Comparison of U.S. Pacific Bluefin Tuna Length Sampling Programs: 2014-2020

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Abstract

Pacific Bluefin tuna (PBF) in the Eastern Pacific Ocean have been fished since the at least the 1950s; however, declines in the U.S. commercial catch have resulted in recreational fishing emerging as the larger sector of the U.S. PBF fishery since the early 2000s. The U.S. recreational fishery is dominated by commercial passenger fishing vessels (CPFVs). The size selectivity of the CPFV fleet was historically mirrored to the U.S. commercial fleet in International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific Ocean stock assessments before 2020, but the current length composition of the recreational fleet may not reflect the length composition of the historical (1950s-1980s) commercial catch. The National Oceanic and Atmospheric Administration (NOAA) conducts both a Pacific Bluefin Tuna Port Sampling Program and supports the Sportfishing Association of California (SAC) Fisheries Sampling Program to determine the length composition of the CPFV fleet. The length sampling conducted by both of these programs were compared here to investigate their overlap, potential bias, and how representative they were of the CPFV fleet. The length compositions between the programs had similar multimodal distributions, but the NOAA program generally sampled larger PBF (median = 97.1 cm FL) due to their port sampling methods. In contrast, the SAC program was able to measure smaller PBF (median = 92.0 cm FL) often filleted at sea and unavailable for port sampling. The SAC program generally sampled fewer vessels than the NOAA program, but a subsampling simulation demonstrated that this did not drastically affect the length composition. The NOAA sampling program measured 4.5% of the CPFV fleet between 2014 and 2019, while the SAC program measured 3.8% of the CPFV fleet between 2015 and 2020; both programs were representative of the CPFV landings of PBF. While the potential of sampling design bias needs to be considered, both programs produced comparable data that are likely more representative of current CPFV landings than the selectivity assumption previously used for the U.S. recreational fleet.

Introduction

The Pacific Bluefin tuna (*Thunnus orientalis*; PBF) is an 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 they are 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. (Itoh et al., 2003; Kitagawa et al., 2007; Boustany et al., 2010). Pacific Bluefin tuna are assessed as one stock using catch, abundance, and length data provided by Japan, Mexico, South Korea, Taiwan, and the U.S. (ISC, 2020b).

Since at least the 1950s, the U.S. and Mexico have harvested juvenile PBF in the EPO primarily using commercial purse seine and recreational hook-and-line methods (ISC, 2018a). From 1952 to 2001, U.S. commercial purse seine (Fleet 13 in the 2020 International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific Ocean (ISC) stock assessment) was the dominant source of PBF catch in the EPO, catching a total of 269,600 mt compared to the 275 mt reported by Mexico purse seine (Fleet 14) and the 272,000 individual PBF caught by U.S. sport fisheries (Fleet 15; ISC, 2018a). However, the mandated exclusion of U.S. commercial vessels from Mexican waters in the 1970s led to the decline of PBF catch by Fleet 13 (Aires-da-Silva et al., 2007). From 2002 to 2016, Fleet 13 catch reported 0 mt, while Fleet 14 and 15 reported increases in PBF catches that totaled 76,030 mt and 310,000 individual PBF, respectively (ISC, 2018a). Given the historically low recreational catch of PBF relative to the commercial catch of PBF in the EPO, the selectivity of Fleet 15 was mirrored to the selectivity of Fleet 13 up until the most recent stock assessment (ISC, 2018a; ISC, 2020b). This approach assumed that Fleet 15 currently catches the same PBF length classes as Fleet 13 did historically.

There are a number of reasons why the use of the historical length data may not accurately reflect the current length composition of PBF in the EPO (Lee et al., 2015; ISC, 2018a; Heberer and Lee, 2019). First, the length classes landed in the EPO vary over time (Foreman and Ishizuka, 1990; Madigan et al., 2017; Heberer and Lee, 2019). Next, large-scale and decadal changes in regional climate (e.g., increased frequency and intensity El Niño events) may have resulted in a northward shift of PBF distribution in the EPO since the 1950s (Runcie et al., 2018). These changes have likely affected the geographic range and seasonal timing of PBF migrations in the EPO, with the potential for larger PBF that can tolerate cooler temperatures (Boustany et al., 2010; Runcie et al., 2018) to be available for longer periods of time off the U.S. coast than in decades past. In addition to environmental changes, factors including gear selectivity, size targeting by the vessel, fisheries mortality, and the recruitment to and retention of fish in the EPO can also influence the length composition of PBF (Aires-da-Silva et al., 2009; Madigan et al., 2017; Piner et al., 2020). U.S. recreational vessels, which are dominated by commercial passenger fishing vessels (CPFVs), have recently caught larger length classes of PBF compared to the last two decades (ISC, 2018b). Consequently, the historical Fleet 13 length data may not accurately reflect the length composition of current landings for Fleet 15.

To measure selectivity of Fleet 15, the collection of recent data on the length composition of PBF was initiated. Currently, there are three programs that collect data on PBF recreational length composition in California. The National Oceanic and Atmospheric Administration (NOAA) Pacific Bluefin Tuna Port Sampling Program, hereafter NOAA program, 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 the NOAA program design, protocols, and operations can be found in Heberer and Snodgrass (in review).

To complement the NOAA program, the NOAA-funded Sportfishing Association of California (SAC)'s Fisheries Sampling Program (hereafter referred to as the SAC program) started in 2015, in which CPFV vessel crew measure PBF FL onboard prior to unloading. The SAC program was established amid questions from the sportfishing community about whether NOAA's portside sampling design inadvertently focused on whole, larger PBF from long-range (LR) vessels fishing in Mexican waters and potentially omitted smaller PBF filleted at-sea from short-range (SR) vessels fishing in local U.S. waters.[1] Short-range CPFVs generally have a 200 nautical mile (nmi) range and make trips ranging from 0.5 to 3 days, while LR vessels can travel up to 650 nmi off the entire Baja peninsula, Mexico, on trips ranging from 4 days to 3 weeks.

Finally, the California Department of Fish and Wildlife (CDFW) has collected data on California's marine recreational fisheries since 1979 using 1) field sampling, 2) telephone surveys, and 3) 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

[1] Sportfishing Association of California Proposal for a Pilot Project Sampling Commercial Passenger Fishing Vessels for Tunas.

while they don't report PBF lengths, the logbooks can help assess the extent to which the NOAA and SAC programs cover the fishery. CDFW collected lengths from the CPFV fleet and from private or rental boats. The latter have different fishing methods (e.g. trip duration and distance) than CPFVs and consequently are not directly comparable to the lengths collected by the NOAA and SAC programs.

The NOAA and SAC programs have different method designs for sampling the CPFV fleet, but both are meant to inform the PBF length composition for Fleet 15. The goals of these analyses were to: 1) examine the extent that the NOAA and SAC programs cover the PBF CPFV fleet; 2) analyze the potential sampling overlap between programs; 3) compare the PBF length composition from each program; 4) compare the coverage by each program across month, year, trip duration, and weekday landed; and 5) explore how representative the NOAA and SAC programs are of CPFV fleet landings. These analyses are intended to provide guidance on the utility of these datasets to the PBF stock assessment and can inform potential future changes to sampling designs.

Methods

To characterize the length composition of the CPFV fleet, we compared the NOAA 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. The NOAA and SAC programs collected similar data including vessel name, trip duration, departure and return date, number of PBF measured, and fork lengths (FL) of landed fish to the nearest 0.1 cm for each trip. The NOAA program often sampled more than one vessel and trip in a sampling day; therefore, the number of days that NOAA sampled was also recorded. For the SAC program, each vessel was assigned one weekday for the season and instructed to measure PBF caught on that day. For trips longer than 1 day, if the assigned weekday fell during the trip, 25 PBF were measured on that trip regardless of 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.

<u>General comparisons</u>

The number of PBF measured by the NOAA and SAC programs 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 the NOAA and SAC programs 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 the NOAA and SAC programs were each compared to the geographic coverage of the whole CPFV fleet. 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.

The number of trips sampled by NOAA and SAC were compared across years. The CPFV logbooks, which were reported by each day fished for multi-day trips and not trip, were omitted from comparison of trips. As NOAA often measured more than one trip per day, unlike SAC, sampling day was also compared to the number of trips across years. The number of PBF measured per trip and sampling day (NOAA only) were examined to understand the return on sampling effort. For example, what percent of trips measure fewer than five PBF? The maximum sampling size per trip was set at 25 for SAC[1] and 40 in 2014 and 30 in 2015-2019 for NOAA (Heberer and Snodgrass, in review).

The number of PBF measured and number of trips sampled were compared by trip length (SR vs LR) between programs.

<u>Overlap of SAC and NOAA data</u>

The degree of overlap between the NOAA and SAC programs (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. Mean FLs were compared between NOAA and SAC for each overlapping trip with one-way ANOVAs in R (R Core Team, 2019) to detect if the measurements made by each program reflect the same length composition. To determine if NOAA and SAC were measuring the same fish, the overlapping trips were matched to CPFV logbook data to compare the number of PBF measured by NOAA and SAC to the number of

PBF reported landed in logbook data. The trips sampled by both programs were removed from further comparisons as there was a possibility the data points were not independent.

Fork Length Analyses

Median FLs were compared between programs, years, and trip length (SR vs LR) with Kruskal-Wallis test by ranks as the data were not normally distributed (Shapiro Normality test: $p < 0.001$) and post hoc Pairwise Wilcoxon rank sum tests in R (R Core Team, 2019). Trips of unknown length were excluded. Length frequency distributions were generated using kernel density estimates for each year where either NOAA or SAC measured PBF. 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, 2020b). These lengths-at-age were compared to the length frequency distributions to examine estimated age distributions among years and programs.

Weekday Analyses

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 impacted the number of PBF measured by each program.

Predicted Future PBF Sampling by NOAA

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 the NOAA program data. The NOAA program's dockside sampling is labor intensive so a modified sampling design of sampling once a week was explored as an alternative to the current design that sampled multiple times a week. To forecast the number of PBF that might be sampled in future years with the modified sampling design of sampling 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 were 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.

Vessel Simulation

One difference between the NOAA and SAC programs was the number of vessels sampled each year (see Results: General Comparisons). To understand whether sampling fewer vessels affected the length composition of PBF, a vessel simulation was conducted by randomly subsampling the NOAA 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 were generated by year using kernel density estimates for the subset data and the original NOAA 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 was compared to the original NOAA data with Mann-Whitney U tests as the data were not normally distributed (Shapiro Normality test: $p < 0.001$) in R (R Core Team, 2019).

Representative of CPFV fleet?

To understand the length composition of the North Pacific PBF stock, available length data were raised to the catch for the stock assessment following the methods described by Lee et al. (2015). The sampled length composition (by NOAA or SAC) needs to reflect the length composition caught by the CPFV fleet. 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 (NOAA 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[2] 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 was compared to the raw data through seasonal analysis and length frequency plots by year using 1 cm FL bins without smoothing.

Results

General comparisons

Length data for PBF landed by the San Diego CPFV fleet were collected by the NOAA program and available for this analysis from 2014 to 2019 and by the SAC program from 2015 to 2020. The NOAA program was unable to sample in 2020 due to COVID-19 restrictions. The NOAA program measured 4.5% of the total number of PBF landed by the California CPFV fleet (range: 2.2-7.3% annually) between 2014 and 2019 (Table 1). The SAC program 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 during the summer and fall months, which was also when landings of PBF were highest (Figure 1). NOAA sampled predominantly in the peak season from June to September, while SAC sampled more evenly throughout the year (Figure 1). The number of fish landed or sampled was highly variable among years between 2014 and 2020 (Table 1). The CPFV fleet from San Diego County landed 82.2% (range: 72.5-91.4%) of all PBF landed by the entire CPFV fleet in CA between 2014 and 2020.

The NOAA program sampled more unique vessels than SAC (NOAA n = 42; SAC n = 19; Figure 2). Combined, the SAC and NOAA programs sampled 52 unique vessels, which represented 20.6% of the 252 total unique California CPFVs landing PBF between 2014 and 2020.

Geographic coverage was compared among the NOAA program, the SAC program, and the CPFV fleet for 2015-2019 (Figure 3). For the NOAA program, 148 trips were matched to the CPFV logbook data, which covered 1,518 PBF measured (53.0% of the total NOAA data). For the SAC program, 128 trips were matched to the CPFV logbook data, which covered 1,527 PBF measured (60.5% of the total SAC data). From 2015-2019, CDFW sampled 59,116 PBF in southern California and Mexican fishing blocks. Both NOAA and SAC sampled PBF that were from fishing blocks representative of the entire CPFV fleet (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 trip type.

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

True to their respective sampling designs, SAC sampled more PBF from SR trips (≤ 3 days) than did NOAA between 2015 and 2019. SAC sampled 2,131 PBF from 179 SR trips and only 152 PBF from 20 LR trips, while NOAA sampled 1,623 PBF from 181 SR trips and 1,028 PBF from 78 LR trips. Interestingly, however, NOAA also sampled more SR than LR trips. Trip duration was not reported for 9 trips sampled by SAC (PBF = 39) and 10 trips sampled by NOAA (PBF = 53) from 2015 to 2019.

<u>Overlap of SAC and NOAA data</u>

Eight vessels were sampled by both NOAA and SAC from 2015 to 2019; NOAA 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 double-sampled by both the NOAA and SAC programs. The PBF from these 11 double-sampled trips account for 5.7% of NOAA sampling totals (162 of 2854 total PBF) and 7.1% of the SAC totals (177 of 2498 total PBF). If each of the 162 lengths measured by NOAA matched a length from SAC, then the overlap rate represented 3.0% of combined trips of SAC and NOAA. 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 NOAA. NOAA measured 54.0% and SAC measured 59.0% of the 298 landed PBF. Lengths from nine of the 10 overlap trips were not significantly different (Figure 6). One of these nine trips had exactly the same FL measurements for both NOAA and SAC for the six fish measured. A tenth trip did display a significant difference in FL, with NOAA measuring larger fish (Figure 6). One trip could not be matched to logbook data; only one PBF was measured by each program from this trip. NOAA provided one length of 143.3 cm FL, while SAC provided one length of 114.9 cm FL. The trips sampled by both programs (a total of 22 trips) were removed from further comparisons as there was a possibility the data points were not independent.

Fork Length Analyses

The median FL for the NOAA program from 2014-2019 was 92.2 cm FL (interquartile range (IQR): 81.1-114.2) and from 2015-2019 was 97.1 cm FL (IQR: 84.5-121.8), while the median FL for the SAC program from 2015-2019 was 92.0 cm FL (IQR: 74.5-114.3) and from 2015-2020 was 87.9 cm FL (IQR: 79.5-106.3). There was a significant difference in median FL between the two programs from 2015-2019 (H = 630.9, df = 9, $p < 0.001$). Pairwise comparisons of median FLs across year and program identified significant differences among program and year (Figure 7). Between programs, the result of the pairwise comparisons was that the median FL from NOAA sampling was significantly larger than the median FL from SAC sampling in 2015, 2017, and 2018 ($p < 0.001$; Table 2). Within the NOAA program, the result of the pairwise comparisons was that the median FL in 2014 and 2015 was significantly smaller than all other years ($p < 0.001$), and the median FL for 2018 was significantly larger than all other years ($p < 0.050$, Figure 7). Within SAC, the result of the pairwise comparisons was that the median FL was significantly different among all years except between 2015 and 2017 ($p < 0.009$) with the highest median FL in 2016 and the lowest median FL in 2017 (Table 2; Figure 7).

Annual medians of FL masked the multimodal nature of the length data. Length frequencies were multimodal and varied by year and program (Figure 8). One to six length modes were identifiable depending on year and program. Length modes aligned moderately well between SAC and NOAA data. 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 PBF between ages 5 and 6 (Figure 8). In 2015 and 2019, the length frequency peaks of NOAA were shifted towards larger lengths than SAC and in 2017 and 2018 NOAA measured more large PBF than SAC (Figure 8).

In addition to year and program, FL was compared between SR and LR trips. Within the NOAA program, there was a significant difference in FL between SR and LR trips (H = 404.87, df = 11, $p < 0.001$). The results of the pairwise comparisons was that 2018 had significantly different median FLs between SR and LR trips (p = 0.014; Table 3). Within the SAC program, there was a significant difference in FL between SR and LR trips (H = 408.32, df = 10, $p < 0.001$). The results of the pairwise comparisons was that 2020 had significantly different median FLs between SR and LR trips (p = 0.010; Table 3).

Weekday Analyses

A Kruskal-Wallis test determined that there was a difference in the number of PBF measured by program and weekday (H = 24.914, df = 14, p = 0.035; Figure 9), but pairwise comparisons between programs did not detect any significant differences (range of p-values: 0.081-1.000).

Predicted Future PBF Sampling by NOAA

From 2014 to 2019, the NOAA program sampled between 9 and 16 weeks annually and averaged 2 days of sampling per week. For each of the three scenarios examining what sampling would look like if it occurred only once 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 years totals (Table 1).

Vessel Simulation

The SAC program sampled less than half as many vessels (39.0%) as the NOAA program between 2015 and 2019 (Figure 2). Length frequency graphs comparing subset NOAA data and original NOAA data were very similar with an equal number of modes present in each year (Figure 10). In 2018, the subset NOAA data did not detect two distinct modes between 80 and 100 cm FL that the original NOAA data had, but those lengths were still represented (Figure 10). The median FLs were statistically different between the subset and the original NOAA data over the entire time period (2015-2019; U = 1232291, p = 0.045). The median FLs were significantly different in 2015 (U = 46855, p = 0.022) and 2019 (U = 68839, p = 0.014), while the others years were not (2016: U = 78793, p = 0.965; 2017: U = 24213, p = 0.106; 2018: U = 35223, p = 0.337).

Representative of CPFV fleet?

Length data were raised to the catch in 1 cm bins for each year and month. Between 2014 and 2020 several months had few PBF measured; NOAA measured fewer than 25 PBF in 7 out of 31 months and SAC measured fewer than 25 PBF in 15 out of 46 months. Those months with few lengths were not removed from seasonal analyses but were removed from length frequencies analyses. Seasonal analysis of data raised to the catch (Figure 11) indicated length sampling by NOAA and SAC reflected seasonal catches by the entire CPFV fleet (Figure 1). NOAA undersampled July and September, while SAC undersampled August and September compared to CPFV logbooks (Figure 1 & 11). Length frequencies of length sampling data raised to the catch reflected the raw length frequencies very closely (Figures 12 & 13).

Discussion

This comparison of the NOAA and SAC programs provided the opportunity to assess the length compositions, the extent of their overlap, and how well they represented the length composition of PBF harvested by the CPFV fleet. These comparisons were made to better understand potential biases in the sampling design and the ultimate utility of the length data as inputs to the PBF stock assessment for Fleet 15. The length composition of Fleet 13 from 1952-1982 averages 60-80 cm (ISC, 2020a). This range was less than the current median FLs from NOAA (97.7 cm FL) and SAC (94.4 cm FL) presented here. The higher median lengths of landed PBF in recent years highlights the need to reexamine the selectivity for Fleet 15. Whether the length compositions of the NOAA and SAC programs reflected the length compositions from current CPFV landings was more difficult to assess, because those two programs are the main programs that sample the CPFV fleet. The spatial distribution of the PBF sampled by NOAA and SAC reflected the spatial distribution of the CPFV fleet. The NOAA and SAC length data raised to the catch also reflected the raw data both seasonally and annually, which together with the spatial distribution, indicated that the length composition from both NOAA and SAC programs represented the length composition landed by the entire CPFV fleet.

A comparison of the length data between the programs indicated differences in length measurements, although differences of median FL between programs varied less than differences of median FL among years. Interannual variation in FL was expected, so the focus here is on differences between programs within years. In three of the five sampling years, the NOAA program measured a larger median PBF FL than the SAC program. This was reflected in the length frequency modes where the NOAA program measured larger PBF in 2015, 2017 and 2018 with more 2, 4 and 5 year old fish measured by NOAA respectively. These differences, which were not always present, could be attributed to a variety of factors. It is possible that the vessels associated with these two programs targeted different length classes of PBF. For example, observed differences in either sampling month and or trip duration (SR and LR trips) may have resulted in vessels encountering fish of different lengths. It is also possible that there was some systematic difference in fish handling before or after they were landed that influenced the length of fish available to each program.

One notable difference between the two sampling programs was that SAC's vessel-based sampling had access to all fish caught whereas NOAA's portside sampling program 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. 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 sea water 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 the NOAA program. This suggests the NOAA program may be slightly biased towards larger fish that are more often unloaded whole rather than because the vessels are targeting different sizes of fish.

The SAC program was established in 2015 in order to ensure fish from both LR and SR vessels were sampled. The SAC program sampling design is rooted in the anecdotal assumption that SR trips that remain within 200 nmi of San Diego and cannot access waters off central and southern Baja California Mexico catch smaller PBF.[1] Concerns that the NOAA program could positively skew the average length of PBF caught by the U.S. recreational fleet are valid if 1) the LR vessels sampled by the NOAA program indeed landed PBF exclusively off Baja, and 2) if these PBF landed off Baja are larger. However, based on the analyses in this study, there was only one year each where the NOAA and SAC program measured significantly different PBF between SR and LR trips. Overall, this suggests that fish length is not influenced by trip duration. Additionally, if fishing conditions are favorable for catching PBF within 200 nmi, 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 nmi 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 nmi from San Diego to 650 nmi off of the Baja Peninsula. While PBF sampled by NOAA 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 sampling season. A majority of sampling by the NOAA program occurred from June through September each year. In contrast, the SAC program started sampling in April in most years and sampled through the following January. This longer sampling season may be reflected in the generally wider peaks of length frequencies than the NOAA program peaks. The seasonal difference may also in part explain the difference in average FL in 2019; SAC sampled a large portion of the year's samples in April and May, while NOAA's sampling didn't ramp up until June. PBF lengths likely increase as the season progresses as the PBF grow and these changes may be detectable month to month. 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. The ages classes can be traced through time, but often, age classes greater than age 3 were not represented. These fish may return to the western Pacific and therefore not be available for the CPFV fleet in the EPO. Two exceptions are 2017 and 2018 where both programs detected 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). However, it is currently not well understood what triggers the return to the WPO for spawning. Additionally, catchability of PBF changes with size with larger PBF being more difficult to catch. The patterns in age classes seen here warrant more in-depth investigation.

The comparison of the NOAA program to the SAC program also 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 in most cases indicating that NOAA and SAC make consistent measurements on these trips. The SAC program participants were taught to measure following the NOAA program protocol. In the one instance where the mean FLs were different, there is no obvious explanation. The low amount of overlap means these two datasets are complementary rather than redundant and overall are sampling unique fish.

The opportunistic vs fixed sampling designs of the NOAA program and the SAC program, respectively, resulted in different sampling strengths. The NOAA program 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 wide range of vessels with a standard maximum of 30 fish measured per vessel. However, the NOAA program relied on catch reports from public landings and therefore may not have sampled if reports of PBF coming in were low. The NOAA program also tended to sample mostly in high catch months and can be restricted by staff availability. In contrast, the SAC program 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 the NOAA program, 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 number of vessels sampled did not impact the length frequencies. There may be a small effect of SAC sampling fewer vessels, particularly in the magnitude of the modes (i.e. 2018). One option to address this issue would be to increase the number of vessels sampled by the SAC program. While each program has strengths and weaknesses, some of the weaknesses of the SAC program may be able to be mitigated in the future.

The results from the comparison of the NOAA and the SAC program can help inform future sampling to improve sampling efficiency and return on sampling effort. Through weekday analyses it was apparent that no one weekday reliably resulted in more PBF measured than other weekdays. If future sampling by the NOAA program is only conducted one day a week for 18 weeks, we can expect on average 556 PBF to be measured annually. The weekdays that the NOAA program 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 reports, therefore tracking individual vessels that are coming in and have historically landed PBF is also recommended.

In 2020, the NOAA program was unable to measure any PBF due to COVID-19 restrictions. The SAC program sampled more PBF in 2020 than in any year previously and more than the combined sampling of both programs most years. The SAC program 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, however it may not be necessary to continue running both.

The PBF stock assessment incorporated the NOAA program length data for the first time in the 2020 stock assessment (ISC, 2020b), but have not considered length data from the SAC program. Concerns over using the historical Fleet 13 data for the current Fleet 15 selectivity drove the inception of both the NOAA program in 2014 and the SAC program in 2015. Based on the analyses performed here, the two datasets are distinct given the minimal overlap and depict larger PBF lengths than the historical Fleet 13 length composition. The NOAA program appears to be slightly biased towards larger fish, likely due to a range of factors including the tendency of anglers to unload the largest fish landed whole. On the other hand, the SAC program samples a smaller portion of the total vessels in the CPFV fleet. For both programs, the potential for the sampling design to bias results needs to be considered, however the data provided by each program are comparable and more representative than the historical data previously used.

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Table 1. Number of Pacific Bluefin tuna (PBF) landed by the CPFV fleet in California as reported by CDFW CPFV logbooks, and measured by the NOAA and SAC programs. The SAC program was not established until 2015 and NOAA did not sample in 2020.

Year	Month	California Recreational CPFV logbook PBF Catch	PBF measured by NOAA	% of PBF Catch measured by NOAA	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%
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%
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%

Table 2. Median fork length (FL; cm) of Pacific Bluefin tuna by program (NOAA and SAC) and year. Asterisks indicate a significant difference between programs. The SAC program was not established until 2015 and NOAA did not sample in 2020.

Year	Median FL of NOAA	Median FL of SAC	
2014	88.6		
2015	88.8	83.4	*
2016	108.7	117.2	
2017	97.3	79.4	*
2018	108.0	96.5	*
2019	95.6	103.1	
2020		85.0	

Table 3. Median fork length (FL; cm) of Pacific Bluefin tuna by program (NOAA and SAC), year, and trip type (short range (SR) vs long range (LR)). Asterisks indicate a significant difference between trip type within a program. The SAC program was not established until 2015 and NOAA did not sample in 2020.

Year	Trip Type	Median FL of NOAA	Median FL of SAC
2014	SR	86.3	
	LR	88.8	
2015	SR	87.9	83.0
	LR	90.1	85.0
2016	SR	108.3	118.0
	LR	109.7	83.0
2017	SR	105.7	80.0
	LR	92.7	71.1
2018	SR	106.9 *****	94.1
	LR	112.05 *****	80.8
2019	SR	96.3	103.1
	LR	94.5	
2020	SR		84.7 *
	LR		86.6 *

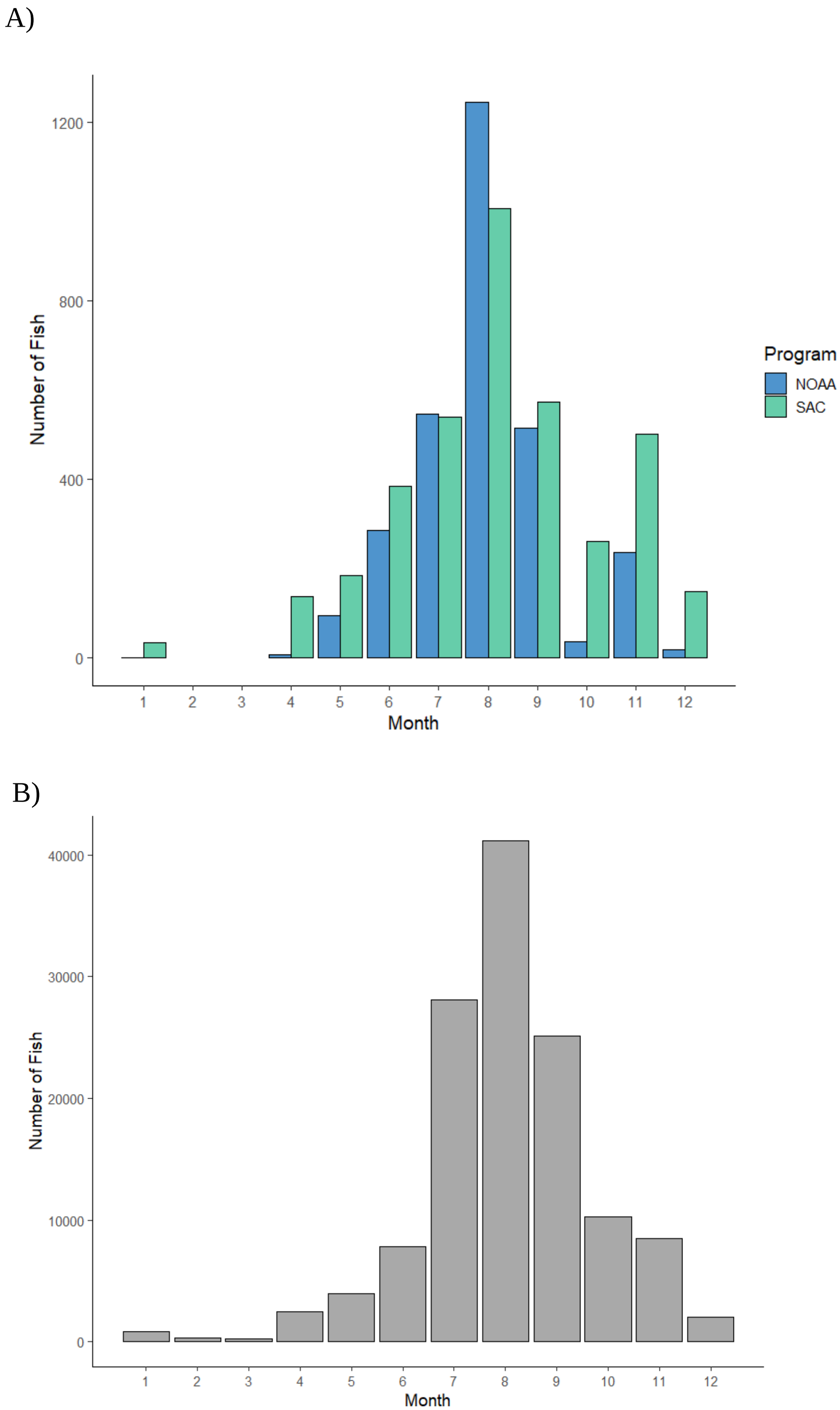

Figure 1. Number of Pacific Bluefin tuna A) measured by NOAA and SAC, and B) reported landed in CDFW CPFV logbooks, by month for data from 2014-2020 combined. SAC was not established until 2015 and NOAA did not sample in 2020.

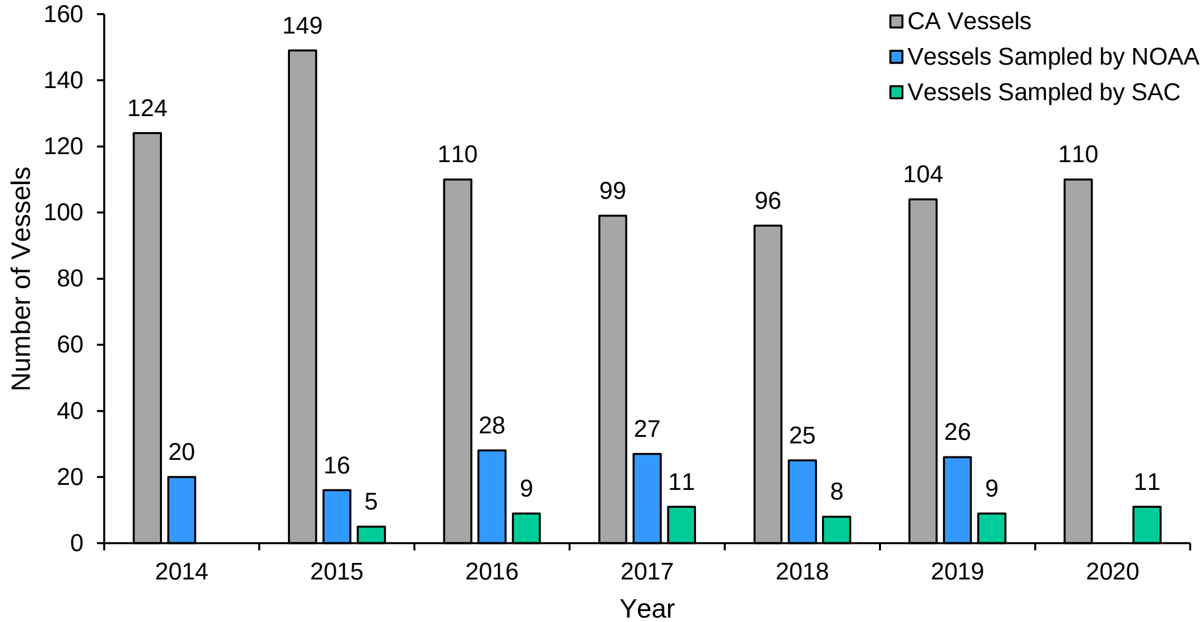

Figure 2. Number of unique vessels landing Pacific Bluefin tuna in California and sampled by NOAA and SAC from 2014-2020. The SAC program was not established until 2015 and NOAA did not sample in 2020.

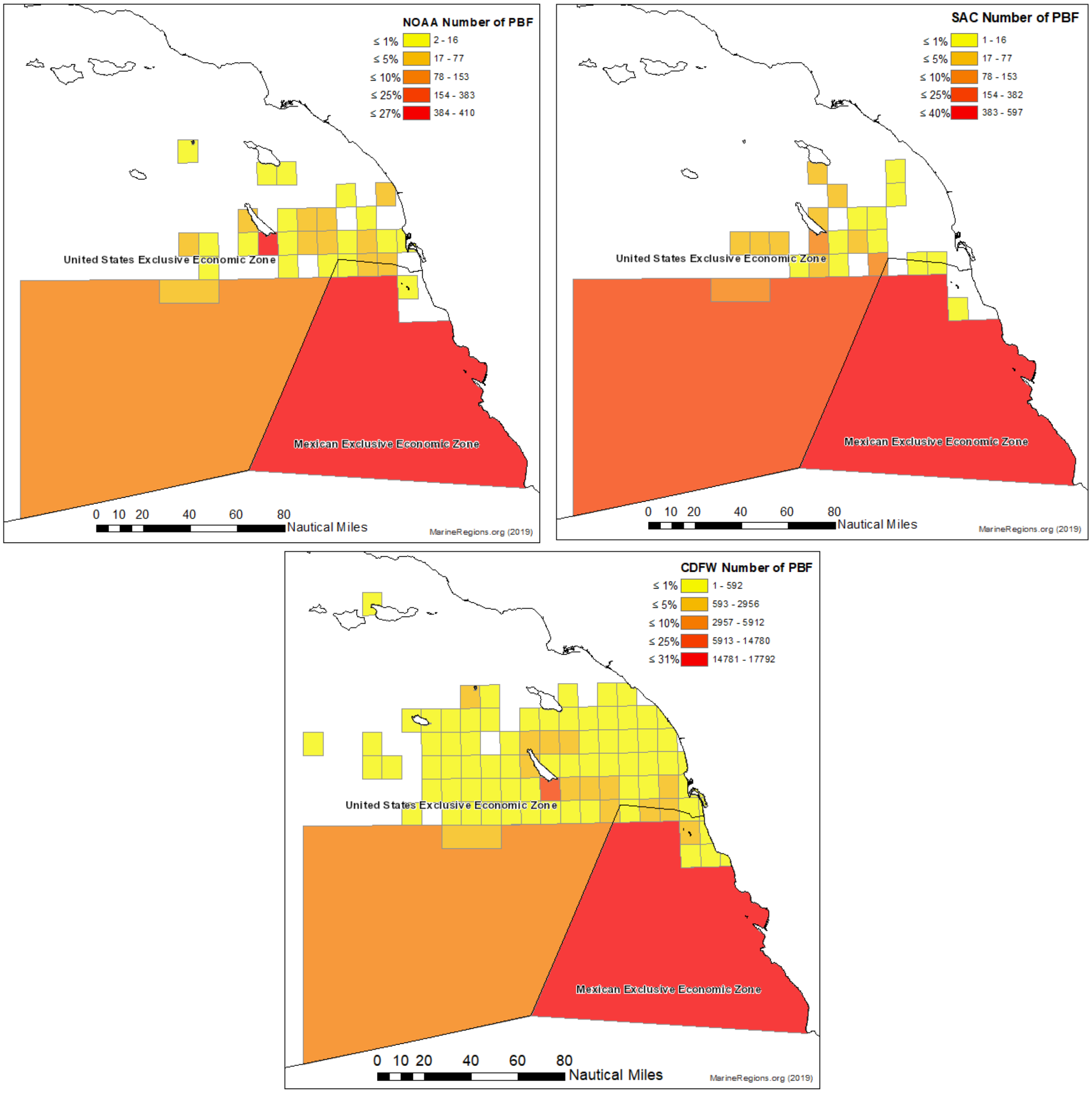

Figure 3. Heat maps of fishing for Pacific Bluefin tuna sampled by NOAA, by SAC, and reported in CPFV logbooks (CDFW) from 2015-2019. CDFW commercial fishing blocks are 10°. All fishing blocks are within 200 nautical miles of San Diego.

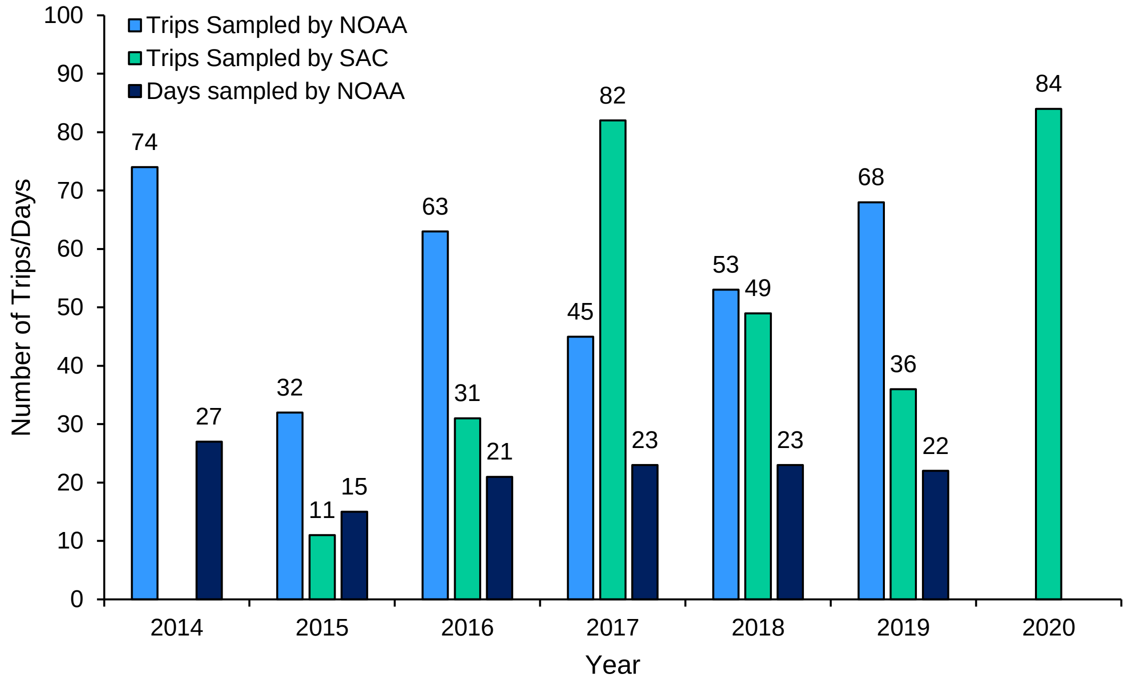

Figure 4. Number of trips and days sampled by NOAA and SAC from 2014-2020. The SAC program was not established until 2015 and NOAA did not sample in 2020.

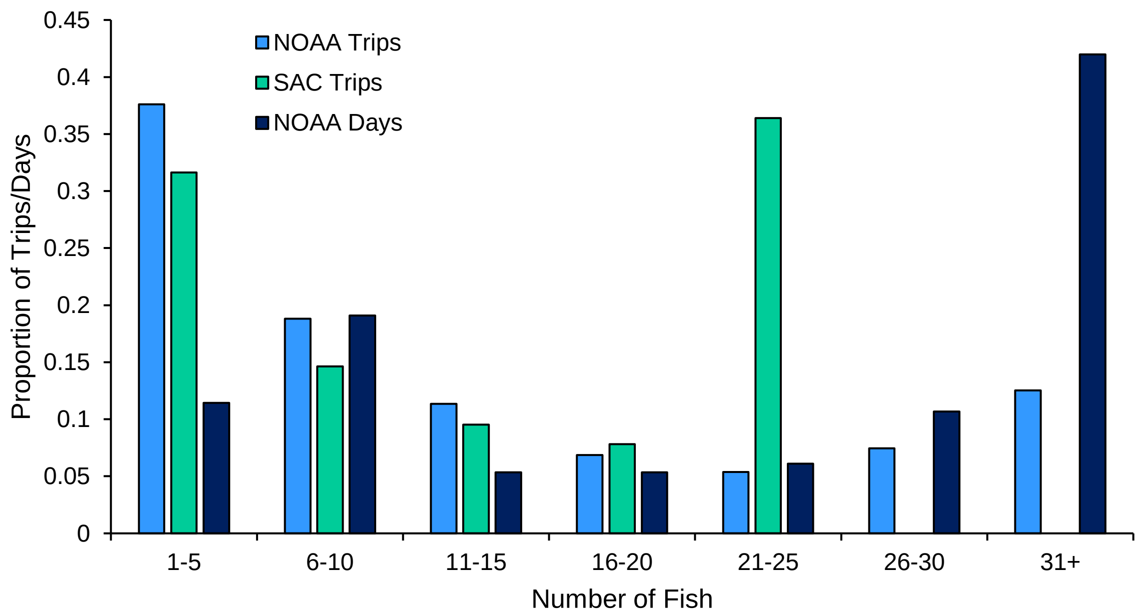

Figure 5. Proportion of trips (NOAA and SAC) and days sampled (NOAA) between 2014 and 2020 where specific numbers of fish were measured. SAC was not established until 2015 and NOAA did not sample in 2020. The maximum number of fish SAC measured per trip is 25 as dictated by sampling method. All NOAA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

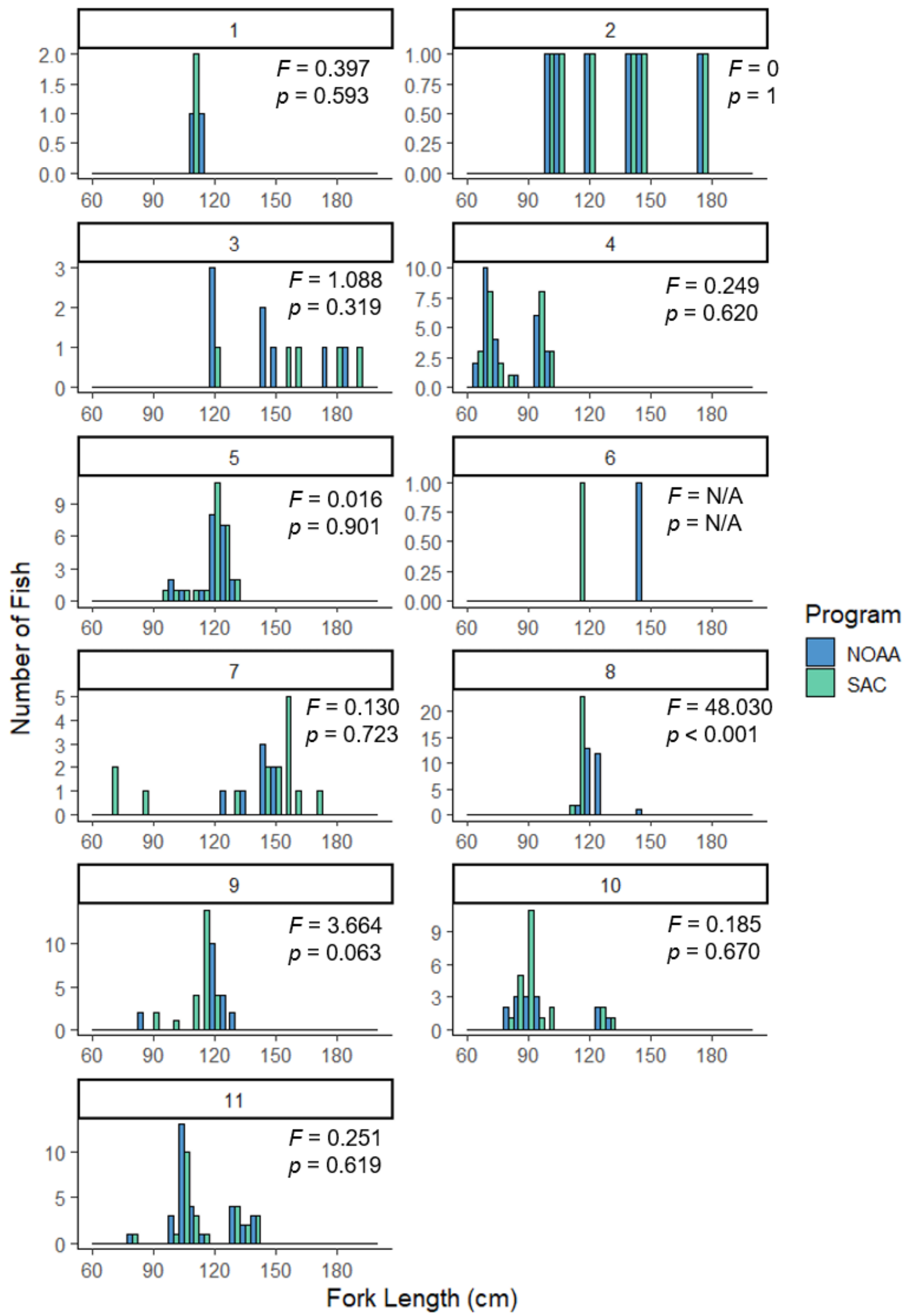

Figure 6. Histograms of each of the 11 overlapping trips using 5 cm bins. Numbers denoting each panel were randomly assigned. ANOVA F statistic and p-value are reported in each pane. For all comparisons df = 1. Trip 6 was unable to be compared statistically. Trip 8 was the only trip with significantly different lengths between the programs.

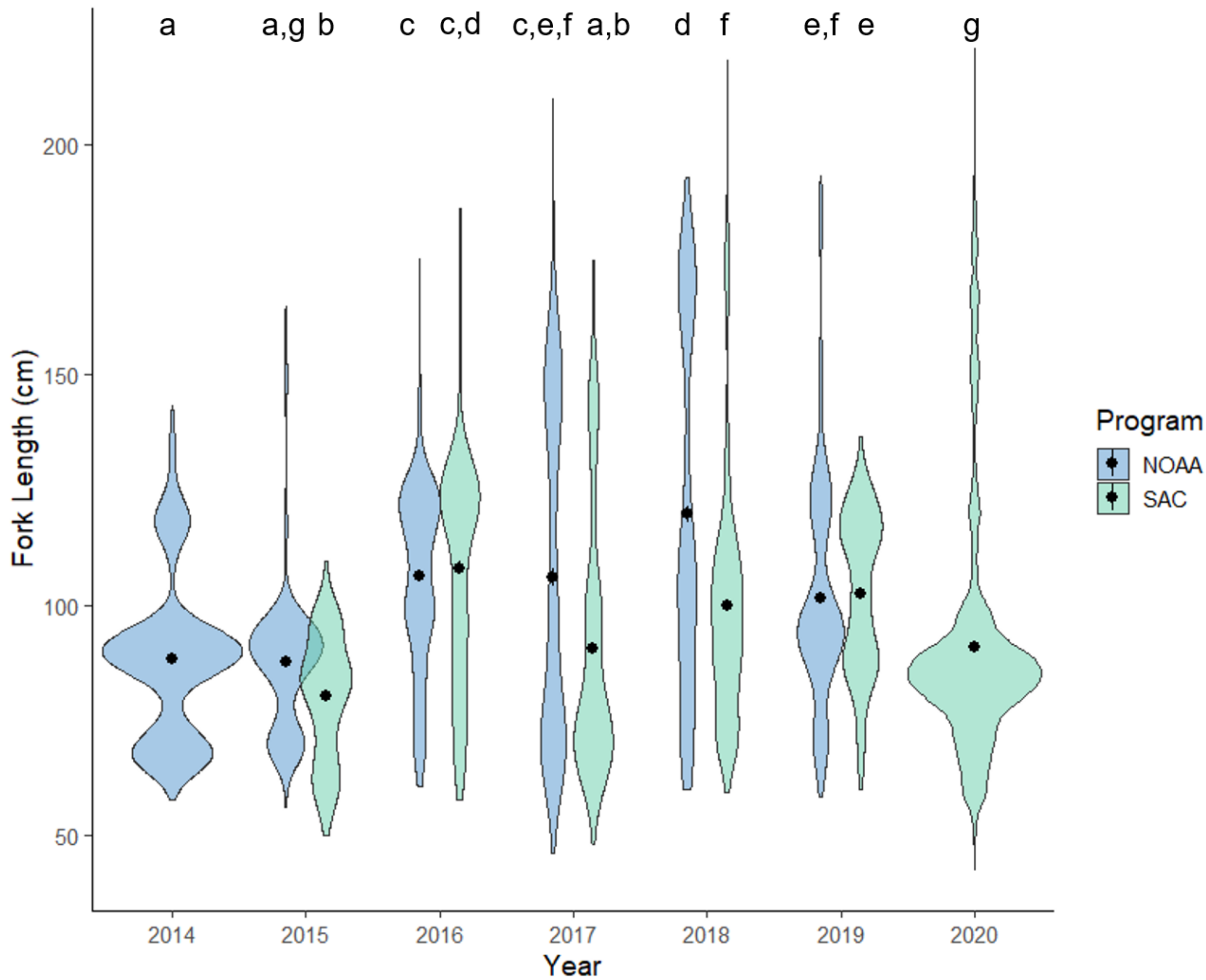

Figure 7. Violin plot with median (●) and interquartile range (|) of fork length (cm) by year and program. The SAC program was not established until 2015 and NOAA did not sample in 2020. Letters indicate significant differences.

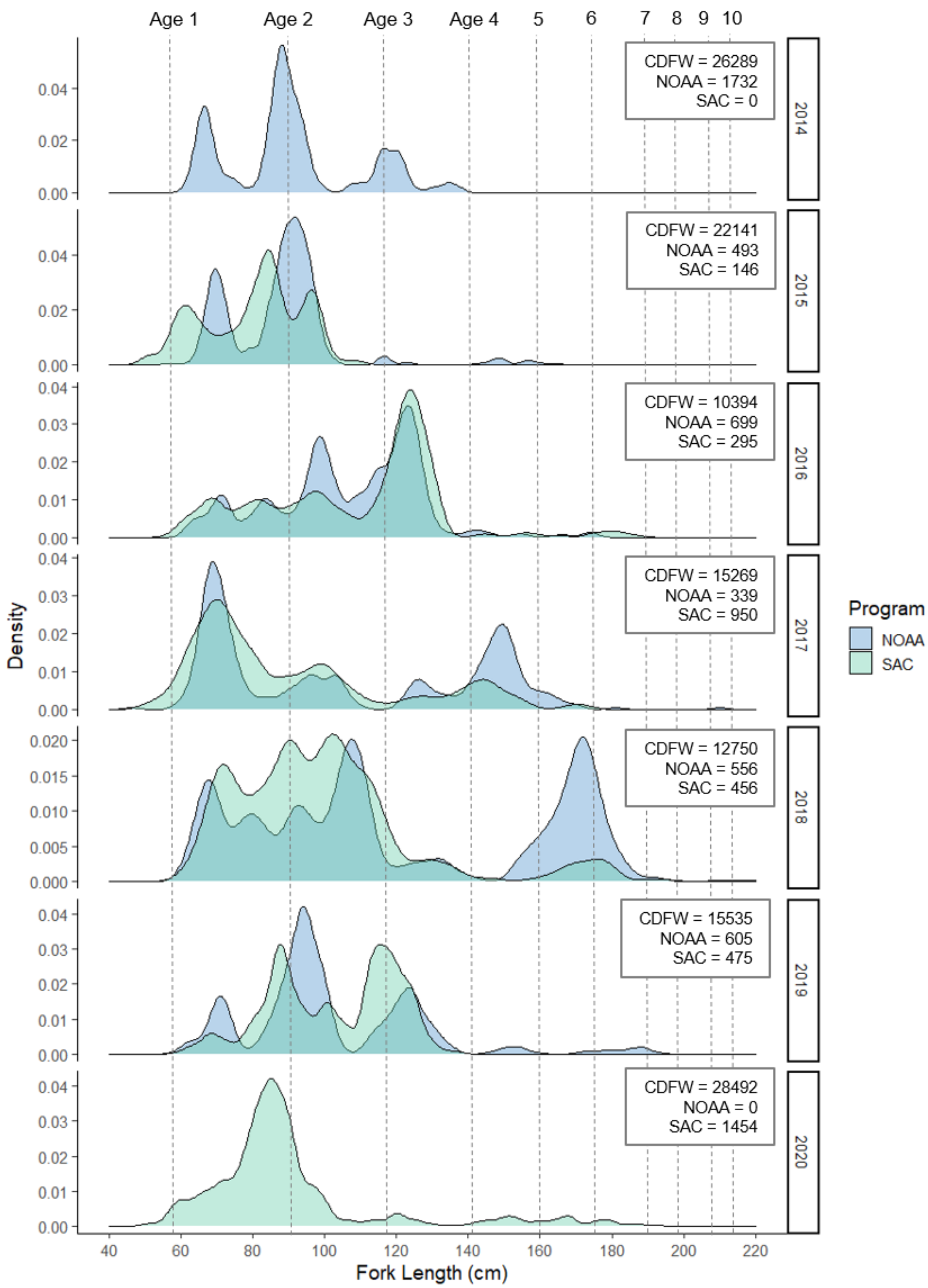

Figure 8. Length frequency distributions of SAC and NOAA samples from 2014-2020. The number of Pacific Bluefin tuna landed in each year from CDFW CPFV logbook data are denoted by 'CDFW ='. The sample size of Pacific Bluefin tuna measured by SAC and NOAA are also listed. The vertical dotted gray lines represent the length-at-age for ages one through ten from ISC (2018a). The scale of the y-axis varies among years. The SAC program was not established until 2015 and NOAA did not sample in 2020.

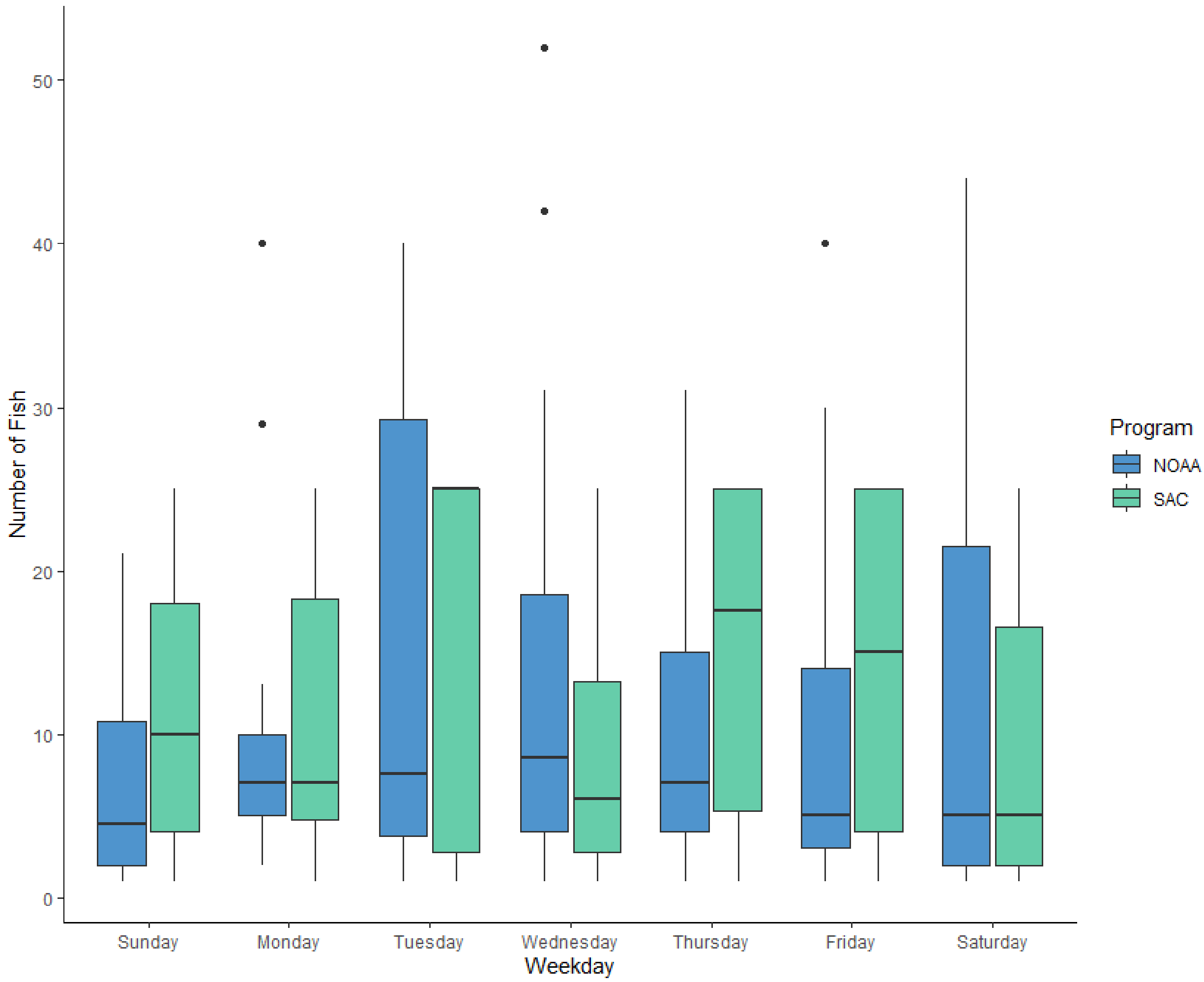

Figure 9. Boxplot (—, median; □, interquartile range; |, 95% range; ●, outliers) of average number of Pacific Bluefin tuna measured by day of the week for SAC and NOAA from 2015-2019.

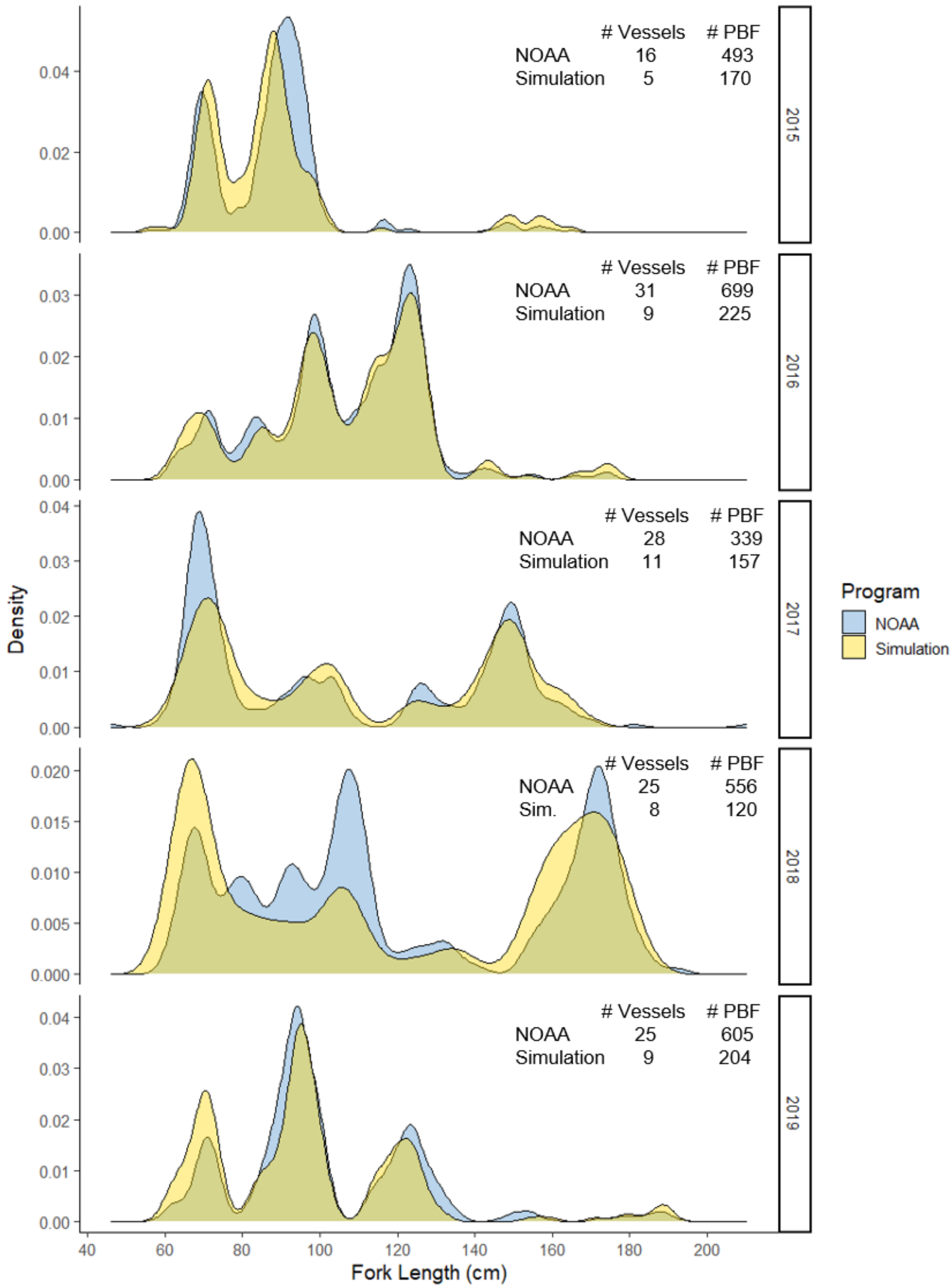

Figure 10. Length frequency distributions of original NOAA data and NOAA data subsampled with fewer vessels represented between 2015 and 2019. The number subsampled reflects the number of vessels SAC sampled each year. The number of vessels and Pacific Bluefin tuna represented in each dataset are included.

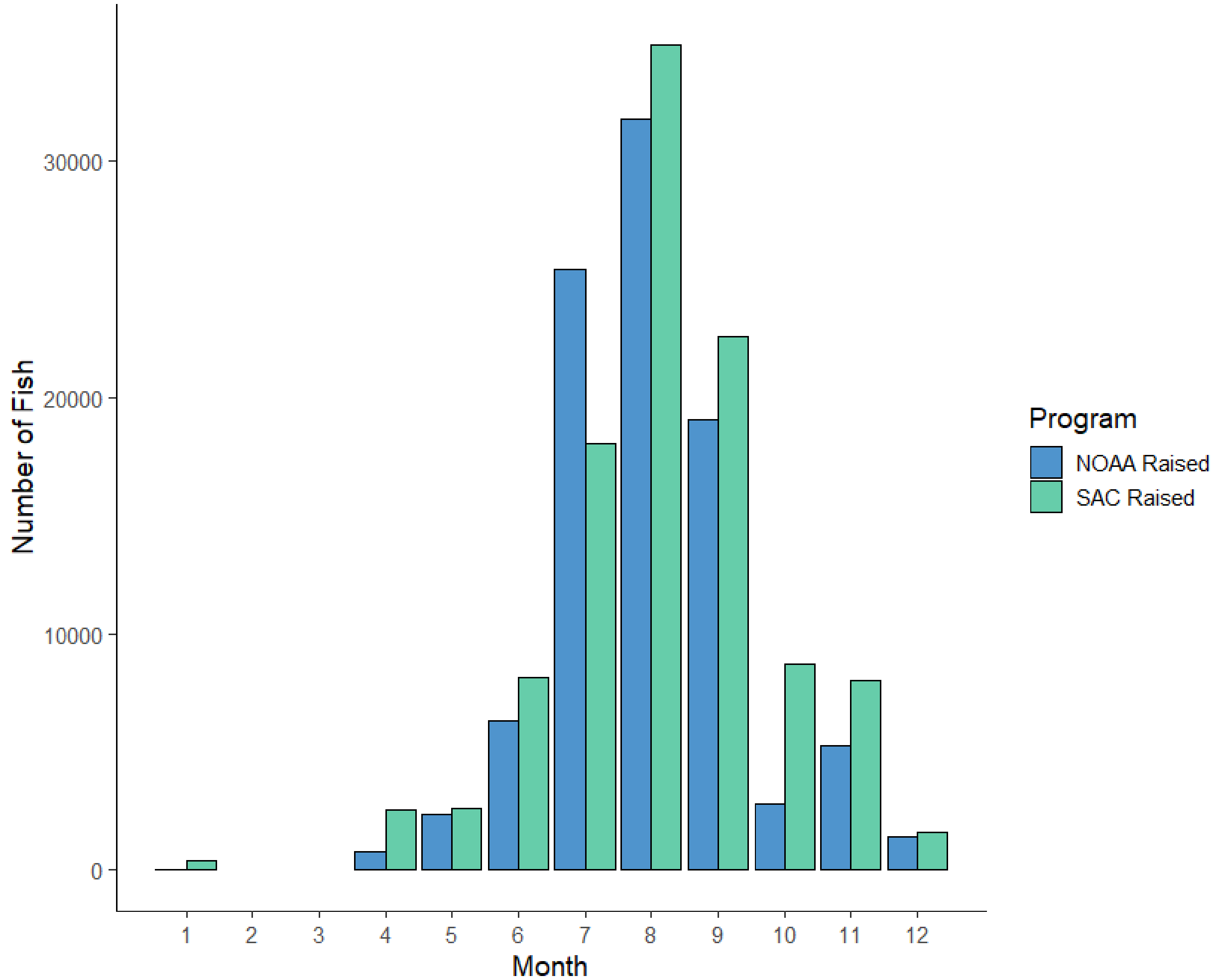

Figure 11. Number of Pacific Bluefin tuna measured by NOAA and SAC by month between 2014 and 2020 raised to the catch.

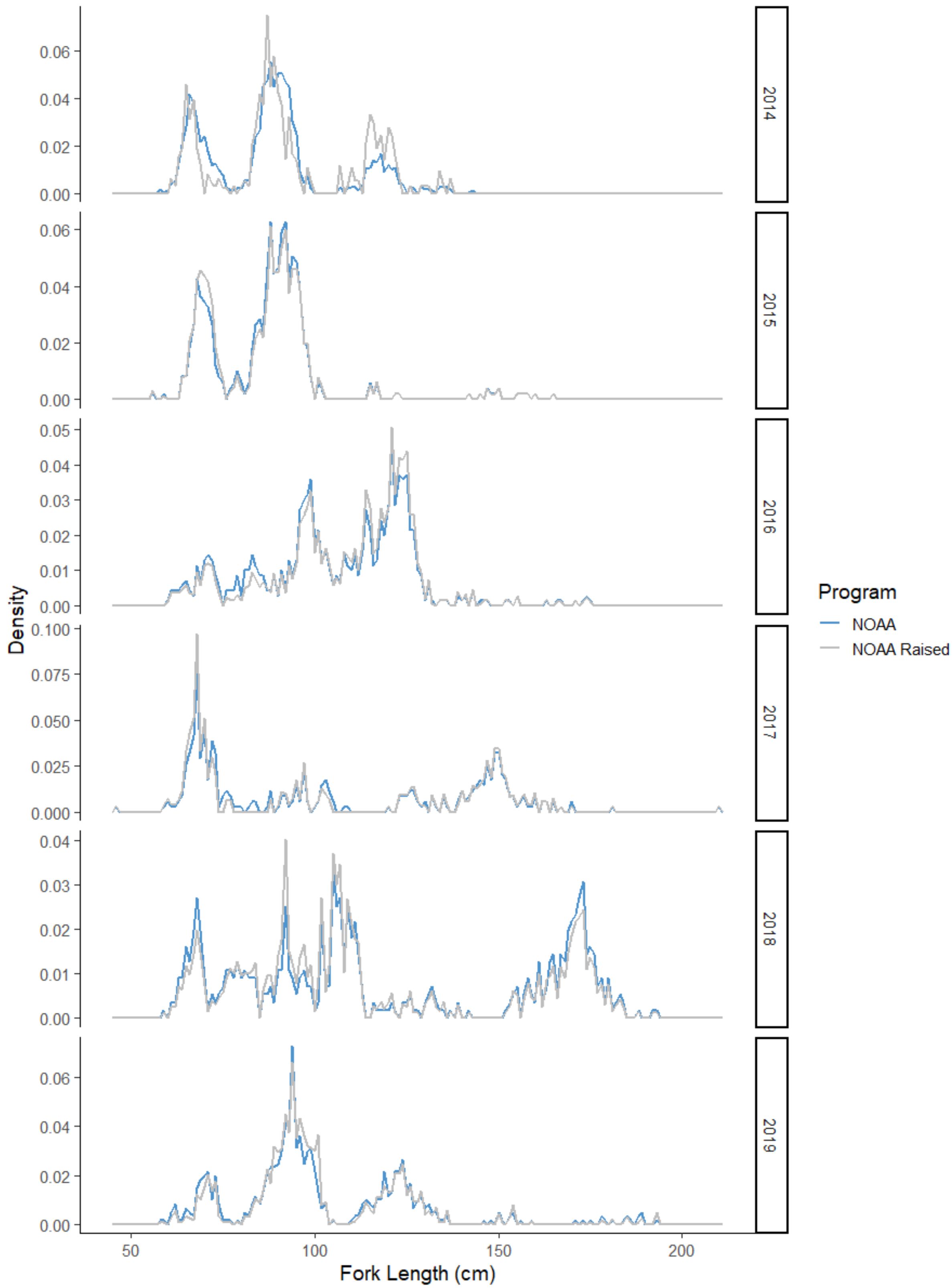

Figure 12. Length frequency distributions in 1 cm FL bins of NOAA raw data and NOAA data raised to the catch.

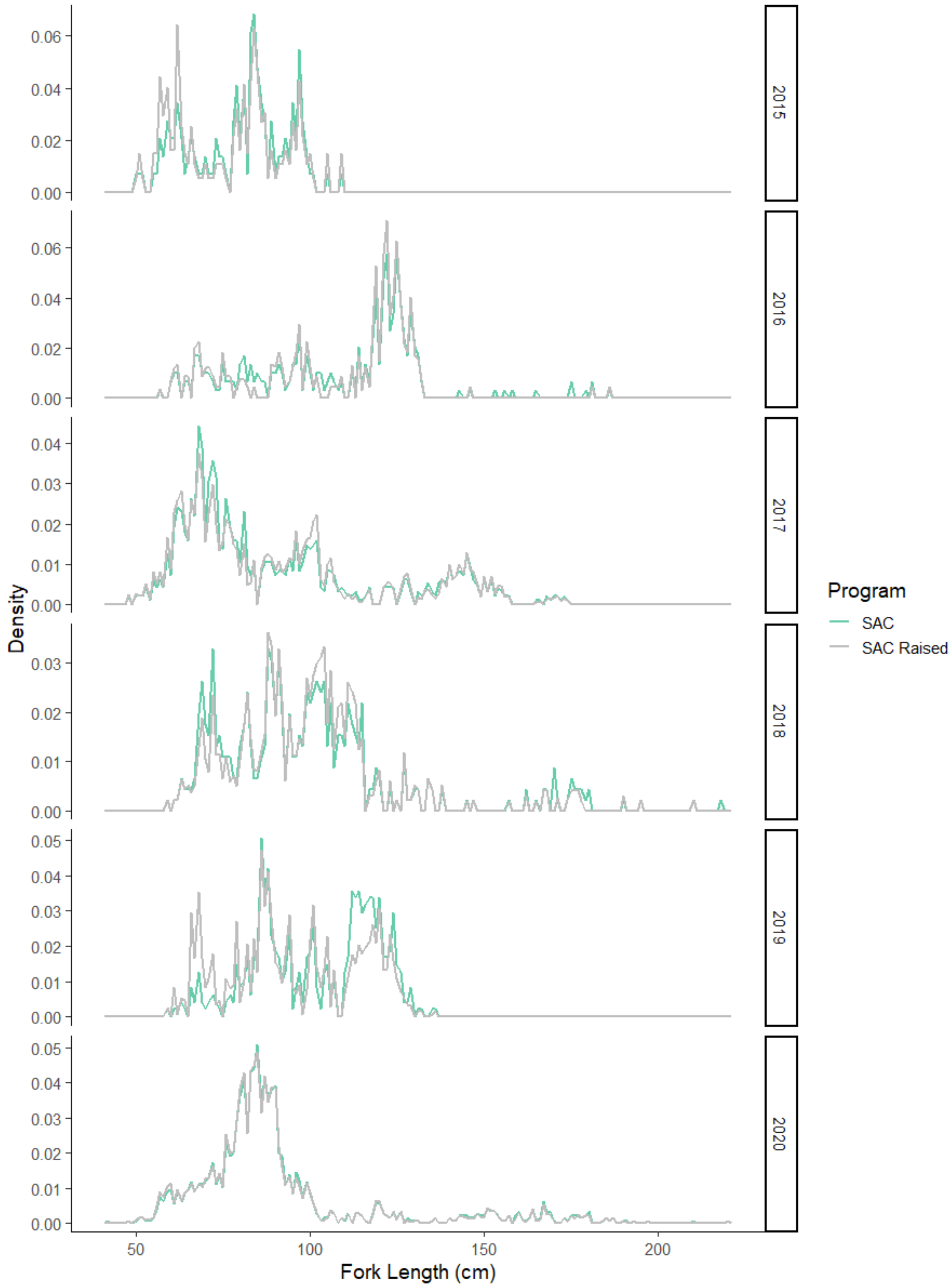

Figure 13. Length frequency distributions in 1 cm FL bins of SAC raw data and SAC data raised to the catch.