts, such as the CDFW Diet and Condition Study, the Department of Water Resources (DWR), Suisun Marsh Salinity Control Gate (SMSCG) Action, and U.S. Bureau of Reclamation (USBR) Directed Outflow Project (DOP) to inform summer and fall resource management actions. Also, the FMWT works collaboratively with the UC Davis Aquatic Health Program laboratory to address measures of fish condition.

The objective of this report is to summarize environmental variables and catch patterns that are not reported in the FMWT Annual Fish Abundance and Distribution Memorandum (Bibliography). The goal of the 2023 field season was to sample all stations safely and efficiently, identifying and counting all fishes and macro-invertebrates, and measuring the fork lengths (FL) of the first 50 randomly selected individuals of each fish species from each station. Meso- and macro-zooplankton samples were also collected at 35 stations to help inform food availability for young fish. A suite of environmental data was also recorded at each station. The first monthly survey began September 4th, 2023, and the final survey was completed on December 20th, 2023.

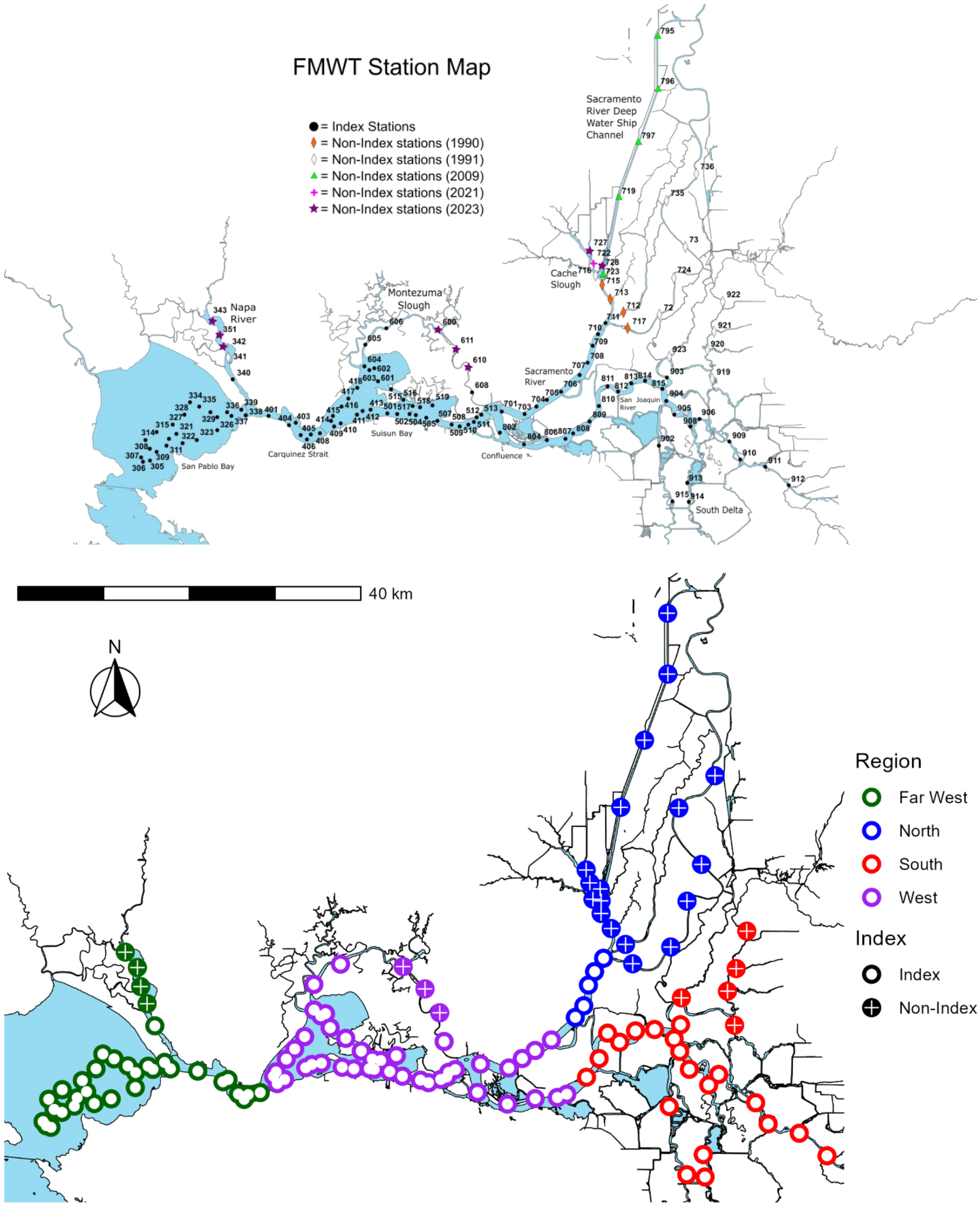

Figure 1. (Top) Map of Fall Midwater Trawl station locations and index designations with associated introduction years. (Bottom) Map of Fall Midwater Trawl station locations and station index designations for regional analyses. Regions are based on the work being conducted by the Monitoring Survey Design Team (Slater et al. 2023).

Methods and Gear

The FMWT trawl net consists of a 12 ft x 12 ft mouth (3.6576 m x 3.6576 m), is 58 ft long (17.68 m), and made of 9 mesh panels starting with 8-inch (203.2 mm) stretched mesh openings near the mouth tapering down mesh sizes to ½-inch (12.7 mm) stretched knotted mesh at the cod end. The net is deployed and allowed to sink with up to 91.4 m (300 ft) of cable let out then retrieved obliquely through the water column according to a cable out tow schedule which varies with water depth. Metal planing doors fixed at each corner of the mouth of the net assist in keeping the net open during sampling. Further details on sampling methods and gear can be found in the FMWT protocol document. Each oblique tow is 12 minutes long and each of the 130 FMWT stations receives one tow. The survey currently takes 12-14 days to cover the FMWT spatial range each month (September-December).

Figure 2. Crew retrieving the midwater trawl net on the back deck of the research vessel.

2023 Field Season

The 2023 field season had its challenges but was completed successfully. This year, an additional eight stations in regional upstream habitats were added to the survey–three in the lower Napa River, three in Montezuma Slough, and two in the Cache Slough/Liberty Island Complex (Figure 1). This put the total number of stations at 130, with a total of 520 fish tows conducted by the end of December's survey (Table 1). Each monthly survey began in San Pablo Bay and stations were sampled upstream to and through the Delta. For the initial San Pablo days, crew members stayed overnight in Vallejo and Benicia. This was cost effective and added to personnel safety by eliminating extraneous commutes before and after long days in the field. Colleagues at the U.S. Bureau of Reclamation (USBR) lent the survey the research vessel (R/V) Compliance, which served as the primary sampling vessel for the month of December.

Routine sampling of 130 fish tows and 35 zooplankton tows (Clark-Bumpus (CB) and Mysid nets) were completed for all months (September-December) in 2023 (Table 1). Besides routine sampling, additional zooplankton and phytoplankton sampling was conducted at 11 stations in September and October for the Suisun Marsh Salinity Control Gate (SMSCG) study on behalf of the California Department of Water Resources (DWR; Table 1). Overall, 2023 sampling contributed to the FMWT annual abundance indices and DWR SMSCG special study, with additional phytoplankton samples collected at a subset of stations.

Table 1. Number of Fish, Clark-Bumpus (CB), Mysid, and Phytoplankton (Phyto) samples collected at each station during the 2023 Fall Midwater Trawl Survey season conducted monthly, September-December. The SCG column denotes the number of samples associated with the SMSCG study.

Station	Region	Index	Fish net	CB net	Mysid net	SCG	Phyto
305	Far West	Index	4	0	0	0	0
306	Far West	Index	4	0	0	0	0
307	Far West	Index	4	0	0	0	0
308	Far West	Index	4	0	0	0	0
309	Far West	Index	4	0	0	0	0
310	Far West	Index	4	0	0	0	0
311	Far West	Index	4	0	0	0	0
314	Far West	Index	4	0	0	0	0
315	Far West	Index	4	0	0	0	0
321	Far West	Index	4	0	0	0	0
322	Far West	Index	4	0	0	0	0
323	Far West	Index	4	0	0	0	0
325	Far West	Index	4	0	0	0	0
326	Far West	Index	4	0	0	0	0
327	Far West	Index	4	0	0	0	0
328	Far West	Index	4	0	0	0	0

Station	Region	Index	Fish net	CB net	Mysid net	SCG	Phyto
329	Far West	Index	4	0	0	0	0
334	Far West	Index	4	0	0	0	0
335	Far West	Index	4	0	0	0	0
336	Far West	Index	4	0	0	0	0
337	Far West	Index	4	0	0	0	0
338	Far West	Index	4	0	0	0	0
339	Far West	Index	4	0	0	0	0
340	Far West	Index	4	0	0	0	0
341	Far West	Non-Index	4	0	0	0	0
342	Far West	Non-Index	4	0	0	0	0
343	Far West	Non-Index	4	0	0	0	0
351	Far West	Non-Index	4	0	0	0	0
401	Far West	Index	4	0	0	0	0
403	Far West	Index	4	0	0	0	0
404	Far West	Index	4	0	0	0	0
405	Far West	Index	4	4	4	0	0
406	Far West	Index	4	0	0	0	0
407	Far West	Index	4	0	0	0	0
408	Far West	Index	4	0	0	0	0
409	West	Index	4	0	0	0	0
410	West	Index	4	0	0	0	0
411	West	Index	4	4	4	0	0
412	West	Index	4	0	0	0	0
413	West	Index	4	0	0	0	0
414	West	Index	4	0	0	0	0
415	West	Index	4	0	0	0	0
416	West	Index	4	4	4	0	0
417	West	Index	4	0	0	0	0
418	West	Index	4	4	4	0	0
501	West	Index	4	4	4	0	0
502	West	Index	4	0	0	0	0
503	West	Index	4	0	0	0	0
504	West	Index	4	4	4	0	0
505	West	Index	4	0	0	0	0
507	West	Index	4	0	0	0	0
508	West	Index	4	4	4	2	0
509	West	Index	4	0	0	0	0
510	West	Index	4	0	0	0	0

Station	Region	Index	Fish net	CB net	Mysid net	SCG	Phyto
511	West	Index	4	0	0	0	0
512	West	Index	4	0	0	0	0
513	West	Index	4	4	4	2	0
515	West	Index	4	0	0	0	0
516	West	Index	4	0	0	0	0
517	West	Index	4	0	0	0	0
518	West	Index	4	0	0	0	0
519	West	Index	4	4	4	2	2
601	West	Index	4	0	0	0	0
602	West	Index	4	4	4	2	2
603	West	Index	4	0	0	0	0
604	West	Index	4	0	0	0	0
605	West	Index	4	2	0	2	2
606	West	Index	4	4	4	2	2
608	West	Index	4	4	4	0	0
609	West	Non-Index	4	4	4	2	2
610	West	Non-Index	4	4	4	2	2
611	West	Non-Index	4	4	4	2	2
701	West	Index	4	0	0	0	0
703	West	Index	4	0	0	0	0
704	West	Index	4	4	4	2	2
705	West	Index	4	0	0	0	0
706	West	Index	4	4	4	2	2
802	West	Index	4	4	4	2	2
804	West	Index	4	4	4	0	0
806	West	Index	4	0	0	0	0
807	West	Index	4	0	0	0	0
808	West	Index	4	0	0	0	0
707	North	Index	4	4	4	0	0
708	North	Index	4	0	0	0	0
709	North	Index	4	0	0	0	0
710	North	Index	4	0	0	0	0
711	North	Index	4	4	4	0	0
712	North	Non-Index	4	0	0	0	0
713	North	Non-Index	4	0	0	0	0
715	North	Non-Index	4	0	0	0	0
716	North	Non-Index	4	4	4	0	0
717	North	Non-Index	4	0	0	0	0

Station	Region	Index	Fish net	CB net	Mysid net	SCG	Phyto
719	North	Non-Index	4	4	4	0	0
72	North	Non-Index	4	0	0	0	0
722	North	Non-Index	4	4	4	0	0
723	North	Non-Index	4	4	4	0	0
724	North	Non-Index	4	0	0	0	0
727	North	Non-Index	4	0	0	0	0
728	North	Non-Index	4	0	0	0	0
73	North	Non-Index	4	0	0	0	0
735	North	Non-Index	4	0	0	0	0
736	North	Non-Index	4	0	0	0	0
795	North	Non-Index	4	4	4	0	0
796	North	Non-Index	4	4	4	0	0
797	North	Non-Index	4	4	4	0	0
809	South	Index	4	4	4	0	0
810	South	Index	4	0	0	0	0
811	South	Index	4	0	0	0	0
812	South	Index	4	4	4	0	0
813	South	Index	4	0	0	0	0
814	South	Index	4	0	0	0	0
815	South	Index	4	4	4	0	0
902	South	Index	4	0	0	0	0
903	South	Index	4	0	0	0	0
904	South	Index	4	0	0	0	0
905	South	Index	4	0	0	0	0
906	South	Index	4	4	4	0	0
908	South	Index	4	0	0	0	0
909	South	Index	4	0	0	0	0
910	South	Index	4	4	4	0	0
911	South	Index	4	0	0	0	0
912	South	Index	4	4	4	0	0
913	South	Index	4	0	0	0	0
914	South	Index	4	0	0	0	0
915	South	Index	4	0	0	0	0
919	South	Non-Index	4	4	4	0	0
920	South	Non-Index	4	0	0	0	0
921	South	Non-Index	4	0	0	0	0
922	South	Non-Index	4	0	0	0	0
923	South	Non-Index	4	0	0	0	0

Station	Region	Index	Fish net	CB net	Mysid net	SCG	Phyto
Total			520	142	140	24	20

Outflow

The 2023 water year provided a much-needed relief since the state had been constricted in a three-year drought cycle. Reprieve was initiated with precipitation beginning in the fall of 2022 and persisting through the spring of 2023, all the while bolstered by record snowpack. The majority of the state's watersheds drain via the Sacramento and San Joaquin rivers into the upper San Francisco estuary.

Freshwater outflow is the most influential factor in the overall water quality of the estuary. It influences water clarity, temperature, dissolved oxygen, and salinity, which impacts fish and plankton communities by association (Kimmerer et al. 1998, Kimmerer 2002 a; Kimmerer 2002 b; Bennett 2005). Variability in freshwater outflow regulates the position of the "low salinity zone" (LSZ) (Jassby et al. 1995; Hobbs et al. 2006), which can occur as far west as San Pablo Bay under high outflow or as far east as the Delta under low outflow conditions. X2 is a measurement of kilometers from the Golden Gate Bridge where water salinity is 2 parts per thousand near the bottom and used to inform the location, roughly at the center, of the LSZ (FLOAT MAST 2022). The 2023 water year provided consistent outflow from February through June (Figure 3). This pushed and kept the LSZ in Suisun Bay. By keeping the LSZ in Suisun Bay, this created a broader area of mixing and a larger nursery habitat as a whole. All of this was occurring during crucial winter to spring spawning and spring to fall rearing months. In the 2022 water year (October-September), outflow was dismal and the LSZ was bottle-necked at the lower Sacramento and San Joaquin rivers. That greatly limited rearing habitat as well as negatively impacted abiotic environmental parameters. The abiotic and biotic trends discussed in this seasonal summary were impacted by this outflow relationship and showed a notable improvement from last season. Outflow and X2 data for Figure 3 were provided by the Dayflow program (DWR 2024).

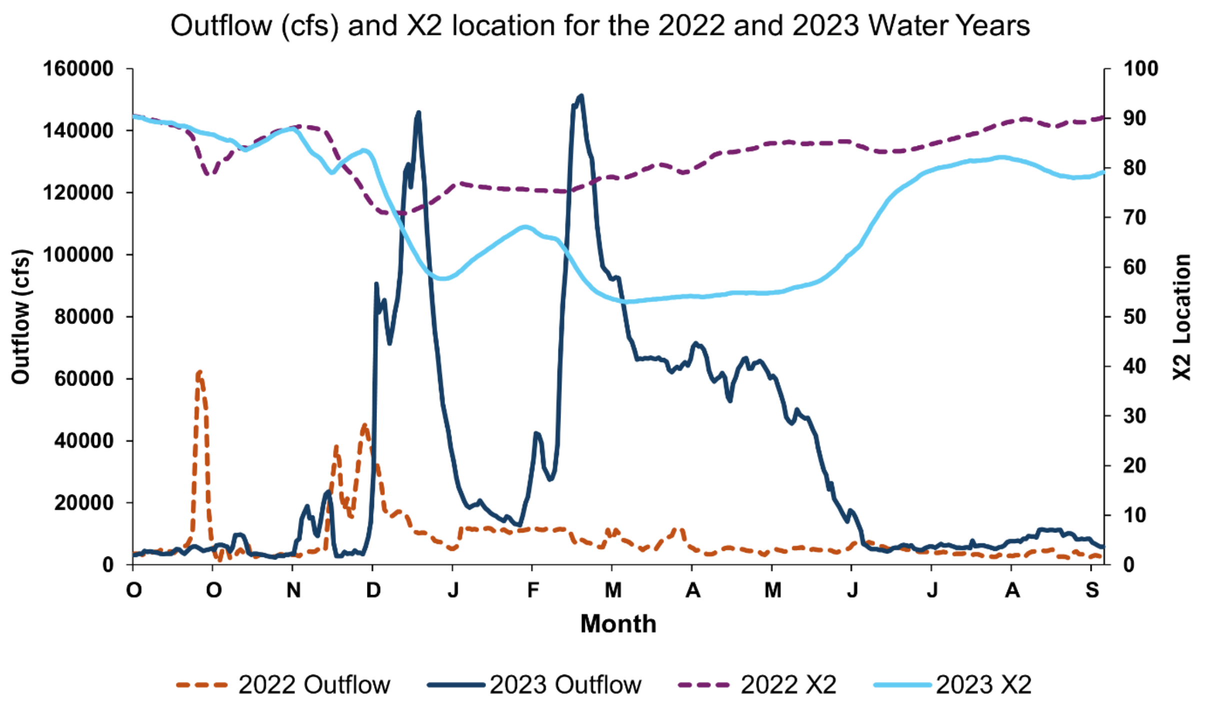

Figure 3. Line plot showing daily net Delta Outflow values and X2 location for water years 2022 and 2023. Outflow is displayed on the left y-axis in cubic feet per second (cfs). X2 location is conveyed on the right y-axis as river kilometers upstream from the Golden Gate Bridge. Months are shown on the x-axis starting with October and ending with September.

Abiotic Variables

Water Clarity

Due to the spatial range of the survey, Secchi disc depth (cm) varied considerably across stations (Figure 4). Water clarity was greatest in the South Delta, Lower San Joaquin River (stations in 800-900's excluding station 912), and the Lower Sacramento River upstream of Rio Vista. Clarity was reduced in San Pablo Bay, Carquinez Strait, Suisun Bay, Montezuma Slough (stations in 300-700 range), and the stations in the middle/upper section of the DWSC (stations 719, 795-797). Previous studies have documented a negative correlation between fish catch and high Secchi values (Mac Nally et al. 2010, Latour 2016), which varies between species. For example, larval Longfin Smelt are more likely to be caught in the Secchi depth range of 0-80 cm (Grimaldo et al. 2017) and adult Longfin Smelt catch is greatest at depths less than 50 cm (Lewis et al. 2019). Historically, 75% of FMWT Longfin Smelt catch has occurred when Secchi depth was ≤ 90 cm.

Turbidity is a more accurate measurement of water clarity or lack thereof. It is measured in Nephelometric Turbidity Units (NTU). Higher turbidity values coincide with decreased water clarity. The heatmap and boxplot of turbidity values during the 2023 FMWT survey (Figures 5 & 6) show a similar pattern to the Secchi values. Despite monthly variability, turbidity was highest in Suisun Bay, Montezuma Slough, and the middle/upper section of the DWSC. Many fishes within the estuary depend on a certain level of turbidity, for instance Delta Smelt persist within a specific turbidity window (12–80 NTU) (Hasenbein et al. 2016).

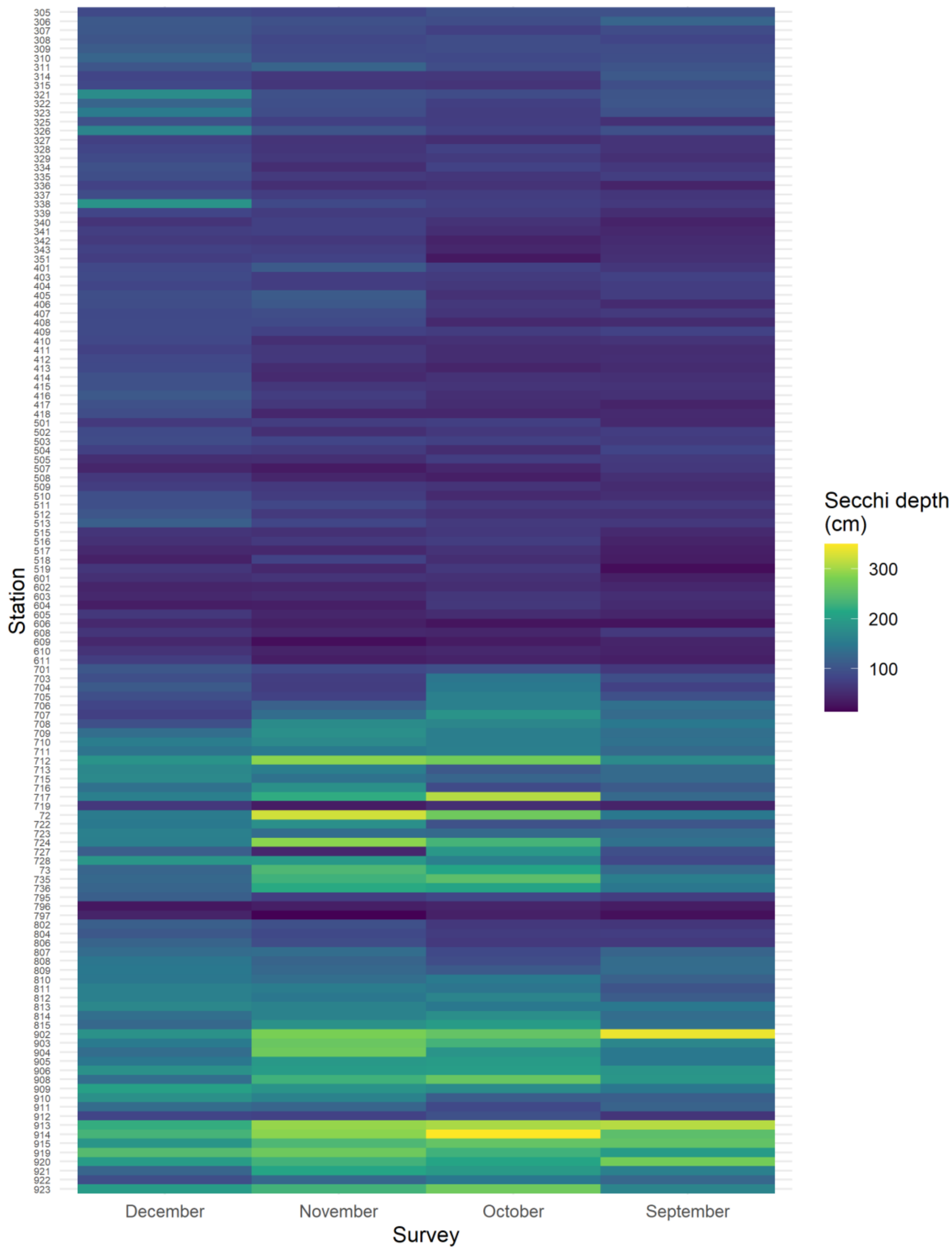

Figure 4. Heatmap of monthly Secchi disk values (cm) recorded during the 2023 FMWT season. Darker values represent lower water clarity, while lighter values are associated with increased water clarity.

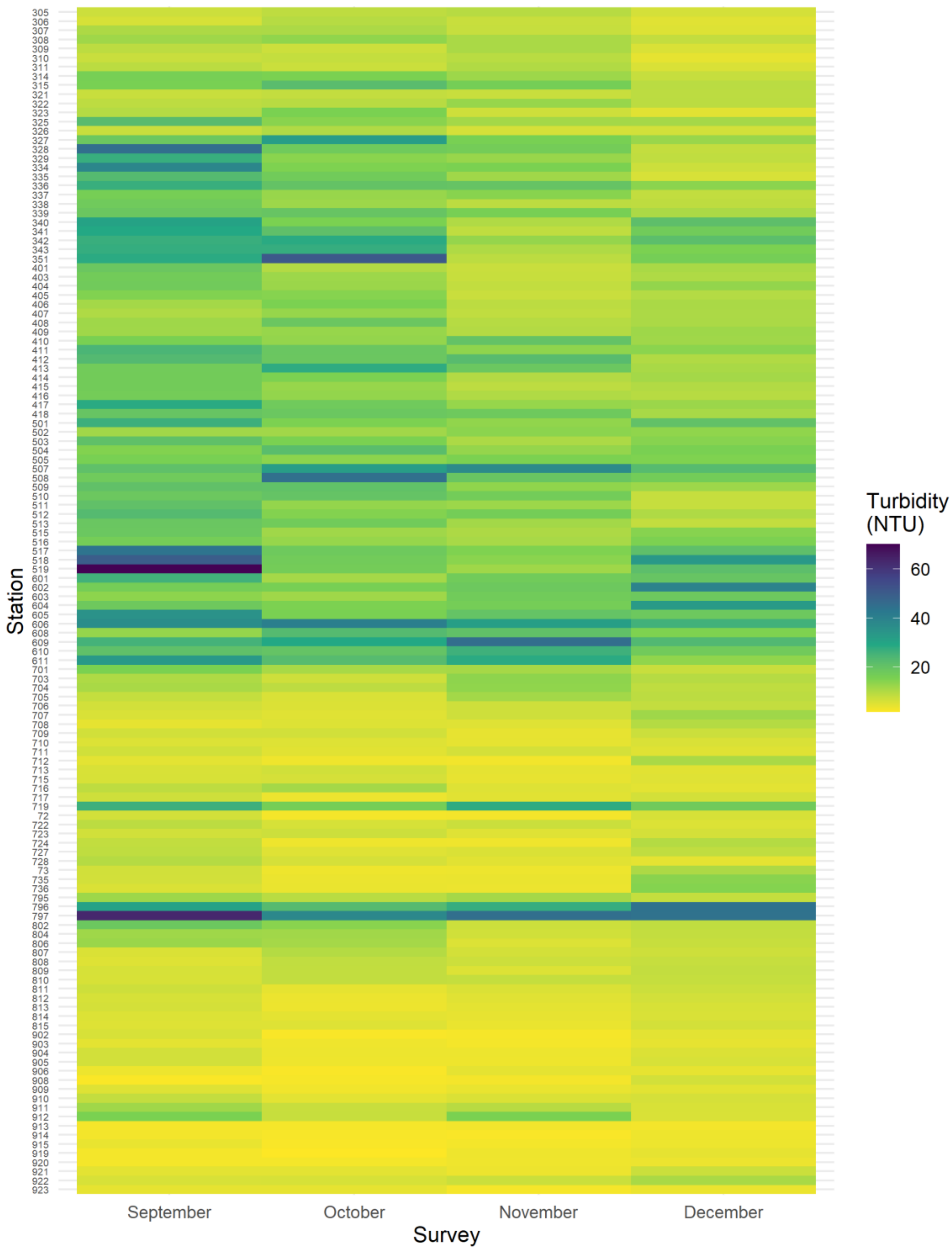

Figure 5. Heatmap of surface water turbidity (NTU) recorded during the 2023 FMWT season. Darker values represent higher turbidity, while lighter values are associated with increased water clarity. The highest turbidity values recorded were at Station 519 in Suisun Bay and Station 797 in the DWSC in September.

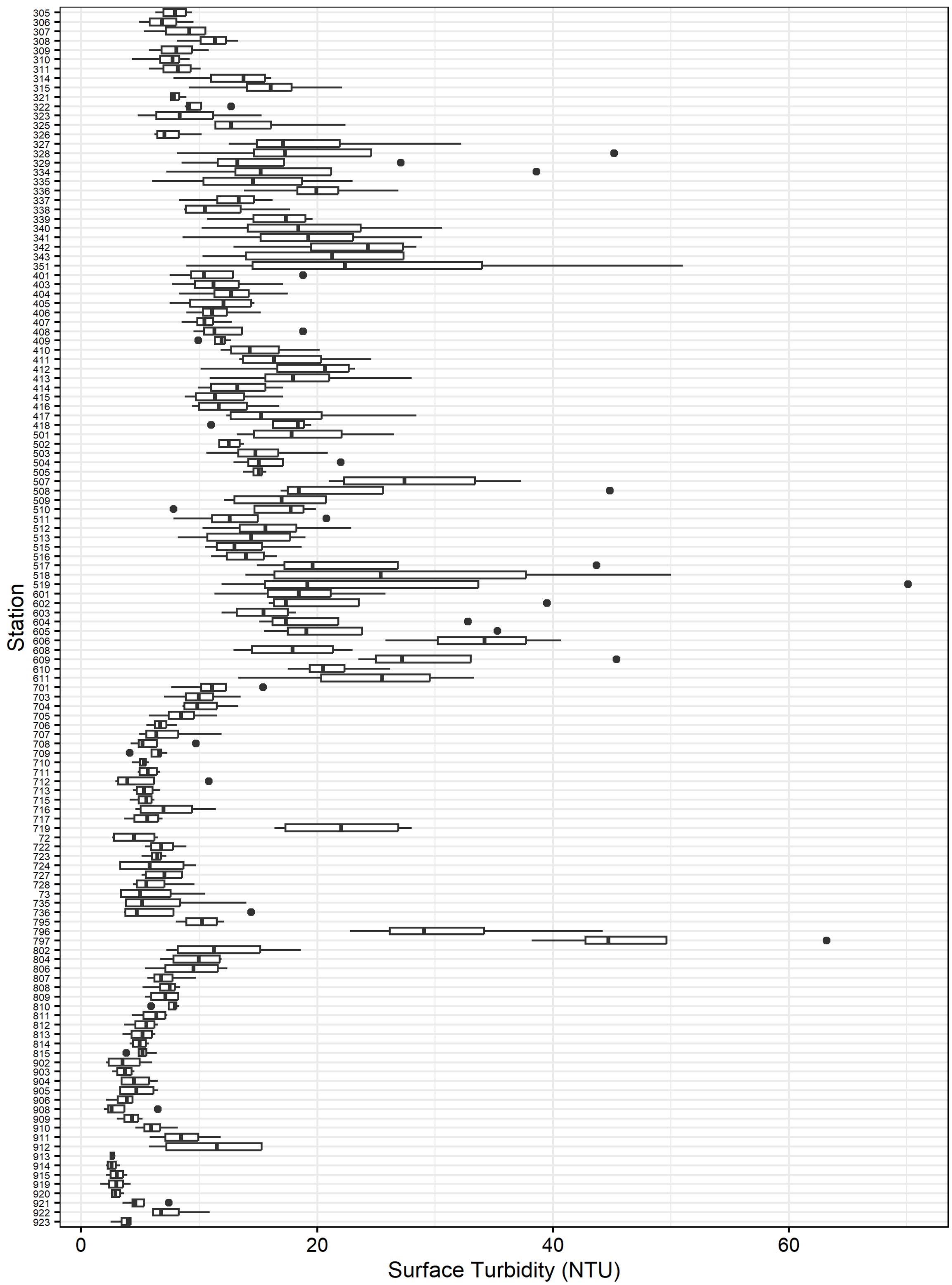

Figure 6. Distribution of monthly surface turbidity (NTU) recorded during the 2023 FMWT season. Boxplots show the median as a vertical line, 1st and 3rd quartile by a box, range by a horizontal line, and outliers by points.

Temperature

Temperature is an integral factor in fish life history (i.e. metabolism, growth, initiation and cessation of spawning, stress, etc.) and influences fish survival within the estuary. Many pelagic estuarine species have thermal tolerances that limit survivorship (Baker et al.1995; Swanson et al. 2000; Moyle et al. 2004; Bennett 2005). Previous studies have connected long term seasonal Delta Smelt detection with changes in environmental parameters like temperature (Feyrer et al. 2007; Nobriga et al. 2008; Feyrer et al. 2011). Research has also shown that thermal tolerance is reduced in native species compared to ecologically overlapping introduced species (Komoroske et al. 2021). Other research has shown adult Longfin Smelt prefer temperatures under 17.8°C (Hobbs and Moyle 2015), larval Longfin Smelt are most abundant in the 8-12°C range (Grimaldo et al. 2017) and adults are most abundant in water 12-16°C (Lewis et al. 2019). Longfin Smelt typically spawn between 7-14.5°C (Moyle 2002), and Delta Smelt have been shown to stop spawning when water temperature increases past 20°C (Swanson et al. 2000).

Research has documented physiological thermal limitations for some anadromous and estuarine species. For example, Jeffries et al. (2016) found Longfin Smelt show a cellular stress response once water temperature is greater or equal to 20°C, Bennett (2005) showed Delta Smelt experience mortality at temperatures above 25°C, and Marine et al. (2003) found that juvenile Chinook Salmon reared at 17–20°C experienced decreased growth rates, variable smoltification impairment, and higher predation vulnerability compared with fish reared at 13–16°C. Historically, 75% of FMWT Longfin Smelt catch has occurred when water temperature is ≤ 19°C and ≥ 4.3°C.

The heatmap of surface water temperature (Figure 7) shows how temperature throughout the estuary changed over the course of the 2023 survey. The seasonal pattern was consistent with warmest temperatures in September followed by cooling through December. Temperatures ranged from 19-24°C in September, 17-22°C in October, 13-17°C in November, and cooled to a range of 10-15°C in December. Stations upstream of Prisoners Point on the Lower San Joaquin River experienced the greatest variation in temperature over the course of the 2023 season (Stations 905-912, Figure 8).

Temperatures were usually warmer at the surface compared to bottom water samples (Figure 9). The most extreme differences were found at Stations 501 (Suisun Bay near Port Chicago) and 606 (Montezuma Slough). However, these temperature differences do not necessarily indicate stratification at these stations since these differences may not be consistent or prolonged across tides.

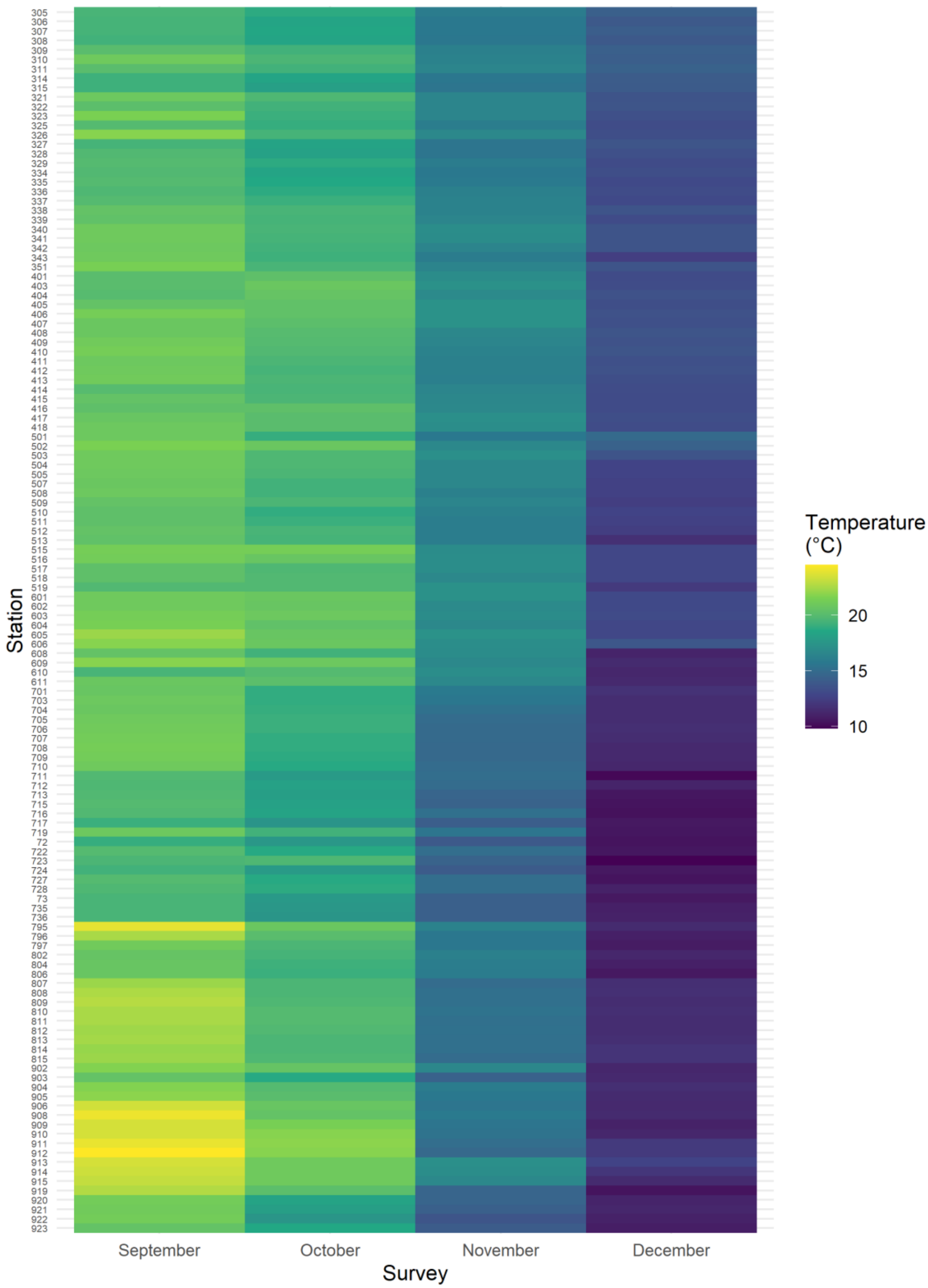

Figure 7. Heatmap of monthly surface water temperatures (°C) among stations recorded during the 2023 FMWT season. Stations in the darker blue to purple range are more suitable for many native species.

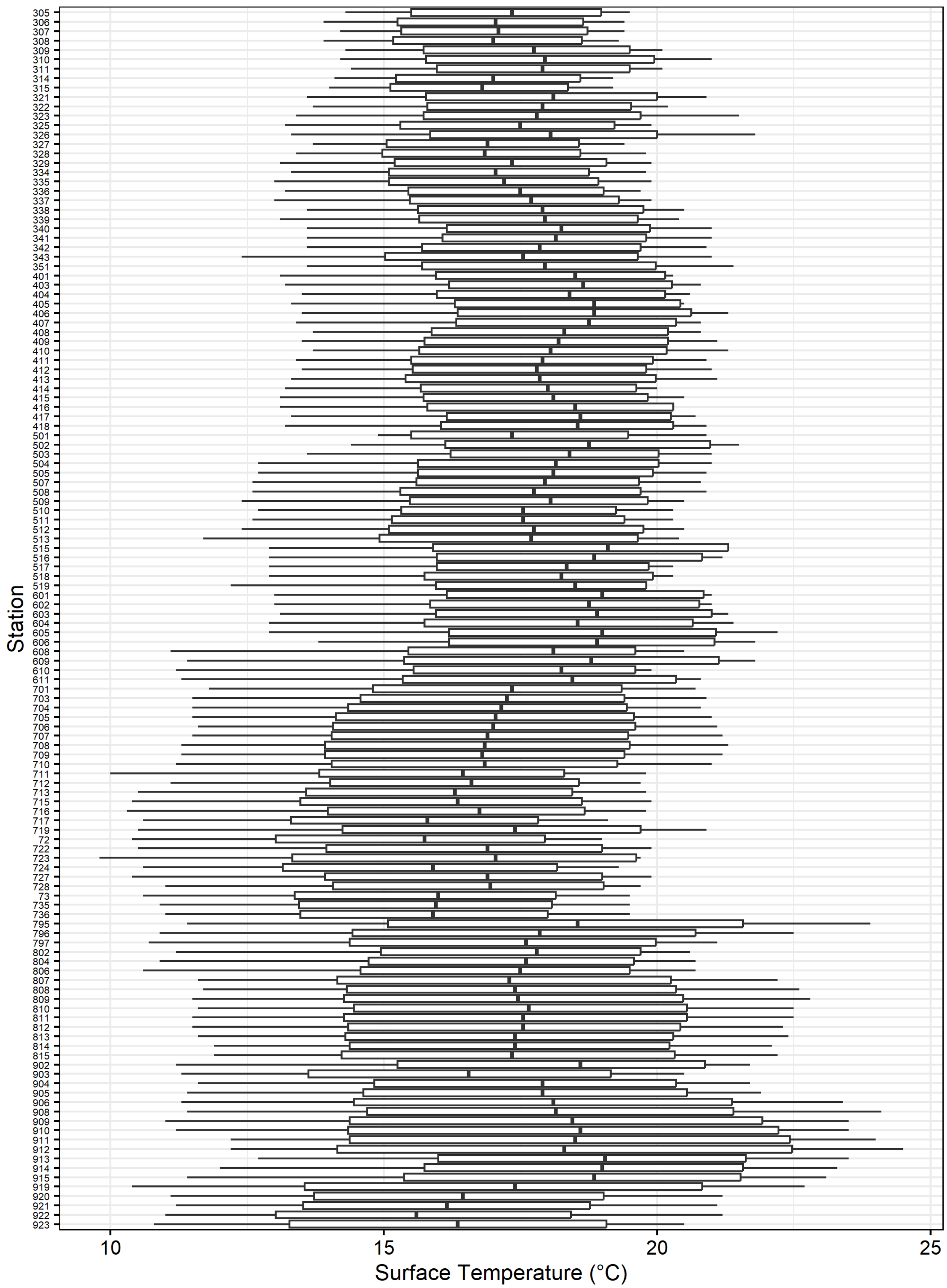

Figure 8. Distribution of monthly surface water temperatures (°C) among stations recorded during the 2023 FMWT season. Boxplots show the median as a vertical line, 1st and 3rd quartile by a box, range by a horizontal line, and outliers by points.

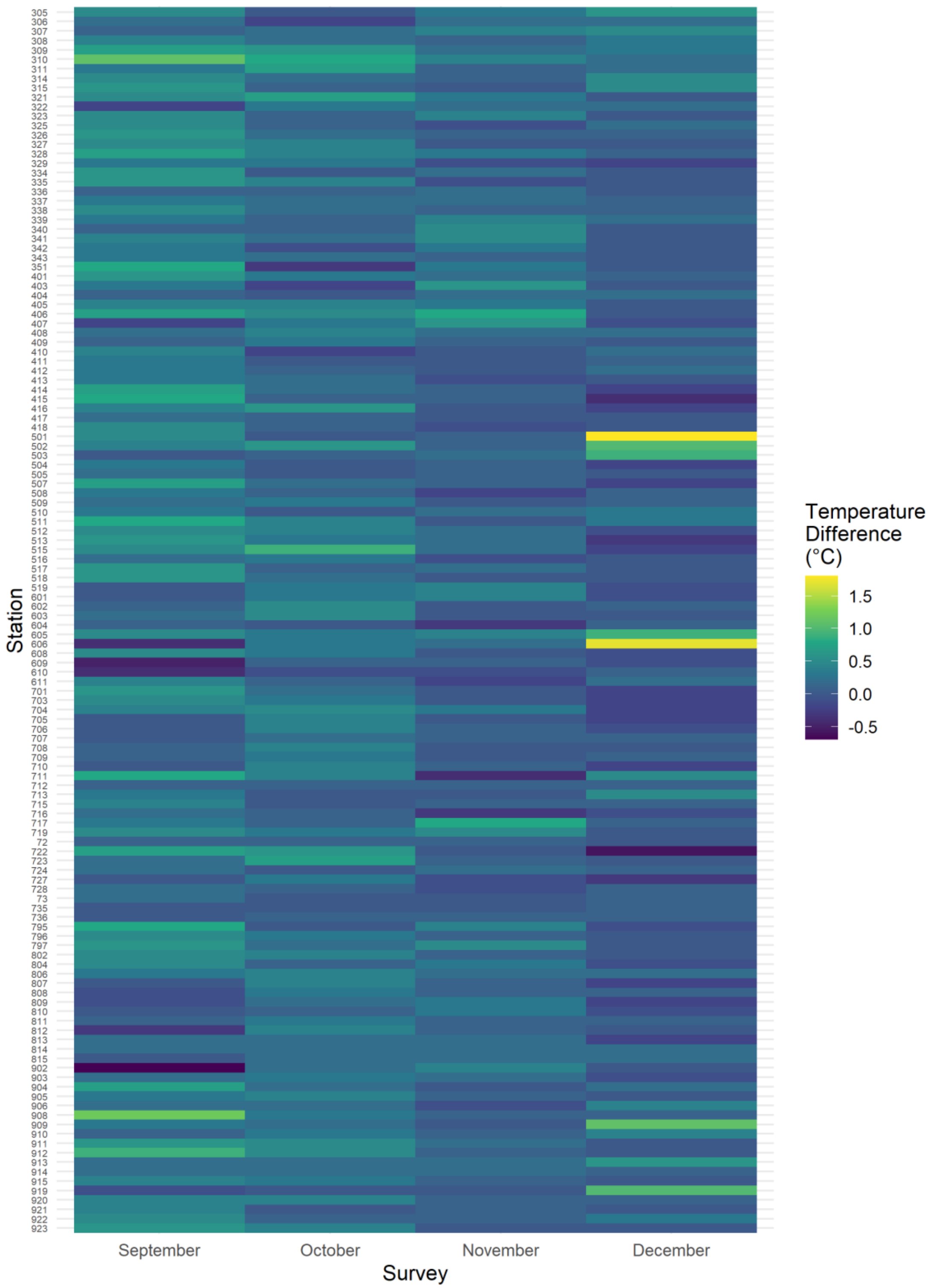

Figure 9. Heatmap of monthly temperature (°C) differences between surface and bottom water recorded among stations during the 2023 FMWT season. Negative (blue to purple) values are warmer bottom temperature compared to the surface. Positive (blue green to yellow) values indicate greater temperatures at the surface.

Salinity

Salinity is an important environmental parameter in determining where pelagic organisms are located and distributed throughout the estuary. In the upper estuary, the LSZ (salinity 0.5-6 ppt) is recognized as a critical variable in the creation of nursery habitat for young fishes. This dynamic well-mixed zone is highly productive and facilitates increased bottom-up ecological processes (Kimmerer 2002 a; Kimmerer 2002 b; Bennett 2005), which correlates with increased turbidity (Kimmerer et al. 1998; Schoellhamer 2000). The heatmap and boxplot of salinity values observed during the 2023 FMWT showed in September that the LSZ persisted just downstream of Chipps Island and the confluence of the Sacramento and San Joaquin rivers, located approximately in Honker Bay, and mid-Montezuma Slough (Figures 10 & 11). The LSZ began moving upstream over the course of this survey, with the location in December being more closely associated with Broad Slough and the confluence. It is worth noting that salinity was slightly higher in the DWSC (Stations 795-797, Figure11) compared to surrounding freshwater stations. Most stations did not have extreme salinity differences between surface and bottom sections of the water column (Figure 12). The 2023 water year was a reprieve from the three driest water years on state record, and the LSZ's location during survey reflected that increased freshwater outflow.

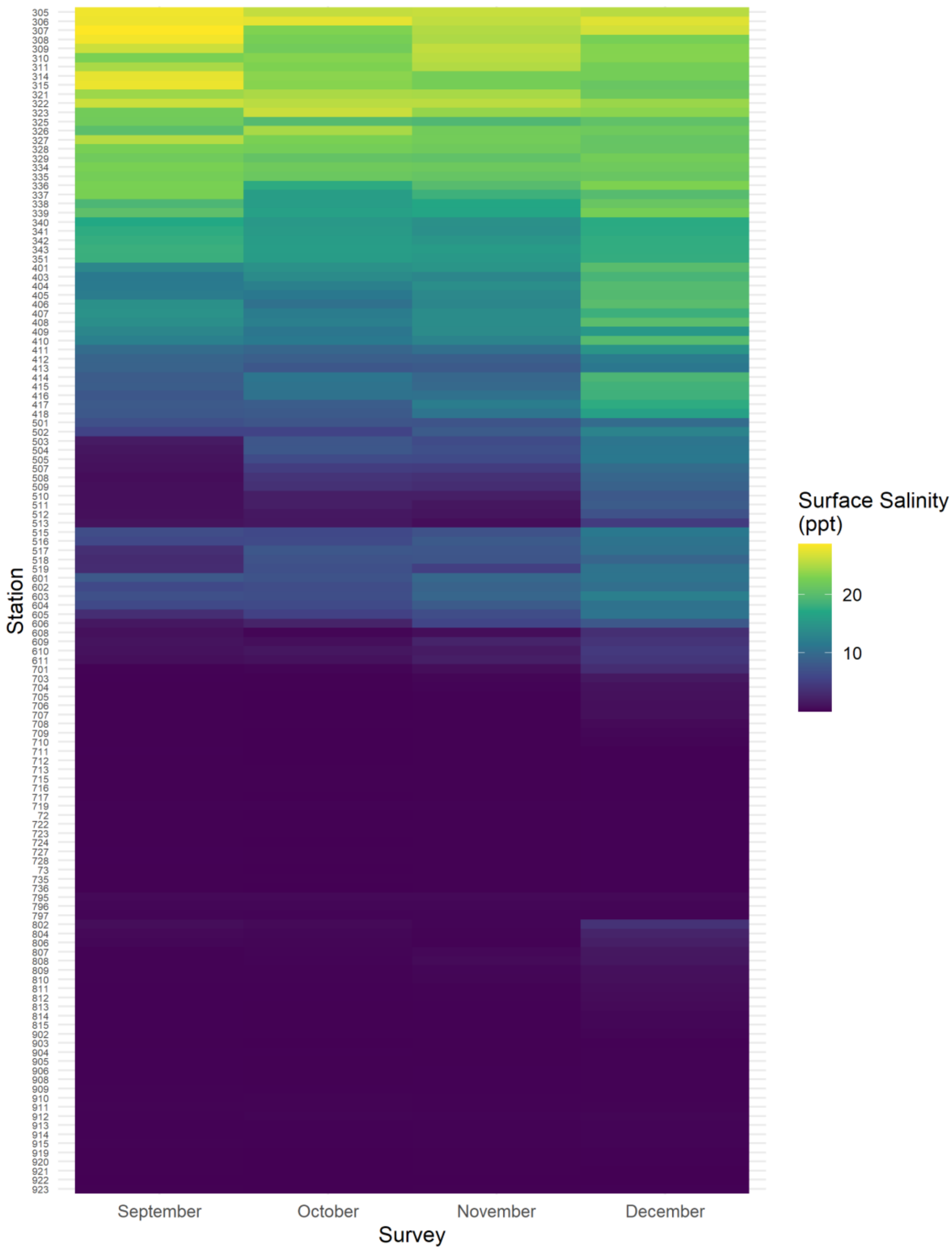

Figure 10. Heatmap of monthly surface water salinity (ppt) among stations recorded during the 2023 FMWT season.

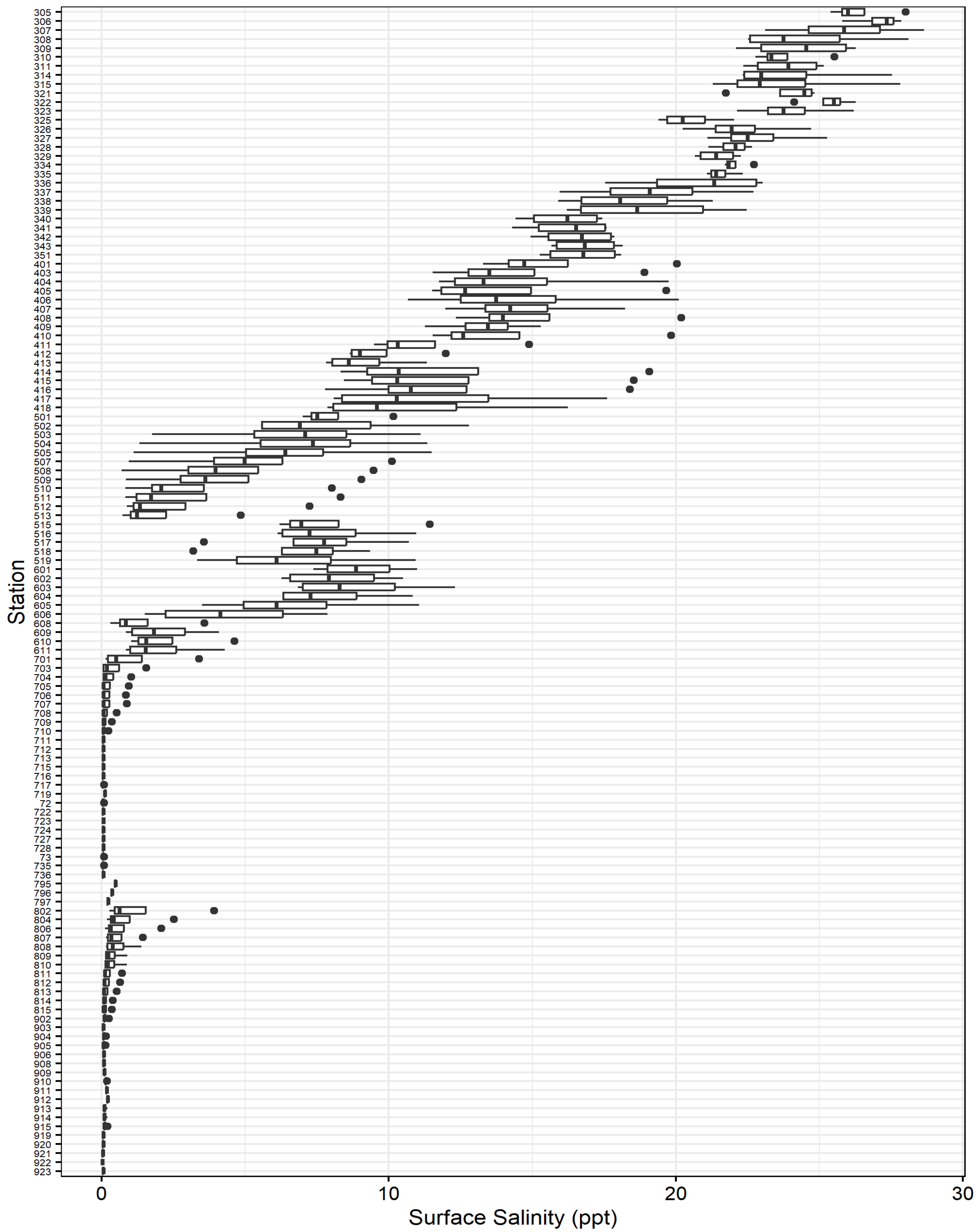

Figure 11. Distribution of monthly surface salinity (ppt) among stations recorded during the 2023 FMWT season. Boxplots show the median as a vertical line, 1st and 3rd quartile by a box, range by a horizontal line, and outliers by points.

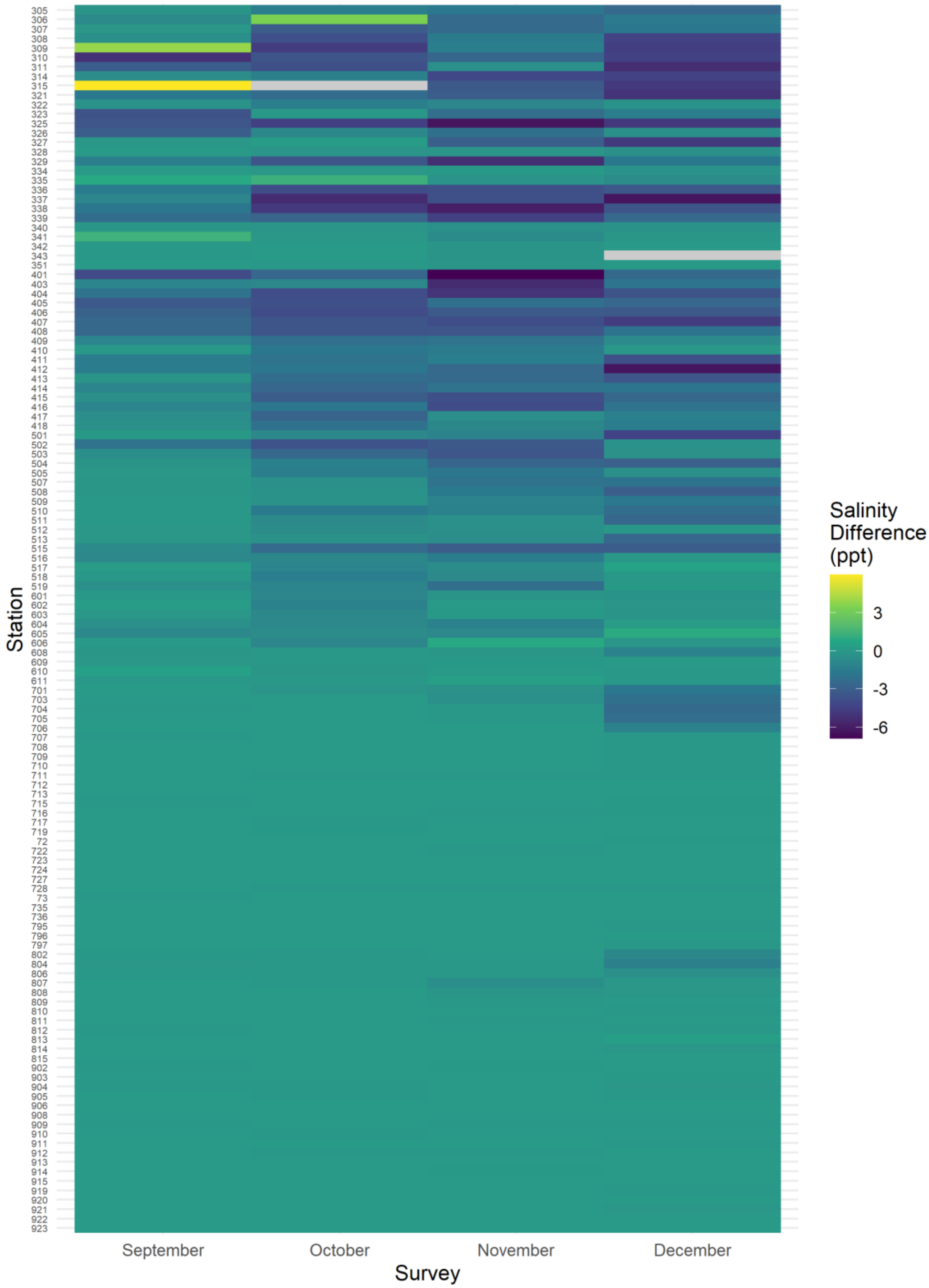

Figure 12. Heatmap of monthly salinity (ppt) differences between surface and bottom water recorded among stations during the 2023 FMWT season. White values indicate missing data. Negative (blue to purple) values are higher salinity on the bottom compared to the surface. Positive (green to yellow) values indicate higher salinity at the surface.

Microcystis

The colonial cyanobacteria *Microcystis aeruginosa* was first discovered in the estuary in the early 2000s (Lehman et al. 2005). *Microcystis* in high abundance has toxic effects on the local food web, accumulating in dominant zooplankton species (Ger et al. 2010) and bioaccumulating up the trophic levels (Lehman et al. 2010). *Microcystis* becomes seasonally abundant during periods of low water flow and high-water temperatures (Lehman et al. 2008). FMWT assigns a qualitative rank of 1-5 based on visual inspection for flakes (Fig. 13; Morris and Civiello (2013)).

During the 2023 FMWT survey, during September and October *Microcystis* was found in low abundance at nine stations in the South Delta (Figure 14). By November, *Microcystis* was no longer detected at any stations. The increased outflow and by association lower water temperatures that occurred this season likely mitigated harmful *Microcystis* blooms.

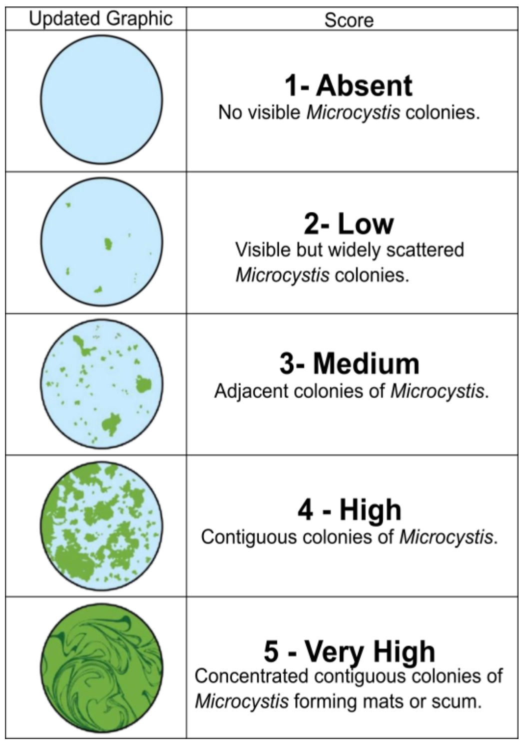

Figure 13. Qualitative rankings are used to assess *Microcystis aeruginosa* blooms on the water surface.

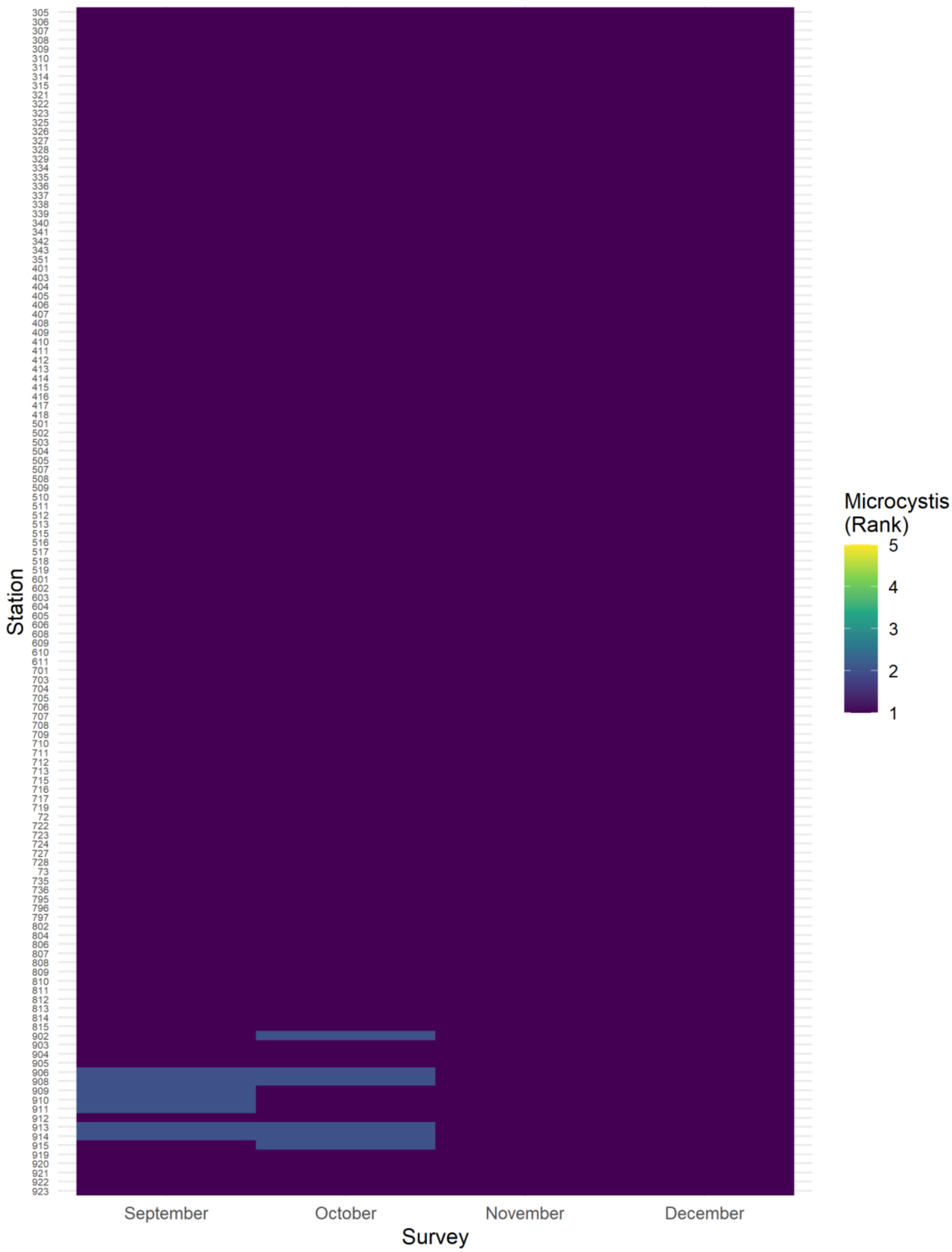

Figure 14. Heatmap of monthly Microcystis spp. rankings among stations recorded during the 2023 FMWT season. Microcystis was only seen at stations within the South Delta region and tapered off after the October Survey. Scale is a qualitative assessment of Microcystis density visible at the surface.

Biotic Variables

Fish

The FMWT survey records all species of fish and macro-invertebrates (i.e. shrimps, crabs, and jellyfish) caught in the trawl net. The 2023 season saw increased catch and abundance of all index species, with the exception of Delta Smelt. No Delta Smelt were captured this season. The typical unit for reporting catch (used below, Tables 2-3, Figure 15), is catch per tow or per unit effort (CPUE). CPUE is calculated as:(([Total species catch]/[Volume])*10,000) or catch per cubic hectare (see CPUE Calculation Instructions).

Generally, CPUE by region matches with the life histories of the species captured (Figure 15). $Log_{10}(x+1)$ transformed fish catch data (Figure 16) shows the variation in catch by station and survey. The top six species caught this season will be discussed in detail below. A variety of other benthic, demersal, littoral, and pelagic fishes were captured this season but constitute less than 1% of total catch (Tables 2-3).

During 2023, Northern Anchovy (*Engraulis mordax*) constituted the majority of total catch (Figure 15, Tables 2-3). Northern Anchovy are marine opportunists with occasional juvenile presence in brackish waters (Moyle 2002). They are the most abundant anchovy species in California (Miller & Lea 1972) and are an important forage fish for a wealth of animals. As such, they were the most caught species in the Far West region of the survey. During the latter half of the 2023 survey, anchovies were detected at stations farther upstream. The farthest upstream detection was at station 507 near Honker Bay and Chipps Island in December. This connects with the increased saltwater intrusion into Suisun Bay in December, and increased Northern Anchovy catch at stations in the West region (Figure 10, Figure 15).

American Shad were the second most caught species (Tables 2-3). The last time FMWT had a higher American Shad catch than Threadfin Shad catch was in 2017. American Shad were detected at a wide range of stations, most likely due to their anadromous life history and euryhaline osmoregulatory abilities. American Shad were initially introduced into California in 1871 as forage fish (Dill and Cordone 1997). It is worth noting that there was modest catch of both American and Threadfin shad at stations 911 and 912 (Figure 16) near the port of Stockton. American Shad catch at station 912 this year was the second highest in survey history. Historically, the Lower San Joaquin River was a stronghold for Clupeids; the FMWT has recorded reduced presence in this area over the last couple decades.

Threadfin Shad were the third most caught species this year. Similar to American Shad, Threadfin Shad were introduced as a forage fish and quickly expanded throughout the state. Threadfin had a greater presence at stations associated with freshwater and had the highest CPUE at stations in the North region (Figure 15). While these fish can tolerate a wide range of salinities, they prefer freshwater, and their spawning abilities are limited by salinity (Hendricks 1961). Like American Shad, they have rapid growth and reproductive abilities. Threadfin Shad are planktivorous as well as opportunistic detritivores. These characteristics have allowed them to spread in California very quickly after their initial introduction. Catch of this species continues to be highest in the DWSC.

Another relatively abundant species caught this season was Pacific Herring (*Clupea pallasii*). This native neritic marine species is known to migrate into estuaries to spawn. Age-0 fish will eventually travel downstream to more marine habitats. Catch of this species this season was greater than the combined FMWT catch from 2010-2022. This was the highest FMWT Pacific Herring catch since 2008. The furthest upstream detection was at Station 511 (near Broad Slough) in December.

Longfin Smelt were the fifth most abundant species captured on survey this year. Longfin Smelt in the estuary are considered an evolutionary significant unit (ESU). Populations of this native anadromous Osmerid have been declining in the estuary for decades. Young of the year fish typically migrate upstream during the fall and winter with adults following suit as environmental conditions transition to winter parameters. Catch this season was the highest since the 2011 survey (Table 2). The population was most likely bolstered by the above average water year, as well as the enhanced abiotic and biotic factors that are associated with increased outflow.

Age-0 Striped Bass were the sixth most caught fish. The 2023 season saw the greatest detection of this species' age class since 2019. After hatching, larvae and young juveniles rely on zooplankton crustaceans with transition from copepods to larger amphipods and mysids. Individuals become more piscivorous as they grow into adults. Adult fish are hardy, but cool and consistent flows are required to keep their eggs and larvae suspended in the water column and off the benthos.

Table 2. Total monthly fish catch during the 2023 FWMT season.

Species	Origin	September	October	November	December	Total	Total %
Northern Anchovy	Native	3,230	5,234	4,095	3,514	16,073	76.5
American Shad	Introduced	567	455	554	468	2,044	9.7
Threadfin Shad	Introduced	596	382	504	440	1,922	9.1
Pacific Herring	Native	169	91	33	92	385	1.8
Longfin Smelt	Native	4	52	81	88	225	1.1
Striped Bass age-0	Introduced	101	41	39	32	213	1
Wakasagi	Introduced	13	6	15	6	40	0.2
Mississippi Silverside	Introduced	13	2	2	0	17	0.1
Striped Bass age-1	Introduced	8	3	1	1	13	0.1
Jacksmelt	Native	7	1	0	4	12	0.1
California Grunion	Native	10	1	0	0	11	0.1
Plainfin Midshipman	Native	0	7	3	0	10	0
Starry Flounder	Native	4	3	1	0	8	0
Bat Ray	Native	0	2	4	1	7	0
Splittail	Native	3	0	0	1	4	0
Striped Bass age-2	Introduced	0	2	2	0	4	0
Chinook Salmon	Native	1	1	0	1	3	0
Tridentiger spp.	Introduced	3	0	0	0	3	0
Yellowfin Goby	Introduced	0	2	1	0	3	0
Striped Bass age-3+	Introduced	0	0	2	0	2	0
Threespine Stickleback	Native	0	1	0	1	2	0
Blue Catfish	Introduced	1	0	0	0	1	0
Bluegill	Introduced	0	0	1	0	1	0
English Sole	Native	0	1	0	0	1	0
Hitch	Native	0	0	1	0	1	0
California Lizardfish	Native	0	1	0	0	1	0
Pacific Staghorn Sculpin	Native	0	1	0	0	1	0
Redear Sunfish	Introduced	0	0	1	0	1	0
Shimofuri Goby	Introduced	1	0	0	0	1	0
White Sturgeon	Native	0	0	1	0	1	0
Total		4731	6289	5341	4649	21010	

Table 3. Total monthly fish catch per 10,000 m³ during the 2023 FWMT season.

Species	Origin	September	October	November	December	Total CPUE	% CPUE
Northern Anchovy	Native	5,351.4	8,450.4	6,971.4	5,656.8	26,430.0	75.4
American Shad	Introduced	959.1	797.9	1,006.1	792.5	3,555.6	10.1
Threadfin Shad	Introduced	1,045.0	684.5	939.1	772.7	3,441.3	9.8
Pacific Herring	Native	293.1	154.3	56.8	146.7	650.9	1.9
Longfin Smelt	Native	7.1	92.7	130.2	146.4	376.4	1.1
Striped Bass age-0	Introduced	170.4	71.9	72.4	52.7	367.4	1.0
Wakasagi	Introduced	23.4	11.2	27.2	10.7	72.5	0.2
Mississippi Silverside	Introduced	23.6	3.5	3.6	0.0	30.7	0.1
Striped Bass age-1	Introduced	14.2	5.2	1.5	1.8	22.7	0.1
Jacksmelt	Native	11.1	2.0	0.0	5.9	19.0	0.1
California Grunion	Native	16.4	1.4	0.0	0.0	17.8	0.1
Plainfin Midshipman	Native	0.0	10.1	4.7	0.0	14.8	0.0
Starry Flounder	Native	6.5	5.7	1.4	0.0	13.6	0.0
Bat Ray	Native	0.0	3.5	6.3	1.5	11.3	0.0
Striped Bass age-2	Introduced	0.0	3.4	3.6	0.0	7.0	0.0
Splittail	Native	4.8	0.0	0.0	1.7	6.5	0.0
Chinook Salmon	Native	1.6	2.2	0.0	2.1	5.9	0.0
Yellowfin Goby	Introduced	0.0	3.9	2.0	0.0	5.9	0.0
Tridentiger spp.	Introduced	5.2	0.0	0.0	0.0	5.2	0.0
Striped Bass age-3+	Introduced	0.0	0.0	3.2	0.0	3.2	0.0
Threespine Stickleback	Native	0.0	1.4	0.0	1.7	3.1	0.0
California Lizardfish	Native	0.0	2.0	0.0	0.0	2.0	0.0
Shimofuri Goby	Introduced	1.9	0.0	0.0	0.0	1.9	0.0
Bluegill	Introduced	0.0	0.0	1.8	0.0	1.8	0.0
Hitch	Native	0.0	0.0	1.8	0.0	1.8	0.0
White Sturgeon	Native	0.0	0.0	1.8	0.0	1.8	0.0
English Sole	Native	0.0	1.7	0.0	0.0	1.7	0.0
Blue Catfish	Introduced	1.6	0.0	0.0	0.0	1.6	0.0
Pacific Staghorn Sculpin	Native	0.0	1.4	0.0	0.0	1.4	0.0
Redear Sunfish	Introduced	0.0	0.0	1.4	0.0	1.4	0.0

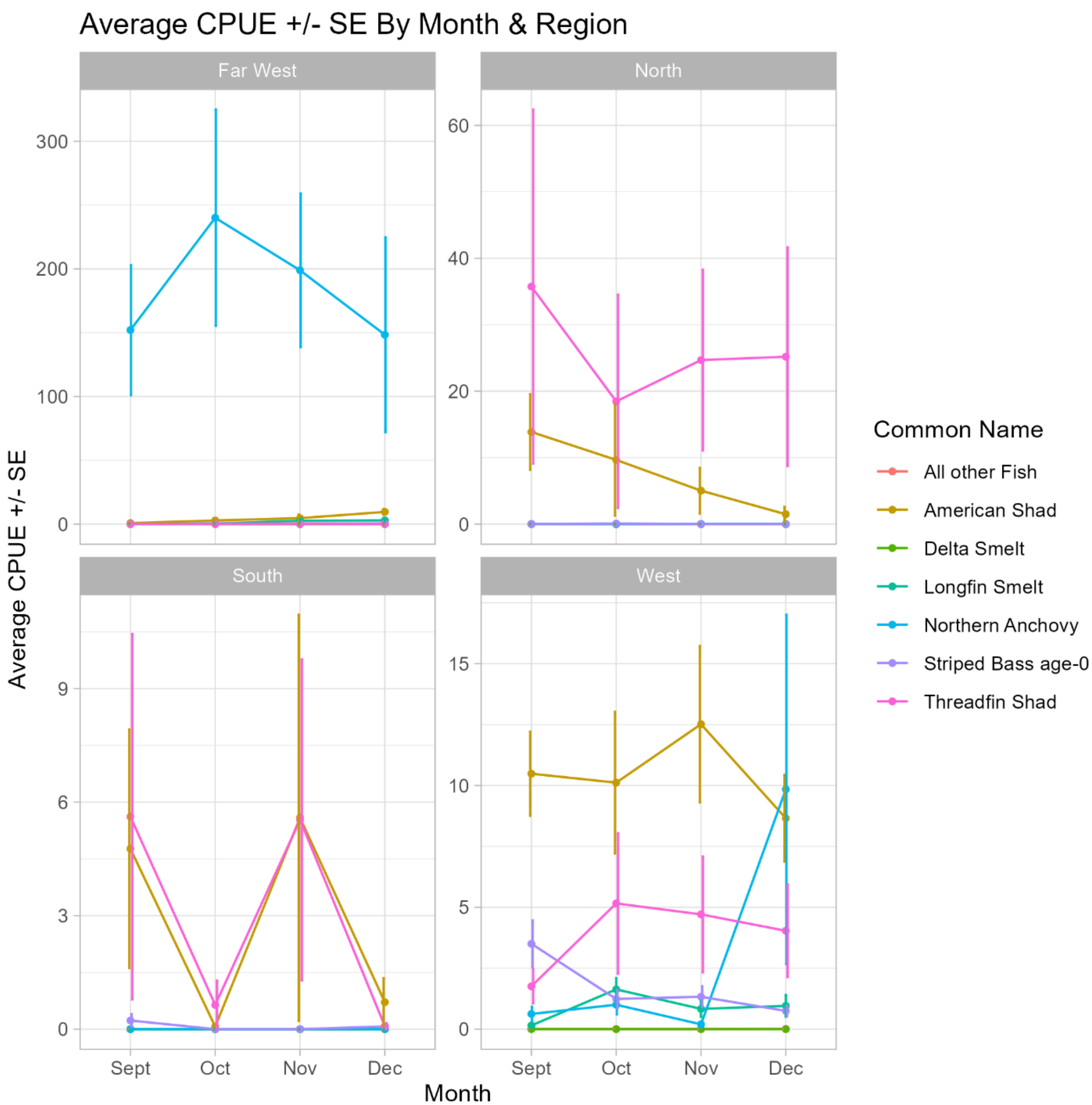

Figure 15. Regional average fish CPUE for the 2023 FMWT survey, organized by species used for index calculations. Northern Anchovy is included because this species constitutes the largest percent of total catch for the survey. Lines represent monthly average CPUE values and error bars represent +/- standard error. Number of stations per region varies; Far West (n=35), North (n=23), South (n=25), West (n=47).

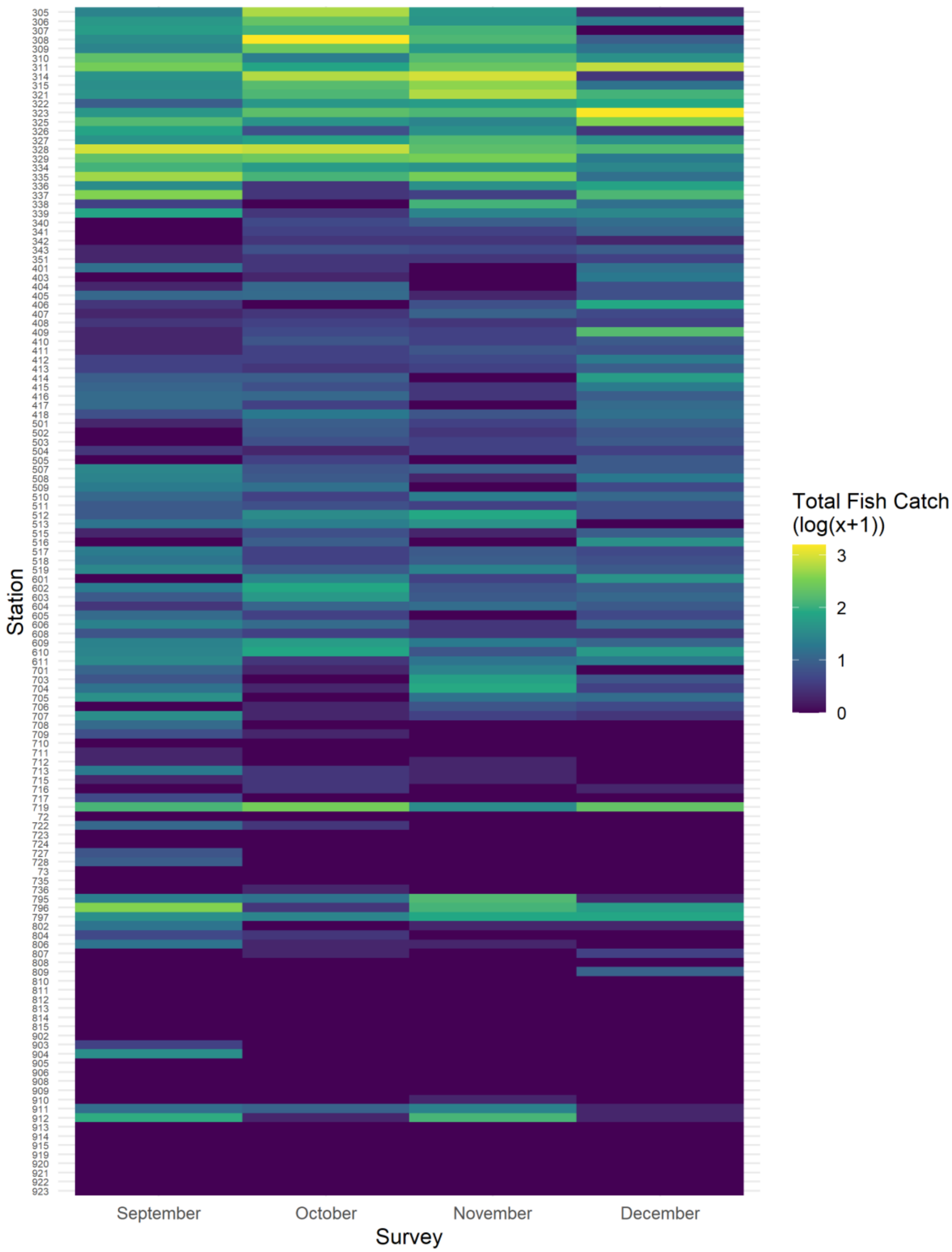

Figure 16. Heatmap of monthly $\log_{10}(x+1)$ transformed total fish catch by station recorded during the 2023 FMWT season. San Pablo Bay and the middle section of the DWSC had the highest fish catch. Catch was most consistent throughout all four months of survey in Suisun Bay and San Pablo Bay. Catch was also higher near the port of Stockton (stations 911 & 912) compared to more recent survey years.

Fork Length Frequencies

Fork length frequency histograms from the 2023 season for the six most caught species are plotted below (Figures 17-22). The FMWT only measures the first 50 randomly selected fish of each species per tow, anything beyond that is plus counted. An adjusted fork length frequency is calculated for fish not measured, or if a fish length cannot be determined for a damaged specimen. This is done by calculating the ratio of total catch to the number of fish measured multiplied by the length frequency. The plots below utilize adjusted fork length frequencies to better quantify the size range of each species.

The fork length frequency histograms are faceted and colored according to the survey number, beginning with survey 3 (September) and ending with survey 6 (December). The bin size for fork lengths was set to one mm. Note that the scale for frequency (y-axis) and fork length (x-axis) in each figure varies between survey and species. The fork length mean and standard deviation as well as number of fish captured are labeled on each histogram. In 2023 the FMWT mostly detected young of the year fish. However, age-class varies by species and month captured.

Northern Anchovy

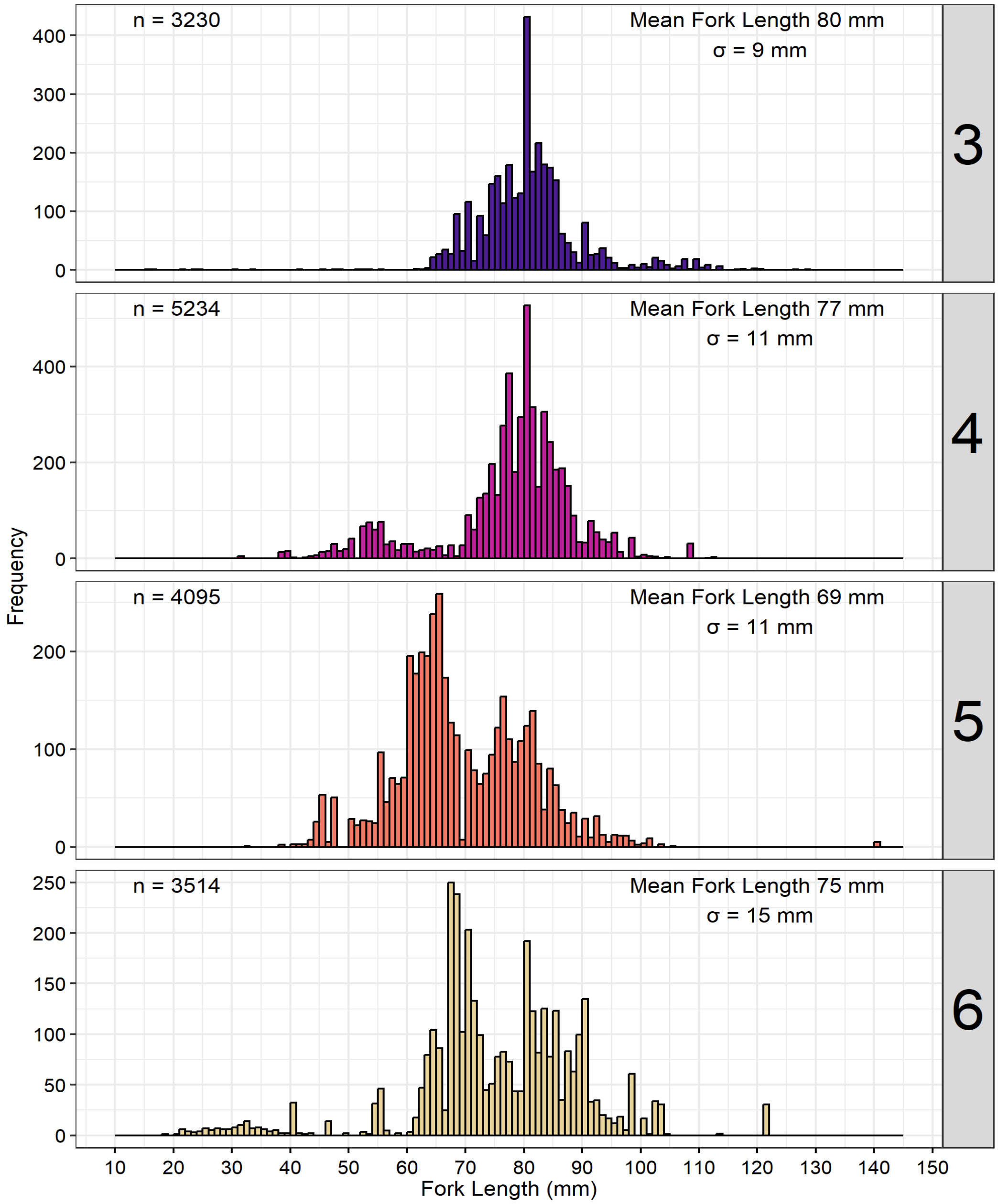

Figure 17. Fork length (mm) frequency histograms for Northern Anchovy among monthly surveys in 2023. Survey number (right panel), number of fish (n), mean fork length (mm), and fork length standard deviation (σ), are displayed on each histogram.

Northern Anchovy were the most caught and measured species of the 2023 season. The smallest individual was measured at 15 mm in September, and the largest was 140 mm in November. Mean fork length was relatively consistent throughout the 2023 season, being approximately 75 mm.

American Shad

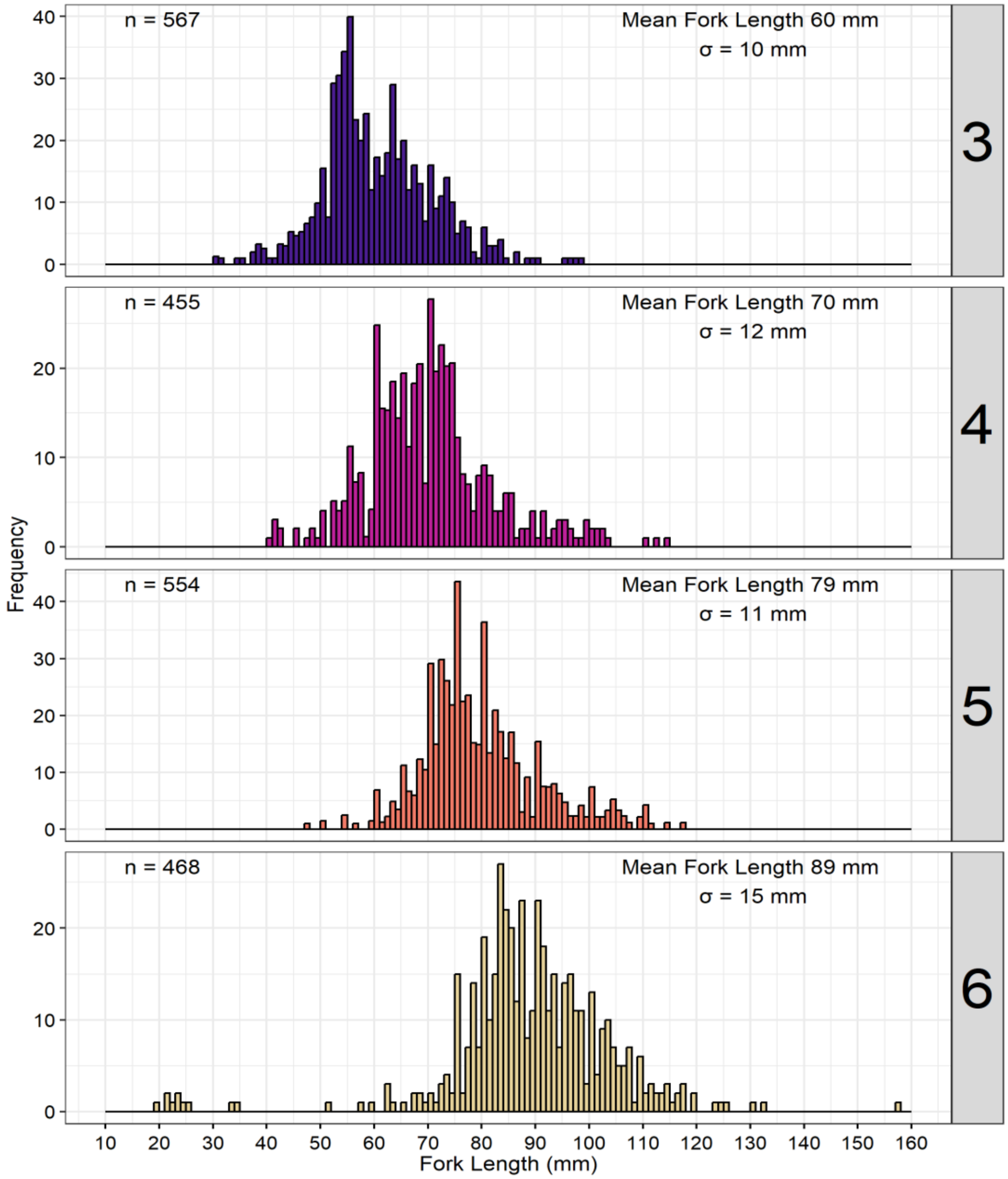

Figure 18. Fork length (mm) frequency histograms for American Shad among monthly surveys in 2023. Survey number (right panel), number of fish (n), mean fork length (mm), and fork length standard deviation (σ), are displayed on each histogram.

American Shad were captured consistently throughout the 2023 season. Detection occurred at stations throughout the FMWT sampling range. The mean fork length increased approximately 10 mm per month. An additional cohort of post-larval juveniles were detected in December.

Threadfin Shad

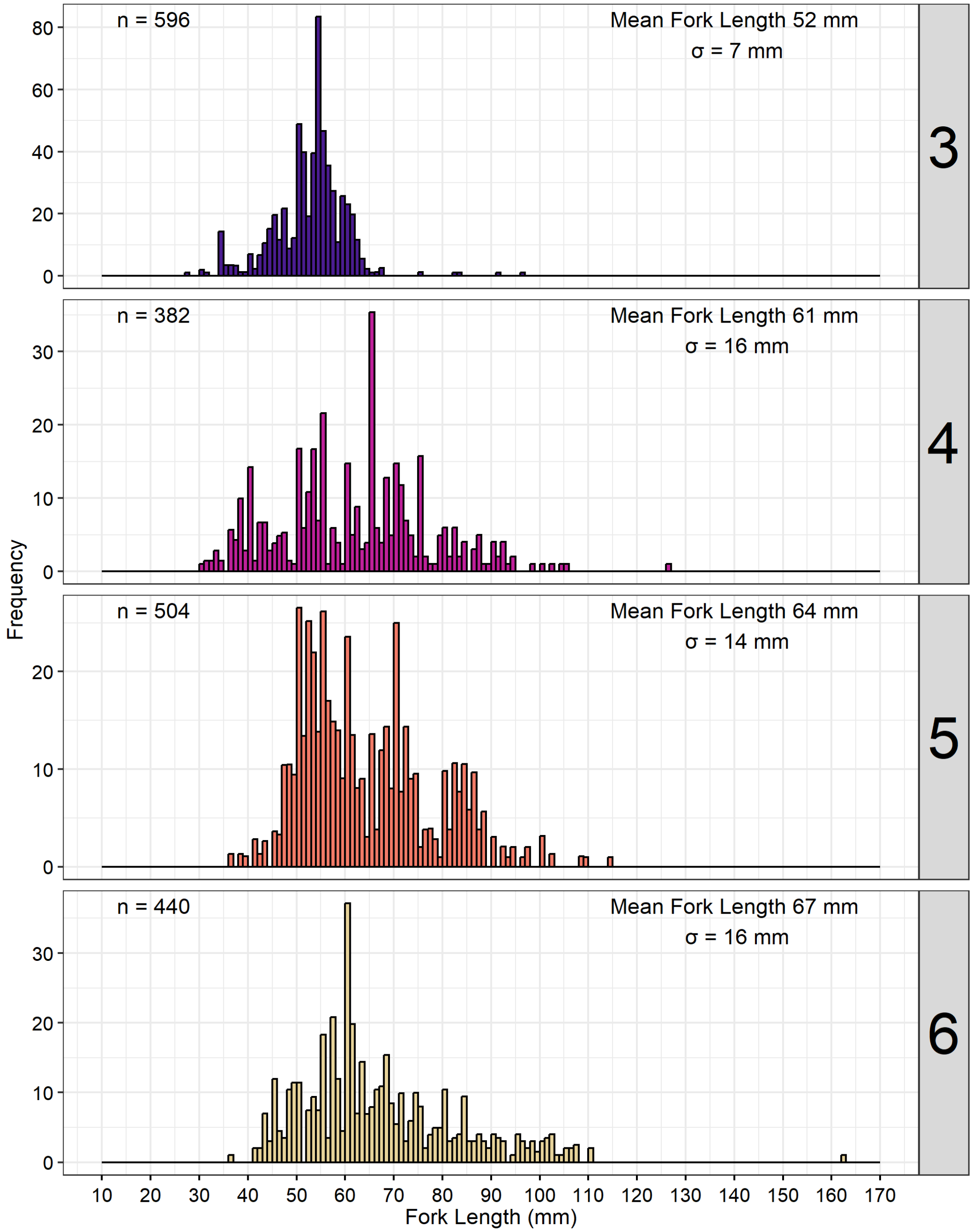

Figure 19. Fork length (mm) frequency histograms for Threadfin Shad among monthly surveys in 2023. Survey number (right panel), number of fish (n), mean fork length (mm), and fork length standard deviation (σ), are displayed on each histogram.

Threadfin Shad were caught consistently throughout the 2023 survey. Catch was greatest in September, and fork length standard deviation was smallest that month. The largest specimen measured had a fork length of 162 mm and was captured in December.

Pacific Herring

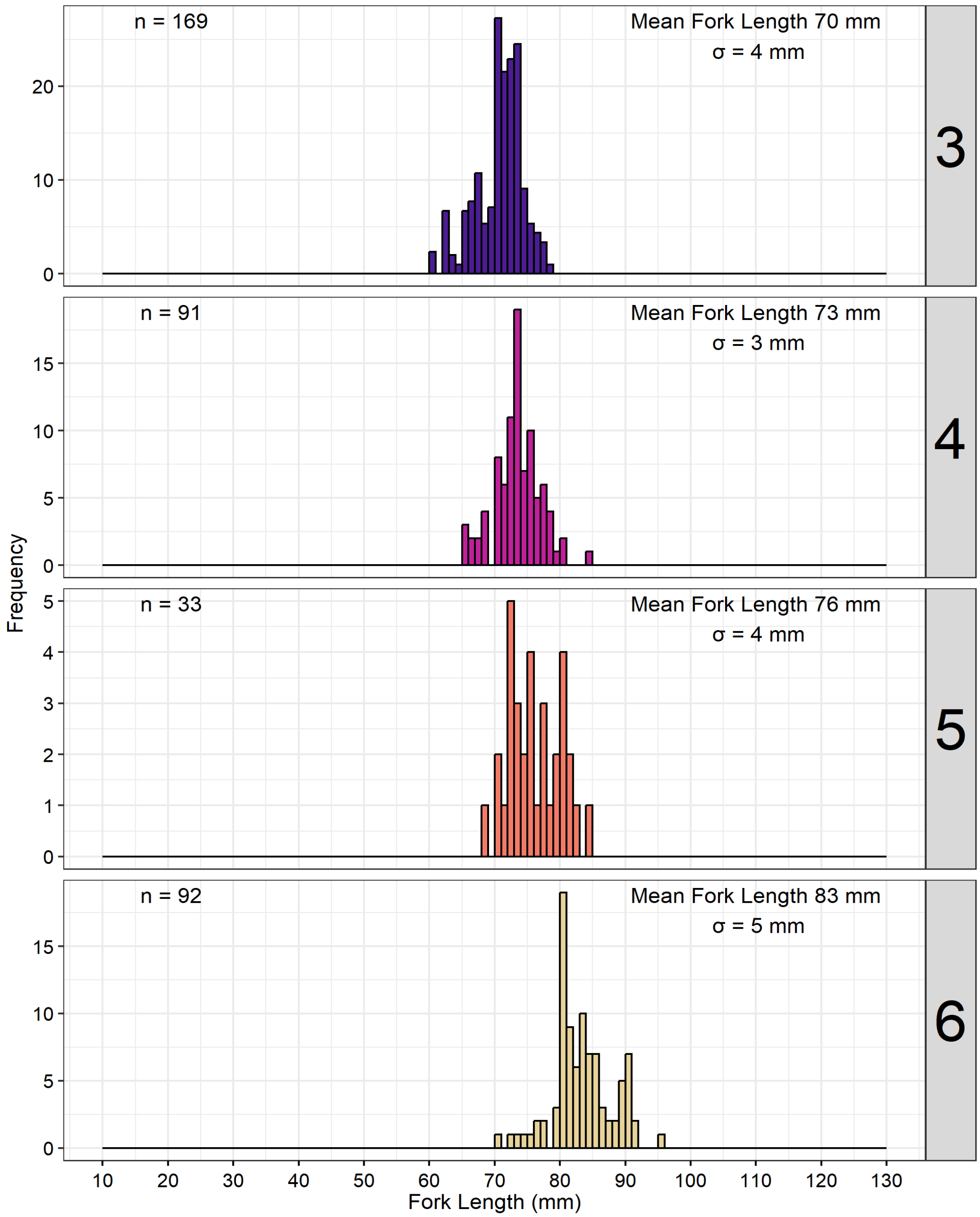

Figure 20. Fork length (mm) frequency histograms for Pacific Herring among monthly surveys in 2023. Survey number (right panel), number of fish (n), mean fork length (mm), and fork length standard deviation (σ), are displayed on each histogram.

Pacific Herring had the overall lowest fork length standard deviation across surveys and amongst the other five species examined. Similar to other species, the mean fork length increased every month.

Longfin Smelt

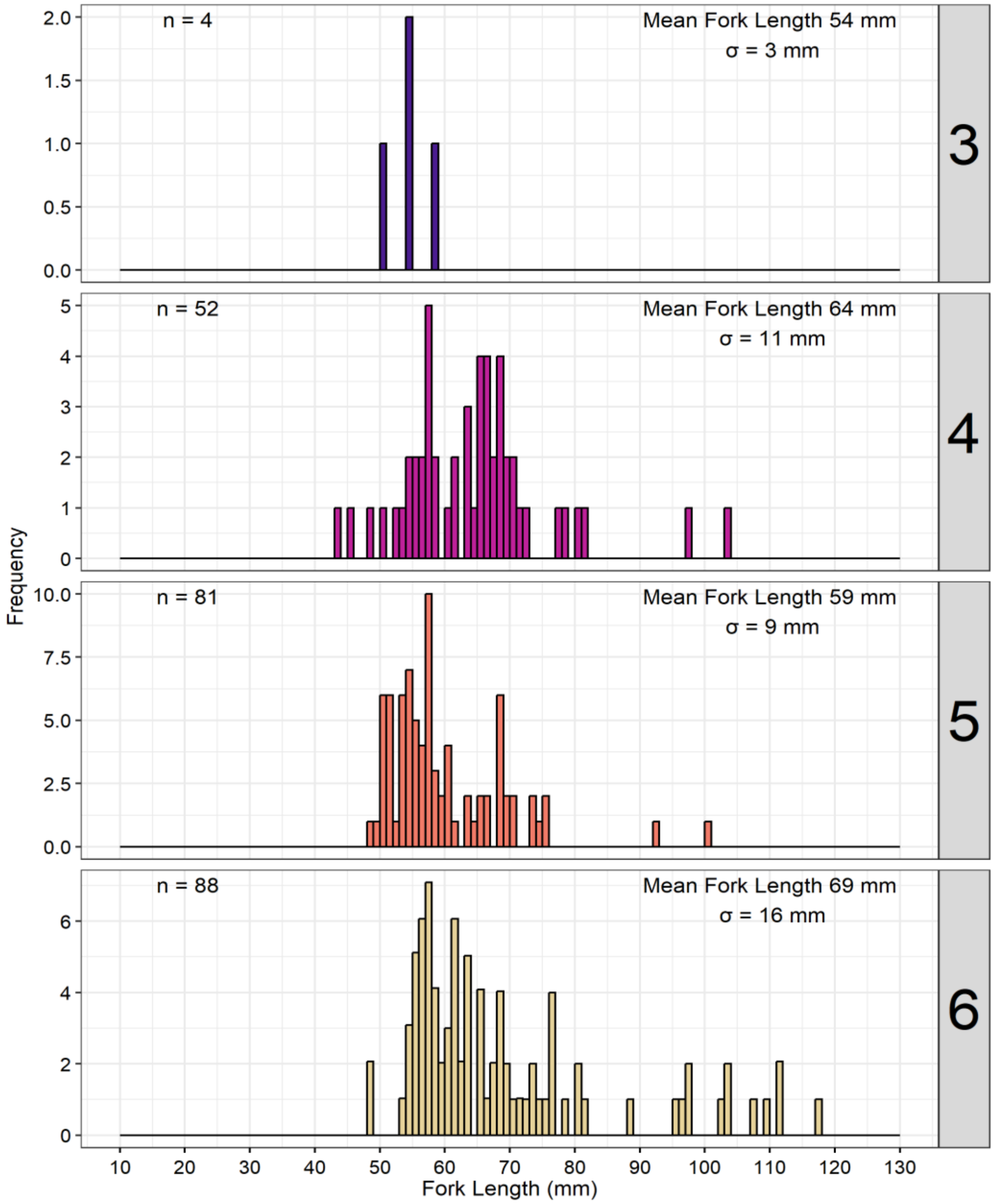

Figure 21. Fork length (mm) frequency histograms for Longfin Smelt among monthly surveys in 2023. Survey number (right panel), number of fish (n), mean fork length (mm), and fork length standard deviation (σ), are displayed on each histogram.

A few Longfin Smelt were initially captured in the September survey. Throughout the 2023 season the majority of Longfin captured were young of the year fish. However, as environmental variables shifted toward winter parameters, there was an increased catch of age-1 Longfin entering the estuary. Increased presence of age-1 Longfin is most evident in the survey 6 histogram. Overall, detection increased as time progressed, and peaked with the December Survey.

Age-0 Striped Bass

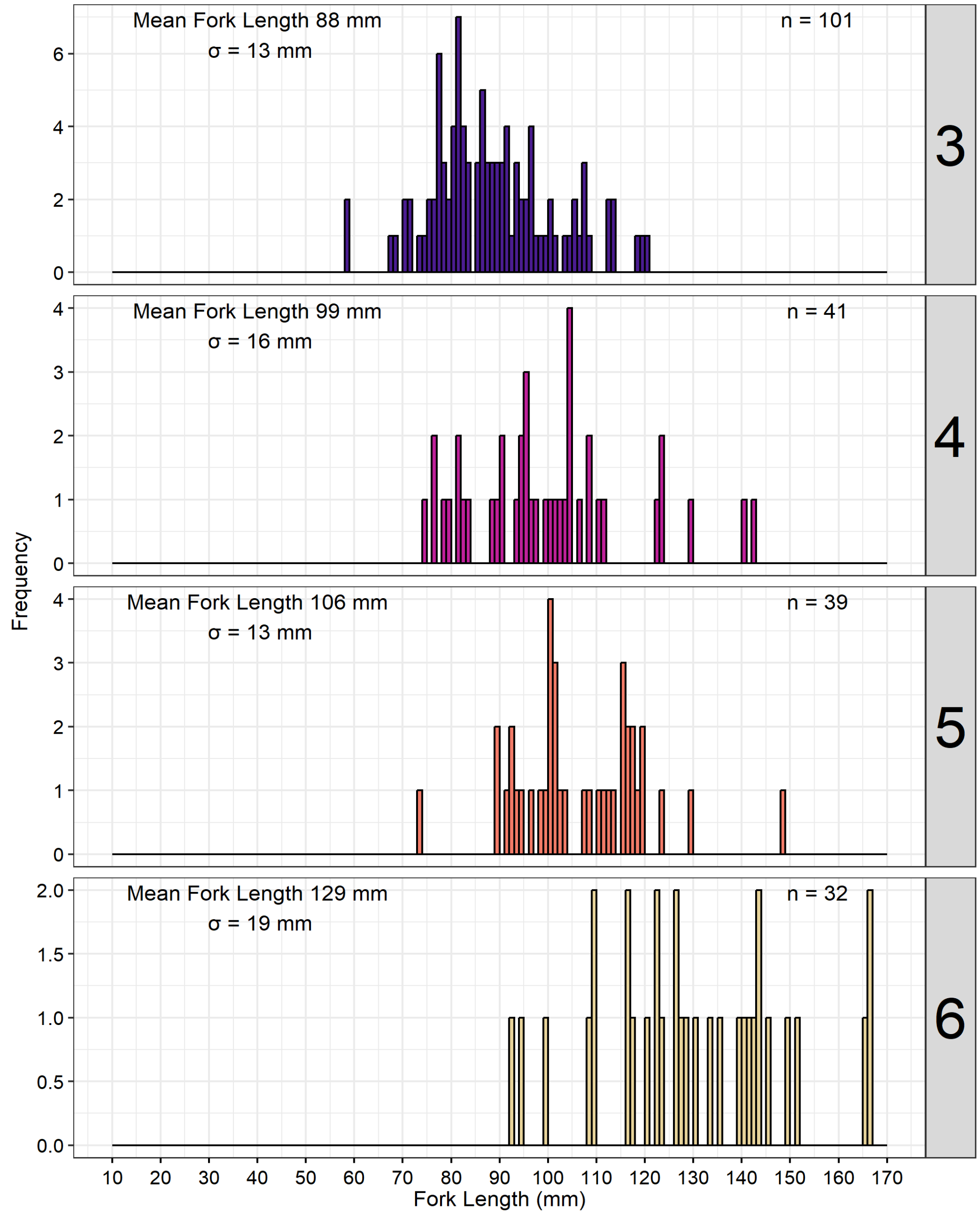

Figure 22. Fork length (mm) frequency histograms for age-0 Striped Bass among monthly surveys in 2023. Survey number (right panel), number of fish (n), mean fork length (mm), and fork length standard deviation (σ), are displayed on each histogram.

Age-0 Striped Bass were detected throughout 2023. Similar to other species, age-0 Striped Bass had a notable increase in mean fork length each month. Detection was greatest in September and decreased each month after that.

Invertebrates

For analysis and data visualization purposes, macro-invertebrate catch is divided into two groups. The first group being jellyfish (phyla: Cnidaria & Ctenophora) and the second group being crustaceans (subphylum Crustacea).

Maeotias marginata constituted the largest amount of total catch for the jellyfish (Table 4, Figure 23). This introduced species prefers lower salinities and warmer water. Catch numbers tapered off in November and there was no detection in December. Native *Polyorchis penicillatus* (red-eye jellyfish) and *Pleurobrachia bachei* (Pacific sea gooseberry) were caught in the December survey. Both of these jellyfish are marine species. The detection in December coincides with the increased saltwater intrusion into the estuary at that time (Figure 10, Figure 23). The most upstream detection in December was near Port Chicago in mid-Suisun Bay. The unidentified jellyfish detected in December were most likely one of these two species, unfortunately specimens were not retained for Identification.

Among crustaceans, *Exopalaemon modestus* (Siberian Prawn) constituted the largest total catch for shrimp (Table 5). This introduced species prefers lower salinities and was the dominant crustacean at most FMWT freshwater to brackish stations (Figure 24). The highest catch for this species occurred at station 797 in the DWSC in October. Crangon spp. shrimp were the second most caught crustaceans, the FMWT only identifies to Genus for these shrimps. These native shrimps typically have a distribution that is limited to marine and brackish environments. The highest Crangon spp. catch occurred at station 337 (East San Pablo Bay) in October (Figure 24). *Palaemon macrodactylus* shrimp, another introduced species, were the third most captured crustacean. The detection of these shrimps was highest during the October survey and was lowest during the December survey (Table 5). No crabs were collected in 2023.

Table 4. Total monthly jellyfish catch during the 2023 FWMT season.

Species	Origin	September	October	November	December	Total	Total %
Maeotias marginata	Introduced	1,885	1,550	62	0	3,497	98.7
Polyorchis penicillatus	Native	0	0	0	30	30	0.8
Jellyfish (unid)		0	0	0	10	10	0.3
Pleurobrachia bachei	Native	0	0	0	6	6	0.2
Total		1,885	1,550	62	46	3,543	

Table 5. Total monthly crustacean catch during the 2023 FWMT season.

Species	Origin	September	October	November	December	Total	Total %
Exopalaemon modestus	Introduced	405	1,989	619	52	3,065	63.7
Crangon spp.	Native	227	1,068	142	14	1,451	30.2
Palaemon macrodactylus	Introduced	13	280	2	0	295	6.1
Total		645	3,337	763	66	4,811	

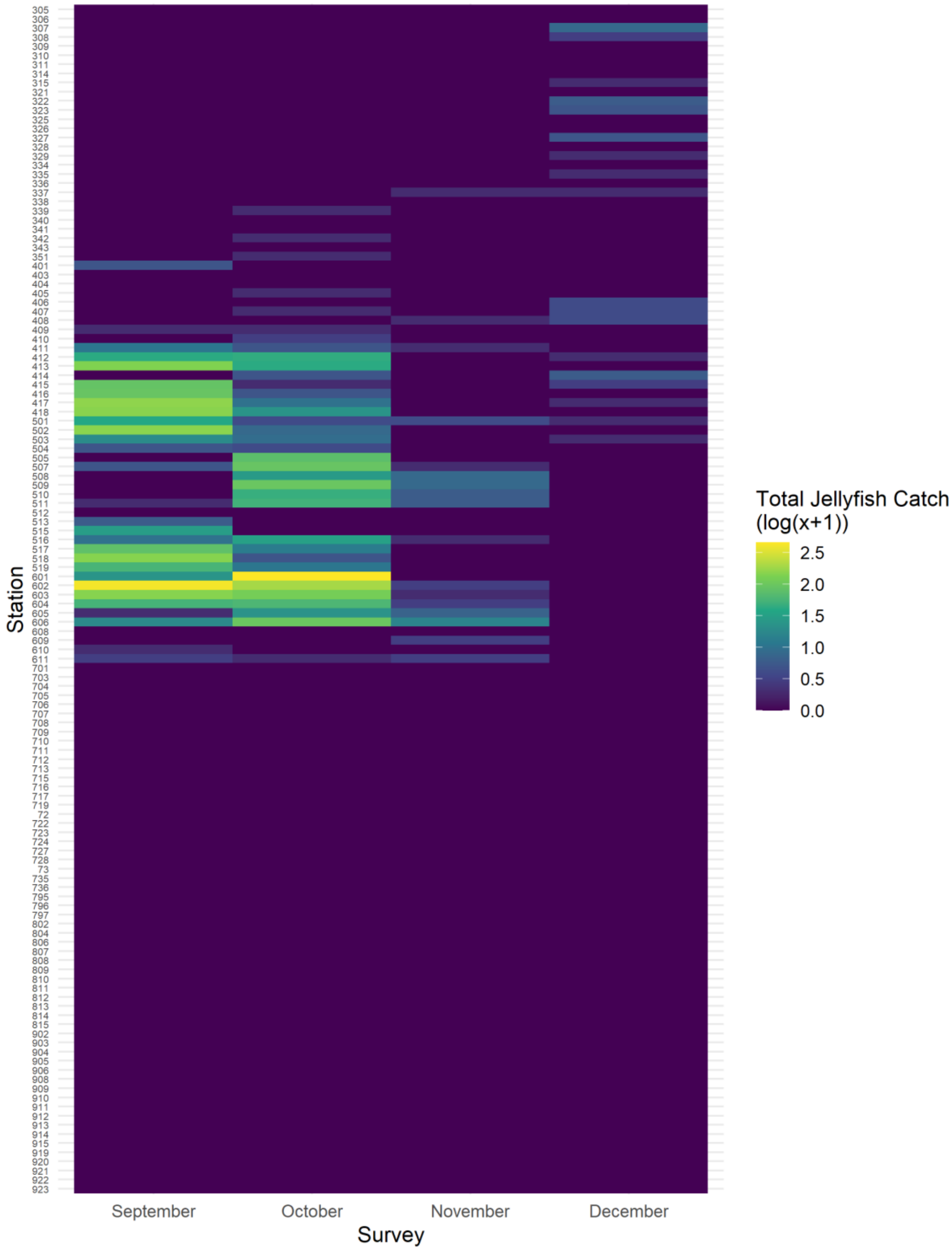

Figure 23. Heatmap of monthly $log_{10}(x+1)$ transformed total jellyfish catch by station recorded during the 2023 FMWT season. Catch was highest at stations 601 and 602 in Grizzly Bay.

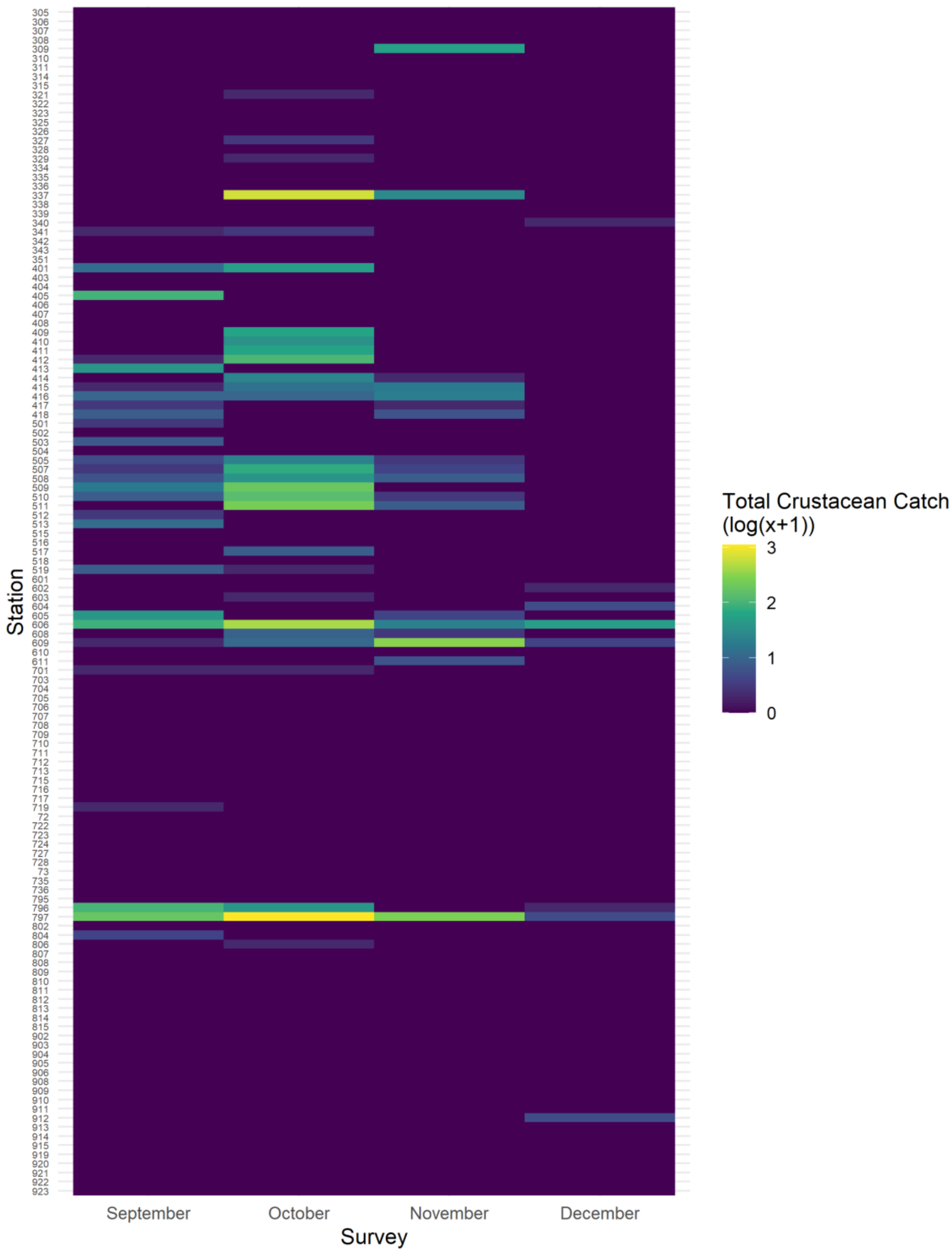

Figure 24. Heatmap of monthly $log_{10}(x+1)$ transformed total crustacean catch by station recorded during the 2023 FMWT season. The middle section of the DWSC, and east San Pablo Bay had the highest crustacean catch.

Acknowledgments

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