https://doi.org/10.25923/bmt9-6435

NOAA Technical Memorandum NMFS

SEPTEMBER 2021

COMPARISON OF LENGTH SAMPLING PROGRAMS FOR RECREATIONAL FISHERIES OF U.S. PACIFIC BLUEFIN TUNA FROM 2014 TO 2020

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NOAA-TM-NMFS-SWFSC-652

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center

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Recommended citation

Kelsey C. James, Liana N. Heberer, Huihua Lee, Heidi Dewar and Alayna Siddall. 2021. Comparison of Length Sampling Programs for recreational fisheries of U.S. Pacific Bluefin Tuna from 2014 to 2020. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-SWFSC-652

Comparison of Length Sampling Programs for recreational fisheries of U.S. Pacific Bluefin Tuna from 2014 to 2020

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Executive Summary

The U.S. recreational fishery for Pacific Bluefin Tuna (PBF) is dominated by commercial passenger fishing vessels (CPFVs), the landings of which are included in stock assessments. The National Oceanic and Atmospheric Administration (NOAA) conducts a Pacific Bluefin Tuna Port Sampling Program (PSP) and supports the Sportfishing Association of California Fisheries Sampling Program (SAC) to collect length data to describe the length compositions of the CPFV fleet catch for use in the PBF stock assessment. For this study, we: 1) compared the number of PBF and trips sampled and geographic extent of PSP and SAC to each other and to the CPFV logbooks; 2) analyzed the potential overlap between PSP and SAC; 3) compared the length compositions of PBF sampled by the two programs; 4) assessed the effect of weekday landed and predicted future PBF sampling by PSP; 5) investigated the effect on the length distributions of sampling fewer vessels; and 6) explored how representative PSP and SAC were of CPFV fleet landings. PSP measured 4.5% of the CPFV fleet between 2014 and 2019, while SAC measured 3.8% of the CPFV fleet between 2015 and 2020. PSP sampled PBF from more vessels than SAC in all years, and it sampled more trips than SAC in most years. Both PSP and SAC sampled PBF from fishing blocks that were representative in space and effort to the entire CPFV fleet. Overlap of PSP and SAC sampling was low; a maximum of 3.0% of PBF were measured by both sampling programs. The length compositions of the programs had similar multimodal distributions and only small (2.5 cm) differences in overall median fork lengths. However, PSP sampled larger PBF than SAC in several years, which may have been partially driven by the availability of smaller PBF to SAC that were often filleted at sea and unavailable to PSP. In both programs, the number of PBF landed differed by weekday landed, but pairwise comparisons by weekday did not have significant differences. Based on previous sampling years, PSP could sample as many as 731 PBF in future years if sampling occurred once a week for 18 weeks. SAC sampled fewer vessels than PSP, but a subsampling simulation demonstrated that sampling fewer vessels had only a minor effect on the length compositions. PSP and SAC data raised to the CPFV logbook catch reflected the raw data both seasonally and spatially. The comparison of SAC and PSP identified similarities and differences in sampling design and catch-at-lengths that could help characterize the size composition of PBF landed by the CPFV fleet.

1. Introduction

The Pacific Bluefin Tuna (*Thunnus orientalis*; PBF) is an economically important component of commercial and recreational fisheries in the North Pacific Ocean. This species spawns in the Western Pacific Ocean (WPO) off eastern Taiwan, the Ryukyu Islands, and in the Sea of Japan (Yonemori, 1989; Ashida et al., 2015) where it is seasonally harvested by fishing fleets from Japan, South Korea, and Taiwan. An unknown portion of age 1-3 juveniles migrate to the Eastern Pacific Ocean (EPO) to forage for a number of years off the west coast of North America before returning to the WPO (Inagake et al., 2001; Itoh et al., 2003; Boustany et al., 2010). In the EPO, PBF seasonally migrate between Baja California, Mexico, and central California, U.S., where they are targeted by commercial and recreational fisheries in both countries (Itoh et al., 2003; Kitagawa et al., 2007; Boustany et al., 2010).

Since 1952, an average 25% of the total catch of PBF from the North Pacific has been harvested by the U.S. and Mexico in the EPO, primarily using commercial purse seine and recreational hook-and-line methods (ISC, 2018). From 1952 to 2001, U.S. commercial purse seine was the dominant source of PBF catch in the EPO, with an annual average at 4,811 mt compared to 645 mt by Mexico commercial purse seine and 79 mt by U.S. recreational fisheries.[1] From 2002 to 2019, Mexico purse seine was the dominant source of catch in the EPO, with an annual average at 4,391 mt compared to 203 mt by U.S. purse seine and 306 mt by U.S. recreational fisheries.[1] However, the EPO catch declined from about 7,000 mt in 2012 to about 3,000 mt in 2018-2019. [1] The decline was likely due to management measures from the Western and Central Pacific Fisheries Commission (WCPFC) and the Inter-American Tropical Tuna Commission (IATTC).

In the U.S., the majority of PBF catch after 2011 was landed by recreational fisheries, including private boaters and Commercial Passenger Fishing Vessels (CPFVs) operating in U.S. and Mexican waters (Heberer and Lee, 2019). The average recreational catch increased from 167 mt (2002-2010) to 446 mt (2011-2019), and the CPFV fleet has recently caught larger length classes of PBF (Heberer and Lee, 2019). The mechanisms driving the availability of more and larger-bodied fish in the EPO are not well understood but may be related to regional environmental variability. Large-scale and decadal changes in regional climate (e.g., increased frequency and intensity of El Niño events) have resulted in a higher frequency of warmer waters

[1] ISC Fisheries statistics. http://isc.fra.go.jp/fisheries_statistics/index.html

in the EPO (Cai et al., 2014; Cai et al., 2018). Runcie et al. (2018) predicted higher probabilities of PBF occurrence in the Southern California Bight in warmer waters (e.g. 20.1°C in 2015) with lower surface chlorophyll and higher sea surface height. These El Niño conditions may have resulted in northward shifts of PBF distribution in the EPO (Runcie et al., 2018; Heberer and Lee, 2019) or contributed to longer residence times, which translated into larger, older fish occurring in the EPO (Madigan et al., 2017; Heberer and Lee, 2019). Other factors such as gear selectivity, size targeting by fishing vessels, fisheries mortality, and the recruitment to and retention of fish in the EPO may also have influenced recent changes in the observed length composition of the recreational fishery for PBF (Aires-da-Silva et al., 2009; Madigan et al., 2017; Piner et al., 2020).

Currently, three programs collect length-at-catch data on PBF landed by the CPFV fleet in California. The National Oceanic and Atmospheric Administration (NOAA) Pacific Bluefin Tuna Port Sampling Program (PSP) started in July 2014 to collect straight fork length (FL) data from whole PBF caught by the CPFV fleet. This program samples fish opportunistically from CPFV trips after they are unloaded at three public landings in San Diego. Comprehensive details of PSP design, protocols, and operations can be found in Heberer and Snodgrass (in review). To complement PSP, the NOAA-funded Sportfishing Association of California Fisheries Sampling Program (SAC) started in 2015,[2] in which CPFV vessel crew measure straight FL of landed PBF while onboard and prior to unloading. CPFVs participating in SAC are assigned a set weekday to sample PBF and can sample weekly throughout the entire season; if a multi-day trip includes the assigned weekday, PBF from the entire trip were measured. Finally, the California Department of Fish and Wildlife (CDFW) has collected data on California's marine recreational fisheries since 1979 using field sampling, telephone surveys, and CPFV logbooks to estimate recreational catch (CDFW 2021). Private boats and anglers fishing from beaches, banks, and man-made structures are covered by field sampling and telephone surveys. The CPFV fleet catch is quantified both through field sampling and in logbooks as mandated by CDFW. Logbooks are self-reported records for each day of a trip, and while they don't report PBF lengths, the logbooks can help assess the extent to which PSP and SAC cover the fishery. CDFW has also collected lengths from the CPFV fleet and from private or rental boats. Unfortunately, the CPFV fleet has collected few PBF lengths and private and rental boats have different fishing methods

[2] SAC Fisheries Sampling Program. https://www.californiasportfishing.org/bluefin-tuna-sampling-project

(e.g. trip duration and distance) than CPFVs and consequently the length data are not directly comparable to the lengths collected by PSP and SAC.

The overall goal of this work was to determine whether the data generated by PSP and SAC are comparable and whether they reflect the CPFV fishery. The specific objectives of this study were to: 1) compare the number of PBF and trips sampled and geographic extent of PSP and SAC to each other and to the CPFV logbooks; 2) analyze the potential sampling overlap between PSP and SAC; 3) compare the PBF length compositions by program, year, and trip duration; 4) assess the effect of weekday landed and predict future PBF sampling by PSP; 5) investigate the effect of sampling fewer vessels on the length distribution; and 6) explore how representative PSP and SAC are of CPFV fleet landings. The 2020 PBF stock assessment incorporates length data from PSP sampled from the CPFV fishery. This is the first comparison of the length data between PSP and SAC, and the results generated here were intended to provide guidance on the utility of the SAC dataset to the PBF stock assessment.

2. Methods

2.1. General comparisons

To examine the potential impacts of the differences in sampling design, we compared the length compositions obtained from PSP and SAC datasets. The CDFW length sampling program sampled a relatively small number of fish (n = 76) from the CPFV fleet in the overlapping time period (2014-2020), and consequently, was not included in the comparison. PSP and SAC collected similar data including vessel name, trip duration, departure and return date, number of PBF measured, and FL of landed fish to the nearest 0.1 cm for each trip. PSP often sampled more than one vessel and trip in a given day; therefore, the number of days that PSP sampled was also recorded. For SAC, each vessel was assigned one weekday for the season and measured up to 25 PBF caught on that day. For trips longer than one day, if the assigned weekday fell during the trip, a maximum of 25 PBF were measured on that trip regardless of the day the PBF were caught. CDFW provided CPFV logbook data that included the vessel name, number of PBF landed, date of logbook landings, CDFW commercial fishing block, and landing port.

The number of PBF measured by PSP and SAC and the number of PBF reported landed in CPFV logbook data were calculated by month and year. The percent coverage of recreational PBF sampled was calculated for PSP and SAC separately as the number of the PBF sampled by each program divided by the total PBF landed in California. The number of vessels sampled was also compared across programs, and the percent coverage was calculated.

The geographic coverage of PSP and SAC were each compared to the geographic coverage of the whole CPFV fleet. To determine fishing location, trips from the sampling programs were matched to the CPFV logbook records through the unique combination of vessel and trip dates. Matched trips were compared to overall CPFV effort using heat maps based on 10-minute CDFW commercial fishing blocks. These fishing blocks were designed for California waters, and the block areas are much larger than 10-minute squares in Mexican waters.

The sampling effort of PSP and SAC (reported as number of trips) were compared across years. The CPFV logbooks, which were reported by each day fished for multi-day trips and not by trip, were not directly comparable and omitted from comparison of trips. As PSP often measured more than one trip per day, the number of sampling days was also examined across years. The number of PBF measured per trip and sampling day (PSP only) were examined to understand the return on sampling effort. For example, what percent of trips measured fewer than five PBF? The maximum sampling size per trip was set at 25 for SAC[2] and 40 in 2014 and 30 in 2015-2019 for PSP (Heberer and Snodgrass, in review).

Within the CPFV fleet, trips are divided into two categories based on duration. Short-range (SR) CPFVs generally have a 200 nautical mile range and make trips ranging from 0.5 to 3 days, while long-range (LR) vessels can travel up to 650 nautical miles off the entire Baja California Peninsula, Mexico, on trips ranging from 4 days to 3 weeks. To address potential differences in sampling efforts of SR and LR trips between PSP and SAC, the number of PBF measured and number of trips sampled were compared by trip duration (SR vs LR) between programs.

2.2. Overlap of PSP and SAC data

The degree of overlap between PSP and SAC (i.e., when both programs measured PBF from the same trip) was assessed by matching trips based on vessel name, departure date, and return date. Based on trips sampled by both programs, the percent maximum overlap was calculated. For each overlapping trip between PSP and SAC, the length frequency distributions were compared using two-sample Kolmogorov-Smirnov (KS) tests in R (R Core Team, 2019) to detect if the measurements made by each program reflect the same length composition. All statistical tests used a p-value of 0.05 to define significant differences. Reported p-values were rounded to 3 digits. To determine if PSP and SAC were measuring the same fish, the overlapping trips were matched to CPFV logbook data to compare the number of PBF measured by PSP and SAC to the number of PBF reported landed in logbook data. The trips sampled by both programs were removed from further comparisons because there was a possibility the data points were duplicates.

2.3. Fork Length Analyses

PBF were measured throughout the year. The relatively quick growth rate of PBF (ISC, 2020) made direct comparison of the FLs across months untenable. To compare lengths from different months, lengths were transformed to a fixed date, August 15, using the von Bertalanffy growth model for this species (ISC, 2020). Each length was converted to age using the growth model, then the difference between the landing date and August 15 was calculated and the difference was applied to the age. The calculated age on August 15 was converted back to FL. These transformed FLs were then compared between programs and years with two-sample KS tests to determine if the length frequencies were from the same distribution. Median FLs calculated from the transformed FL data were also compared between programs and years. Length frequency distributions were generated using kernel density estimates for each year or histograms for each year. Kernel density estimation used Gaussian kernels and were smoothed using the Sheather-Jones method (Sheather and Jones, 1991; Venables and Ripley, 2002). Length-at-ages from ages 0 to 10 were taken from the 2020 PBF ISC stock assessment (ISC, 2020). These lengths-at-age were used to examine estimated age distributions among years and programs.

To assess if PBF lengths were different between SR and LR trips, transformed FLs were compared by trip duration (SR vs LR) with two-sample KS tests and median FLs calculated within and across programs. Trips of unknown duration were excluded from the analysis.

2.4. Weekday Analyses and Predicted Future PBF Sampling by PSP

To determine the effect of weekday on number of fish sampled, a Kruskal-Wallis test by ranks was conducted on the number of PBF measured by weekday and program in R (R Core Team, 2019) as the data were not normally distributed (Shapiro Normality test: $p < 0.001$). This analysis was used to inform future sampling efforts by determining whether the weekday sampled affected the number of PBF measured by each program.

The average number of days sampled per week (Sunday to Saturday) and the average number of weeks sampled per year from 2014 and 2019 were calculated from PSP data. PSP's dockside sampling is labor intensive, so a modified sampling design of sampling once a week was explored as an alternative. To forecast the number of PBF in which future sampling might occur only once a week, the number of PBF measured on a given day was analyzed for three scenarios: the day of the week that (1) the lowest number of PBF were measured, (2) the highest number of PBF was measured, and (3) the first day of the week that was sampled. The third scenario was included because it represented a randomly chosen day since the lowest and highest days cannot be predicted at the beginning of each week and therefore most closely approximated the average number of PBF measured a week. These analyses assumed similar conditions in future years.

2.5. Vessel Simulation

PSP and SAC differed in the number of vessels sampled each year (see Results: General Comparisons). Therefore, to understand whether sampling fewer vessels affected the length composition of PBF, a vessel simulation was conducted by randomly subsampling PSP data. One simulation was performed for each year and years combined (2015-2019). The number of randomly generated vessels for each simulation matched the number of vessels SAC sampled during that time period. Length frequency plots using transformed FLs (see Fork Length Analyses) were generated by year using kernel density estimates for the subset data and the original PSP data and compared. Kernel density estimation used Gaussian kernels and were smoothed using the Sheather-Jones method (Sheather and Jones, 1991; Venables and Ripley, 2002). The subset data were compared to the original PSP data using two-sample KS tests.

2.6. Representative of the CPFV fleet?

To understand the length composition of CPFV-fished PBF stock, available length data were raised to the catch for the stock assessment following the methods described by Lee et al. (2015). Here, we raised the sampled length compositions to the catch and compared these data with the raw length data for each program. The PBF lengths were binned into 1 cm bins, and each fish in a length bin was counted by program (PSP or SAC), month, and year. The total number of PBF measured was counted by program, year, and month. The proportion each length bin represented in the recreational catch was calculated as the number in each length bin (by program, month, and year) divided by the total PBF measured in that program, month, and year. The total California catch was the sum of the CPFV logbook landings and landings reported by CDFW dock and telephone surveys (CDFW 2021) by month and year. The proportion was then multiplied by the total California catch to get the number of fish measured raised to the catch. The data raised to the catch were compared to the raw data by month for the entire time period and two-sample KS tests of length frequency plots by year using 1 cm FL bins without smoothing. These analyses did not use transformed FLs (see Fork Length Analyses), as month was included in the process to raise the data to the catch.

3. Results

3.1. General comparisons

Length data were collected by PSP from 2014 to 2019 and by SAC from 2015 to 2020. PSP was unable to sample in 2020 due to COVID-19 restrictions. PSP measured 4.5% of the total number of PBF landed annually by the California CPFV fleet (range: 2.2-7.3%) between 2014 and 2019 (Table 1). SAC measured 3.8% of the total number of PBF landed by the CPFV fleet (range: 0.7-6.3%) between 2015 and 2020 (Table 1). Length composition data were collected primarily from July to September for both programs when landings of PBF were highest (Figure 1). PSP sampled predominantly in the peak-fishing season from July to September, while SAC sampled more evenly throughout the year (Figure 1). The number of fish landed or sampled was highly variable among years (Table 1). The CPFV fleet from San Diego County landed on average 82.0% (range: 72.5-91.4%) of the 102,378 PBF landed by the entire CPFV fleet in all of CA between 2014 and 2019.

Table 1. Number of PBF landed by the CPFV fleet in California as reported by CDFW CPFV logbooks, and measured by PSP and SAC. SAC was not established until 2015, and PSP did not sample in 2020.

Year	Month	California Recreational CPFV logbook PBF Catch	PBF measured by PSP	% of PBF Catch measured by PSP	PBF measured by SAC	% of PBF Catch measured by SAC
2014	2	16	-	-	-	-
2014	3	3	-	-	-	-
2014	5	822	-	-	-	-
2014	6	599	-	-	-	-
2014	7	12930	631	4.9%	-	-
2014	8	7331	649	8.9%	-	-
2014	9	2941	452	15.4%	-	-
2014	10	1182	-	-	-	-
2014	11	426	-	-	-	-
2014	12	39	-	-	-	-
2014 Total	-	26289	1732	6.6%	-	-
2015	1	420	-	-	-	-
2015	2	268	-	-	-	-
2015	3	20	-	-	-	-
2015	4	11	-	-	-	-
2015	5	716	-	-	-	-
2015	6	866	46	5.3%	1	0.1%
2015	7	4436	132	3.0%	1	0.0%
2015	8	9539	234	2.5%	118	1.2%
2015	9	5730	81	1.4%	25	0.4%
2015	10	96	-	-	1	1.0%
2015	11	37	-	-	-	-
2015	12	2	-	-	-	-
2015 Total	-	22141	493	2.2%	146	0.7%
2016	1	-	-	-	1	-
2016	4	663	7	1.1%	25	3.8%
2016	5	296	57	19.3%	13	4.4%
2016	6	473	57	12.1%	9	1.9%
2016	7	548	72	13.1%	34	6.2%
2016	8	3391	353	10.4%	114	3.4%
2016	9	3183	216	6.8%	109	3.4%
2016	10	469	-	-	-	-
2016	11	1195	-	-	44	3.7%
2016	12	176	-	-	8	4.5%
2016 Total	-	10394	762	7.3%	357	3.4%

Year	Month	California Recreational CPFV logbook PBF Catch	PBF measured by PSP	% of PBF Catch measured by PSP	PBF measured by SAC	% of PBF Catch measured by SAC
2017	2	1	-	-	-	-
2017	3	52	-	-	-	-
2017	4	472	-	-	15	3.2%
2017	5	762	30	3.9%	7	0.9%
2017	6	340	10	2.9%	26	7.6%
2017	7	462	3	0.6%	43	9.3%
2017	8	4815	139	2.9%	278	5.8%
2017	9	3396	127	3.7%	189	5.6%
2017	10	1622	-	-	56	3.5%
2017	11	1976	18	0.9%	210	10.6%
2017	12	1371	20	1.5%	142	10.4%
2017 Total	-	15269	347	2.3%	966	6.3%
2018	1	415	-	-	34	8.2%
2018	2	25	-	-	-	-
2018	3	86	-	-	-	-
2018	4	225	-	-	26	11.6%
2018	5	224	-	-	18	8.0%
2018	6	1293	48	3.7%	79	6.1%
2018	7	1592	82	5.2%	95	6.0%
2018	8	2500	192	7.7%	12	0.5%
2018	9	1666	-	-	91	5.5%
2018	10	1364	30	2.2%	2	0.1%
2018	11	3267	218	6.7%	122	3.7%
2018	12	93	-	-	-	-
2018 Total	-	12750	570	4.5%	479	3.8%
2019	1	3	-	-	-	-
2019	4	1099	-	-	71	6.5%
2019	5	1177	9	0.8%	148	12.6%
2019	6	2465	189	7.7%	184	7.5%
2019	7	2037	92	4.5%	43	2.1%
2019	8	2882	293	10.2%	34	1.2%
2019	9	3453	61	1.8%	4	0.1%
2019	10	1360	38	2.8%	34	2.5%
2019	11	937	-	-	32	3.4%
2019	12	122	-	-	-	-
2019 Total	-	15535	682	4.4%	550	3.5%

Year	Month	California Recreational CPFV logbook PBF Catch	PBF measured by PSP	% of PBF Catch measured by PSP	PBF measured by SAC	% of PBF Catch measured by SAC
2020	2	9	-	-	-	-
2020	3	121	-	-	-	-
2020	4	15	-	-	-	-
2020	5	7	-	-	-	-
2020	6	1788	-	-	162	9.1%
2020	7	6108	-	-	335	5.5%
2020	8	10661	-	-	475	4.5%
2020	9	4753	-	-	195	4.1%
2020	10	4161	-	-	194	4.7%
2020	11	629	-	-	93	14.8%
2020	12	240	-	-	-	-
2020 Total	-	28492	-	-	1454	5.1%
2014-2019 Total	-	102378	4586	4.5%	-	-
2015-2020 Total	-	104581	-	-	3952	3.8%
2015-2019 Total	-	76089	2854	3.8%	2498	3.3%

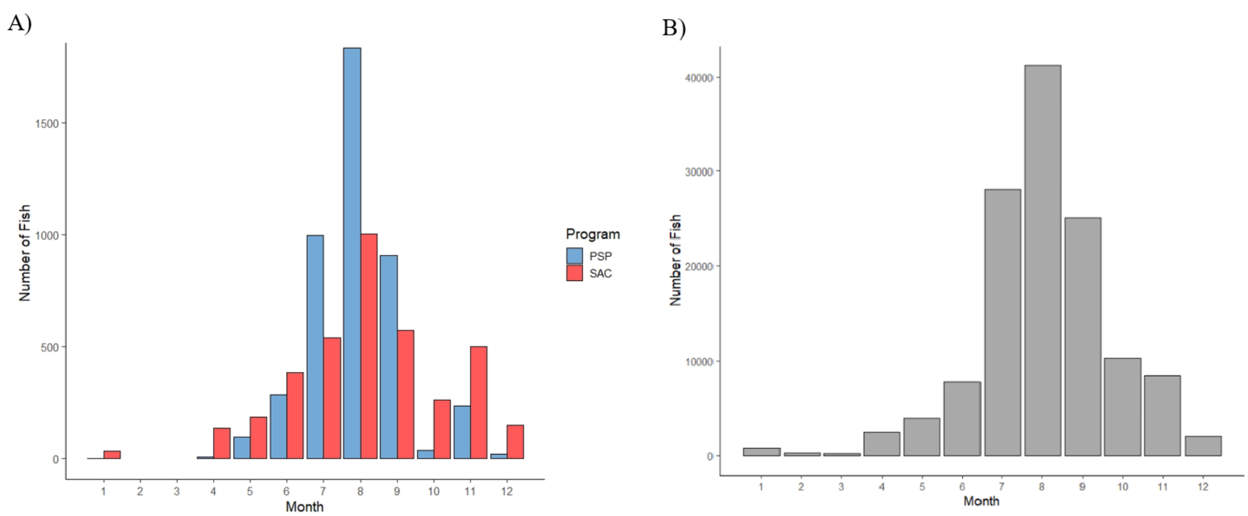


Figure 1. Number of PBF A) measured by PSP and SAC, and B) reported landed in CDFW CPFV logbooks, by month for data from 2014-2020 combined. SAC was not established until 2015 and PSP did not sample in 2020.

PSP sampled more vessels than SAC in each year (Figure 2). Combined, SAC and PSP sampled 52 unique vessels between 2014 and 2020 (vessels that fished in multiple years were only counted once), which represented 20.6% of the 252 total unique California CPFVs landing PBF between 2014 and 2020.

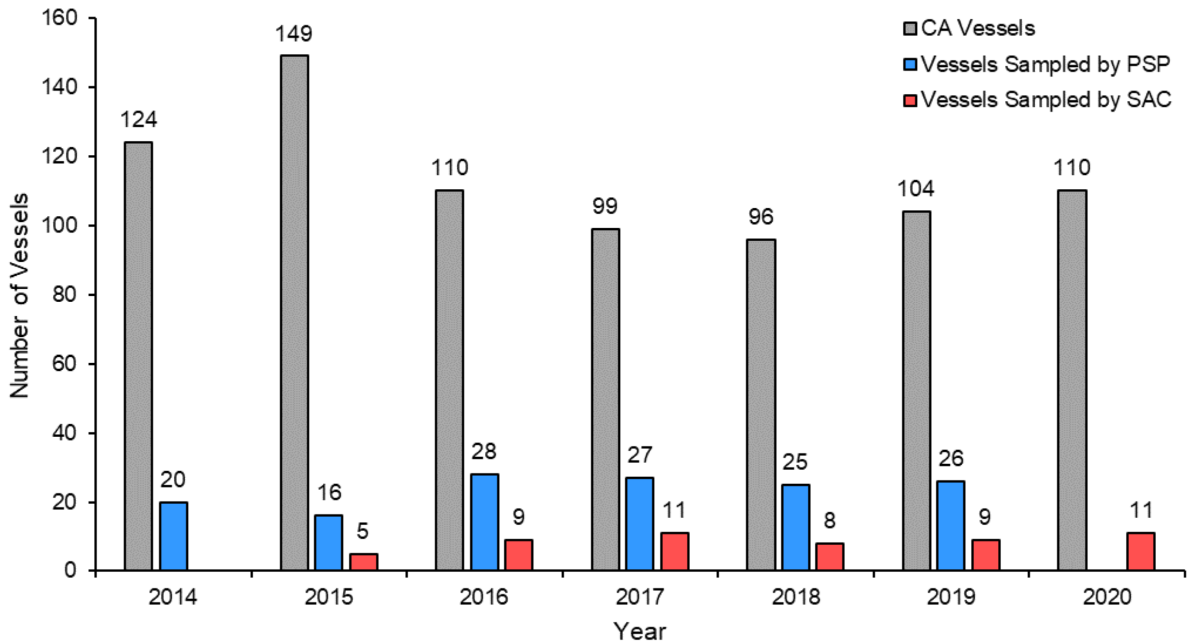
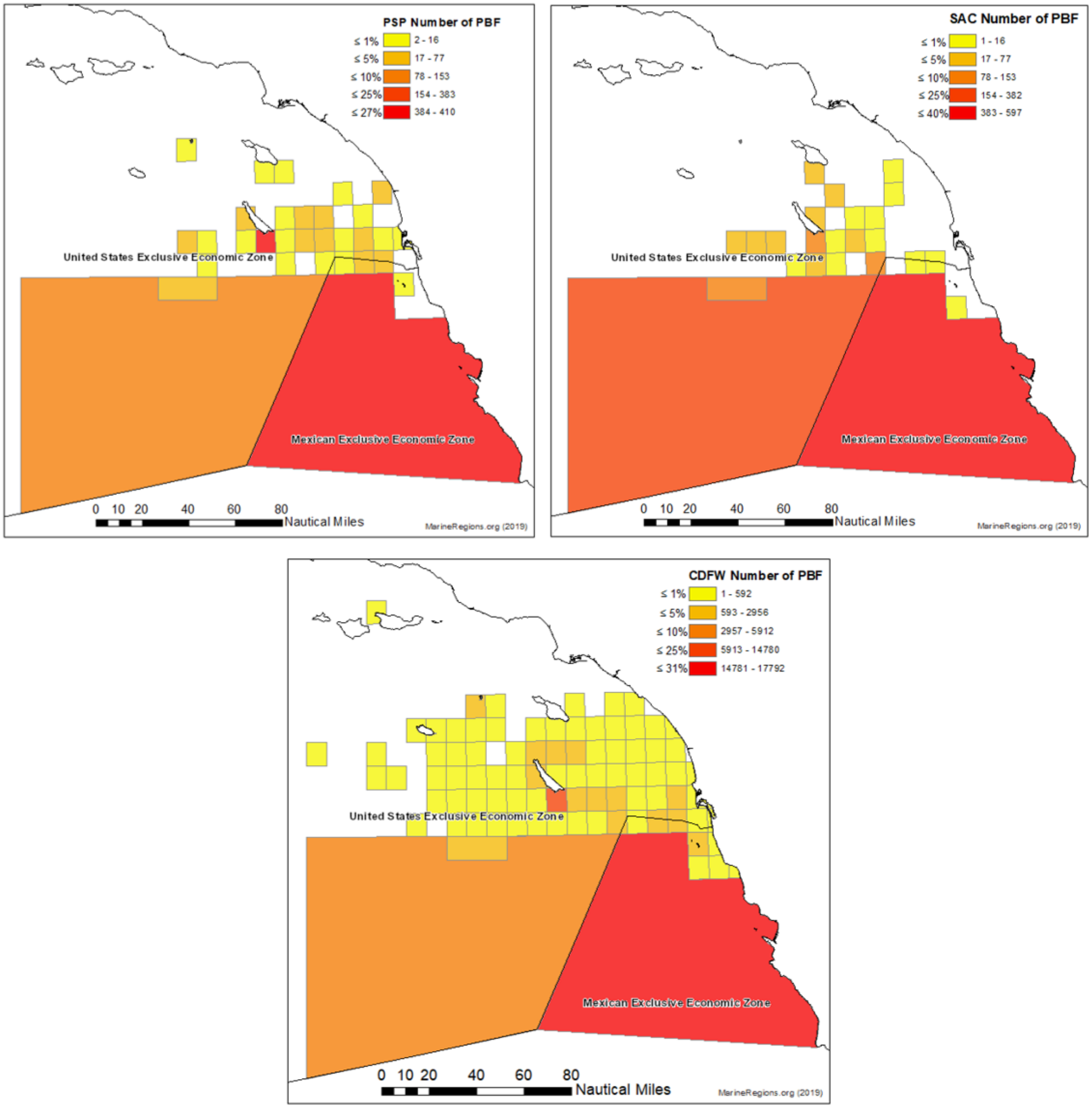


Figure 2. Number of vessels landing PBF in California and sampled by PSP and SAC from 2014-2020. SAC was not established until 2015, and PSP did not sample in 2020.

Geographic coverage was compared among PSP, SAC, and the CPFV fleet for 2015-2019 (Figure 3). For PSP, 148 trips were matched to the CPFV logbook data, which covered 1,518 PBF measured (53.0% of the total PSP data). For SAC, 128 trips were matched to the CPFV logbook data, which covered 1,527 PBF measured (60.5% of the total SAC data). The rest of the PSP and SAC data had a unique combination of vessel and trip dates that were unable to be matched to CDFW logbook data. From 2015-2019, CDFW sampled 59,116 PBF in southern California and Mexican fishing blocks. Both PSP and SAC sampled PBF that were from fishing blocks representative of the entire CPFV fleet and, overall, blocks with the highest efforts matched across PSP, SAC, and CDFW (Figure 3). All fishing blocks represented are within 200 nautical miles of San Diego, which put them within the range of SR trips, regardless of the duration of the trip.



PSP sampled more trips than SAC in most years and often sampled multiple trips per day (Figure 4). Both PSP and SAC measured 5 or fewer fish per trip more than 30% of the time (Figure 5) compared to other numbers of fish. SAC measured between 21 and 25 fish per trip more than 35% of the time (Figure 5). However, PSP often sampled several vessels in a given sampling day, and therefore, sampling day better reflects sampling efficiency; PSP measured fewer than 5 fish per sampling day only 12% of the time (Figure 5). Sampling day was not a useful metric to assess SAC, because each vessel reported fish lengths from a trip regardless of whether another vessel was also reporting lengths that day. Therefore, trip was determined to be the appropriate unit for SAC.

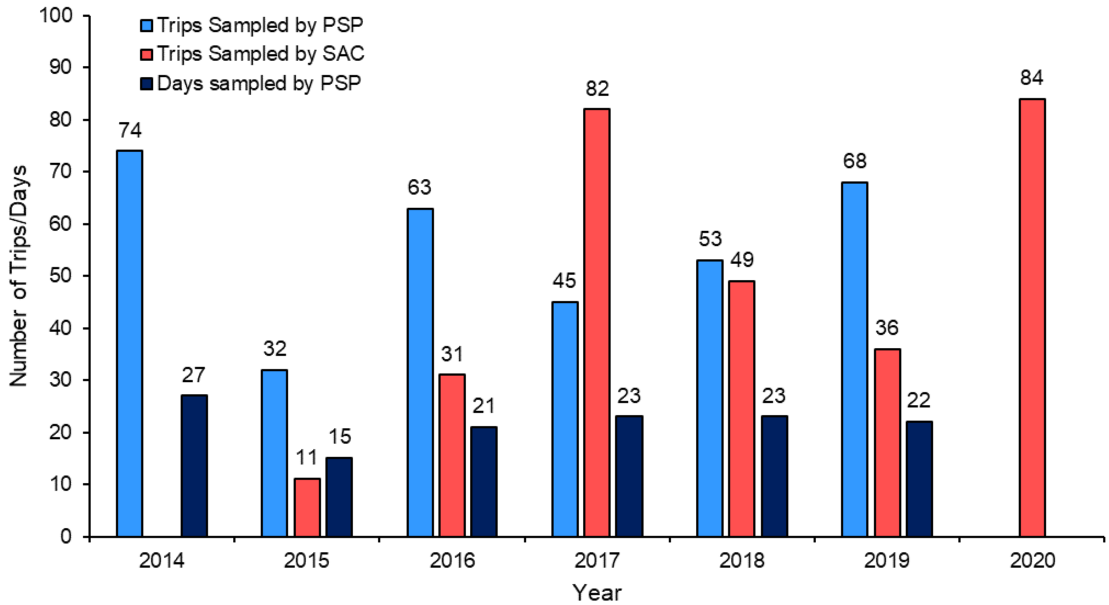


Figure 4. Number of trips and days sampled by PSP and SAC from 2014-2020. SAC was not established until 2015, and PSP did not sample in 2020.

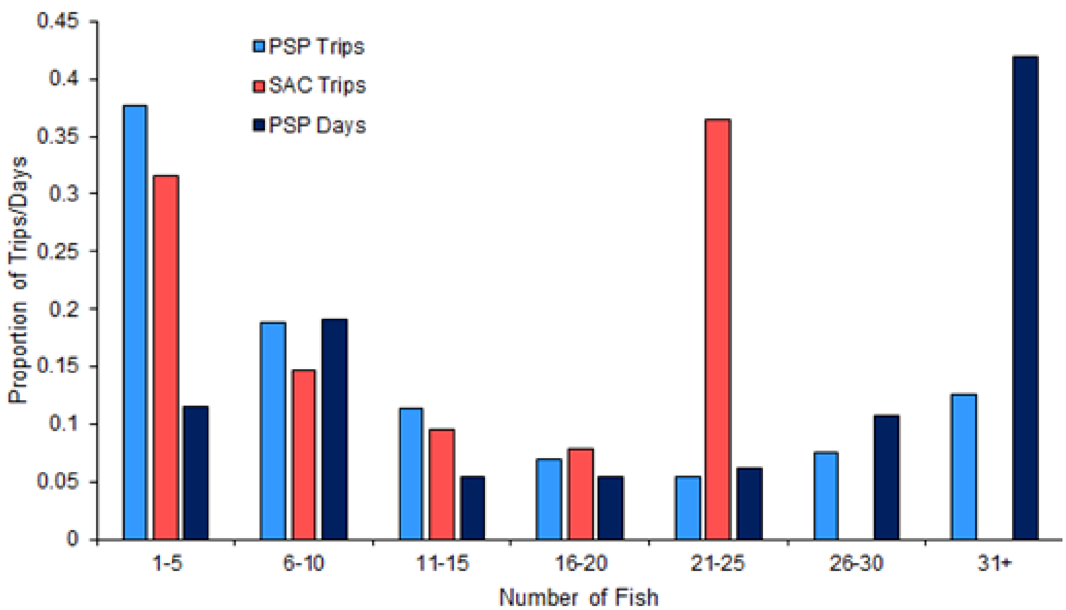


Figure 5. Proportion of trips (PSP and SAC) and days sampled (PSP) between 2014 and 2020 where specific numbers of fish were measured. SAC was not established until 2015, and PSP did not sample in 2020. The maximum number of fish SAC measured per trip is 25 as dictated by sampling method. All PSP trips and days that measured 31 or more fish are grouped into the 31+ category.

Overall, SAC sampled more PBF from SR trips (≤3 days) than PSP between 2015 and 2019. SAC sampled 2,131 PBF from 179 SR trips (11.9 PBF per trip) and only 152 PBF from 20 LR trips (7.6 PBF per trip), while PSP sampled 1,623 PBF from 181 SR trips (9.0 PBF per trip) and 1,028 PBF from 78 LR trips (13.2 PBF per trip). Both programs sampled both more PBF and more trips that were SR than LR. Trip duration was not reported for 9 trips sampled by SAC (PBF = 39) and 10 trips sampled by PSP (PBF = 53) from 2015 to 2019.

3.2 Overlap of PSP and SAC data

Eight vessels were sampled by both PSP and SAC from 2015 to 2019; PSP sampled 105 trips from these eight vessels, while SAC sampled 85 trips from the same vessels. Only 11 trips on six of these vessels were sampled by both PSP and SAC. The PBF from these 11 double-sampled trips account for 5.7% of PSP sampling totals (162 of 2,854 total PBF) and 7.1% of SAC totals (177 of 2,498 total PBF). If each of the 162 lengths measured by PSP matched a length from SAC, then the overlap rate represented 3.0% of combined trips of SAC and PSP. However, the number of individual fish sampled per trip could not be directly compared due to a lack of sufficient metadata provided by each sampling program.

The CDFW CPFV logbooks reported 298 PBF landed from 10 of the 11 trips double-sampled by SAC and PSP. PSP measured 54.0% and SAC measured 59.0% of the 298 landed PBF. Length distributions from eight of the 11 double-sampled trips were not significantly different based on two-sample KS tests (Figure 6). One of these eight trips had exactly the same FL measurements for both PSP and SAC for the six fish measured. Two of the 11 double-sampled trips did display significantly different length frequencies (Figure 6). One trip only had one PBF measured by each program and could not be statistically compared (Figure 6, trip 6); this trip also could not be matched to logbook data. A total of 22 trips were sampled by both programs, which were then removed from further comparisons due to potential issues of non-independence.

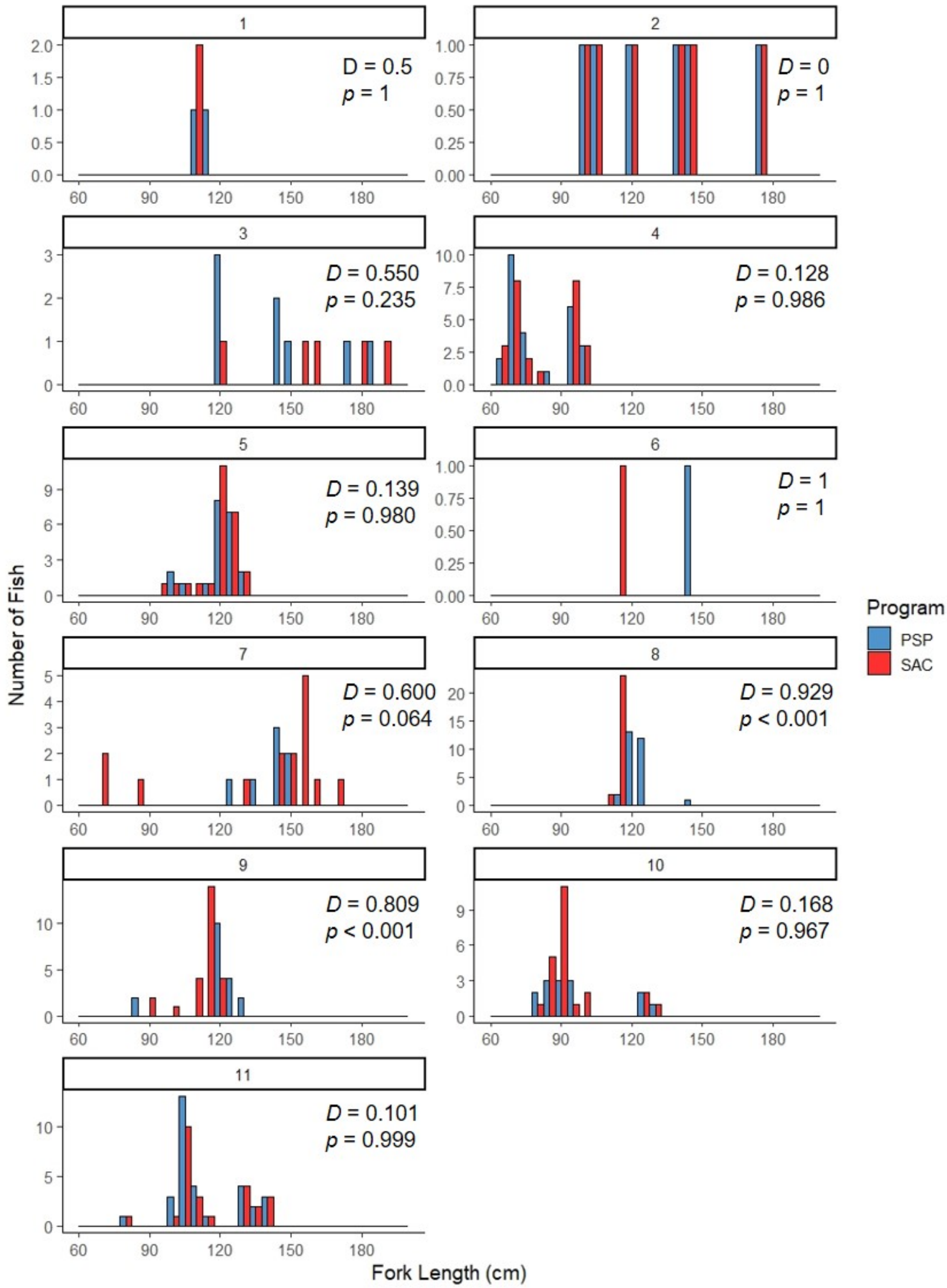


Figure 6. Histograms of each of the 11 overlapping trips using 5 cm bins. Numbers denoting each panel were randomly assigned. Two-sample Kolmogorov-Smirnov D statistics and p-value are reported in each panel. For all comparisons df = 1. Trip 8 and 9 were the only trips with significantly different length distributions between the programs ($p < 0.05$).

3.3 Fork Length Analyses

The length frequencies transformed to August 15 from PSP and SAC were multimodal, and the overall length distributions were significantly different between two programs based on the two-sample KS test for 2015-2019 (Table 2; Figure 7). Despite the different distributions, the median transformed FL for PSP for 2015-2019 was 96.5 cm FL (IQR: 87.7-122.0), similar to the median transformed FL for SAC for 2015-2019 at 94.0 cm FL (IQR: 72.8-117.8).

Table 2. Median fork length (FL; cm) and two-sample Kolmogorov-Smirnov test results of PBF by program (PSP and SAC) and year. P-values are approximate due to ties in the data. An asterisk indicates significantly different distributions ($p < 0.05$). SAC was not established until 2015 and PSP did not sample in 2020.

Year	Median FL of PSP	Median FL of SAC	*D*	p-value
2014	89.3	-	-	-
2015	90.6	82.3	0.396	< 0.001*
2016	111.8	117.1	0.093	0.054
2017	95.1	74.9	0.232	< 0.001*
2018	102.4	96.6	0.285	< 0.001*
2019	95.6	107.8	0.239	< 0.001*
2020	-	85.7	-	-
2015-2019	**96.5**	**94.0**	**0.134**	**< 0.001***

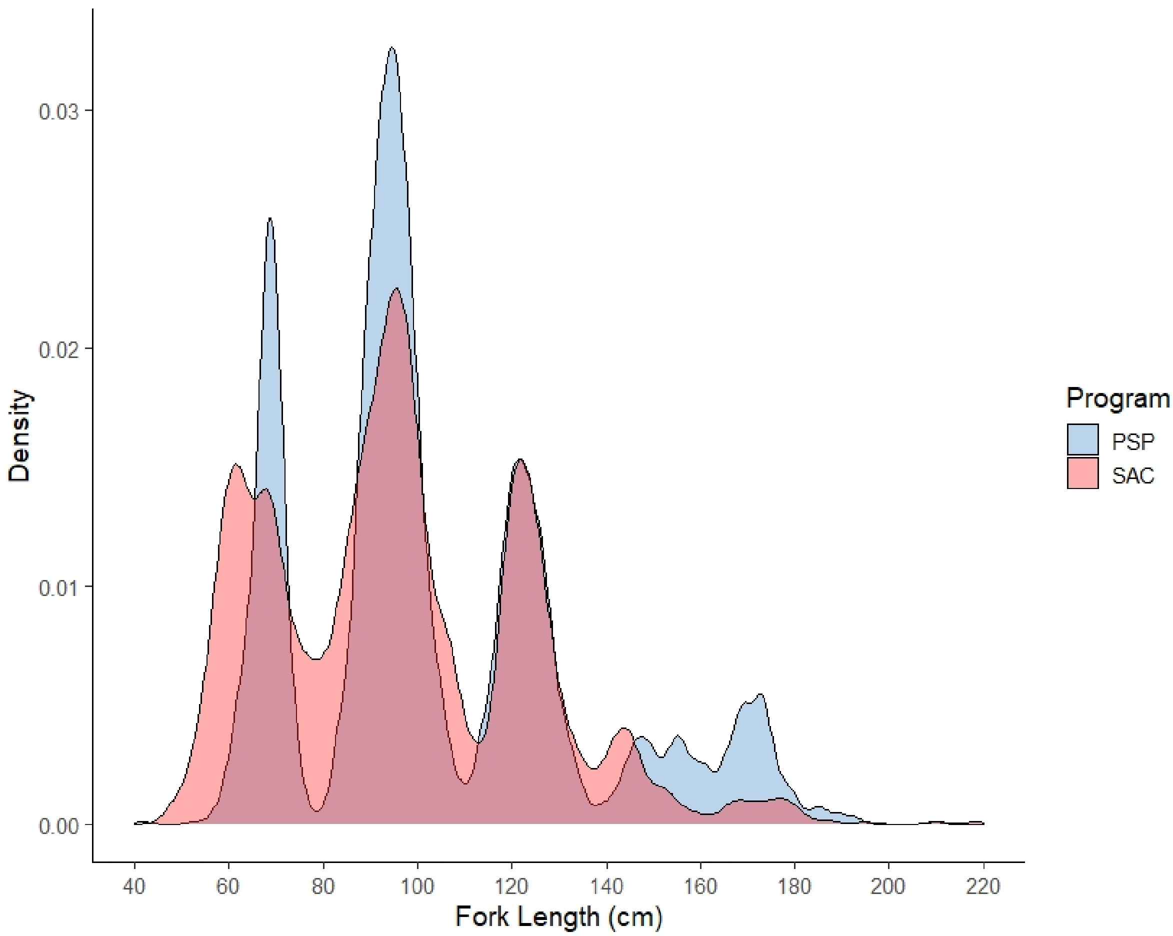


Figure 7. Transformed length frequency distributions of PSP and SAC from 2015-2019.

When each program was compared by year, only the length distributions of PBF measured in 2016 were not significantly different between two programs (p-value = 0.05); all other years had significantly different length distributions (Table 2; Figure 8). Three to five length modes were identifiable depending on year and program. Length modes (after transformation) generally aligned well between SAC and PSP. The most prominent modes were apparent for fish from 1 to 5 years of age. Fish aged 1-3 dominated both sampling programs in all years. However, 2017 also had a peak of approximately age 4, and 2018 also had a peak of approximately age 5 (Figure 8). In 2015, the length frequency peaks of PSP were shifted towards larger lengths than SAC, and in 2017 and 2018, PSP measured more large PBF than SAC (Figure 8).

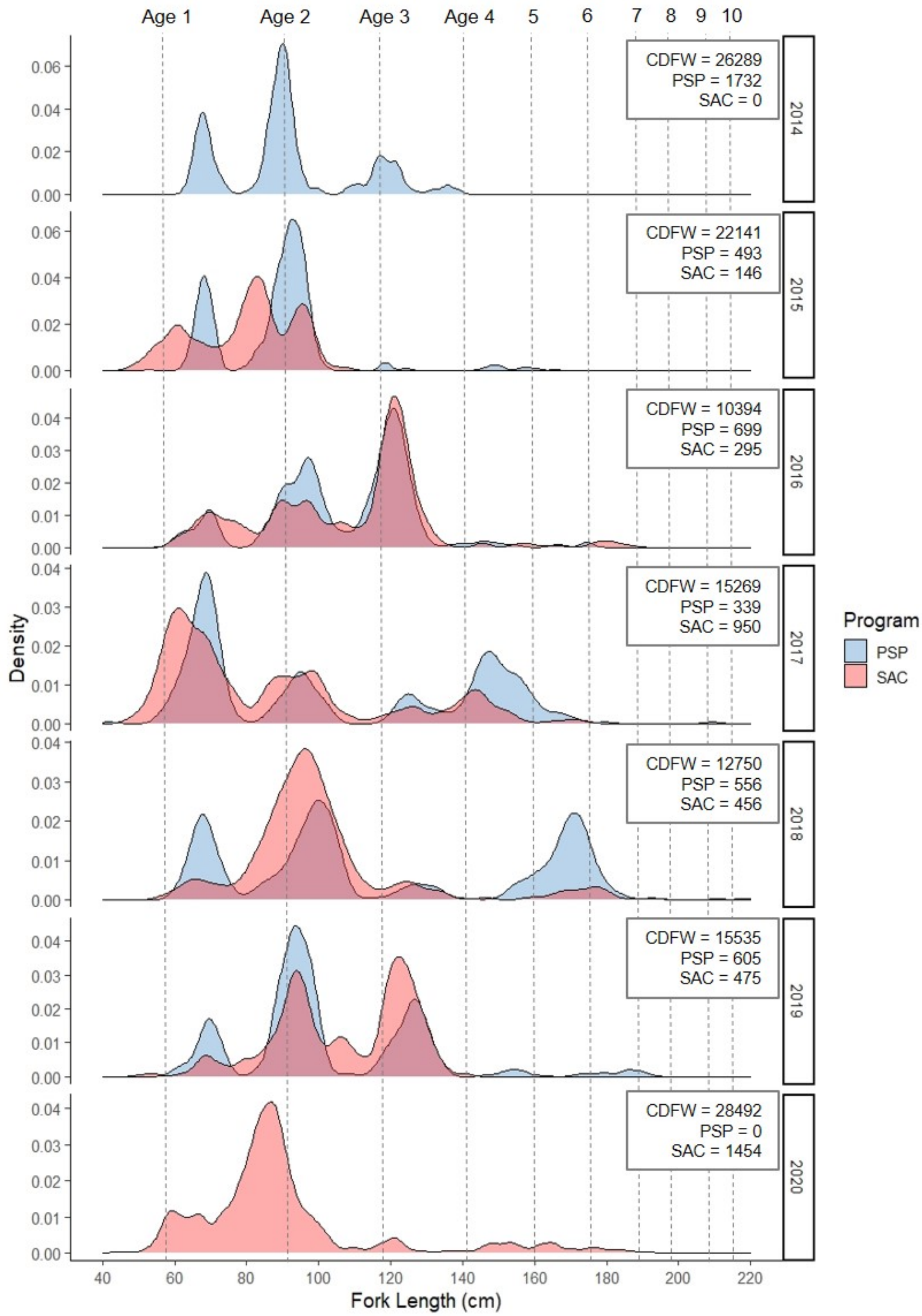


Figure 8. Transformed length frequency distributions of PSP and SAC samples from 2014-2020. The number of PBF landed in each year from CDFW CPFV logbook data are denoted by 'CDFW ='. The sample size of PBF measured by PSP and SAC are also listed. The vertical dotted gray lines represent the length-at-age for ages one through ten from ISC (2020). The scale of the y-axis varies among years. SAC was not established until 2015, and PSP did not sample in 2020.

In addition to year and program, transformed FLs were compared between SR and LR trips. Within PSP, only SR and LR length distributions from 2014 were not significantly different (p-value = 0.08), all other years had significantly different FL distributions between SR and LR trips (p-value < 0.05, Table 3). Within SAC, only SR and LR length distributions from 2018 were not significantly different, all other years had significantly different FL distributions between SR and LR trips, except 2019, where SAC did not sample any LR trips (Table 3). Median transformed FLs were larger for LR trips in 4 out of 6 years for PSP and 2 out of 5 years for SAC. Differences in transformed FLs between SR and LR trips were less than 5 cm in 6 of 11 comparisons (Table 3). In several years, sample size was relatively small for these comparisons (smaller sample size was <20% of larger sample size); in 2014, PSP sampled relatively few PBF from SR trips and in 2016, 2017, and 2018 SAC sampled relatively few PBF from LR trips (Figure 9). Despite the KS results, PBF length frequency modes were similar for years with comparable sample sizes (Figure 9).

Table 3. Median fork length (FL; cm) and Kolmogorov-Smirnov test results of PBF comparing trip duration (short range (SR) vs long range (LR)) within program (PSP and SAC) by year. P-values are approximate due to ties in the data. An asterisk indicates significantly different distributions (p < 0.05). SAC was not established until 2015 and PSP did not sample in 2020. In 2019, SAC did not sample from LR trips.

Year	**Program**	**Median FL of SR**	**Median FL of LR**	***D***	**p-value**
2014	PSP	88.1	89.7	0.410	0.077
	SAC	-	-	-	-
2015	PSP	89.9	91.2	0.132	0.028*
	SAC	81.5	84.9	0.239	0.044*
2016	PSP	109.0	113.1	0.165	< 0.001*
	SAC	117.4	88.5	0.578	0.021*
2017	PSP	99.5	92.0	0.215	< 0.001*
	SAC	75.6	70.3	0.191	0.008*
2018	PSP	100.5	107.3	0.17	0.003*
	SAC	95.9	87.4	0.408	0.107
2019	PSP	96.1	95.0	0.137	0.019*
	SAC	107.8	-	-	-
2020	PSP	-	-	-	-
	SAC	85.0	87.1	0.116	< 0.001*

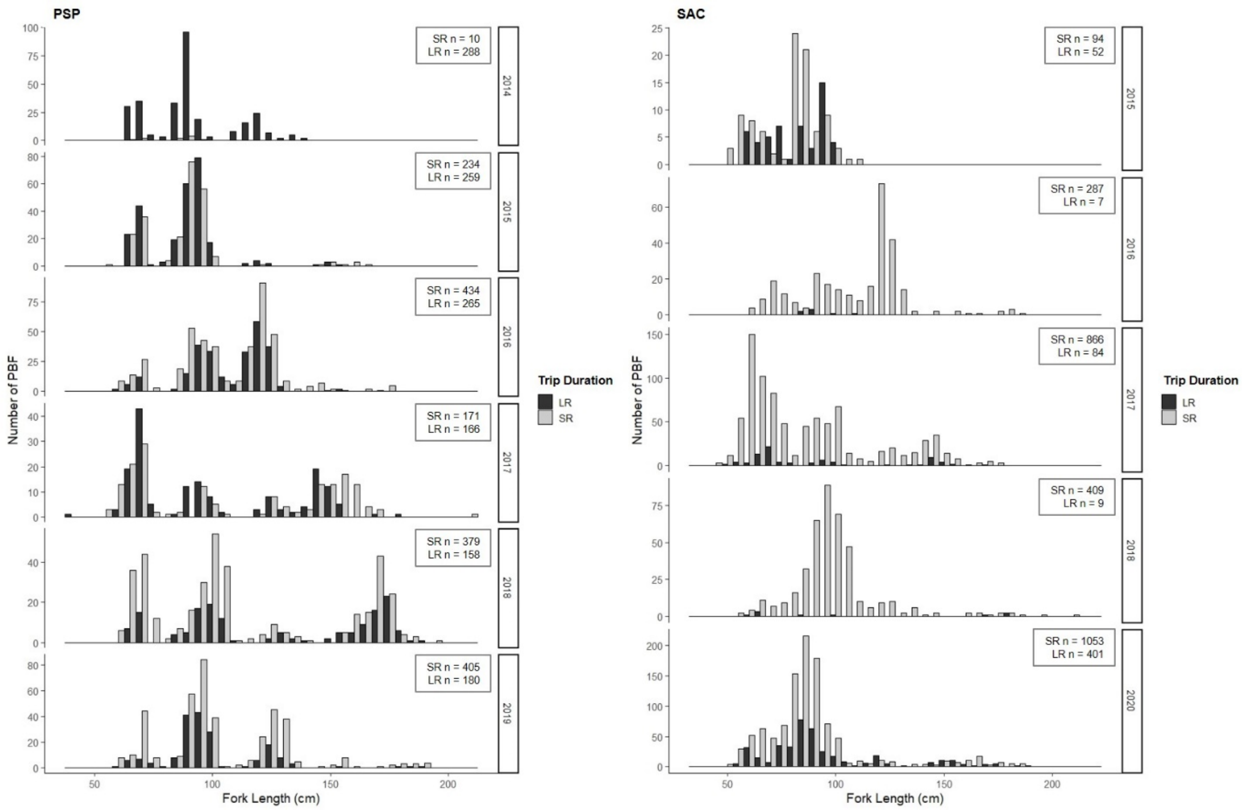


Figure 9. Histograms of length distributions of PSP (left) and SAC (right) comparing the number of PBF measured in 5 cm length bins from short-range (SR) and long-range (LR) trips by year. Sample sizes are shown in each panel.

Between PSP and SAC, SR trips had significantly different FL distributions between 2015 and 2019 (Table 4). Between PSP and SAC, LR trips had significantly different FL distributions for 2015, 2016, and 2017, but not in 2018 (Table 4). In 2019, SAC did not measure any PBF from LR trips. Therefore, a direct comparison was not possible. PSP sampled relatively few PBF (smaller sample size was <20% of larger sample size) from SR trips compared to SAC in 2017, while SAC sampled relatively few PBF from LR trips compared to PSP in 2015, 2016, and 2018 (Figure 10). When sample sizes were comparable (smaller sample size >20% of larger sample size), PSP often measured more large PBF than SAC (i.e. SR: 2015, 2018 & 2019; Figure 10).

Table 4. Median fork length (FL; cm) and Kolmogorov-Smirnov test results of PBF comparing trip duration (short range (SR) vs long range (LR)) between programs (PSP and SAC) by year. P-values are approximate due to ties in the data. An asterisk indicates significantly different distributions ($p < 0.05$). In 2019, SAC did not sample from LR trips.

Year	Trip Duration	Median FL of PSP	Median FL of SAC	*D*	p-value
2015	SR	89.9	81.5	0.47	< 0.001*
	LR	91.2	84.9	0.28	0.003*
2016	SR	109.0	117.4	0.11	0.037*
	LR	113.1	88.5	0.58	0.020*
2017	SR	99.5	75.6	0.31	< 0.001*
	LR	92.0	70.3	0.21	0.013*
2018	SR	100.5	95.9	0.26	< 0.001*
	LR	95.9	87.4	0.41	0.120
2019	SR	96.1	107.8	0.20	< 0.001*
	LR	95.0	-	-	-

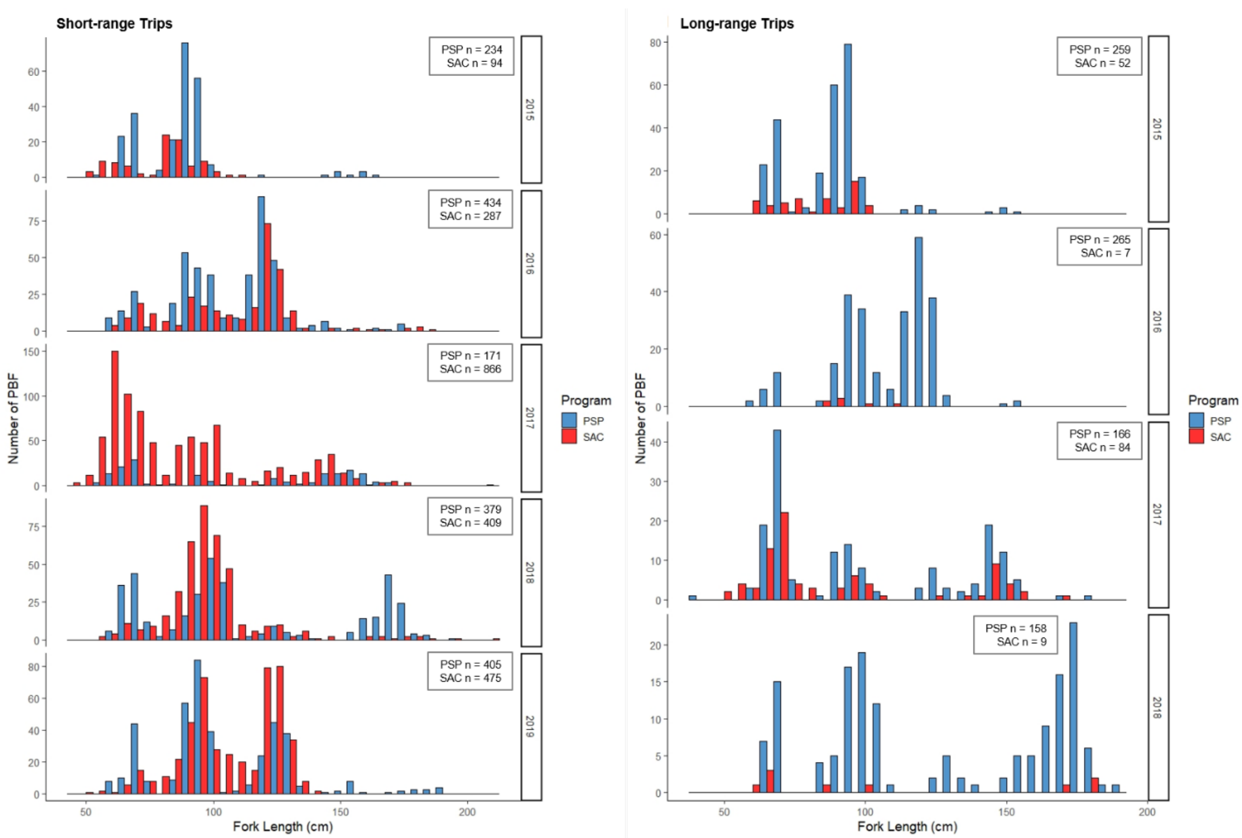
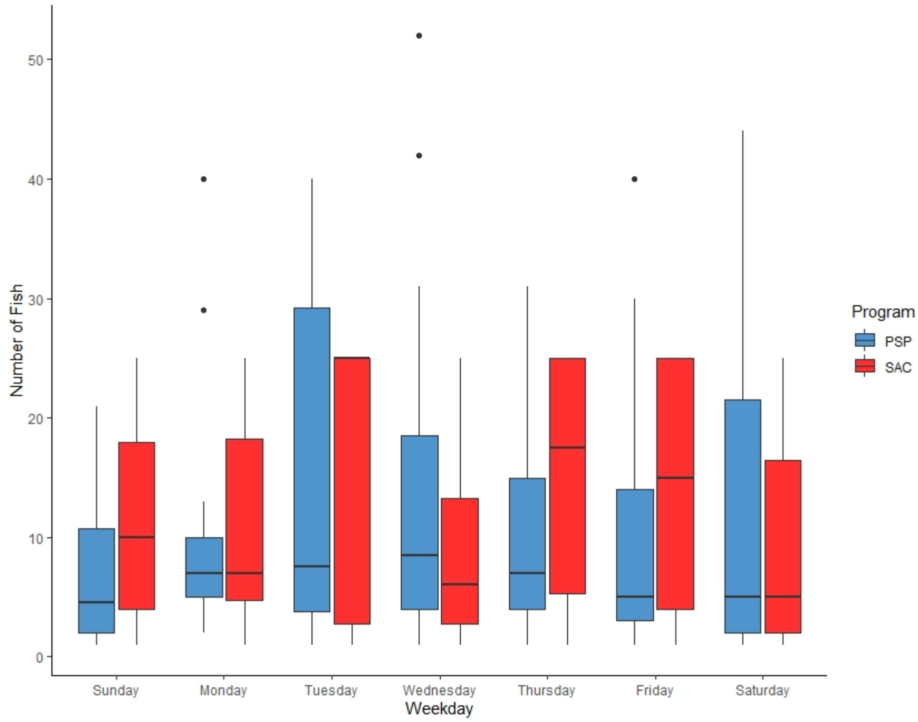


Figure 10. Histograms of length distributions of short-range (left) and long-range (right) trips comparing the number of PBF measured in 5 cm length bins from PSP and SAC by year. Sample sizes are shown in each panel.

3.4 Weekday Analyses and Predicted Future PBF Sampling by PSP

For both programs, the number of fish sampled differed significantly across weekdays (Kruskal-Wallis test $H = 24.914$, df = 14, p = 0.035; Figure 11). However, pairwise comparisons between programs did not detect any significant differences on a given weekday (range of p-values: 0.081-1.000).



From 2014 to 2019, PSP sampled between 9 and 16 weeks annually and averaged 2 days of sampling per week. For each of the three scenarios examining sample size if sampling occurred only one day a week, the lowest day of the week (scenario 1) measured an average of 23 PBF, the highest day of the week (scenario 2) measured an average of 41 PBF, and the first day of the week (scenario 3) measured an average of 31 PBF. Assuming similar 2014-2019 conditions in future years, a modified sampling design sampling once a week for 18 weeks could expect on average 405 PBF under the lowest scenario (1), 556 PBF with the first day of the week scenario (3), and 731 PBF with the highest scenario (2). These three scenarios forecast comparable annual PBF totals to most previous year totals (Table 1).

3.5 Vessel Simulation

SAC sampled less than half as many vessels (39.0%) as PSP between 2015 and 2019 (Figure 2). Length frequency graphs comparing subset PSP data and original PSP data were very similar with an equal number of modes present in each year (Figure 12). Over the entire time period, 2015-2019, the subset PSP data were significantly different from the original PSP data ($D = 0.067$, $p = 0.005$). When analyzed by year, only 2019 was significantly different between the subset PSP data and the original PSP data ($D = 0.130$, $p = 0.011$), and all other years were not significantly different ($p > 0.067$; Figure 12).

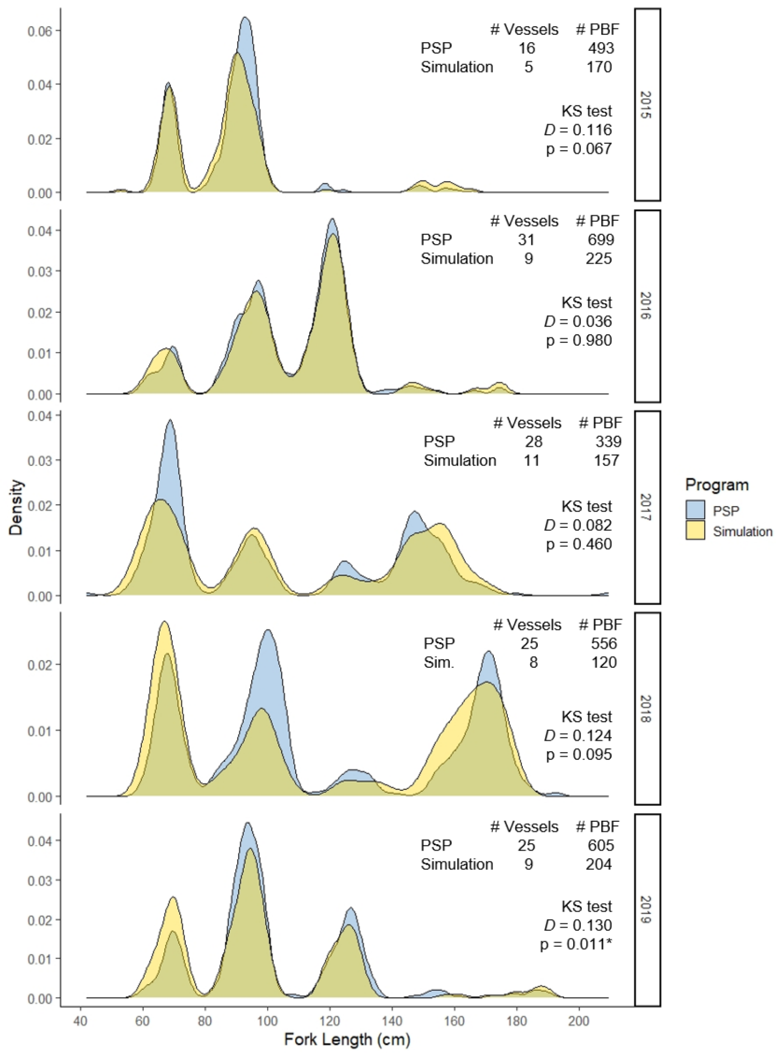


Figure 12. Transformed length frequency distributions of original PSP data and PSP data subsampled with fewer vessels represented between 2015 and 2019. The number subsampled reflects the number of vessels SAC sampled each year. The number of vessels and PBF represented in each dataset are included along with the results of the Kolmogorov-Smirnov (KS) tests. An asterisk indicates significantly different distributions ($p < 0.05$).

3.6 Representative of the CPFV fleet?

Length data were raised to the CPFV catch in 1 cm bins for each year and month. Between 2014 and 2020, several months had few PBF measured; PSP measured fewer than 25 PBF in 7 of the 31 months and SAC measured fewer than 25 PBF in 15 out of 46 months. Those months with few lengths were not removed from analysis by month, but were removed from length frequencies analyses. Analysis of data raised to the catch (Figure 13) by month indicated length sampling by PSP and SAC reflected seasonal catches by the entire CPFV fleet (Figure 1). Length frequencies of length sampling data raised to the catch reflected the raw length frequencies very closely; however, significant differences in distributions were detected in 2014, 2016, and 2018 for PSP and in 2019 for SAC (Figures 14 & 15).

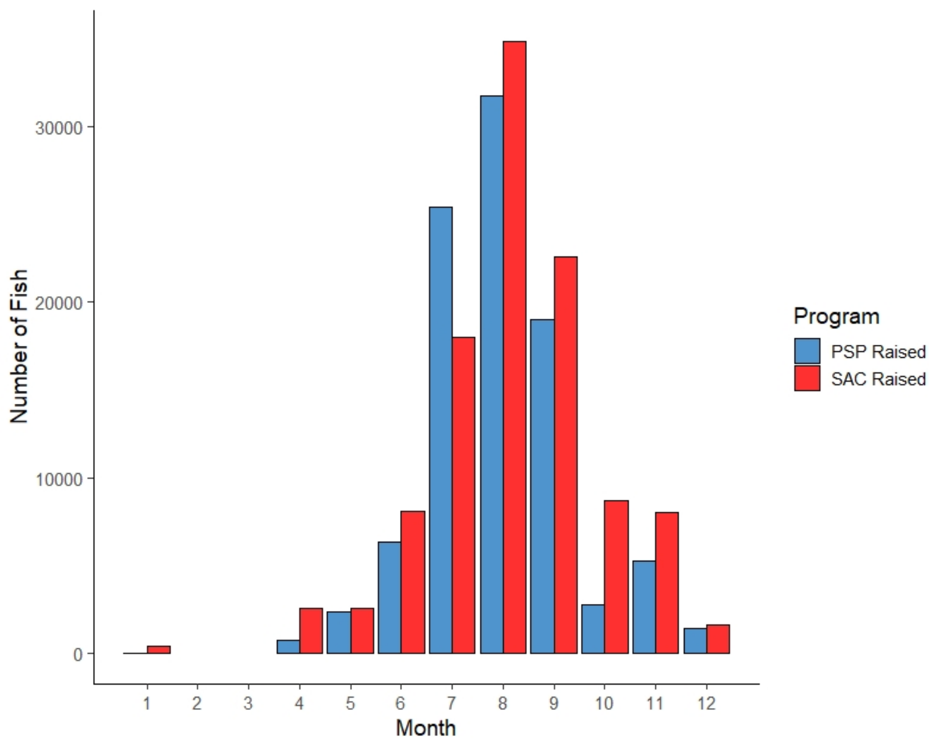


Figure 13. Number of PBF measured by PSP and SAC by month between 2014 and 2020 raised to the catch.

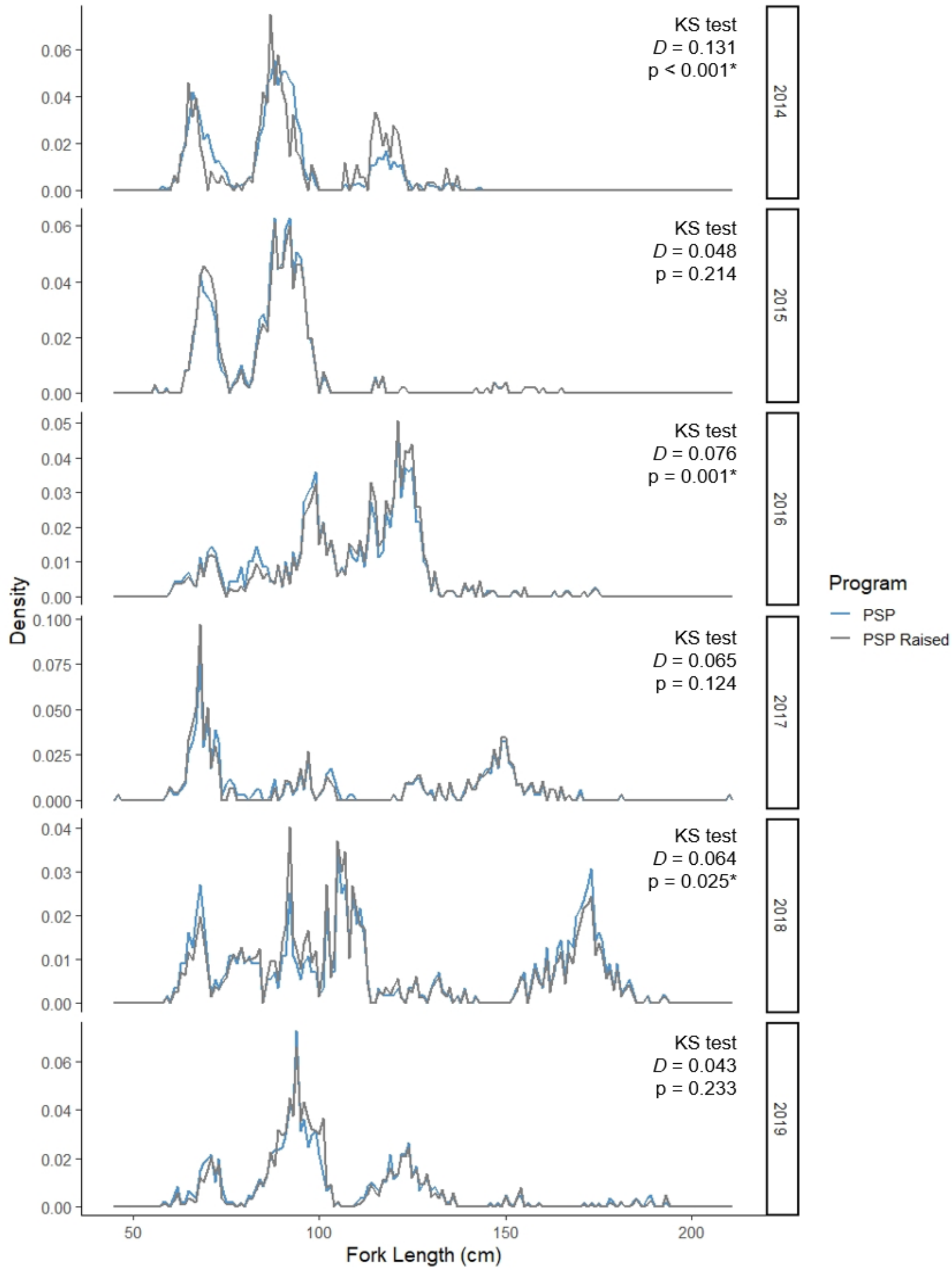


Figure 14. Length frequency distributions in 1 cm FL bins of PSP raw data and PSP data raised to the catch. Two-sample Kolmogorov-Smirnov D statistics and p-value are reported in each panel. An asterisk indicates significantly different distributions ($p < 0.05$).

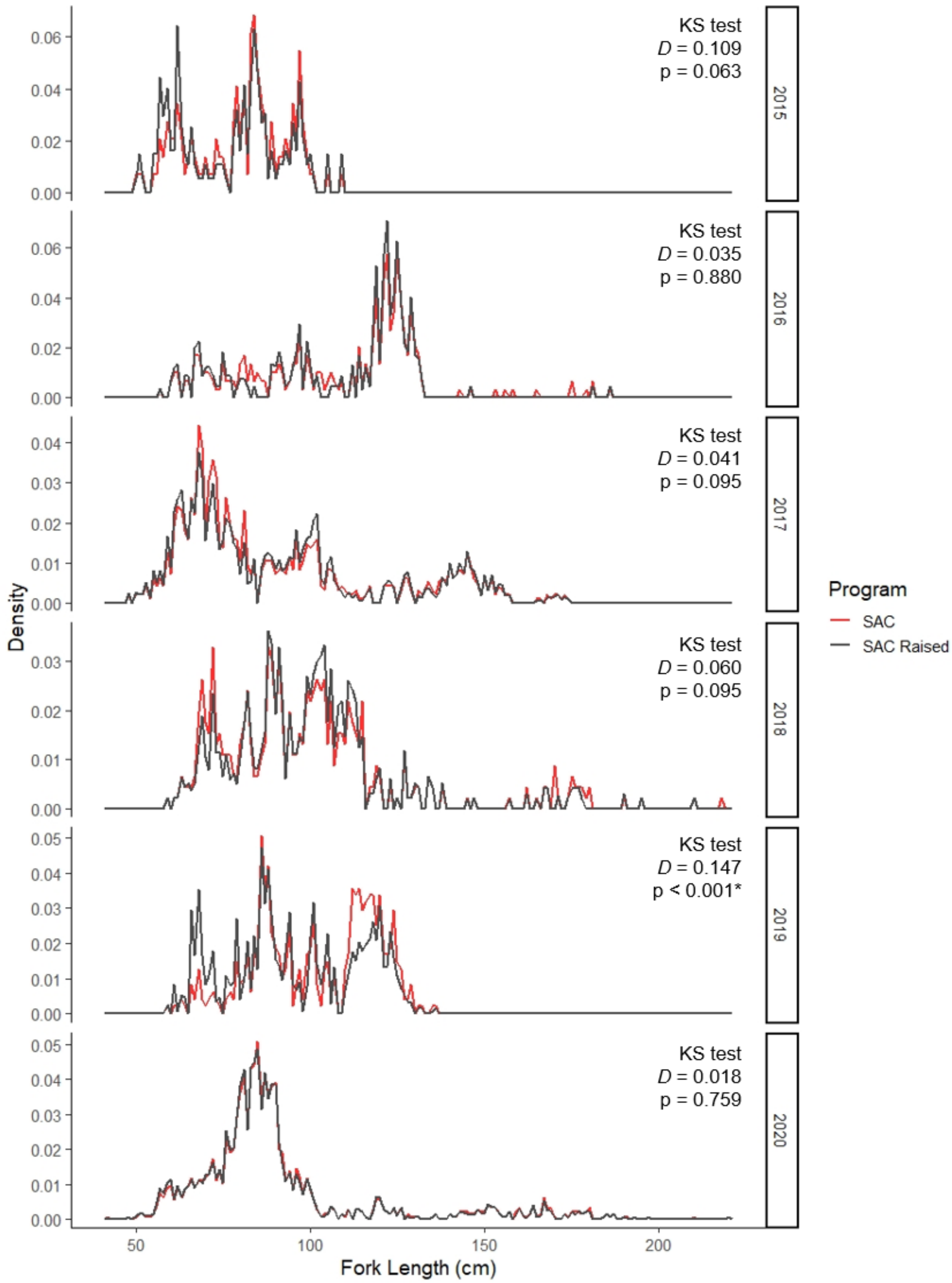


Figure 15. Length frequency distributions in 1 cm FL bins of SAC raw data and SAC data raised to the catch. Two-sample Kolmogorov-Smirnov D statistics and p-value are reported in each panel. An asterisk indicates significantly different distributions ($p < 0.05$).

4 Discussion

The comparative analyses of PSP and SAC datasets provided the opportunity to examine the extent and overlap in sampling effort of the two programs, study the length compositions of PBF sampled by the two programs, assess the effect of weekday landed and predict future PBF sampling by PSP, investigate the effect on the length distributions of sampling fewer vessels, and determine how well the programs sampled the CPFV fleet. These comparisons were made to better understand potential differences in the length distributions, the impact of sampling design, and the ultimate utility of the length data as inputs to the PBF stock assessment. Overall, both PSP and SAC sampled PBF lengths from the CPFV fishery to a similar extent as evidenced by the comparable percent of PBF sampled, trips sampled, and similar spatial distributions.

The comparison of PSP to SAC allowed an examination of the overlap between programs (both programs measuring PBF from the same trip). Despite sampling from the same fleet and occasionally from the same vessels, overlap in which the same PBF were measured by both programs was very low, a maximum of 3.0%. Overlap may be less if the vessel brought back more PBF than measured by either sampling program. When overlap occurred, the mean FLs were not significantly different between programs, indicating that PSP and SAC made consistent measurements on these trips. SAC participants were taught to measure fish following the PSP protocol. The low amount of overlap means these two datasets are complementary rather than redundant, and overall they are sampling unique fish.

A comparison of the length data between the programs indicated differences in median values and length distributions for most years. Interannual variation in FL was not unexpected given potential differences in recruitment and year class strength over the course of the programs. Consequently, the focus here was on differences between programs within years. In three of the five sampling years, PSP measured more fish in the larger size classes and consequently had a higher median PBF FL than SAC. It should be noted, however, that in three of the five sampling years, the differences in median FL were relatively small (<10 cm). These differences could be attributed to a variety of factors. The length distributions are multimodal and therefore median FLs have limited utility for accurately describing the distributions. It is also possible that the vessels associated with these two programs encountered different length classes of PBF.

One notable difference between the two sampling programs was that SAC's vessel-based sampling had access to all fish caught, whereas PSP's dockside sampling only saw fish that were unloaded at the dock whole. Whether PBF were filleted at sea or kept whole for post-trip filleting is a combination of angler choice, vessel design, trip duration, and PBF size. Anglers may not want to pay for fillet service and opt to do it themselves back at home. With regard to trip duration, typically, catch on short SR trips (0.5 days) are kept topside in numbered gunny sacks and are easy to retrieve for at-sea filleting, while catch on longer SR trips (overnight-3 days) and LR trips (>3 days) are kept in refrigerated seawater holds below deck and cannot be easily or safely retrieved for at-sea filleting. Additionally, many CPFV vessels run a "jackpot" where the angler catching the largest fish is awarded a cash prize, so some of the larger fish are kept whole to be more precisely weighed at dockside scales and photographed to boost their online reporting. Alone, or in combination, these factors influence the PBF unloaded whole and may influence the size of the subset of fish available to PSP. This suggests PSP may have a tendency to measure larger fish that are more often unloaded whole rather than because the vessels are targeting different sizes of fish.

Trip duration was assessed as a potential factor in differences in length distributions between PSP and SAC. SAC sampled predominantly SR trips, which represent 70% of the CPFV fleet,[2] while PSP more evenly sampled SR and LR trips. The length distributions between SR and LR trips were significantly different in most comparisons. However, differences between LR and SR within each program were relatively small (<10 cm) in all but one case, and were both positive and negative. The average difference in median length values between LR and SR within each program was -2.9 cm. Between programs, LR trips were difficult to compare since SAC sampled so few; however, when comparing SR trips between programs, PSP often sampled more large PBF. Overall, this suggests that there was no consistent difference in fish length associated with trip duration. Additionally, if fishing conditions are favorable for catching PBF within 200 nautical miles, LR vessels will fish during transit through these waters, which results in these vessels fishing the same waters as SR vessels. Using SR and LR as a proxy for distance fished from port was further confounded by where CPFVs are fishing. The U.S. fishing blocks lie entirely within 200 nautical miles of San Diego, and thus, trip duration is not analogous to distance from San Diego. Fishing in Mexican waters is reported as one fishing block that ranges from ~20 nautical miles from San Diego to 650 nautical miles off of the Baja California

Peninsula. While PBF sampled by PSP were sometimes larger than those sampled by SAC, the duration of the trip (LR vs SR) was not a good indicator of distance traveled to fish or the length of PBF landed.

Another difference between the two sample programs was the months sampled. A majority of sampling by PSP occurred from June through September each year. In contrast, SAC started sampling in April in most years and sampled through the following January. The extended sampling period, particularly of SAC, prompted transforming the PBF FLs to the same date for comparison. PBF lengths should increase as the PBF grow as the season progresses and these changes may be detectable month to month. While lengths were transformed, growth rates can vary which would impact the comparison of transformed lengths. It is also possible that different size classes of fish are available seasonally in waters off San Diego. A more detailed comparison of length by month was beyond the scope of this paper.

Length measurements provided the opportunity to estimate the age distribution of PBF landed by the CPFV fleet. The dominant age classes in the recreational catch were 1-3 years, as observed historically and consistent with known PBF migratory patterns (Inagake et al., 2001; Itoh et al., 2003; Boustany et al., 2010). For most years, each age class was represented by a well-defined peak that could be traced through time. Fish older than three may return to the WPO and therefore not be available for the CPFV fleet in the EPO. Two exceptions are 2017 and 2018, in which both programs detected larger numbers PBF of older age classes. The presence of older fish in large numbers in 2017 and 2018 may be a result of inter-annual variation in environmental factors and prey availability (Boustany et al., 2010; Madigan et al., 2018; Runcie et al., 2018) that influences retention in the EPO. However, it is not well understood what influences availability of larger fish in the EPO or what triggers the return to the WPO for spawning. Factors that influence the availability of larger size classes and their retention in EPO warrant more in-depth investigation.

The results from the comparison of PSP and SAC can help inform future sampling programs to improve efficiency. Through weekday analyses, it was apparent that no one weekday reliably resulted in more PBF measured than other weekdays. If future sampling by PSP is only conducted one day a week for 18 weeks, we can expect on average 556 PBF to be measured annually. The weekdays that PSP chose to sample were opportunistic and relied on daily online fishing reports of the CPFV fleet. Without knowing what PBF landings will be for the rest of the week, online reports of 23 or more PBF coming in warrants sampling as this would result in approximately 400 PBF sampled a year. Not all vessels report to these online forums; therefore, tracking individual vessels that are coming in and have historically landed PBF is also recommended.

The opportunistic versus fixed sampling designs of PSP and SAC, respectively, resulted in different sampling strengths. PSP chose sampling days each week conditional on non-zero PBF catch and sampled multiple vessels (and therefore multiple trips) within each sampling day (Heberer and Snodgrass, in review). This method proved efficient to sample a larger number of vessels with a standard maximum of 30 fish measured per vessel. However, PSP relied on catch reports from public landings and therefore may not have sampled if reports of PBF coming in were low. PSP also tended to sample mostly in high catch months and can be restricted by staff availability. In addition, as mentioned above, this program only had access to fish unloaded at the dock, a potentially non-random subset of fish landed. In contrast, SAC assigned one set weekday to each vessel to sample up to 25 PBF per trip throughout the entire year. The fixed, predetermined sampling scheme relied on vessels fishing for and catching PBF on their assigned sampling day (or a longer trip that includes their sampling day), otherwise no lengths were recorded. This scheme allowed sampling over the entire PBF season, which was an advantage over PSP. However, the number of boats that participated was relatively low, 5-11 each year. Despite the lower number of vessels, the vessel simulation analysis indicated that the number of vessels sampled had little impact on the length frequencies. There may be a small effect of SAC sampling fewer vessels, particularly in the magnitude of the modes (i.e., 2018). In comparison to PSP, SAC had access to all fish landed. While each program has strengths and weaknesses, some of the weaknesses of SAC may be able to be mitigated in the future.

Another advantage of SAC became apparent during the 2020 COVID-19 pandemic. In 2020, PSP was unable to measure any PBF due to COVID-19 restrictions. SAC sampled more PBF in 2020 than in any year previously and more than the combined sampling of both programs most years. SAC benefitted in 2020 from its design where the crew performs the length sampling so when CPFVs (that participate in SAC) catch PBF on their assigned day, those fish are guaranteed to be sampled. NOAA currently supports both sampling programs, and while continued annual sampling is imperative to provide robust length distributions to the ISC stock assessment, it may not be necessary to continue running both programs.

Whether the length compositions of PSP and SAC reflected the length compositions from current CPFV landings was difficult to assess, because those two programs are the main programs that sample the CPFV fleet. PSP and SAC length data raised to the catch reflected the raw data both seasonally and annually. When combined with the spatial distribution, this indicated that the length composition from both PSP and SAC represented the catch landed by the entire CPFV fleet. We support continued efforts to confirm that the PSP and SAC data are representative of the CPFV fleet through continued length sampling and comparison with CPFV logbooks.

The PBF stock assessment incorporated the PSP length data for the first time in the 2020 stock assessment (ISC, 2020). The comparison of SAC to PSP performed here demonstrated similarities and differences in sampling design and catch-at-lengths that are valuable resources to help characterize the size composition of PBF landed by the CPFV fleet. However, missing 2020 length data from PSP created a data gap that could be potentially important in the future stock assessment. This further highlights the need for continuative size sampling of PBF in the EPO through programs like PSP and SAC.

Acknowledgements
The authors would like to thank Steve Teo, Barb Muhling, and Brad Erisman of the Fisheries Resources Division of NOAA for technical expertise and editing, the California Department of Fish and Wildlife, particularly Michelle Horezcko and Leeanne Laughlin, for fulfilling data requests, and the Sportfishing Association of California for dedicated staff and members who collect length data on PBF and other species every day.

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