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Executive Summary

Conceptual models developed for selected San Francisco Bay margin areas (referred to as priority margin units, or PMUs) have identified shiner surfperch as a crucial indicator of PCB impairment, due to their explicit inclusion as an indicator species in the PCBs TMDL, importance as a popular sport fish species, tendency to accumulate high PCB concentrations, site fidelity, and other factors. The conceptual models recommend periodic monitoring of shiner surfperch to track trends in the PMUs, and as the ultimate indicator of progress in reduction of impairment. The objectives of this study were to 1) establish baselines for long-term monitoring of PCB concentrations in shiner surfperch in four PMUs, and 2) understand local spatial variation in shiner PCB concentrations to support optimization of the long-term sampling design. This study also provided valuable information on the presence of shiner surfperch and other species in the PMUs.

Robust baselines for tracking long-term trends in PCB impairment have been established for San Leandro Bay, Richmond Harbor, and the Redwood Creek portion of the Steinberger Slough/Redwood Creek PMU. Two recent rounds of sampling in San Leandro Bay yielded similar results that appear to firmly establish the current status and high degree of impairment (mean of 345 ppb [or ng/g] in 2019). This study performed the first robust characterization of PCBs in Richmond Harbor shiner surfperch, establishing a baseline for the area that varies from high mean concentrations in two Harbor stations (Santa Fe Channel and Lauritzen Channel, 269 and 280 ppb, respectively) to a more moderate mean concentration in the Main Channel (113 ppb). Redwood Creek has the best long-term time series, encompassing eight rounds of sampling over 25 years that indicate a lack of trend and a most recent mean of 178 ppb. Given the difficulty of obtaining shiner surfperch at Emeryville Crescent and Steinberger Slough, it appears that other means of tracking long-term trends in contamination of these areas will be required.

The observations within the Richmond Harbor PMU indicate that shiner surfperch have the potential to exhibit distinct variation on a within-PMU scale. This information should be considered in designing and interpreting the results of shiner surfperch monitoring in Richmond Harbor and other PMUs, and in formulating management strategies to reduce PCB concentrations in the fish that are monitored.

Continued monitoring of shiner surfperch from San Leandro Bay, Richmond Harbor, and Redwood Creek on a five-year cycle in conjunction with RMP sport fish monitoring will provide valuable information on the long-term recovery of these areas from PCB impairment. Other long-term PCB indicators will be needed for Emeryville Crescent and Steinberger Slough. Prey fish and passive samplers are two possible approaches that are being tested and implemented in the San Leandro Bay and Steinberger Slough/Redwood Creek PMUs.

Introduction

The RMP has conducted a series of PCB special studies in recent years with the goal of informing review and possible revision of the PCBs TMDL and the corresponding requirements in the Municipal Regional Permit for Stormwater. Conceptual models have been developed for selected margin areas (referred to as priority margin units, or PMUs) downstream of watersheds that are high priorities for management (Davis et al. 2017, Yee et al. 2019, Yee et al. 2021). The PMU conceptual models provide a foundation for establishing effective and efficient monitoring plans to track responses to load reductions, and will also help guide management actions.

The PMU conceptual models identified shiner surfperch as a crucial indicator of PCB impairment in these areas, due to their explicit inclusion as an indicator species in the TMDL, importance as a popular sport fish species, tendency to accumulate high PCB concentrations, site fidelity, and other factors. The conceptual site models recommend periodic monitoring of shiner surfperch to track trends in the PMUs, and as the ultimate indicator of progress in reduction of impairment. A coordinated sampling of PCBs in shiner surfperch in four PMUs was conducted as a cost-effective add-on to the 2019 Status and Trends (S&T) sport fish sampling (Buzby et al. 2021). This sampling has generated a dataset for shiner surfperch that is directly comparable across the four PMUs and the five locations that are sampled in S&T, and has also yielded some limited data for other species.

The objectives of the shiner surfperch PMU special study were to:

1. establish baselines for long-term monitoring of PCB concentrations in shiner surfperch in four PMUs, and
2. understand local spatial variation in shiner PCB concentrations to support optimization of the long-term sampling design.

The special study also provided valuable information on the presence of shiner surfperch and other species in the PMUs. Findings of the study with regard to fish species presence, spatial patterns, and temporal trends are provided below for each PMU.

Methods

Details on the methods for fish collection, chemical analysis, and data analysis are provided in Buzby et al. (2021).

ANOVA and linear regression were used to evaluate spatial differences and long-term trends. Pairwise comparison tests were used to analyze spatial distributions and some temporal trends, and were conducted using a one-way ANOVA followed by Tukey's Honestly Significant Difference post-hoc tests. These ANOVAs were conducted on log-transformed data. Long-term temporal trends for datasets in which fewer than six sampling rounds were available were evaluated using pairwise comparison tests between 2019 and previous sampling years; long-term datasets in which more than six sampling rounds were available (i.e., Redwood Creek) were evaluated using simple linear regressions.

Richmond Harbor

Fish Availability

The sampling plan called for collection of three composites (20 fish in each composite) of shiner surfperch at each of three stations within Richmond Harbor (Figures 1 and 2): at the northwest end of Santa Fe Channel, Lauritzen Channel, and the Main Harbor Channel. A previous study (Young et al. 2001) followed this design and detected substantial spatial variation in DDT concentrations in shiner surfperch.

Three composites of shiner surfperch were successfully collected at each station. The only deviation from the targets was that one of the composites from Lauritzen Channel had 15 fish instead of 20. Samples of two other species were also collected as bycatch from Richmond Harbor and analyzed for PCBs: staghorn sculpin and white croaker. The two samples of white croaker collected were analyzed for PCBs to support the general RMP S&T sampling effort, without the expectation that they would be a specific indicator of PCB bioaccumulation in Richmond Harbor due to their wide-ranging movements. Staghorn sculpin, on the other hand, are a benthic species with the potential to be an indicator of finer scale spatial variation. Three composite samples of sculpin, with 20, 20, and 18 fish in the composites, one from each of the three stations in Richmond Harbor, were analyzed as a secondary indicator of spatial variation within the Harbor and in the broader Bay (samples were also analyzed from San Pablo Bay, Berkeley, South Bay [Redwood Creek]).

Concentrations Observed and Spatial Patterns

The concentrations observed in Richmond Harbor spanned a relatively wide range, approaching both the highest and lowest values observed in the Bay-wide dataset for shiner surfperch in 2019 (Figure 3). The highest concentration in Richmond Harbor (356 ppb [or ng/g]) was the second highest observed in the Bay overall, and the lowest concentration in the Harbor (99 ppb) was only slightly greater than the lowest in the Bay overall (92 ppb). In spite of this wide range, Richmond Harbor still had the third highest mean concentration among the areas sampled throughout the Bay (Figure 3).

Statistically significant spatial variation was observed in Richmond Harbor between stations that were only 0.9 km apart from each other. Mean concentrations for the Santa Fe Channel (269 $\pm$ 20 [se] ppb) and Lauritzen Channel (306 $\pm$ 50 ppb) were significantly higher than the mean for the Main Channel (113 $\pm$ 7 ppb) (Figure 4). Similar to the findings for the individual composites, the means for these stations ranged from among the highest means for the Bay as a whole for Santa Fe Channel and Lauritzen Channel, to nearly the lowest mean for the Bay as a whole for the Main Channel. The sub-PMU scale spatial variation observed in this study was very similar to that observed by Young et al. (2001) in their DDT study, which found a mean concentration in shiner in the Lauritzen Channel (7500 ppb) that was almost two orders of magnitude higher than the mean for the Main Channel (100 ppb). These datasets provide a

clearer understanding of the site fidelity of shiner surfperch, and strong support for the notion that this species has the potential to indicate spatial variation at the within-PMU scale.

The congener profiles of the samples from these stations were also examined and did not show substantial variation. The Santa Fe Channel samples had a slightly higher contribution of Aroclor 1248 congeners, while the Lauritzen Channel samples had a slightly higher dominance of Aroclor 1254 congeners (data not shown).

Three staghorn sculpin samples were analyzed from Richmond Harbor, and six samples were analyzed for the overall Bay-wide dataset. One of the three Richmond Harbor samples had the highest concentration by far for the Bay-wide dataset (172 ppb from the Santa Fe Channel station). Concentrations in the other two samples from Lauritzen Channel (62 ppb) and Main Channel (52 ppb) were essentially equal and within the range of those measured at other Bay locations (three samples at 29, 87, and 91 ppb).

Temporal Trends

The 2019 effort was the first sampling of PCBs in shiner surfperch in the Main Channel and upstream areas by the RMP. In 1994 a Richmond Harbor station was sampled by the Bay Protection and Toxic Cleanup Program, but it was located outside of the Harbor Channel. Based on the observations from the present study and Young et al. (2001), the 1994 station should not be directly compared to the data from the interior stations. For reference, however, the data are shown as part of the Richmond Harbor plot in Figure 5. The 2019 survey has established a good baseline for evaluation of long-term trends in the Richmond Harbor PMU, and helped to clarify the need for precise selection of station locations within the PMU.

Emeryville Crescent

Fish Availability

Shiner surfperch were not obtained in the Emeryville Crescent, in spite of a concerted effort over the span of four sampling days (Figure 6). The Cruise Report (Sigala 2019) attributed this to Emeryville Crescent being a broad, shallow area without channels or structure to target. Only white surfperch (*Phanerodon furcatus*) and jacksmelt (*Atherinopsis californiensis*) were obtained. The one white surfperch sample was analyzed as a potential alternative to shiner surfperch for this PMU: this species is in the same family as shiner surfperch (*Embiotocidae*), has a similar diet, and in a limited statewide dataset on co-occurrence with shiner surfperch (Davis et al. 2012) had generally similar concentrations as shiner surfperch. However, only one sample was obtained so this species is also not sufficiently abundant to serve as a robust indicator for this PMU. The jacksmelt were analyzed as one of the target species for the Bay-wide sampling. Given the difficulty of obtaining shiner surfperch at this location, it appears that other means of tracking long-term trends in contamination of this PMU and its food web will be required. Prey fish and passive samplers are two possible

approaches that are being tested and implemented in other PMUs (San Leandro Bay and Steinberger Slough/Redwood Creek).

Concentrations Observed

The one white surfperch sample obtained had a concentration of 107 ppb. No other white surfperch samples were obtained in the Bay-wide sampling. This concentration is high, however, relative to observations in prior studies. One other white surfperch sample from the Central Bay (but away from the East Bay shoreline) analyzed by the Bay RMP in 2014 had a concentration of 8 ppb. The concentration in the Emeryville Crescent sample is in fact the highest observed for this species across eight locations in California (Davis et al. 2012). This concentration, however, is toward the low end of the range observed for shiner surfperch in the Bay in 2019 (92-397 ppb). Overall, the concentration in the one white surfperch sample from Emeryville Crescent appears to indicate a signal of PCB contamination, but the number of samples obtained was not sufficient to establish a solid baseline for tracking long-term trends.

Three samples of jacksmelt were obtained from Emeryville Crescent, and had PCB concentrations ranging from 6-16 ppb. No other samples in the Bay were analyzed in 2019. This species is not a strong accumulator of PCBs: in the last RMP sampling in which they were analyzed (2014) their average concentration was 22 ppb. Jacksmelt are therefore not a good indicator species for tracking long-term trends in Emeryville Crescent.

San Leandro Bay

Fish Availability

As observed in past sampling (2000 and 2016), shiner surfperch continued to be available in San Leandro Bay in sufficient quantities to support long-term monitoring. Yee et al. (2019) recommended shiner surfperch as an indicator of long-term trends, and after examining different locations within this PMU recommended a focus on the “main back channel” area (Figure 1). The target number of three composites was obtained with fish from this area. No other species were collected for PCB analysis in San Leandro Bay.

Concentrations Observed

The three concentrations observed in composite samples from San Leandro Bay (289, 350, and 397 ppb) had the highest mean (345 ± 31 [se] ppb) among any of the areas sampled in the 2019 Bay-wide effort (Figure 3). The one statistically significant difference among areas in the 2019 dataset was between San Leandro Bay and Berkeley (Figure 3). The sample with 397 ppb had the highest concentration of any shiner surfperch sample in the Bay-wide 2019 dataset.

Temporal Trends

Successful sampling in 2016 and 2019 appears to have established a solid baseline for the current status of PCB impairment in the San Leandro Bay food web. Figure 5 shows the long-term time series for San Leandro Bay and the other long-term Bay stations. The concentrations are presented as the sum of 40 congeners and on a lipid weight basis to provide for better comparisons across the years. The mean lipid weight concentrations in 2019 (8,000 ppb) and 2016 (8,200 ppb) were very similar. These recent means were much lower, however, than the mean measured in 2000 (12,700 ppb). Without additional measurements across the years it is not possible to conclude whether the lower concentrations in recent years are indicative of a long-term decline rather than interannual variation. Data from other locations where the time series are more complete (Oakland and South Bay [Redwood Creek]) indicate that unusually high concentrations sometimes occur in the long-term time series (Figure 5).

Steinberger Slough/Redwood Creek

Fish Availability

This PMU consists of two hydrologically connected subareas: Redwood Creek (referred to as “South Bay [Redwood Creek]” in the 2019 RMP sport fish report) and Steinberger Slough (Yee et al. 2021). The Redwood Creek long-term sport fish monitoring station is near Redwood City Harbor and a public fishing pier (Figure 7), and has been sampled successfully in every round of RMP sport fish sampling (Figure 5). Steinberger Slough, on the other hand, had not previously been sampled for shiner surfperch prior to this study. Shiner surfperch were not obtained in Steinberger Slough, in spite of a concerted effort (Figure 7). In the Cruise Report, Sigala (2019) commented that “Steinberger Slough seems to be an anomaly since the channel and nearby wetlands should support shiner surfperch and other fish species. The shiner surfperch population in the main Redwood City channel seems healthy so it would be expected to find them in nearby Steinberger Slough…The crew was surprised at the paucity of life found in Steinberger Slough after all of the trawls and net sets in the area.” As for Emeryville Crescent, given the difficulty of obtaining shiner surfperch at this location, it appears that other means of tracking long-term trends in contamination of this PMU and its food web will be required. A study using passive samplers in SS/RC was funded by the RMP in 2020 and is currently in progress. A survey of prey fish is under consideration for 2022.

Concentrations Observed

Redwood Creek had a mean concentration of 178 $\pm$ 28 [se] ppb, based on three samples at 148, 150, and 234 ppb. This mean was intermediate between the areas with the highest concentrations (San Leandro Bay, Richmond Harbor, and Oakland), and the area with the lowest concentration (Berkeley) (Figure 3), and was not statistically significantly different from any other area. While Redwood Creek concentrations are not among the highest in San

Francisco Bay, they are still well above OEHHA's advisory tissue level for no consumption (120 ppb) and 18 times higher than the Water Board target of 10 ppb.

In Steinberger Slough only two samples suitable for PCB analysis were obtained, and these were analyzed to gain a small amount of insight into the level of contamination in this food web. A sample of anchovy (23 fish in the composite) collected near the mouth of Steinberger Slough had a concentration of 118 ppb. This concentration was intermediate relative to the distribution of concentrations found in seven other samples Bay-wide in 2019 (28 ppb in San Pablo Bay, 110, 110, and 111 ppb in Oakland, and 114, 116, and 174 ppb in Redwood Creek). A striped bass sample (two fish in the composite) collected further upstream in the Slough had a concentration of 30 ppb. This was the highest observed from a total of 10 samples collected Bay-wide (the other nine samples ranged from 10-27 ppb). Overall, these two samples suggest that concentrations in Steinberger Slough are similar to those in other contaminated locations (i.e., Oakland Harbor and Redwood Creek), and higher than those from a less contaminated area (San Pablo Bay). The congener profiles in these samples were similar to those for these species observed in the other Bay samples.

Temporal Trends

Redwood Creek has a very robust time series, with eight rounds of sampling covering a span of 25 years in a very well-constrained sampling area. The time series indicates that concentrations have not declined over this period. A linear regression of the lipid weight annual means shown in Figure 5 was not significant. The mean concentration observed in 2019 (7500 ppb lipid weight) was tied with 2000 for the second highest in the eight rounds. The mean concentration in 2003 was the highest on record, standing out from the rest of the time series and indicating that interannual variation can be high and caution is warranted in interpreting time series with small numbers of years included.

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Figure 1. Targeted shiner surfperch sampling stations in the PMUs. A station in Redwood City Harbor (not shown) was also sampled as part of the routine Status and Trends sampling.

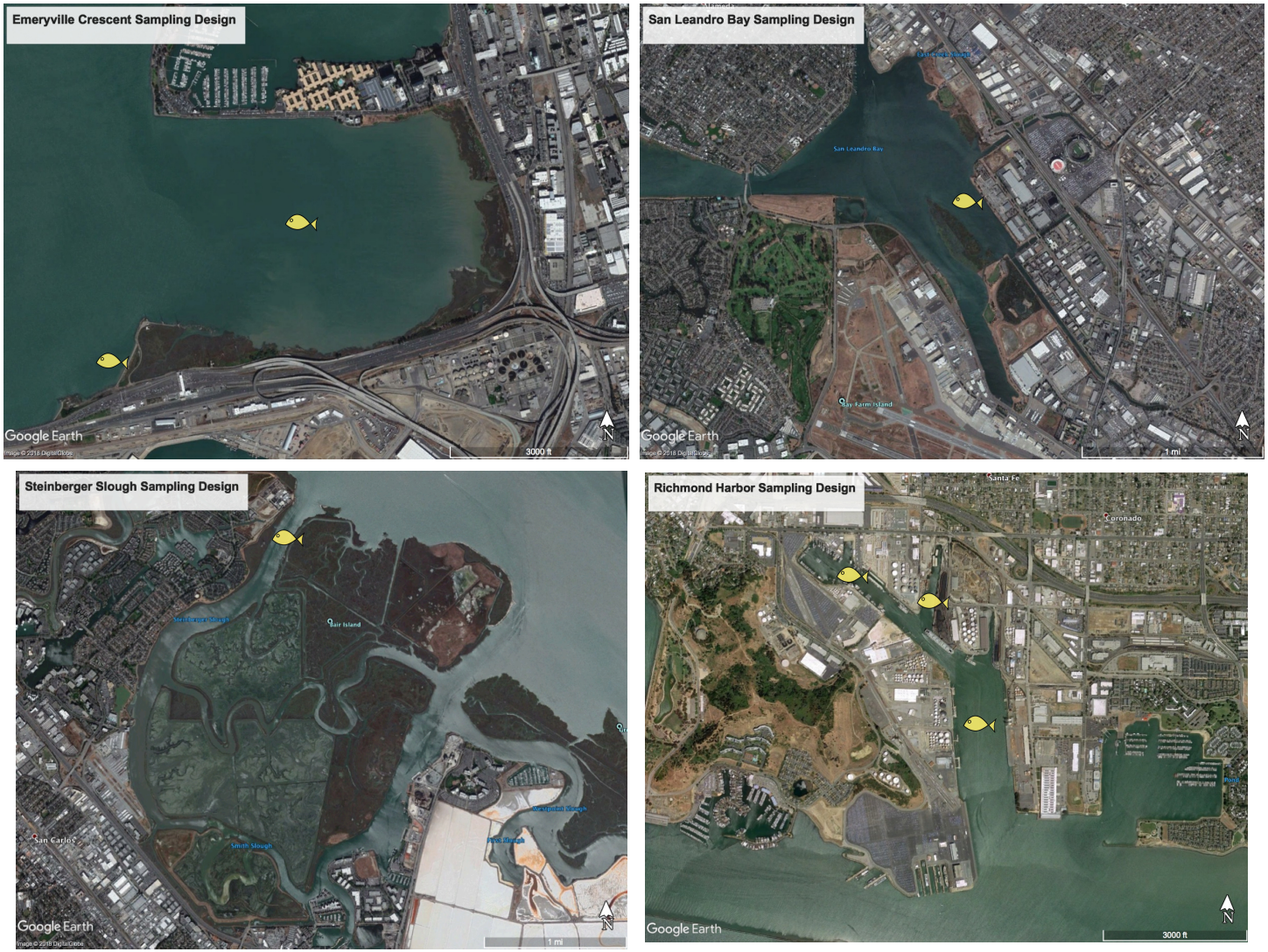

Figure 2. Shiner surfperch sampling stations in Richmond Harbor.

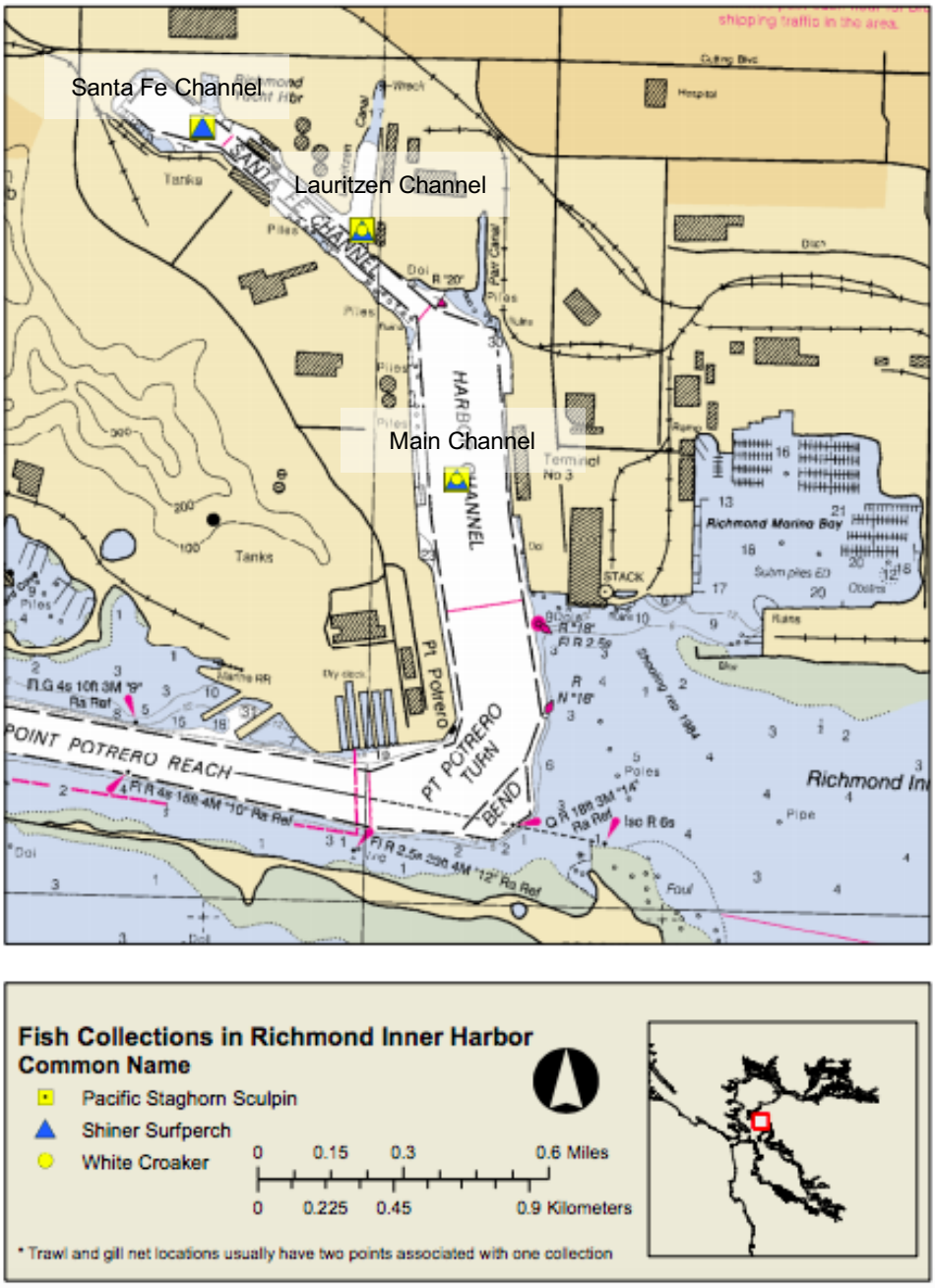

Figure 3. PCB concentrations (ppb ww) in shiner surfperch in San Francisco Bay, 2019. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. Locations labeled with the same letter did not have significantly different means (Tukey HSD, alpha = 0.05). The colored lines indicating ATL thresholds show the lower end of the ATL ranges.

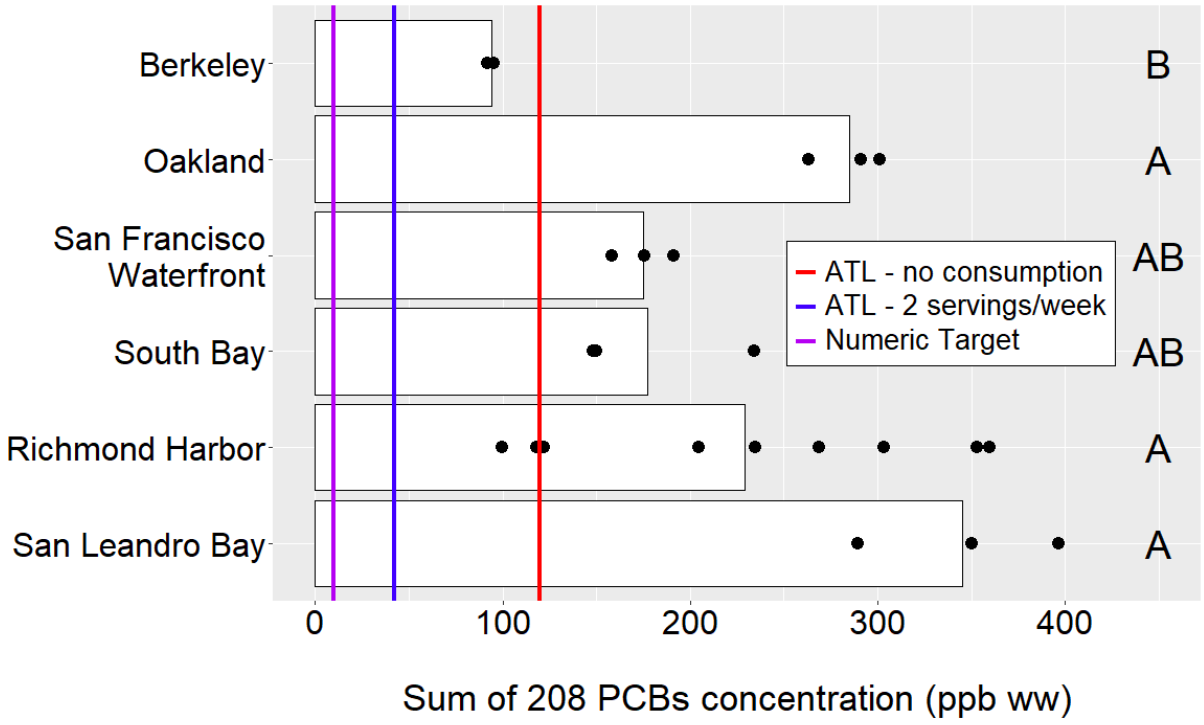

Figure 4. PCB concentrations (ppb ww) in shiner surfperch in Richmond Harbor, 2019. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. Locations labeled with the same letter did not have significantly different means (Tukey HSD, alpha = 0.05). The colored lines indicating ATL thresholds show the lower end of the ATL ranges.

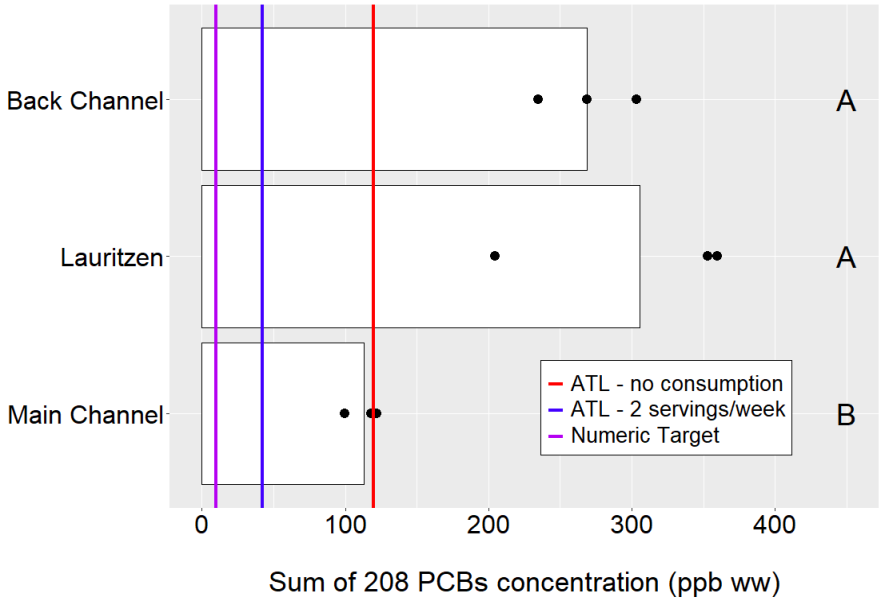

Figure 5. PCB concentrations (Sum of 40 PCBs, ppb lipid weight) in shiner surfperch in each region of San Francisco Bay, 1994-2019. Bars indicate average concentrations. Points represent composite samples with 20 fish in each composite. Data were obtained from the Bay Protection and Toxic Cleanup Program (1994) and the Regional Monitoring Program (all other years). Samples collected in 1994 at sites that were not subsequently monitored by the RMP are not included.

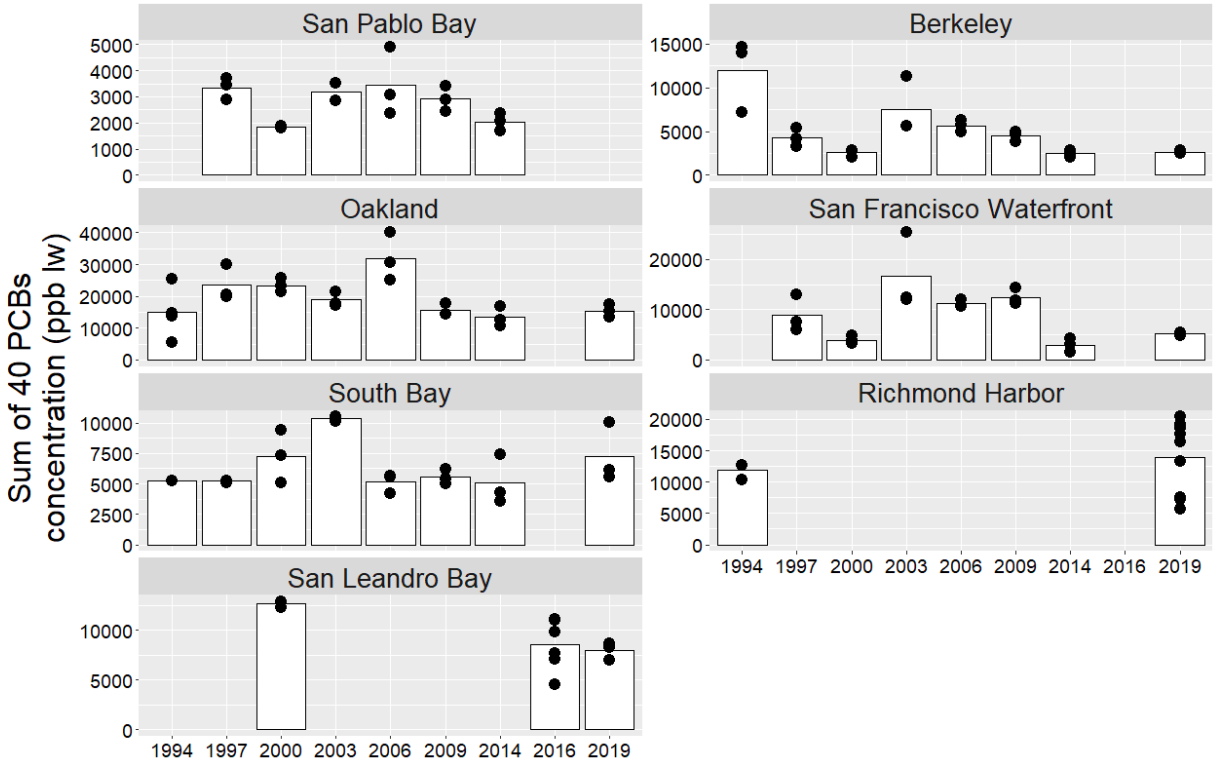

Figure 6. Fishing effort in Emeryville Crescent.

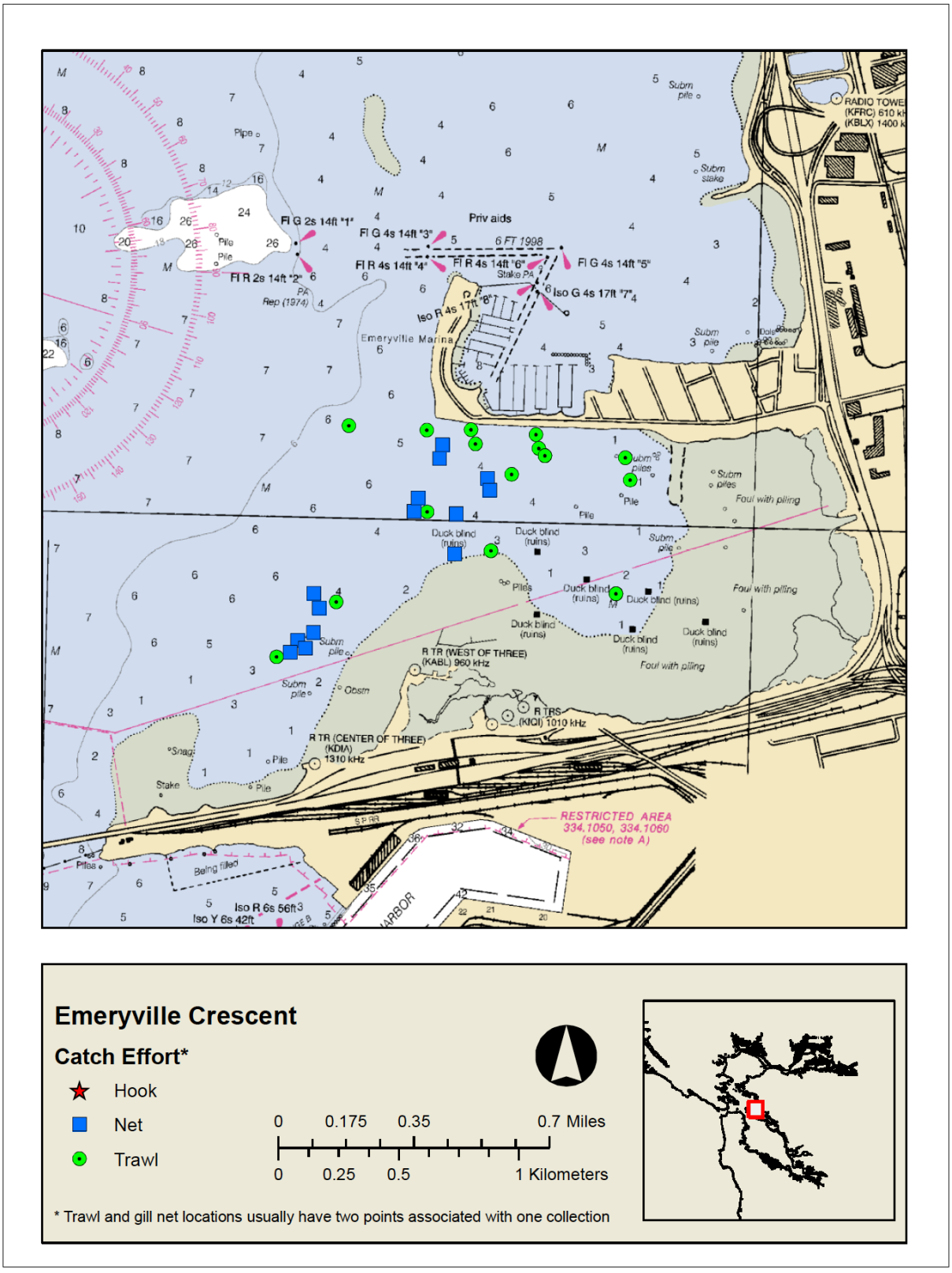

Figure 7. Fishing effort in Steinberger Slough/Redwood Creek.