



NOAA Technical Memorandum NMFS

MARCH 2026

EVALUATING POST-SURVEY OTOLITH SUBSAMPLING STRATEGIES FOR NORTHERN ANCHOVY (*ENGRAULIS MORDAX*) FOR INCLUSION IN STOCK ASSESSMENTS

Brittany D. Schwartzkopf

NOAA Southwest Fisheries Science Center
Fisheries Resources Division
La Jolla, California

NOAA-TM-NMFS-SWFSC-734

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

About the NOAA Technical Memorandum series

The National Oceanic and Atmospheric Administration (NOAA), organized in 1970, has evolved into an agency which establishes national policies and manages and conserves our oceanic, coastal, and atmospheric resources. An organizational element within NOAA, the Office of Fisheries is responsible for fisheries policy and the direction of the National Marine Fisheries Service (NMFS).

In addition to its formal publications, the NMFS uses the NOAA Technical Memorandum series to issue informal scientific and technical publications when complete formal review and editorial processing are not appropriate or feasible. Documents within this series, however, reflect sound professional work and may be referenced in the formal scientific and technical literature.

SWFSC Technical Memorandums are available online at the following websites:

SWFSC: <https://swfsc-publications.fisheries.noaa.gov/>

NOAA Repository: <https://repository.library.noaa.gov/>

Accessibility information

NOAA Fisheries Southwest Fisheries Science Center (SWFSC) is committed to making our publications and supporting electronic documents accessible to individuals of all abilities. The complexity of some of SWFSC's publications, information, data, and products may make access difficult for some. If you encounter material in this document that you cannot access or use, please contact us so that we may assist you.
Phone: 858-546-7000

Recommended citation

Schwartzkopf, Brittany. 2026. Evaluating Post-Survey Otolith Subsampling Strategies for Northern Anchovy (*Engraulis mordax*) for Inclusion in Stock Assessments. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-SWFSC-734. <https://doi.org/10.25923/ha5s-y538>

CONTENTS

EXECUTIVE SUMMARY	1
2. INTRODUCTION.....	2
3. METHODS.....	3
2.1. Sample collection	3
2.2. Reference datasets	3
2.3. Otolith Subsampling Strategies	6
2.4. Comparing Subsampling Strategies	7
4. RESULTS.....	10
3.1. All years combined simulations	10
3.2. Year-specific simulations	13
5. DISCUSSION	19
6. ACKNOWLEDGMENTS.....	21
7. DATA AVAILABILITY STATEMENT.....	21
8. REFERENCES.....	21
9. APPENDIX	24

EXECUTIVE SUMMARY

Identifying otolith subsampling strategies that are efficient and maintain data quality for stock assessments is imperative given limited resources to meet age estimation demands of managed fish stocks. My objective was to evaluate the performance of three different subsampling strategies for northern anchovy (*Engraulis mordax*): (1) fixed otolith subsampling, (2) proportional otolith subsampling with targeted supplemental sampling, and (3) hybrid otolith sampling for estimating age composition and proportions of individuals-at-age within length bins. Hybrid strategies generally performed better for all years compared to fixed and proportional strategies. The performance of subsampling strategies was less consistent among combinations of age and length bins for estimates of proportions of ages-at-length than for estimates of age composition, due in part to high variation in age-at-length that caused uncertainty in predicted ages from lengths.

Across subsampling strategies, the minimum number of otoliths needed to accurately and reliably estimate age composition for a large dataset with pooled years ranged from 964 to 1933 otoliths per year (average = 1307) and 549 to 964 (average = 719) otoliths for proportions of age-at-length. For estimating age composition and proportions of age-at-length for the large dataset, accuracy did not increase markedly above a sample size of 2000 otoliths and would be a good reference point to generate a reliable growth curve and/or compare growth curves across regions or time periods. For individual years with disparate length distributions and sample sizes of otoliths, the minimum number of otoliths needed to accurately and reliably estimate age composition ranged from 255 to 658 otoliths per year (average = 362) and 200 to 516 otoliths for proportions of age-at-length (average = 375). For estimating age composition and proportions of age-at-length, accuracy did not increase markedly above a sample size of 300–400 otoliths and would be a good reference point to generate year-specific age-length keys (ALK).

I recommend the hybrid strategy that increases sample sizes at extremes of the length distribution and within length bins with multiple age classes. Although processing 300–400 otoliths per year for age estimation is expected to maintain accuracy and reliability for a year-specific ALK, understanding the underlying processes of the hybrid subsampling strategies is more important than the exact number. The hybrid subsampling strategy employed should be adjusted annually as appropriate based on the length distribution of the survey catch in a given year and to make sure that a balance of efficiency with respect to total sample size is achieved.

1. INTRODUCTION

Having a large enough sample size of age structures (e.g., fish otoliths) that spans the entire fish length distribution is required to accurately and reliably estimate age-at-length (Miranda and Colvin 2017). Age and length data are central inputs in age-structured stock assessments, many of which use an age-length key (ALK) to convert lengths to ages to estimate age composition for use in estimating biomass (Francis 2016; Lorenzen 2016). Due to large annual costs of survey data collection and age estimation, the efficiency of sampling and age estimation, while maintaining accuracy and reliability for stock assessment, is of great importance (Hulson et al. 2024).

Age composition and growth are usually estimated through a two-stage sampling design to reduce the number of fish age estimates needed (Miranda and Colvin 2017). Stage-1 samples include all fish sampled with recorded lengths, while stage-2 samples are subsampled from stage-1 samples whose otoliths were collected to estimate age (Miranda and Colvin 2017). In the laboratory, ages are often estimated from a fraction of otoliths collected, in what could be considered stage-3 sampling. An ALK is constructed from stage-2 or stage-3 samples by determining proportions-at-age within each length bin to estimate the age of fish in the stage-1 sample that were not subsampled for age determination (Coggins et al. 2013; Chang et al. 2019).

Clupeoid fishes (i.e., sardines, anchovies, and herring), have an opportunistic life-history strategy characterized by a small body size, fast growth, early maturation, and a short lifespan that has evolved in response to unstable environmental conditions (Blaxter and Hunter 1982; King and McFarlane 2003; Erisman et al. 2025). Clupeoid fishes support important commercial and recreational fisheries in the California Current Ecosystem (CCE) and are subject to management measures, some of which occur annually (PFMC, 2024). An acoustic-trawl survey, conducted by the National Oceanic and Atmospheric Administration Southwest Fisheries Science Center, that targets coastal pelagic species (CPS: e.g., Pacific sardine *Sardinops sagax*, northern anchovy *Engraulis mordax*, Pacific mackerel *Scomber japonicus*) is used to produce length- and age- composition data for acoustic biomass estimates and stock assessment models (Stierhoff et al. 2025).

With compressed timelines to meet ageing needs of annual, age-structured stock assessments for Pacific sardine, Schwartzkopf et al. (2025) sought to determine if post-survey otolith subsampling could increase efficiency while maintaining the accuracy and reliability of age composition and proportions of individuals-at-age within length bins. Schwartzkopf et al. (2025) found that uncertainties in predicted ages from length, due to high variation in age-at-length, caused less consistent performance for subsampling strategies for proportion of age-at-length compared to age composition. For temperate clupeoid fishes that have multiple age classes contained in a length bin, which occurs across many length bins, it was recommended to start with a hybrid subsampling strategy to increase sample sizes at extremes of the length distribution and within length bins with greater sample sizes that also tend to contain a larger number of age classes. For Pacific sardine, processing 300–500 otoliths per year for age estimation was expected to maintain accuracy and reliability, but it was suggested that northern anchovy would be another good species to examine to see if the results can be more generally applied to other CPS in the CCE (Schwartzkopf et al. 2025).

Similar to Pacific sardine, northern anchovy is a small-bodied, fast-growing, short-lived species that is characterized by high interannual variability in recruitment success and population abundance in response to environmental conditions (Methot 1983; MacCall et al. 2016; Thayer et al. 2017; Sydeman et al. 2020). Northern anchovy also have highly overlapping length distributions among age classes, and some length bins contain all ages sampled (ages 0–6+; Schwartzkopf et al. 2023). Estimated survey abundance and trawl catches of Northern anchovy in recent years have been among the highest in the CCE (Thompson et al. 2019; Stierhoff et al. 2023), and a large number of otoliths are collected from fish, thus a 3-stage sampling design would be of benefit.

The goal of this work was to determine if post-survey otolith subsampling (stage-3) could increase efficiency while maintaining the accuracy and reliability of age composition and proportions of individuals-at-age within length bins for northern anchovy. This was done by using the same framework as Schwartzkopf et al. (2025), but instead using length and age data of northern anchovy collected from the acoustic-trawl survey.

2. METHODS¹

2.1. Sample collection

Northern anchovy assigned to the central subpopulation (McHugh 1951; Vrooman et al. 1981) were collected during spring and summer acoustic-trawl surveys of CPS between Cape Mendocino, California and Punta Eugenia, Mexico using a Nordic 264 rope trawl during 2015–2023 (Dorval et al. 2022) and a multifunction trawl net during 2024 (Stierhoff et al. 2025). COVID-19 prevented data collection in 2020. Stage-1 and stage-2 sampling protocols were described in detail by Dorval et al. (2022). Briefly, up to three surface trawls were conducted from sunset to sunrise each sampling period. A random sample of 50–75 northern anchovy were collected from each trawl and measured in standard length (SL; mm) and total weight (g) (stage-1). Otoliths were extracted from all northern anchovy in the stage-1 sample during 2015 and a two-stage sampling design during 2016–2024. Otoliths were collected proportionally from 50 fish during 2016 and 25 fish during 2017–2019 in the stage-1 sample using 20-mm length-bins. During 2021–2024, otoliths were collected from several of the smallest and largest individuals, and otoliths from additional fish were randomly selected from the stage-1 sample until 25 fish were subsampled (Dorval et al. 2022; Schwartzkopf et al. 2022).

2.2. Reference datasets

A reference dataset was composed of 6439 central subpopulation northern anchovy collected during spring and summer acoustic-trawl surveys of coastal pelagic species with age estimates and SL measurements (Figure 1). Northern anchovy were aged following best practices established for CPS (Dorval et al. 2025). All northern anchovy age-6 or older were grouped into an 6+ age class due to the low sample sizes of older fish ($n = 21$ for age-6 fish and $n = 4$ for age-7 fish).

¹ Since this paper directly follows Schwartzkopf et al. (2025), there are instances in which the text in the methods is the same.

It is important to note that the reference dataset for northern anchovy was a subsample, and thus all analyses that follow are considered resampling from a subsample. With high northern anchovy survey trawl catches in recent years, a large number of otoliths were collected, and time and resources constrained ageing all otoliths. For northern anchovy, all otoliths collected in summer 2015 and 2017 were aged, at least 70% of samples were aged from all the other trawl surveys through 2019 (Schwartzkopf et al. 2022), and around 500 samples per year were aged during 2021-2024. Subsampling data from an existing subsampled dataset is a valid technique if the initial subsample is representative of the original population (Wu et al. 2023). The subsampled otoliths for northern anchovy maintained the spatial and temporal integrity of the trawl sampling and the distribution of length at age in space and time (Schwartzkopf et al. 2022), thus I assume that the already subsampled reference dataset used was representative of the population.

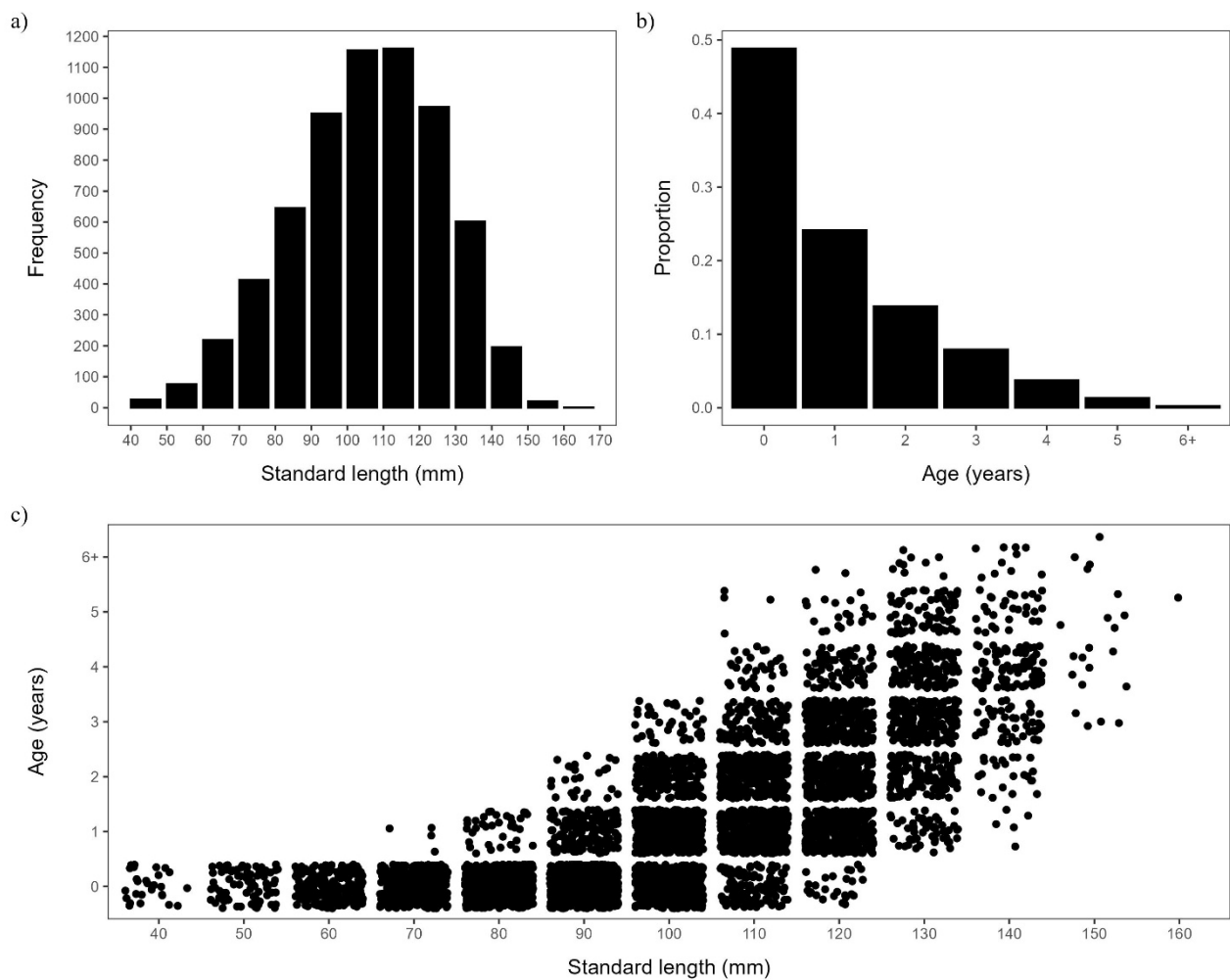


Figure 1. Distribution of (a) standard length (mm), (b) age, and (c) age within 10-mm length bins for 6439 central subpopulation of northern anchovy (*Engraulis mordax*) sampled during acoustic-trawl surveys by the National Oceanic and Atmospheric Administration, Southwest Fisheries Science Center that targeted coastal pelagic species in the California Current Ecosystem during 2015–2024.

To estimate the minimum number of otoliths needed for age estimation in a given year, we examined 10 of 11 acoustic-trawl surveys of CPS in the reference dataset. Surveys were in spring (n = 2) or summer (n = 8) and covered a range in the total number of fish age estimates and total number of length bins sampled (Table 1; Appendix Figure A1). Only one survey (summer 2017) was excluded from year-specific analysis, because it contained too low a sample size (n = 129) for any subsampling strategy to reduce the sample size enough to yield informative results from a simulation. Although ages and lengths varied among trawl samples, I pooled age data across trawls within a survey, because I assumed northern anchovy collected annually were representative of the population and that ages were pooled in the ALK for the stock assessment for northern anchovy (Kuriyama et al. 2022). Additionally, spring and summer surveys were separated if they occurred within a year as survey specific ALKs are generated for the northern anchovy stock assessment (Kuriyama et al. 2022).

Table 1. Numbers of northern anchovy (*Engraulis mordax*) otolith age estimates, total number of otoliths collected and available for age estimates, and 10-mm length bins for each of 11 CPS acoustic-trawl surveys by the SWFSC during 2015–2024.

Survey	Season	Age estimates	Total otoliths available	Length bins
2015	Summer	490	498	9
2016	Summer	731	1051	9
2017	Spring	548	616	6
2017*	Summer	129	132	10
2018	Summer	666	956	10
2019	Summer	1070	1559	10
2021	Spring	879	910	10
2021	Summer	559	1780	9
2022	Summer	490	1258	11
2023	Summer	464	773	11
2024	Summer	415	797	12

*Survey that was not included in the year-specific analysis.

2.3. Otolith Subsampling Strategies

I evaluated the performance of stage-3 otolith subsampling scenarios for both the full reference data and each of the 11 year-specific reference sets by calculating measures of accuracy and reliability for two population metrics. Population metrics included: (1) age composition (the proportion of sampled fish in each age class); and (2) proportion of individuals of each age within each length bin (used in the construction of an age-length key).

Three otolith subsampling strategies, each with five different reduced dataset scenarios, were evaluated to identify the stage-3 subsampling strategy that produced more accurate and reliable results than the others: (1) fixed subsampling; (2) proportional subsampling with targeted supplemental sampling; and (3) hybrid subsampling which is a combination of fixed and proportional subsampling (Table 2). For all scenarios within a subsampling strategy, 10-mm length bins were used based on bin width used in stock assessments for northern anchovy (Kuriyama et al. 2022). Bins ranged from 40 to 160 mm, wherein, for example, the 40-mm length bin included fish from 40 to 49 mm SL.

For fixed subsampling simulations, five different scenarios were run for both the all years combined and year-specific analyses, but the sample sizes varied between analyses. For all years combined, bin sample sizes were 50, 100, 150, 200, and 250 otoliths per 10-mm length bin, whereas for year-specific analyses, bin sample sizes were 10, 20, 30, 40, and 50 otoliths (Table 2). More otoliths per length bin were used for all years combined to produce similar sample sizes to proportional subsampling with targeted supplemental sampling and hybrid subsampling scenarios. Fish in either the full or year-specific reference datasets were assigned to a length bin based on measured length and then sampled without replacement to draw the fixed number of otoliths, n , from each length bin (e.g., 10, 20, 30, 40, 50) until all length bins were filled or all available otoliths from the entire reference dataset were sampled (Miranda and Colvin 2017). For example, for a sample size of 50 otoliths per length bin, sampling without replacement led to unequal sample sizes for length bins with fewer than 50 available otoliths (Appendix Figures A2 and A3).

For proportional subsampling simulations, a range of percentages (10%, 30%, 50%, 70%, and 90%) of reference datasets were sampled without replacement from each length bin, rounded to the nearest whole number (Table 2). Targeted supplemental sampling, with at least one otolith selected from each length bin with otoliths, was used to ensure that tails of the length distributions were not removed. The same proportional scenarios were used for all years combined and year-specific analyses.

For hybrid subsampling simulations, aspects of fixed and proportional subsampling were both used. For each 10-mm length bin, a minimum number of otoliths per length bin (30 or 40) were randomly subsampled without replacement. If a length bin had more than either 30 or 40 otoliths, 10%, 30%, or 50% of the remaining otoliths were proportionally subsampled from that bin (Table 2). The hybrid strategy was evaluated to (1) allow a fixed number of otoliths to be sampled across small and large individuals, and (2) better represent total variability across the length bins with the most individuals by proportionally sampling those with the largest number of age classes. I used 30 or 40 otolith subsamples to approximate the ~600 otoliths targeted each year for CPS stock assessments (Schwartzkopf et al. 2022) if fish from all length bins were collected within a year. The same hybrid scenarios were simulated for all years combined and year-specific analyses.

2.4. Comparing Subsampling Strategies

For each otolith subsampling strategy, the reference dataset (either full or year-specific) was subsampled using one of the 15 scenarios (Table 2), thereby leading to varying otolith sample sizes (Table 3). An ALK was generated using an ordinal generalized additive regression, the same method used for the stock assessment for northern anchovy (Kuriyama et al. 2022), on stage-3 subsampled data to generate proportions of ages-at-length, to estimate the age composition for the

Table 2. Descriptions of fixed, proportional with targeted supplemental sampling, and hybrid otolith subsampling strategies for estimating age composition and proportions of ages-at-length of northern anchovy (*Engraulis mordax*) sampled during CPS acoustic-trawl surveys by the SWFSC during 2015–2024.

Otolith subsampling strategy	Scenarios	Description
Fixed	50, 10	50, 100, 150, 200, or 250 otoliths chosen per length bin for the all years combined analysis
	100, 20	
	150, 30	
	200, 40	
	250, 50	
Proportional with targeted supplemental sampling	10%	10%, 30%, 50%, 70%, or 90% of reference dataset otoliths chosen per length bin with at least one otolith from each length bin where otoliths were present
	30%	
	50%	
	70%	
	90%	
Hybrid	30+10%	Take up to either 30 or 40 otoliths chosen per length bin and then sample either 10%, 30%, or 50% of the rest of the otoliths if there are more than 30 or 40 otoliths per bin
	30+30%	
	30+50%	
	40+30%	
	40+50%	

fraction of data that were not used to build the ALK. Subsampling for each scenario was iterated 1000 times to simulate the range of variability generated by random sampling. Absolute percent deviation (APD) and mean absolute percent deviation (MAPD) were used to evaluate the accuracy and reliability of subsampling scenarios relative to reference data. For age composition, APD for each age a and iteration i was calculated as:

$$APD_{a,i} = \left| \frac{X_a - E_{a,i}}{X_a} \right| \times 100\% \quad (Eqn. 1)$$

and the MAPD was calculated as

$$MAPD = \frac{\sum_{i=1}^I \sum_{a=1}^A APD_{a,i}}{A \times I} \quad (Eqn. 2)$$

where X_a is the observed proportion of fish in age a for the entire dataset under consideration, $E_{a,i}$ is the estimated proportion based on the simulated subsample for iteration i , I is the total number of simulated iterations, and A is the total number of ages (Miranda and Colvin 2017). For proportion of individuals of each age within a length bin, APD for each age, iteration, and length bin l , in addition to MAPD, were calculated as:

$$APD_{a,l,i} = \left| \frac{X_{a,l,i} - E_{a,l,i}}{X_{a,l,i}} \right| \times 100\% \quad (Eqn. 3)$$

$$MAPD = \frac{\sum_{i=1}^I \sum_{l=1}^L \sum_{a=1}^A APD_{a,l,i}}{A \times L \times I} \quad (Eqn. 4)$$

where L is the total number of length bins.

I concluded that estimates of age composition or proportions of age-at-length were accurate if APD for an age, iteration, or length bin was less than 10%, because simulated data has the lowest noise (σ) and performance of MAPD is as good as any other statistic when percent accuracy (reliability) is $\geq 86\%$ (Tofallis 2015). I concluded that estimates of age composition or proportions across simulations were reliable if $\geq 80\%$ of iterations produced accurate estimates (based on APD) for an age or length bin (Miranda and Colvin 2017). I concluded that an overall otolith subsampling strategy or scenario was accurate if MAPD across ages, iterations, or length bins was $< 10\%$, based on previous, similar analyses, although no standard threshold has been

Table 3. Nur sampling, and

ental

Year	Fixed					Proportional					Hybrid				
	10	20	30	40	50	10%	30%	50%	70%	90%	30+10%	30+30%	30+50%	40+30%	40+50%
2015	77	142	202	255	291	—	146	246	342	440	234	290	347	327	373
2016	70	130	190	240	289	75	219	365	512	658	245	354	461	389	486
2017	56	97	130	160	190	55	164	275	384	493	173	257	340	278	355
2018	76	144	204	264	324	69	201	335	467	600	254	345	436	387	387
2019	95	185	275	359	439	106	322	536	747	964	359	516	675	574	717
2021sp.	75	140	200	260	317	91	365	443	615	792	271	407	541	449	571
2021su.	85	156	226	290	340	56	168	279	390	503	262	328	393	372	425
2022	96	174	240	300	360	50	148	245	344	441	268	318	367	360	397
2023	94	170	240	310	375	47	139	230	325	419	266	311	354	360	389
2024	113	220	291	344	382	—	124	209	291	374	306	331	355	367	381
All years	549	1025	1475	1921	2290	646	1933	3220	4506	5796	964	2180	3397	2250	3447

Note: Dash (—) indicates when the ordinal generalized additive regression model could not converge due to low sample sizes. Fixed strategies are fixed numbers (10–50 otoliths), proportional strategies are fixed proportions (10%–90%), and hybrid strategies are fixed numbers + fixed proportions (30 + 10% – 40 + 50%) of otoliths subsampled per 10-mm length bin. For all years, sample sizes were 50, 100, 150, 200, or 250 otoliths per length bin. For the two surveys in 2021, 2021sp refers to the spring survey and 2021su refers to the summer survey.

developed for quantifying reliability of simulations (Miranda and Colvin 2017). Code was a combination of modified code by Miranda and Colvin (2017), Schemmel et al. (2022), and Appendix A in Kuriyama et al. (2022).

3. RESULTS

3.1. All years combined simulations

Length and age distributions were unimodal, with visual peaks at the 100 and 110-mm SL length bins (Figure 1a) and age-0 (Figure 1b). The length distribution was skewed slightly left (Figure 1a) and the age distribution was skewed right (Figure 1b). Ages overlapped greatly within length bins, with ages 0–6+ present in the 120-mm SL length bin and ages 1-6+ present in the 120 mm, 130 mm, and 140 mm SL length bins (Figure 1c).

Accuracy and reliability of age compositions varied greatly among otolith subsampling strategies and among scenarios within subsampling strategies (Figure 2). For fixed subsampling, reliability decreased as age increased, and when averaged over age, simulated data were within 10% of reference data over 80% of the time for all scenarios, except 50 otoliths per length bin (Figure 2). Proportional and hybrid subsampling produced more accurate and reliable age compositions than fixed subsampling, but this may be related to sample size (Figure 2). At similar sample sizes, all three strategies were comparable in terms of accuracy and reliability. For example, fixed subsampling of 200 otoliths per length bin required a slightly lower sample size of otoliths than 30% proportional subsampling ($n=1921$ and $n=1933$, respectively), but the fixed subsampling was slightly more accurate and reliable overall (MAPD = 7) compared to 30% proportional subsampling (MAPD = 7.2). It should be noted however, that although overall accuracy and reliability was lower for fixed subsampling of 200 otoliths compared to 30% proportional subsampling, 30% proportional subsampling was more accurate and reliable for ages 4 and 5. In addition, 30% proportional subsampling of all length bins and hybrid subsampling of 30 otoliths + 30% proportional subsampling of all length bins were both above 80% reliability for age-0 through age-4 (Figure 2). Age composition was accurate and reliable for all age classes only for 90% proportional subsampling, but required a sample size of 5796 otoliths (Figure 2).

Accuracy and reliability of estimated age composition increased as sample size increased, with diminishing returns as effort increased to ~2000 otoliths subsampled (Figure 3). The smallest sample sizes for each strategy that produced accurate and reliable age compositions were 1025 otoliths with fixed subsampling of 100 otoliths per length bin, 1933 otoliths with 30% proportional subsampling of all length bins, and 964 otoliths with hybrid subsampling of 30 otoliths + 10% proportional subsampling of all length bins (Figures 2, 3; Table 3). As sample size increased, APD decreased among ages (Figures 2, 3). A sample size of 5796 with 90% proportional subsampling of all length bins yielded accurate and reliable age compositions for all age classes but increased accuracy only ~6% over a sample of 1933 otoliths subsampled for age estimation (with 30% proportional subsampling of all length bins).

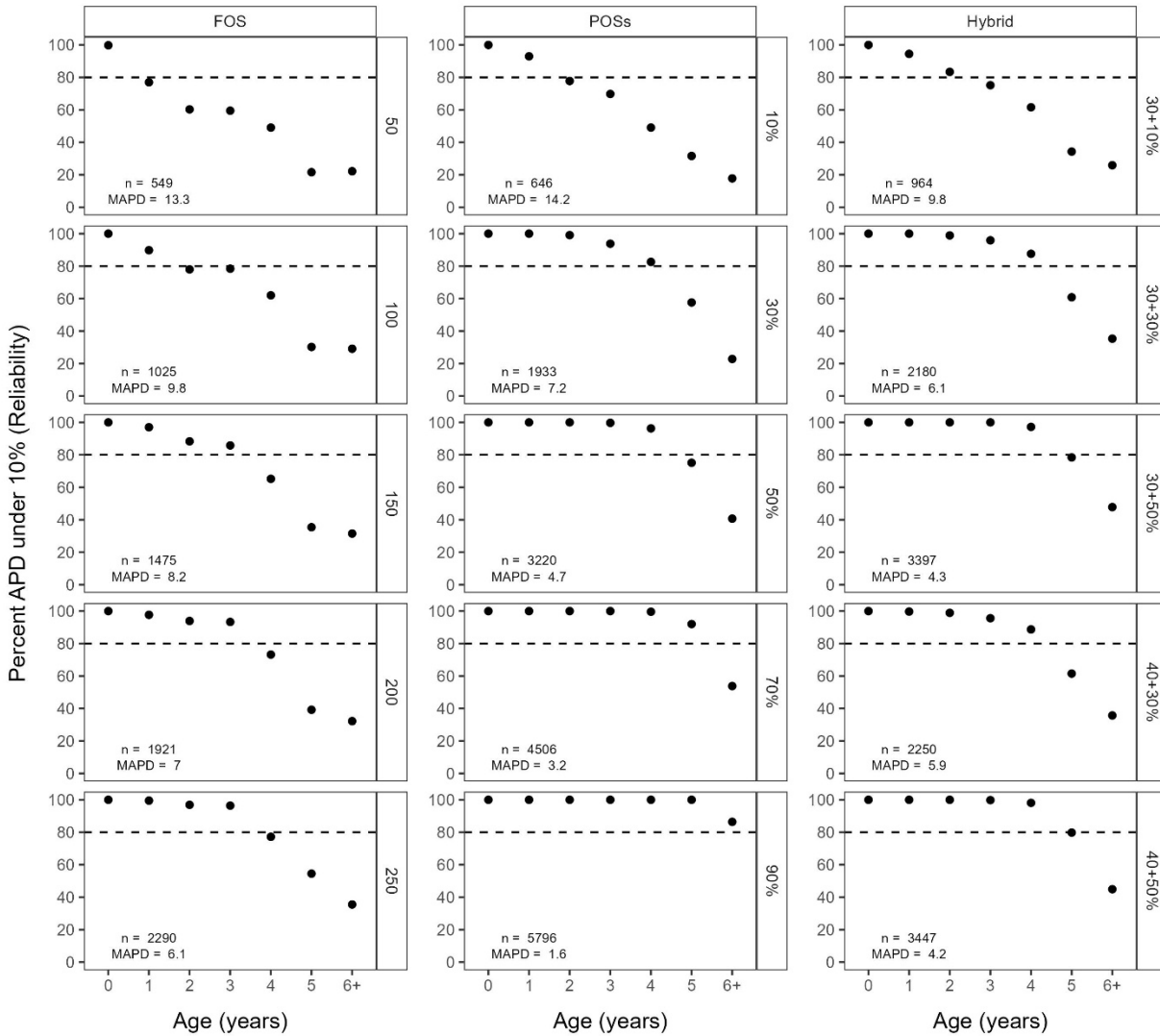


Figure 2. The percentage of 1000 iterations for which the absolute percent deviation (APD) of age compositions was less than 10% of the reference value for each age class of northern anchovy (*Engraulis mordax*) sampled during CPS acoustic-trawl surveys by the SWFSC during 2015–2024. Points above the 80% dashed line were defined as both accurate and reliable based on our criteria. FOS, fixed otolith subsampling; POSs, proportional otolith subsampling with targeted supplemental sampling; and Hybrid, hybrid otolith subsampling within 10-mm length bins. Sample size and overall Mean APD (MAPD) are included for each scenario.

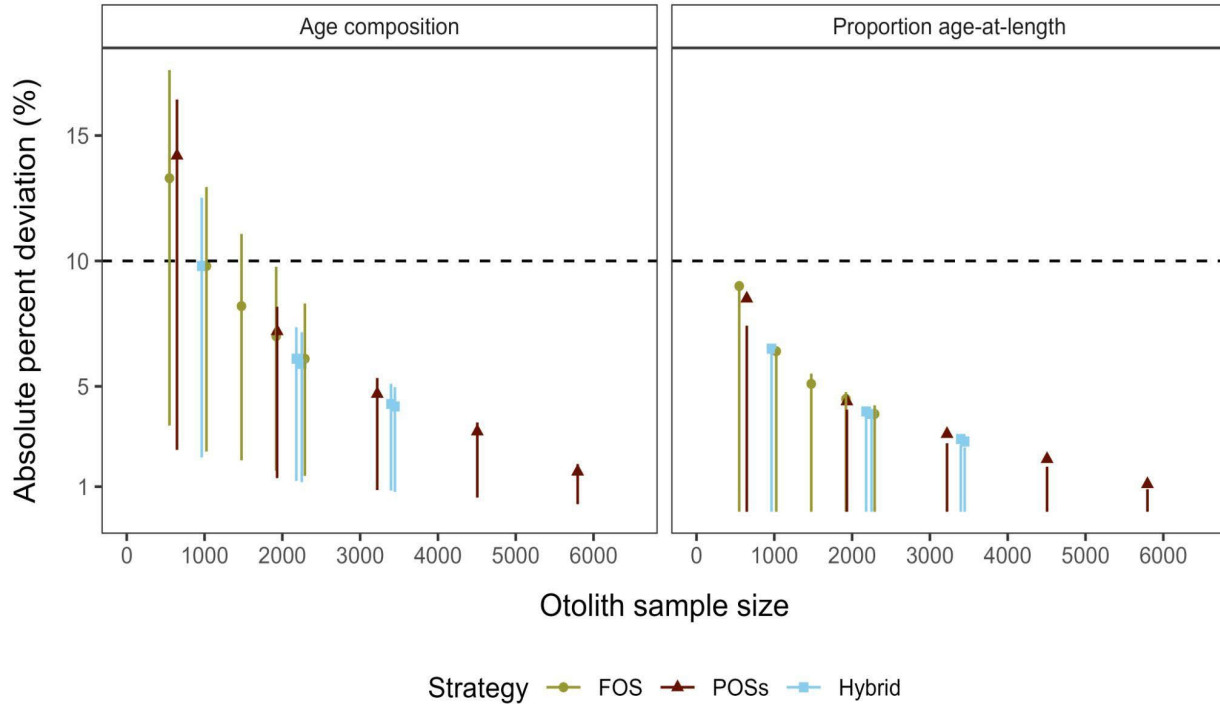


Figure 3. Absolute percent deviation (APD) for fixed (FOS, yellow circles), proportional with targeted supplemental sampling (POSs, red triangles), and hybrid (blue squares) otolith subsampling strategies in relation to otolith sample size of northern anchovy (*Engraulis mordax*) sampled during CPS acoustic-trawl surveys by the SWFSC during 2015–2024. Mean absolute percent deviation (MAPD) is represented by points and the 25% and 75% quantiles for APD values represented as lines. Points below 10% (dashed line) were defined as accurate.

Accuracy and reliability (APD and MAPD) of proportions of age-at-length varied greatly among subsampling scenarios and simulations (Figure 4). Estimates of proportions of age-at-length were more reliable for the smallest (< 60 mm SL) and largest (≥ 140 mm SL) length bins for all scenarios (Figure 4). Proportional and hybrid subsampling produced more accurate and reliable age compositions than fixed subsampling (Figure 4). However, this was likely related to proportion and hybrid scenarios having a larger sample size, because at similar sample sizes, all three strategies were comparable in terms of accuracy and reliability (Figure 4), as was also observed for age composition. No subsampling strategy accurately and reliably estimated all proportions of ages-at-length even when sampling 90% of each length bin. Accuracy of proportions of ages-at-length for fixed subsampling was similar to proportional subsampling and hybrid subsampling for similar sample sizes, but accuracy did not increase greatly as sample size increased above 2000 otoliths (Figure 3).

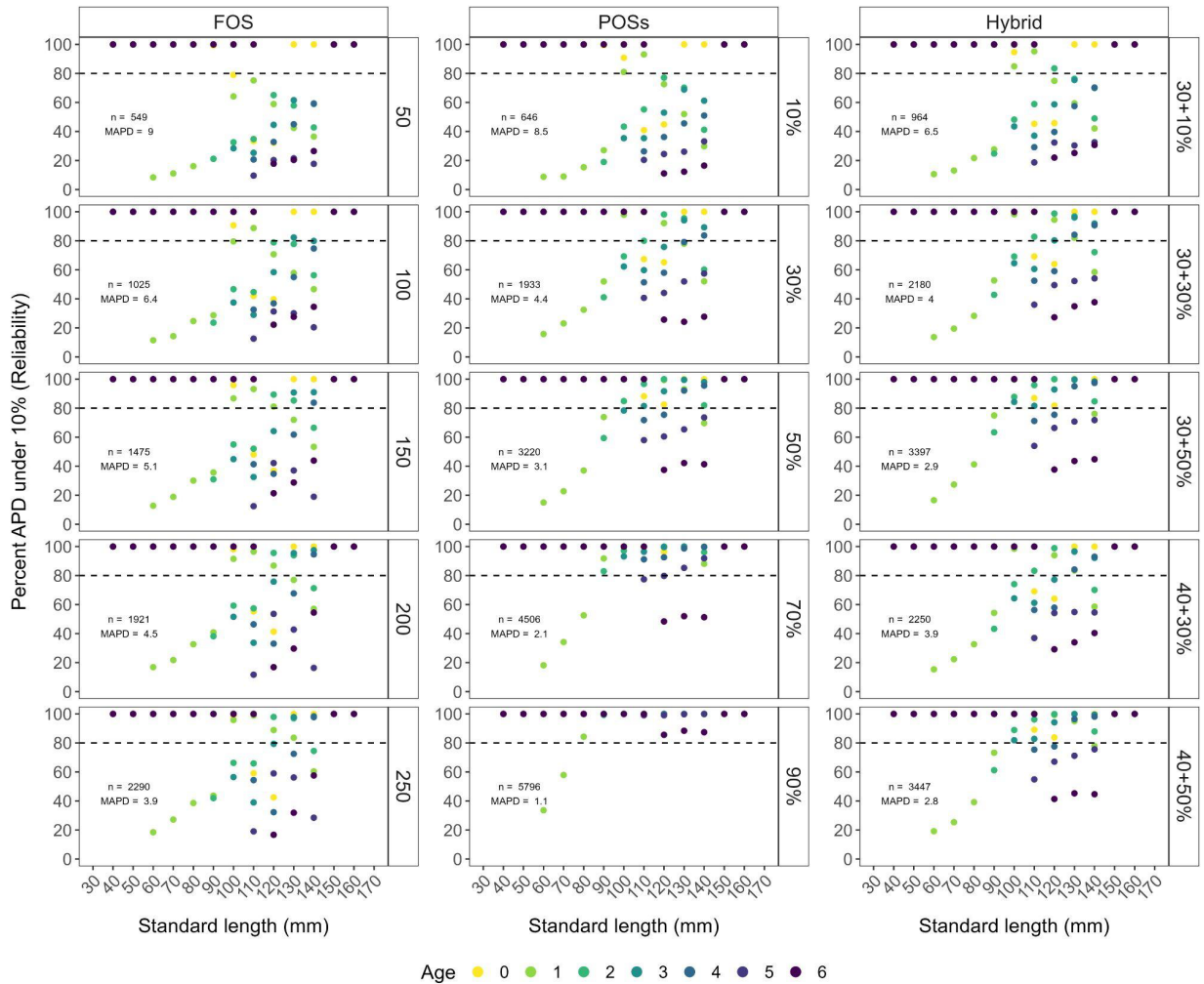
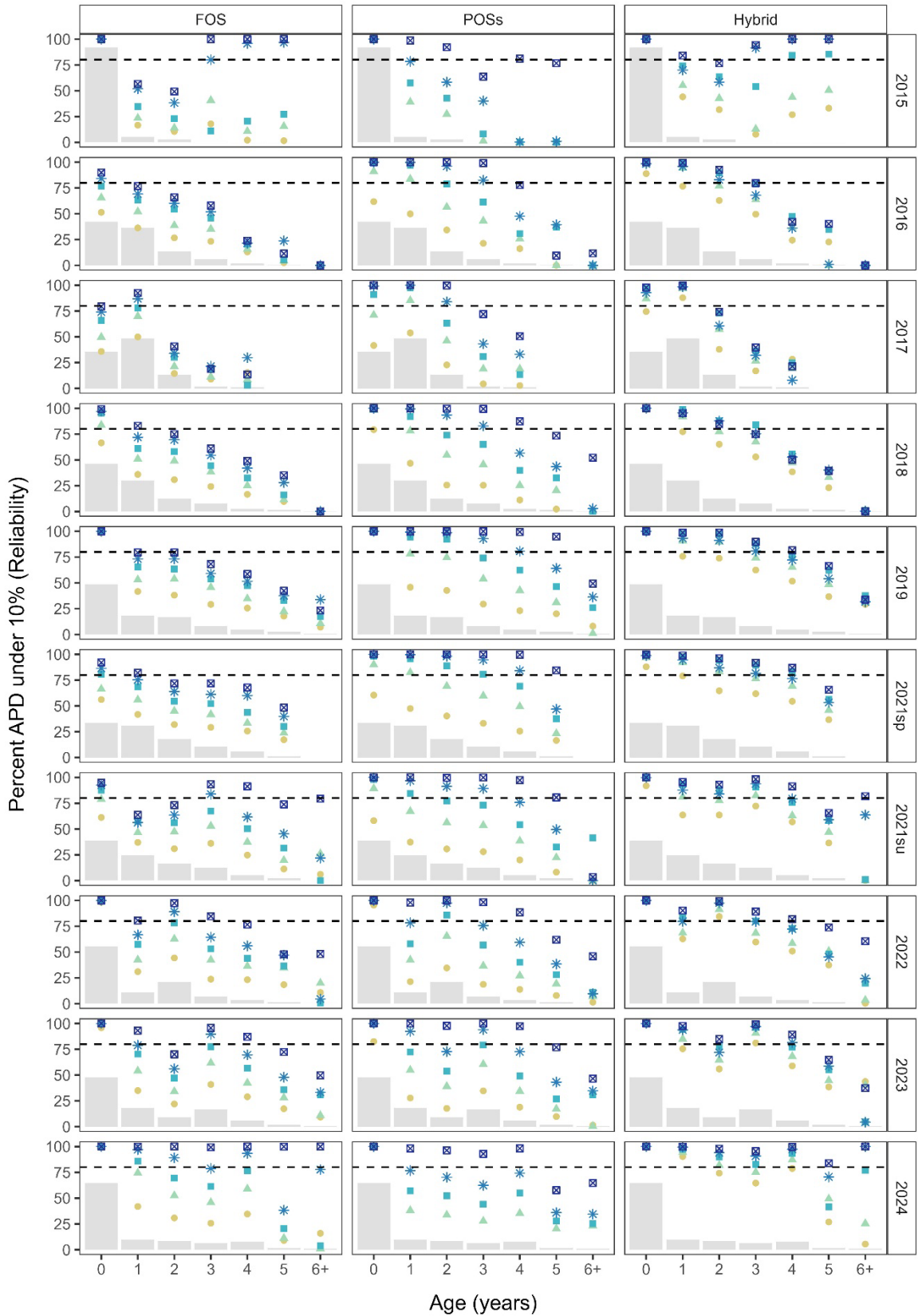


Figure 4. The percentage of 1000 iterations for which the absolute percent deviation (APD) of the proportion of individuals of each age within a length bin was less than 10% of the reference value for each age class of northern anchovy (*Engraulis mordax*) sampled during CPS acoustic-trawl surveys by the SWFSC during 2015–2024. Points above the 80% dashed line were defined as both accurate and reliable. FOS, fixed otolith subsampling; POSs, proportional otolith subsampling with targeted supplemental sampling; Hybrid, hybrid otolith subsampling within 10-mm length bins. Sample size and overall mean APD (MAPD) are also shown for each scenario.

3.2. Year-specific simulations

Length distributions were unimodal or bimodal depending on the year sampled (Appendix Figure A1), and age distributions also varied among years but were unimodal or uniform, depending on the year (Figure 5). Ages overlapped multiple length bins, with ages 1–6+ present in multiple length bins in some years (e.g., 120 mm SL in 2016 and 120 mm, 130 mm, and 140 mm SL length bins in 2019; Appendix Figure A4).



Scenario ● 10/10%/30+10% ▲ 20/30%/30+30% ■ 30/50%/30+50% * 40/70%/40+30% □ 50/90%/40+50%

Figure 5. The percentage of 1000 iterations for which the absolute percent deviation (APD) of age compositions was less than 10% of the reference value for each age class of northern anchovy (*Engraulis mordax*) sampled during CPS acoustic-trawl surveys by the SWFSC during 2015–2024. For the two surveys in 2021, 2021sp refers to the spring survey and 2021su refers to the summer survey. Points above the 80% dashed line were defined as both accurate and reliable. FOS, fixed otolith subsampling; POSs, proportional otolith subsampling with targeted supplemental sampling; Hybrid, hybrid otolith subsampling within 10-mm length bins. Gray shaded bars represent observed age compositions.

Relative performance of otolith subsampling strategies for estimating age composition varied among age classes within years, with better average reliability for younger age classes (Figure 5). Regardless of the sample size or number of length bins in a year (Table 1; Table 3), no subsampling strategy accurately and reliably estimated the age composition for all ages in a year, except for fixed subsampling of 50 otoliths per length bin and hybrid subsampling of 40 otoliths + 50% proportional subsampling of all length bins in 2024 (Figure 5). Overall, hybrid subsampling performed better for all years compared to fixed and proportional subsampling (Figures 5, 6).

Age compositions were estimated accurately and reliably across ages for 90% proportional subsampling of all length bins for all years except 2016. Additionally, in 2019 and spring 2021, age compositions were estimated accurately and reliably across ages for 70% proportional subsampling of all length bins. For hybrid subsampling, age compositions were estimated accurately and reliably across ages for hybrid sampling 40 otoliths + 30% proportional subsampling, and 40 otoliths + 50% proportional subsampling in 2015 and summer 2021, 30 otoliths + 50% proportional subsampling, 40 otoliths + 30% proportional subsampling, and 40 otoliths + 50% proportional subsampling in spring 2021 and 2024, and 40 otoliths + 50% proportional subsampling in 2019, 2022, and 2023. For fixed subsampling, age compositions were estimated accurately and reliably across 50 otoliths from each length bin in 2015, summer 2021, and 2023, and both 40 and 50 otoliths from each length bin in 2024 (Figure 6). For 2016, no subsampling strategy accurately and reliably estimated the age composition.

Proportions of ages-at-length were never accurately and reliably estimated in any year except in spring 2021 with 90 proportional subsampling of all length bins and in 2024 with fixed sampling of 50 otoliths per length bin (Figure 6). Overall, hybrid subsampling performed slightly better compared to fixed and proportional in each year. The minimum number of otoliths needed to accurately and reliably estimate age composition ranged from 255 to 658 otoliths per year (average = 362; Table 3; Figure 7) and 200 to 516 otoliths for proportions of age-at-length (average = 375; Table 3; Figure 8). For estimating age composition and proportions of age-at-length, accuracy did not increase markedly above a sample size of 300–400 otoliths (Figure 7; Figure 8).

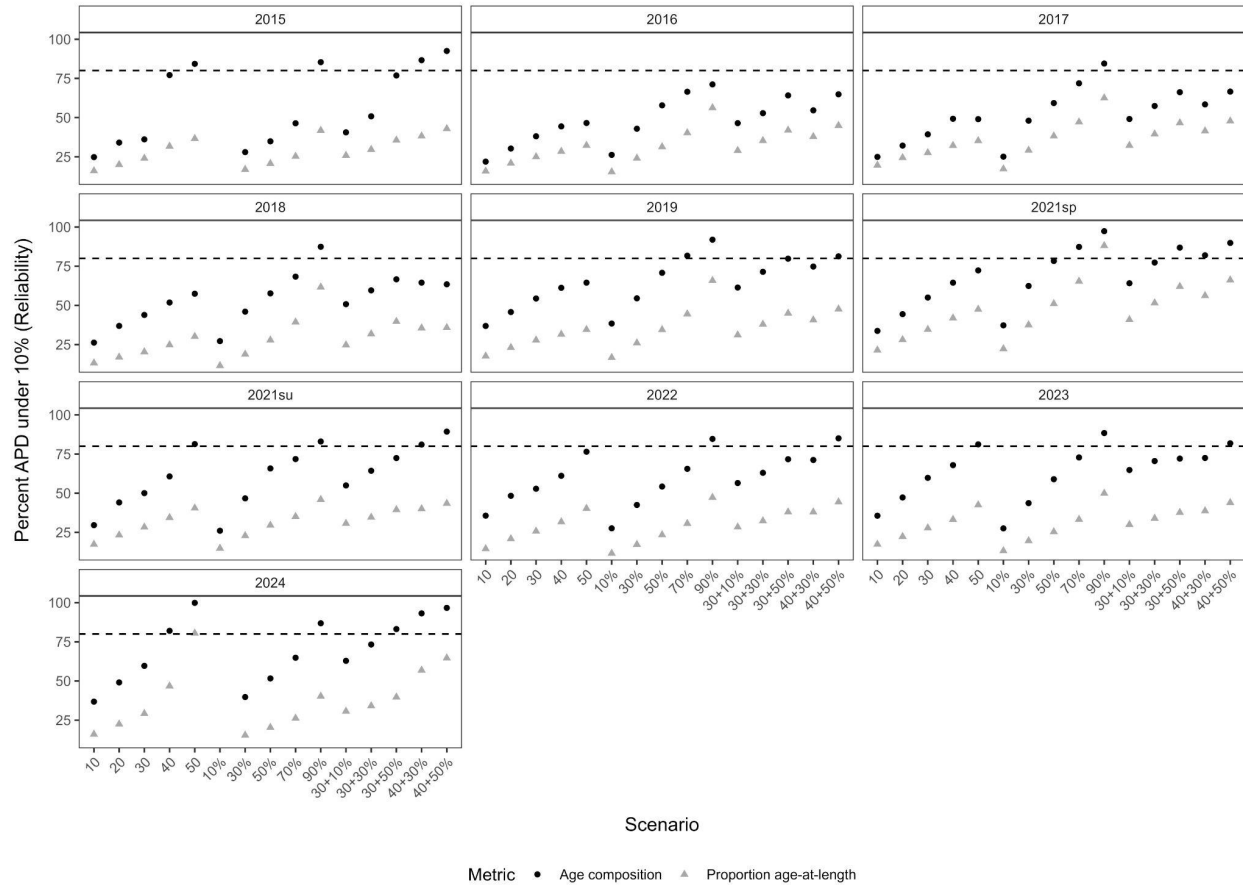


Figure 6. Percentage of 1000 iterations for which the absolute percent deviation (APD) of age composition (black circles) and proportion of individuals of each age within a length bin (gray triangles) was less than 10% of the reference value for northern anchovy (*Engraulis mordax*) sampled during CPS acoustic-trawl surveys by the SWFSC during 2015–2024. For the two surveys in 2021, 2021sp refers to the spring survey and 2021su refers to the summer survey. Points above the 80% dashed line were defined as accurate and reliable. The first five scenarios on the x-axis depict fixed otolith subsampling, the next five depict proportional otolith subsampling with targeted supplemental sampling, and the last five depict hybrid otolith subsampling. The 5 scenarios within a subsampling strategy indicate either the fixed number (e.g., 10) or proportional number (e.g., 10%) of samples chosen within a 10-mm length bin.

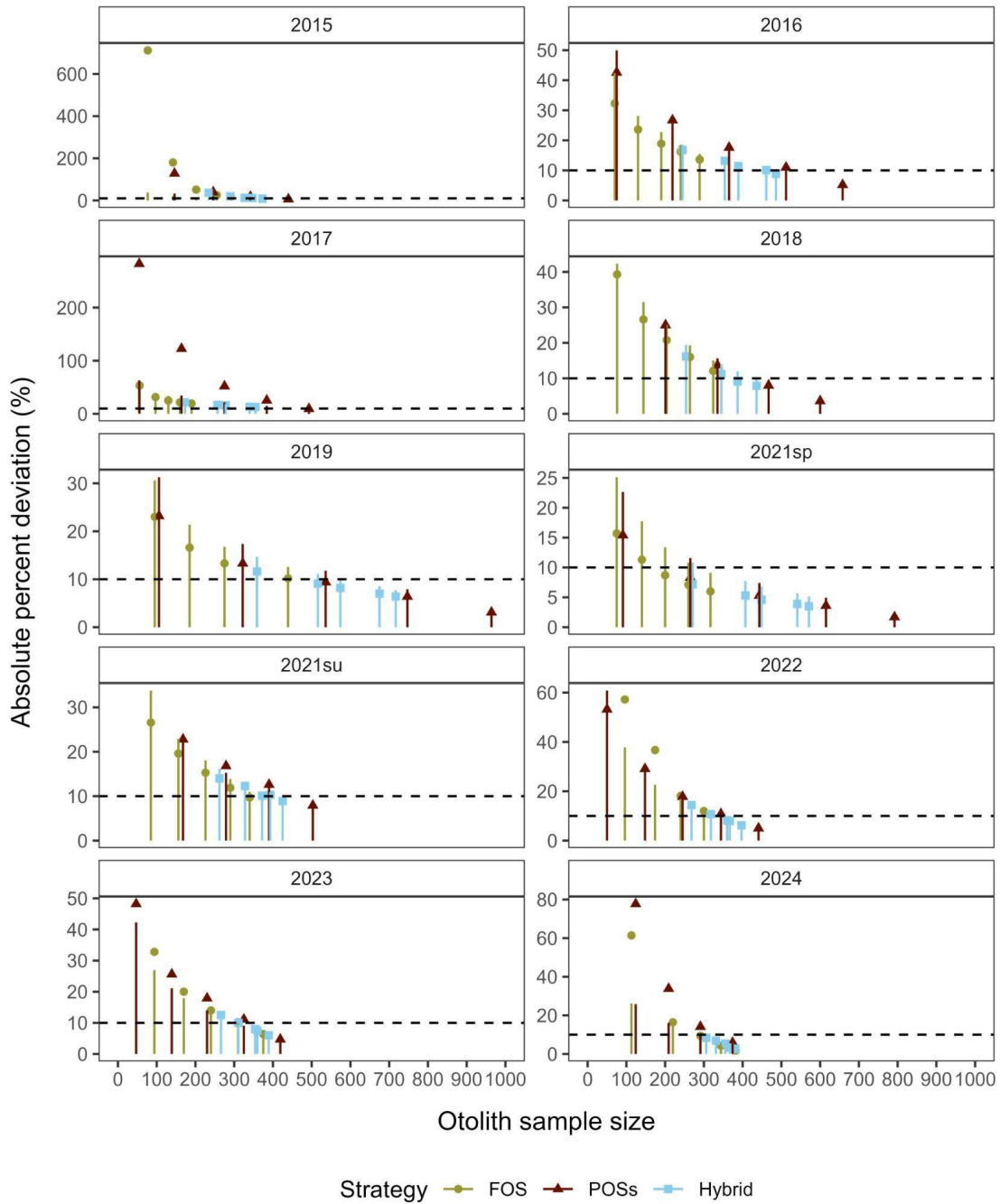


Figure 7. Absolute percent deviation (APD) of the age composition for fixed (FOS, yellow circles), proportional with targeted supplemental sampling (POSs, red triangles), and hybrid (blue squares) otolith subsampling strategies in relation to sample size for northern anchovy (*Engraulis mordax*) sampled during CPS acoustic-trawl surveys by the SWFSC during 2015–2024. For the two surveys in 2021, 2021sp refers to the spring survey and 2021su refers to the summer survey. Mean absolute percent deviation (MAPD) is represented by points and 25% and 75% quantiles for APD values are represented as lines. Points below 10% (dashed line) were defined as accurate.

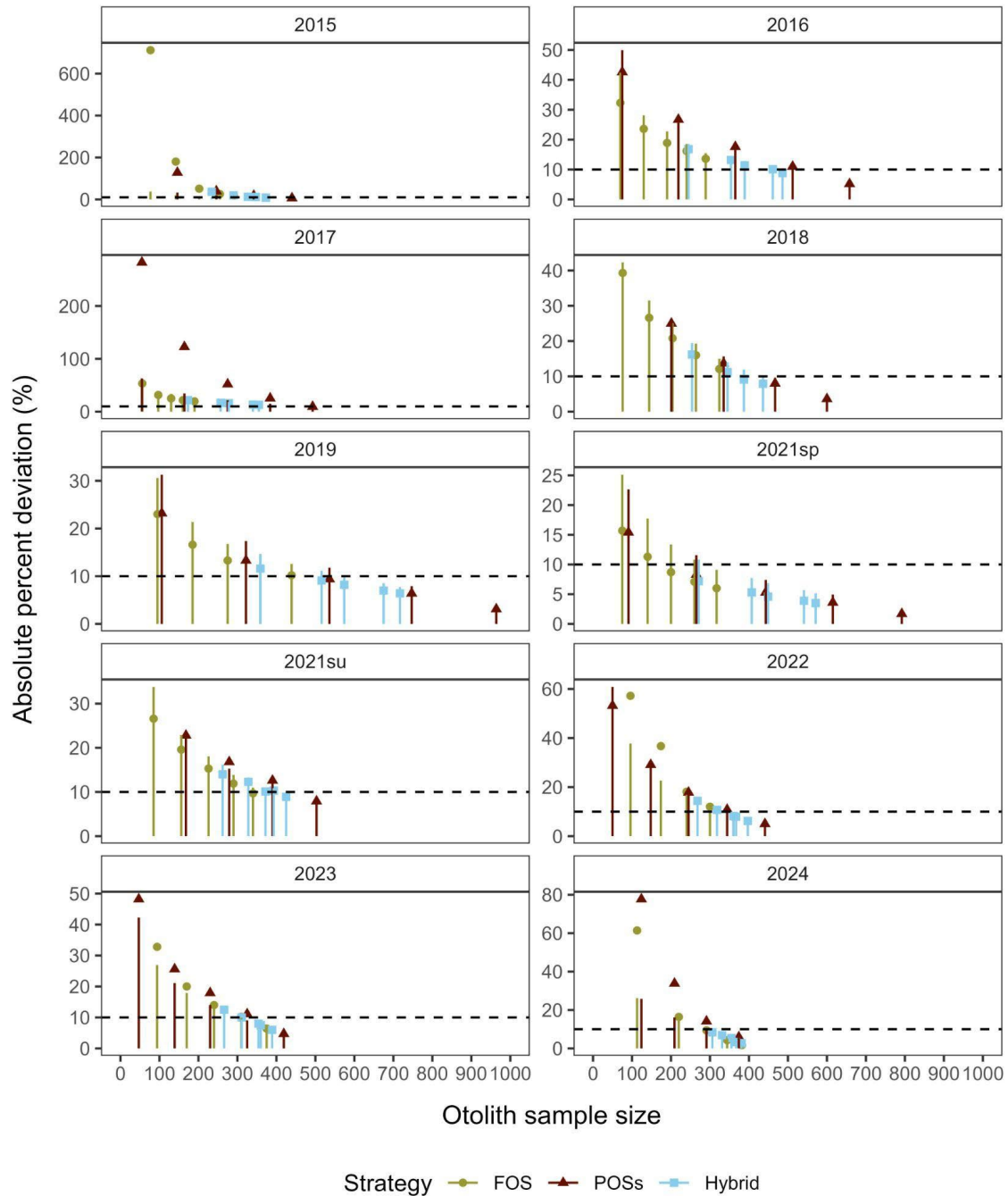


Figure 8. Absolute percent deviation (APD) of the proportion of individuals of each age within a length bin for fixed (FOS, yellow circles), proportional with targeted supplemental sampling (POSs, red triangles), and hybrid (blue squares) otolith subsampling strategies in relation to sample size for northern anchovy (*Engraulis mordax*) sampled during CPS acoustic-trawl surveys by the SWFSC during 2015–2024. For the two surveys in 2021, 2021sp refers to the spring survey and 2021su refers to the summer survey. Mean absolute percent deviation (MAPD) is represented by a point and 25% and 75% quantiles for APD values are represented as lines. Points below 10% (dashed line) were defined as accurate.

4. DISCUSSION

I identified an appropriate otolith subsampling strategy and threshold beyond which the performance of metrics did not improve substantially with increasing numbers of otoliths subsampled for age estimation of northern anchovy. I recommend starting with hybrid subsampling 30 otoliths + 30% proportional subsampling of all length bins, which was also recommended for Pacific sardine (Schwartzkopf et al. 2025). If age estimation resources are unlimited, a sample size larger than 2000 otoliths did not substantially increase accuracy and reliability. This large sample size of 2000 otoliths would be a good reference point to generate a reliable growth curve and/or compare growth curves across regions or time periods. For individual years with disparate length distributions and sample sizes of otoliths, 300–400 otoliths were sufficient in accuracy and reliability and would be a good reference point to generate year specific ALKs.

High variability of age-at-length, with 4 to 6 age classes within numerous length bins for northern anchovy, directly impacts the accuracy and reliability of proportions of age-at-length (Schwartzkopf et al. 2025). In the present study and Schwartzkopf et al. (2025), the accuracy and reliability of the proportion of age-at-length were higher for length bins with fewer age classes present and no subsampling strategy was able to accurately and reliably estimate all proportions of age-at-length. Obtaining more otoliths from length bins with multiple age classes is needed to capture variability (Miranda and Colvin 2017), so it's not surprising that the hybrid subsampling strategy performed well. One difference between studies was that for northern anchovy, fixed subsampling performed comparably to proportional and hybrid subsampling strategies at similar sample sizes, whereas fixed subsampling performed worse than hybrid and proportional subsampling for Pacific sardine (Schwartzkopf et al. 2025). With the small number of age classes for northern anchovy (0-6+) and rarity of older age classes (age 4+), it seems more important for northern anchovy to make sure there is a greater minimum sample size of ages from length bins containing larger-sized fish.

The decreased performance of different otolith subsampling strategies for individual years relative to the full dataset was due in part to differing length and age distributions, in conjunction with multiple age classes within length bins. For example, with the random resampling without replacement, samples within a length bin with many age classes had a greater likelihood of being assigned a different age than what was observed, which would lead to decreased accuracy. This may explain length-at-age data collected during the 2016 summer survey, in which no subsampling strategy accurately and reliably estimated the age composition or proportion of ages-at-length. For 2016, there was a high sample size of aged fish ($n = 731$), a smaller number of length bins ($n = 9$), and a low proportion of older fish ages 3+. Additionally, the largest sample size was in length bins with an overlap of younger age classes (100 to 120 mm SL), so it's likely that samples within these bins were assigned a different age than what was observed. For years that have a small aged sample size but a large number of length bins, such as 2024, the fixed subsampling strategy produced a greater sample size than proportional subsampling strategy because the samples were spread out among age classes. In 2024, only 3 of the 12 length bins had more than 50 individuals (Appendix

Figure A1), so the fixed strategy scenario where 50 samples are taken from each length bin captured almost 100% of the data.

Collecting otoliths in the field and estimating age in the laboratory requires balancing time and effort to minimize highly repetitive motions that lead to acute and repetitive stress injuries (Hulson et al. 2024). A minimum sub-sample size of 2000 otoliths per year for age estimation for northern anchovy to represent a full reference sample of 6439 fish is unrealistic for field sampling and a non-production, age-estimation laboratory with limited staff (i.e., does not solely focus on processing a large number of ages for multiple fish stocks), whereas a minimum sample size of 300–400 otoliths for year-specific analyses is more realistic. The current otolith subsampling strategy for CPS off the U.S. west coast is as follows: if < 600 otoliths are randomly collected in stage-2 sampling, all otoliths are assigned to age readers, or else a subsample is randomly selected in stage-3 sampling within haul and length bins to maintain the temporal and spatial integrity of the distribution of length-at-age (Schwartzkopf et al. 2022). In instances where only one age reader is available, sample size targets are typically reduced to a reasonable workload to meet stock assessment deadlines (~half the sample size of a normal year). With this type of subsampling, the threshold sample sizes I identified can easily be met, so effort could be optimized further by using a priori knowledge of the number of age classes in each length bin (Ailloud and Hoenig 2019). For example, otoliths collected from northern anchovy < 60 mm SL could be assigned to age-0, and effort could be allocated to estimate the age of more fish from length bins known to contain more ages (i.e., 120–140 mm SL) using the hybrid otolith subsampling strategy.

As the strategy employed here involved the resampling of a subsampled reference dataset, caution should be given with focusing on the exact recommended sample size numbers, and instead should be placed on understanding the underlying processes of these subsampling strategies. The hybrid strategy is a conservative option that will ensure there are representative samples from all age classes at a minimum sample size, thereby improving sample sizes from the ends of the length distribution while also making sure a greater number of samples are obtained from those length bins with a larger sample size, which tend to be those that contain multiple age classes. Although starting with hybrid subsampling 30 otoliths + 30% proportional subsampling of all length bins is recommended, the most appropriate hybrid subsampling strategy (e.g., 30-30% vs 40-30%) depends on the length distribution of the catch from the survey in a given year and should be adjusted annually as appropriate. It's important to look at different subsampling scenarios to make sure that the proposed subsampled dataset: (1) achieves a balance of efficiency with respect to total sample size; (2) has a good representation from each length bin; and (3) maintains a comparable length frequency shape as the total sample. Before age reading occurs, the geographic range of the proposed subsample dataset could also be compared to the geographic range of the total dataset to make sure spatial integrity is maintained if that is something important to consider for a given stock, population, or species.

5. ACKNOWLEDGMENTS

I thank participants of the SWFSC CPS Surveys, which regularly include those from the Life History, CalCOFI, and Advanced Survey Technologies Programs at the SWFSC along with the countless numbers of volunteers from other programs at SWFSC, other NOAA centers and outside institutions. The data presented in this report would not have been possible without the help and knowledge of the NOAA Corps officers and crews of NOAA Ships Reuben Lasker and Bell M. Shimada. I also thank A. Ostrowski, K. James, B. Erisman, and A. Yau of NOAA for their internal reviews.

6. DATA AVAILABILITY STATEMENT

The data used in this study are openly available on Github at:
https://github.com/SWFSC/anchovy_otolith_sampling_analysis.

7. REFERENCES

- Ailloud, L. E., and J. M. Hoenig. 2019. A general theory of age-length keys: combining the forward and inverse keys to estimate age composition from incomplete data. *ICES Journal of Marine Science* 76:1515–1523. doi:10.1093/icesjms/fsz072.
- Blaxter, J. H. S., and J. R. Hunter. 1982. The biology of the clupeoid fishes. *Advances in Marine Biology* 20:3–223. doi:https://doi.org/10.1016/S0065-2881(08)60140-6.
- Chang, Y. J., H. Jhen, J. C. Shiao, and S. K. Chang. 2019. Evaluation of the effects of otolith sampling strategies and ageing error on estimation of the age composition and growth curve for Pacific bluefin tuna. *Marine and Freshwater Research* 70:1838–1849. doi:10.1071/Mf18241.
- Coggins, L. G., D. C. Gwinn, and M. S. Allen. 2013. Evaluation of age-length key sample sizes required to estimate fish total mortality and growth. *Transactions of the American Fisheries Society* 142:832–840. doi:https://doi.org/10.1080/00028487.2013.768550.
- Dorval, E., K. C. James, D. Porzio, B. D. Schwartzkopf, A. Claiborne, J. Topping, and M. Schultz. 2025. Age determination for managed and assessed coastal pelagic species in the northeast Pacific. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-SWFSC-726. doi:https://doi.org/10.25923/9esm-ke24.
- Dorval, E., D. Porzio, B. D. Schwartzkopf, K. C. James, L. Vasquez, and B. Erisman. 2022. Sampling methodology for estimating life history parameters of coastal pelagic species along the U.S. Pacific Coast. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-SWFSC-660. doi:https://doi.org/10.25923/e8wq-xf39.
- Erisman, B. E., M. Craig, K. C. James, B. D. Schwartzkopf, and E. Dorval. 2025. Systematic review of somatic growth patterns in relation to population structure for Pacific sardine (*Sardinops sagax*) along the Pacific coast of North America. U.S. Department of Commerce, NOAA Technical Memorandum NOAA-SWFSC-708. doi:https://doi.org/10.25923/0j1j-xv61.
- Francis, R. I. C. C. 2016. Growth in age-structured stock assessment models. *Fisheries Research* 180:77–86. doi:10.1016/j.fishres.2015.02.018.

- Hulson, P. J. F., B. C. Williams, M. D. Bryan, J. Conner, and M. R. Siskey. 2024. Reductions in sampling effort for fishery-independent age and length composition: balancing sampling efficiency, data uncertainty, and workforce health. *Canadian Journal of Fisheries and Aquatic Sciences* 81:63–78. doi:10.1139/cjfas-2023-016463.
- King, J. R., and G. A. McFarlane. 2003. Marine fish life history strategies: applications to fishery management. *Fisheries Management and Ecology* 10:249–264. doi:https://doi.org/10.1046/j.1365-2400.2003.00359.x.
- Kuriyama, P. T., J. P. Zwolinski, S. L. H. Teo, and K. T. Hill. 2022. Assessment of the northern anchovy (*Engraulis mordax*) central subpopulation in 2021 for U.S. management. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-SWFSC-665:114. doi:https://doi.org/10.25923/jv24-1539.
- Lorenzen, K. 2016. Toward a new paradigm for growth modeling in fisheries stock assessments: Embracing plasticity and its consequences. *Fisheries Research* 180:4–22. doi:10.1016/j.fishres.2016.01.006.
- MacCall, A. D., W. J. Sydeman, P. C. Davison, and J. A. Thayer. 2016. Recent collapse of northern anchovy biomass off California. *Fisheries Research* 175:87–94. doi:https://doi.org/10.1016/j.fishres.2015.11.013.
- McHugh, J. L. 1951. Meristic variations and populations of northern anchovy, (*Engraulis mordax*). *Bulletin of the Scripps Institution of Oceanography of the University of California* 6:123–160.
- Methot, R. D. 1983. Seasonal variation in survival of larval northern anchovy, *Engraulis mordax*, estimated from the age distribution of juveniles. *Fishery Bulletin* 81:741–750.
- Miranda, L. E., and M. E. Colvin. 2017. Sampling for age and growth estimation. Pages 107–125 in M. C. Quist and D. A. Isermann, editors. *Age and Growth of Fishes: Principles and Techniques*. American Fisheries Society, Bethesda, MD.
- PFMC (Pacific Fishery Management Council). 2024. Coastal Pelagic Species Fishery Management Plan as Amended through December 2024. Pacific Fishery Management Council, Portland, OR.
- Schemmel, E., E. C. Bohaboy, M. J. Kinney, and J. M. O'Malley. 2022. An assessment of sampling approaches for estimating growth from fishery-dependent biological samples. *ICES Journal of Marine Science* 79:1497–1514. doi:10.1093/icesjms/fsac075.
- Schwartzkopf, B. D., E. Dorval, K. C. James, J. M. Walker, O. E. Snodgrass, D. L. Porzio, and B. E. Erisman. 2022. A summary report on life history information on the central subpopulation of Northern Anchovy (*Engraulis mordax*) for the 2021 stock assessment. U.S. Department of Commerce, NOAA Technical Memorandum NOAA-SWFSC-659. doi:https://doi.org/10.25923/ckvg-va49.
- Schwartzkopf, B. D., E. Dorval, D. L. Porzio, J. M. Walker, K. C. James, and B. E. Erisman. 2023. Modeling somatic and otolith growth of the central subpopulation of northern anchovy by incorporating seasonality. *Fishery Bulletin* 121:172–187. doi:10.7755/Fb.121.4.3.
- Schwartzkopf, B. D., K. C. James, E. Dorval, A. J. Jensen, D. G. Bolser, and B. E. Erisman. 2025. Evaluating post-survey otolith subsampling strategies for a small-bodied, fast-growing pelagic fish for inclusion in stock assessments. *Fisheries Management and Ecology* 33:24–39. doi:10.1111/fme.70005.
- Stierhoff, K. L., J. S. Renfree, and J. P. Zwolinski. 2025. Distribution, biomass, and demographics of coastal pelagic fishes in the California Current Ecosystem during summer 2024 based

- on acoustic trawl sampling. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-SWFSC-721. doi:<https://doi.org/10.25923/v99f-me72>.
- Stierhoff, K. L., J. P. Zwolinski, J. S. Renfree, and D. A. Demer. 2023. Distribution, biomass, and demographics of coastal pelagic fishes in the California Current Ecosystem during summer 2022 based on acoustic-trawl sampling. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-SWFSC-683:84. doi:<https://doi.org/10.25923/40x3-b146>.
- Sydeman, W. J., S. Dedman, M. Garcia-Reyes, S. A. Thompson, J. A. Thayer, A. Bakun, and A. D. MacCall. 2020. Sixty-five years of northern anchovy population studies in the southern California Current: a review and suggestion for sensible management. *ICES Journal of Marine Science* 77:486–499. doi:<https://doi.org/10.1093/icesjms/fsaa004>.
- Thayer, J. A., A. D. MacCall, P. C. Davison, and W. J. Sydeman. 2017. California anchovy population remains low, 2012-2016. *California Cooperative Oceanic Fisheries Investigations Reports* 58:69–76.
- Thompson, A. R., I. D. Schroeder, S. J. Bograd, E. L. Hazen, M. G. Jacox, A. Leising, B. K. Wells, J. L. Largier, J. L. Fisher, K. Jacobson, S. Zeman, E. P. Bjorkstedt, R. R. Robertson, M. Kahru, R. Goericke, C. E. Peabody, T. R. Baumgartner, B. E. Lavaniegos, L. E. Miranda, E. Gomez-Ocampo, J. Gomez-Valdes, T. D. Auth, E. A. Daly, C. A. Morgan, B. J. Burke, J. C. Field, K. M. Sakuma, E. D. Weber, W. Watson, J. M. Porquez, J. Dolliver, D. E. Lyons, R. A. Orben, J. E. Zamon, P. Warzybok, J. Jahncke, J. A. Santora, S. A. Thompson, B. Hoover, W. Sydeman, and S. R. Melin. 2019. State of the California Current 2018–19: A novel anchovy regime and a new marine heat wave? *California Cooperative Oceanic Fisheries Investigations Reports* 60:1–65.
- Tofallis, C. 2015. A better measure of relative prediction accuracy for model selection and model estimation. *Journal of the Operational Research Society* 66:524–524. doi:[10.1057/jors.2014.103](https://doi.org/10.1057/jors.2014.103).
- Vrooman, A. M., P. A. Paloma, and J. R. Zweifel. 1981. Electrophoretic, morphometric, and meristic studies of subpopulations of northern anchovy, *Engraulis mordax*. *California Fish and Game Bulletin* 67:39–51.
- Wu, S., X. Zhu, and H. Wang. 2023. Subsampling and jackknifing: a practically convenient solution for large data analysis with limited computational resources. *Statistica Sinica*. doi:[10.5705/ss.202021.0257](https://doi.org/10.5705/ss.202021.0257).

8. APPENDIX

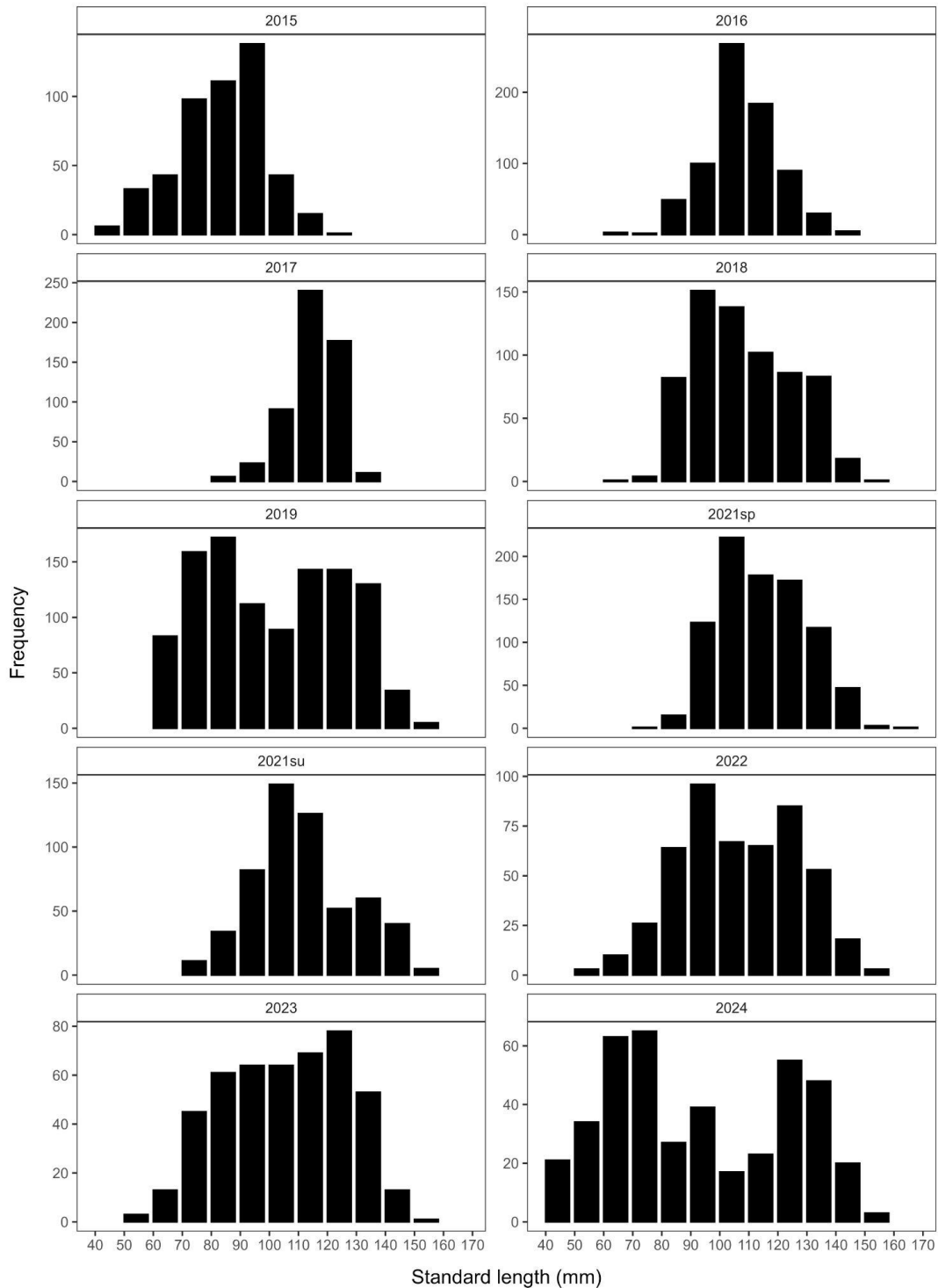


Figure A.1. Frequency of aged northern anchovy (*Engraulis mordax*) sampled during CPS acoustic-trawl surveys by the SWFSC during 2015–2024 in 10-mm length bins for each of the 10 years included in the year-specific analysis. Note that the y-axis scale differs for each year. For the two surveys in 2021, 2021sp refers to the spring survey and 2021su refers to the summer survey.

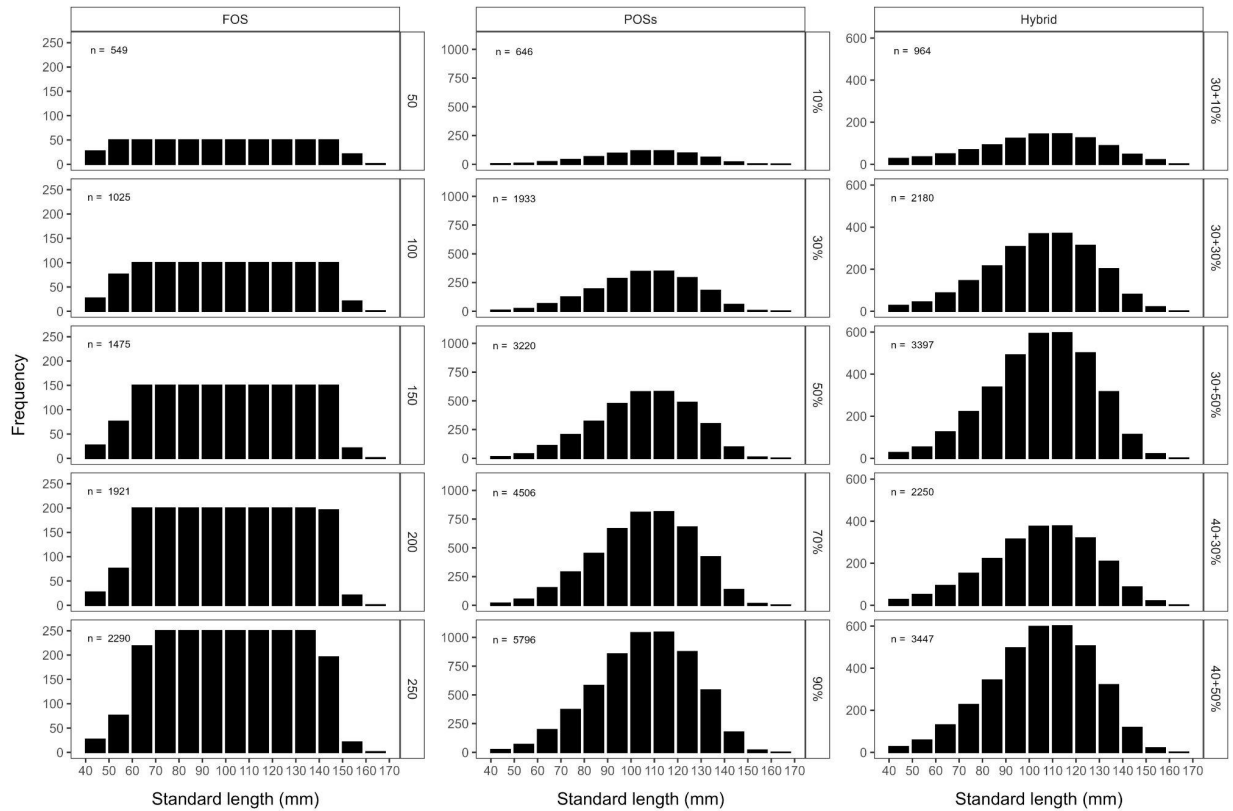
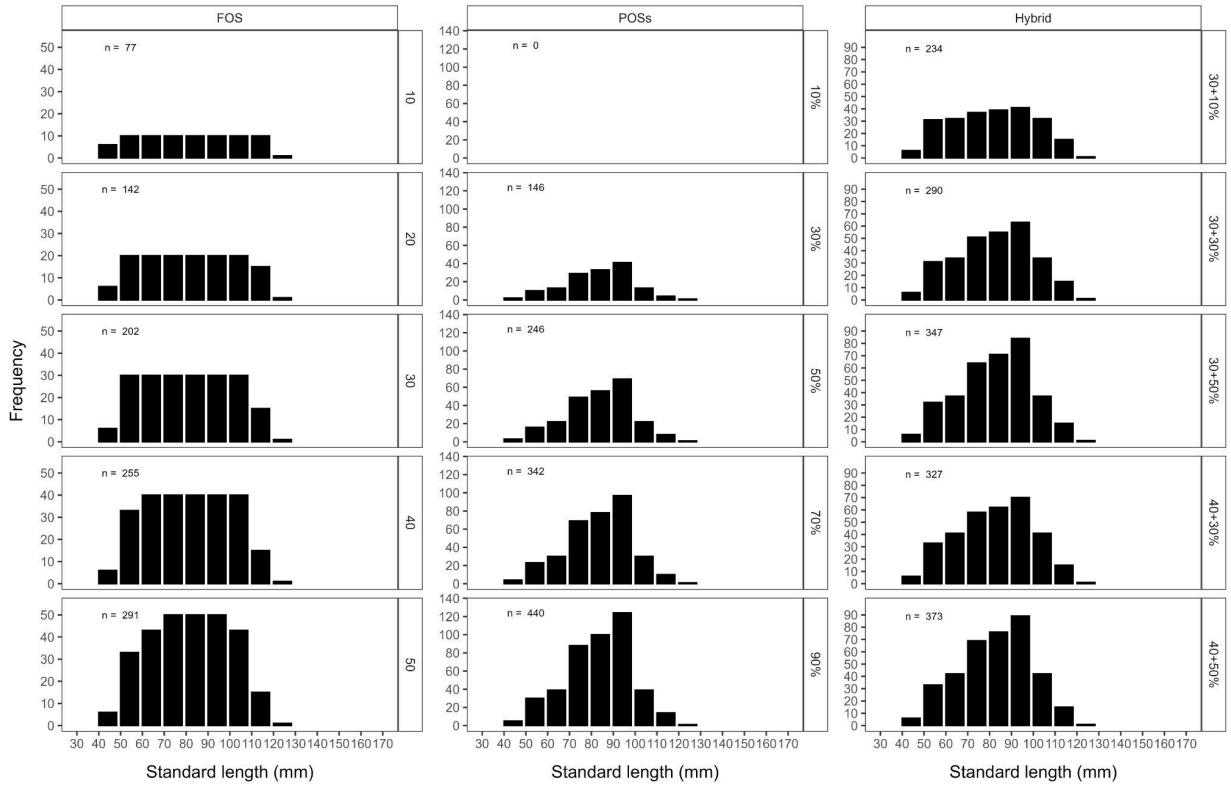
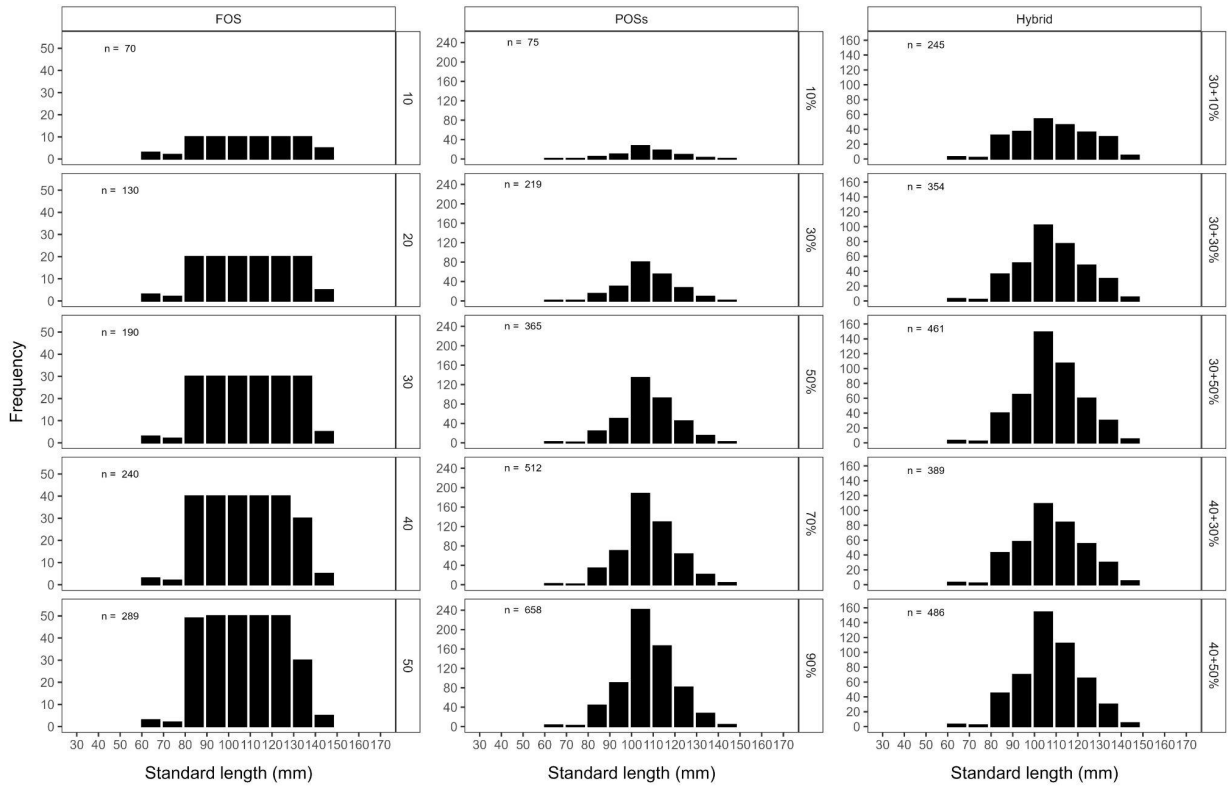


Figure A.2. Length distributions of northern anchovy (*Engraulis mordax*) sampled during CPS acoustic-trawl surveys by the SWFSC during 2015–2024 for each of the 15 otolith subsampling scenarios (FOS = Fixed Otolith Sampling; POSs = Proportional Otolith Sampling with supplemental sampling; Hybrid = Hybrid Otolith Sampling). The 5 scenarios within a subsampling strategy indicate either the fixed number (e.g., 50) or proportional number (e.g., 10%) of samples chosen within a 10-mm length bin. Total sample size (n) is also provided.

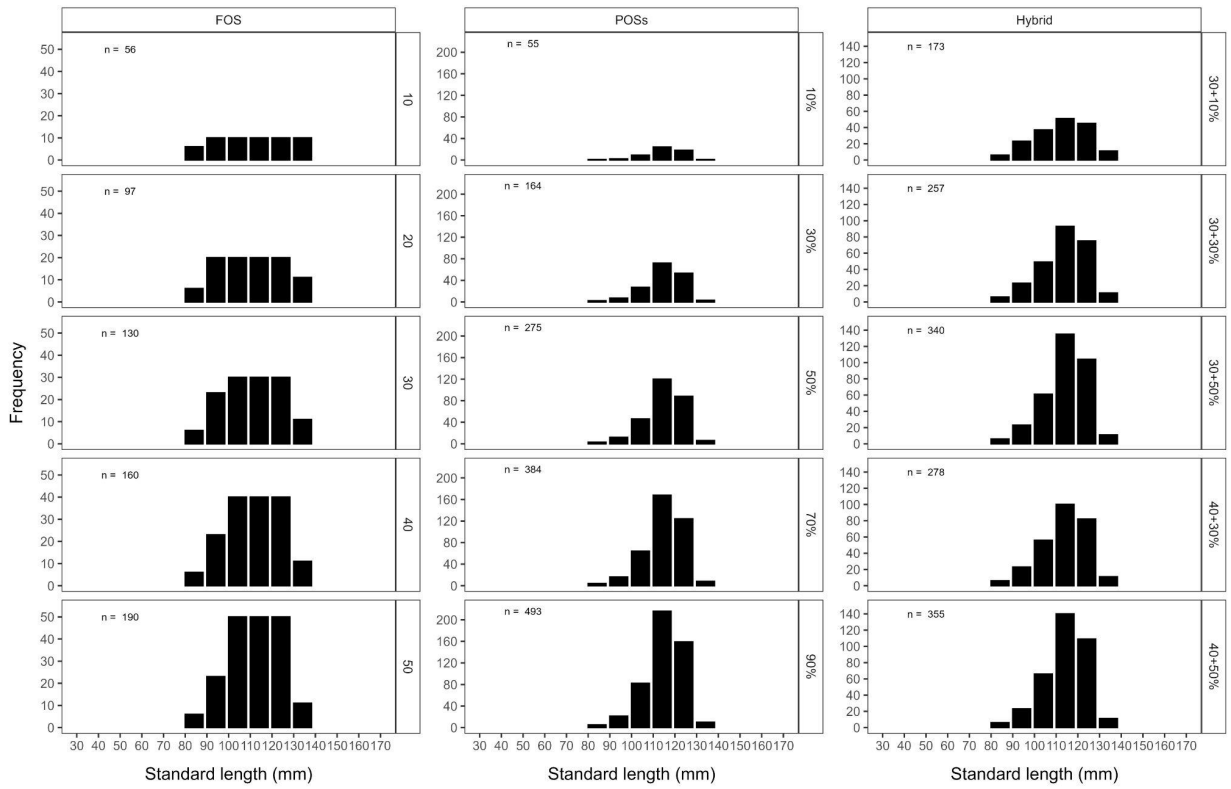
2015



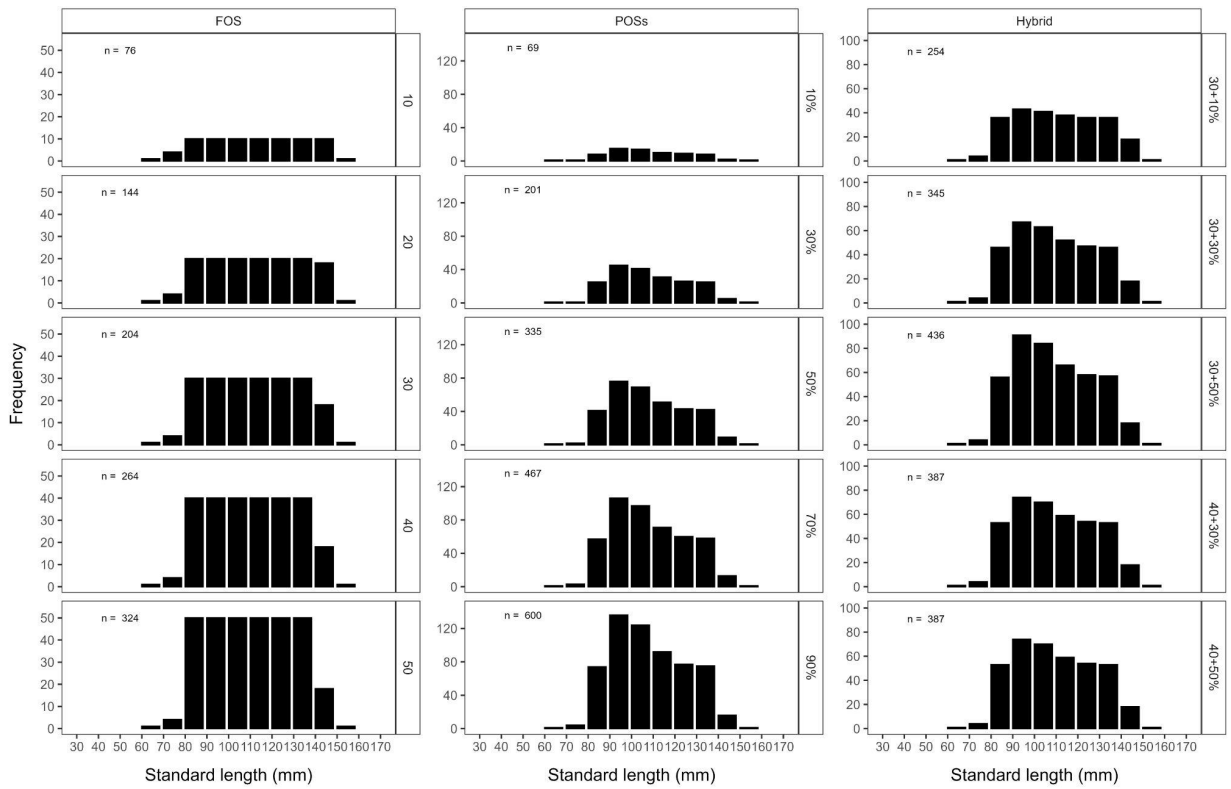
2016



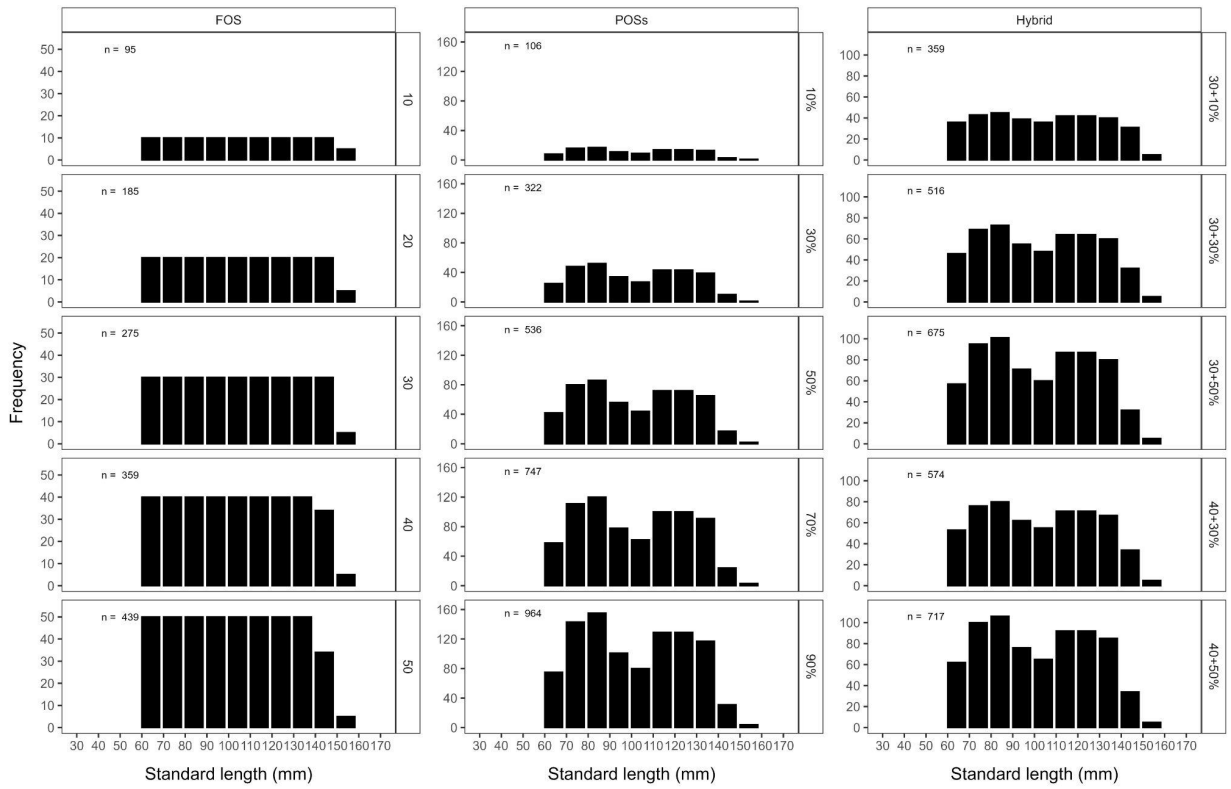
2017



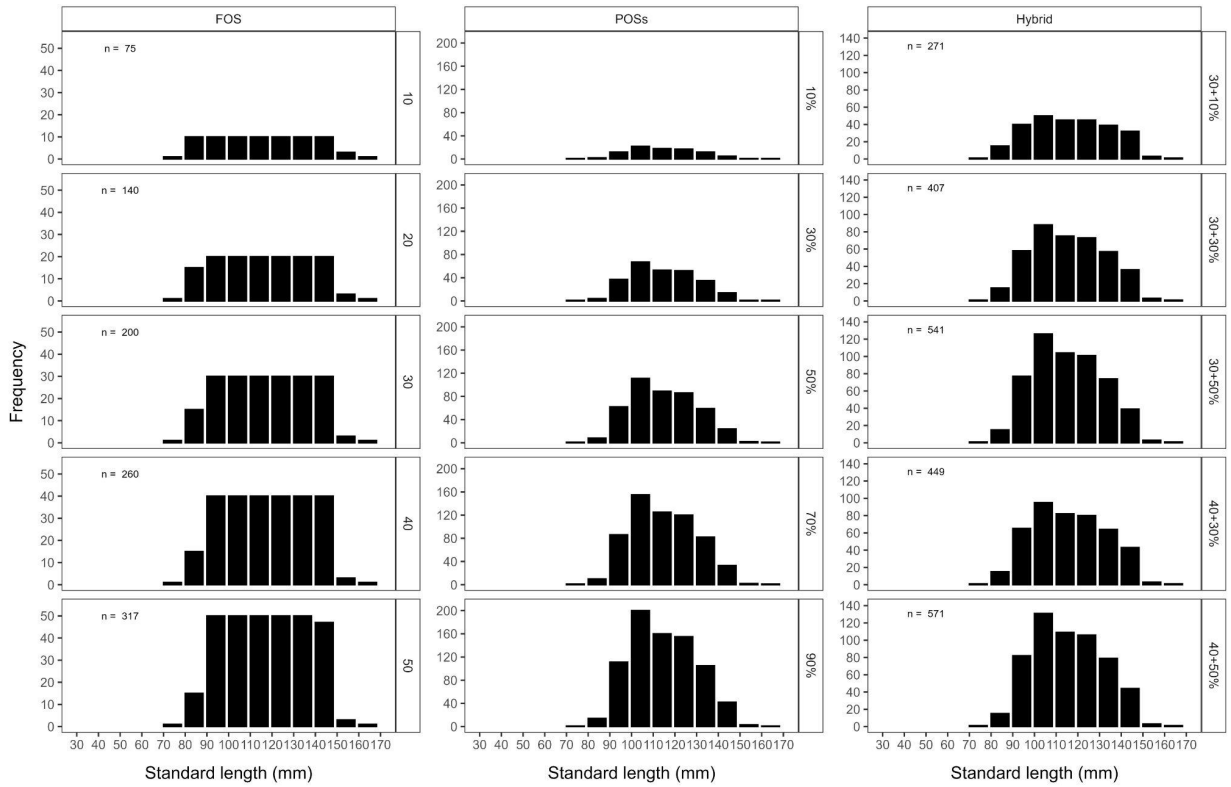
2018



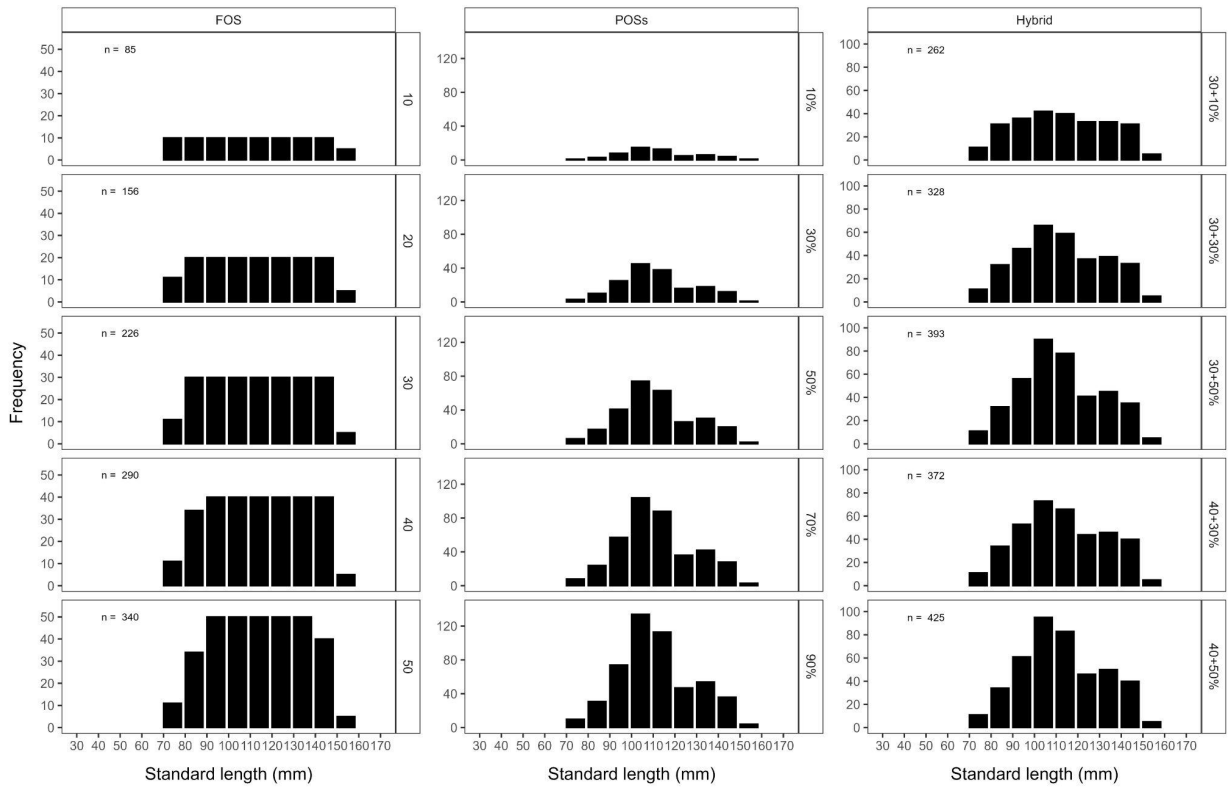
2019



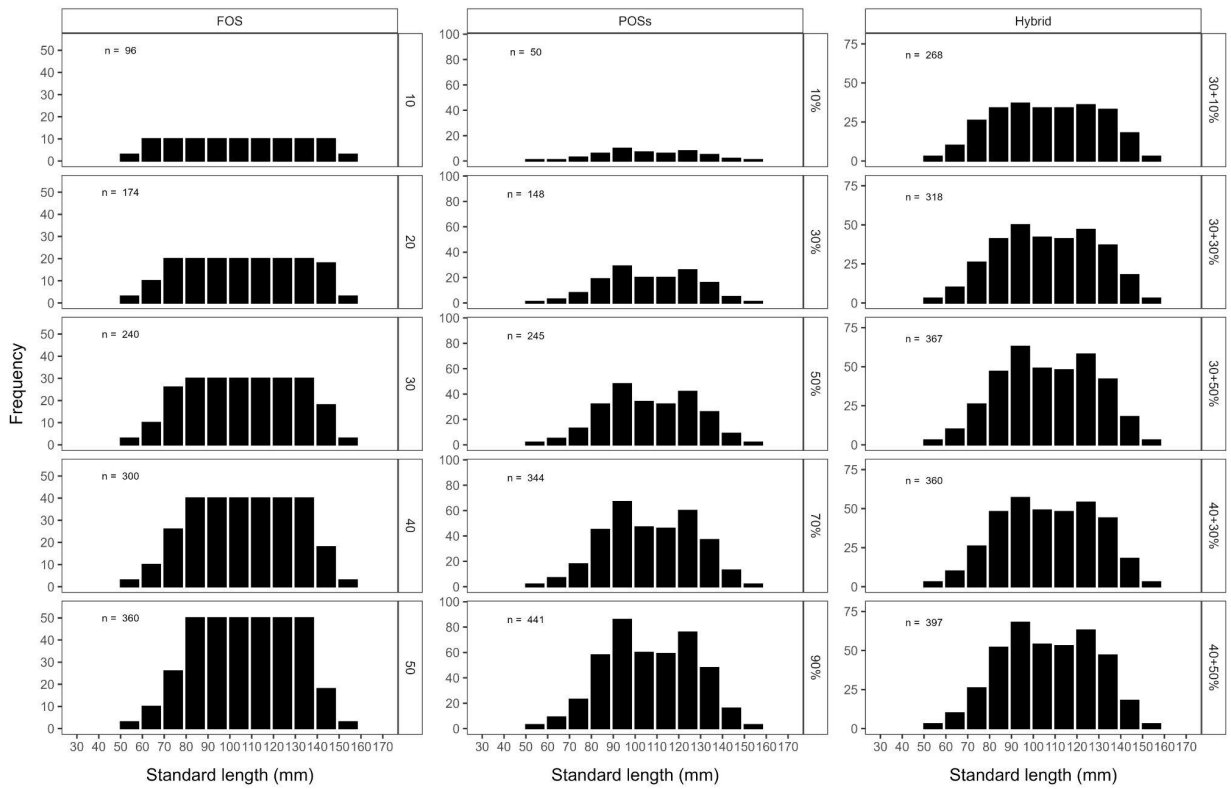
2021 sp.



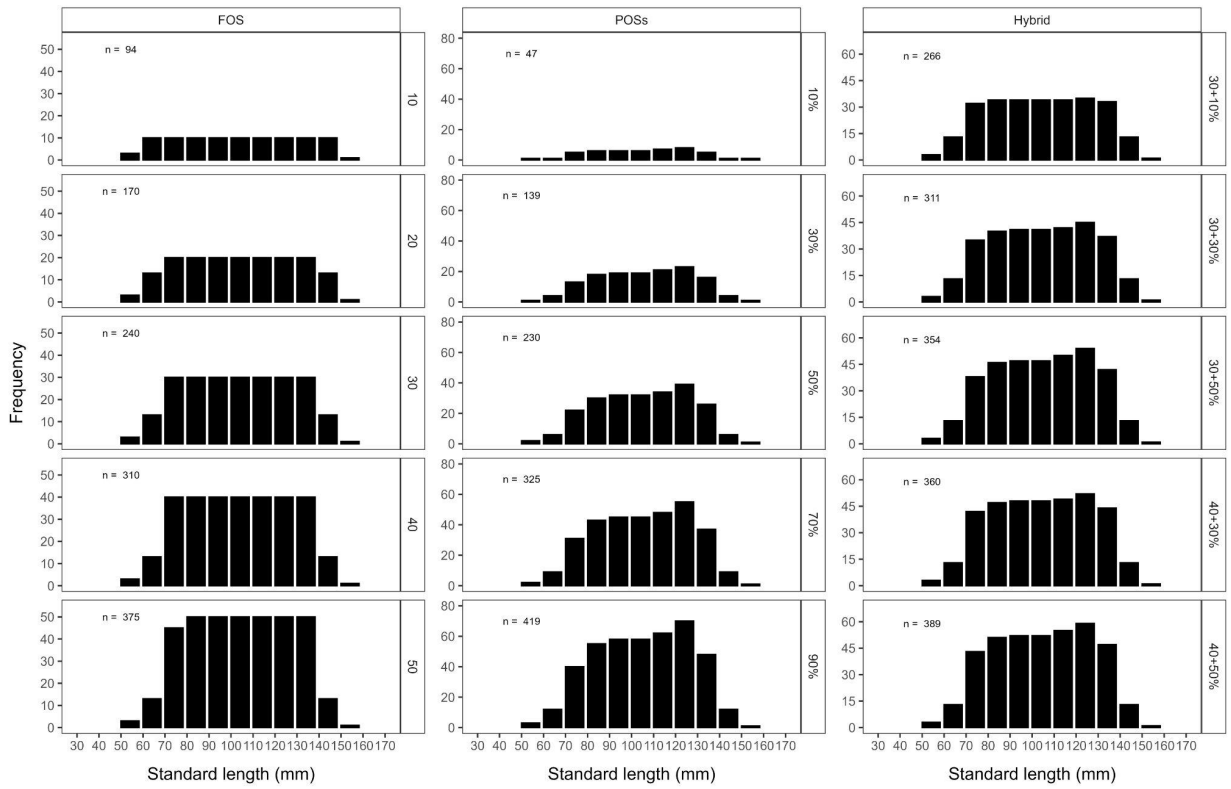
2021 su.



2022



2023



2024

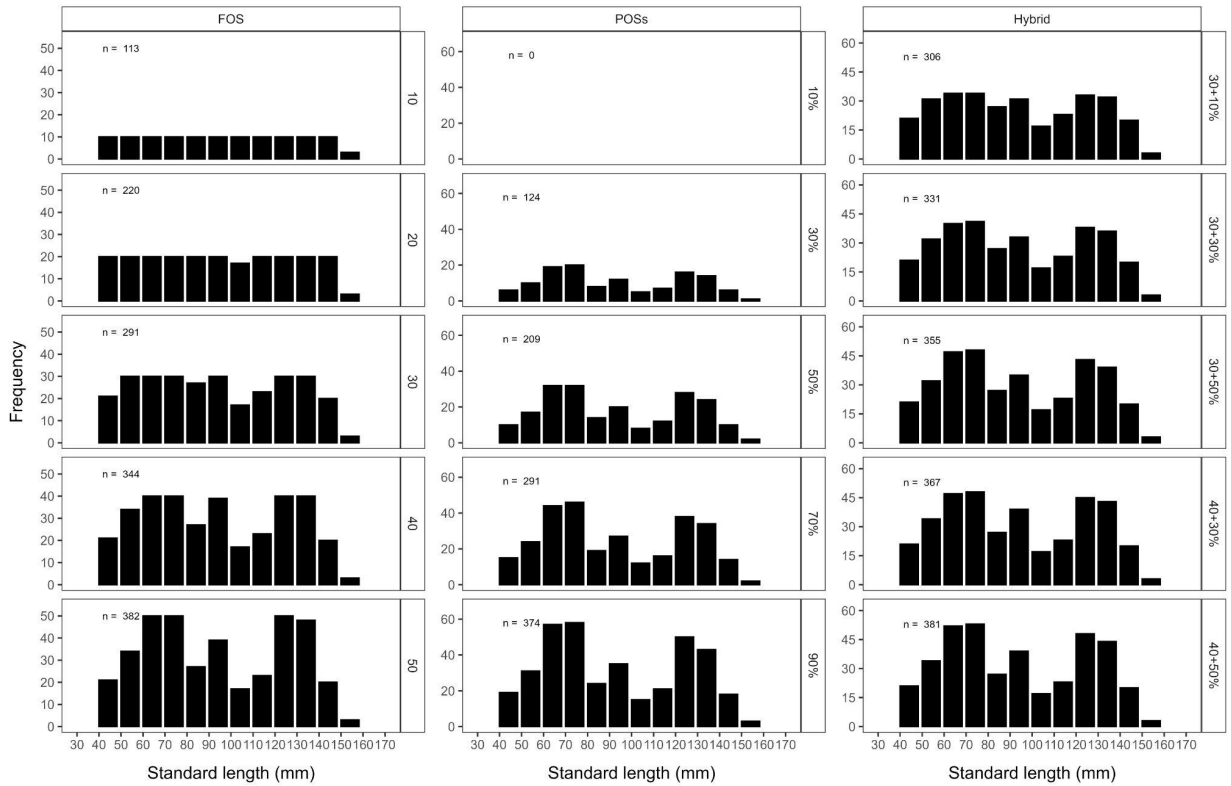


Figure A.3 Length distributions of northern anchovy (*Engraulis mordax*) sampled during CPS acoustic-trawl surveys by the SWFSC during 2015–2024 for each of the 15 otolith subsampling scenarios (FOS = Fixed Otolith Sampling; POSs = Proportional Otolith Sampling with supplemental sampling; Hybrid = Hybrid Otolith Sampling) for each of the 10 individual years examined. The 5 scenarios within a subsampling strategy indicate either the fixed number (e.g., 10) or proportional number (e.g., 10%) of samples chosen within a 10-mm length bin. Total sample size (n) is also provided. For the two surveys in 2021, 2021sp refers to the spring survey and 2021su refers to the summer survey.

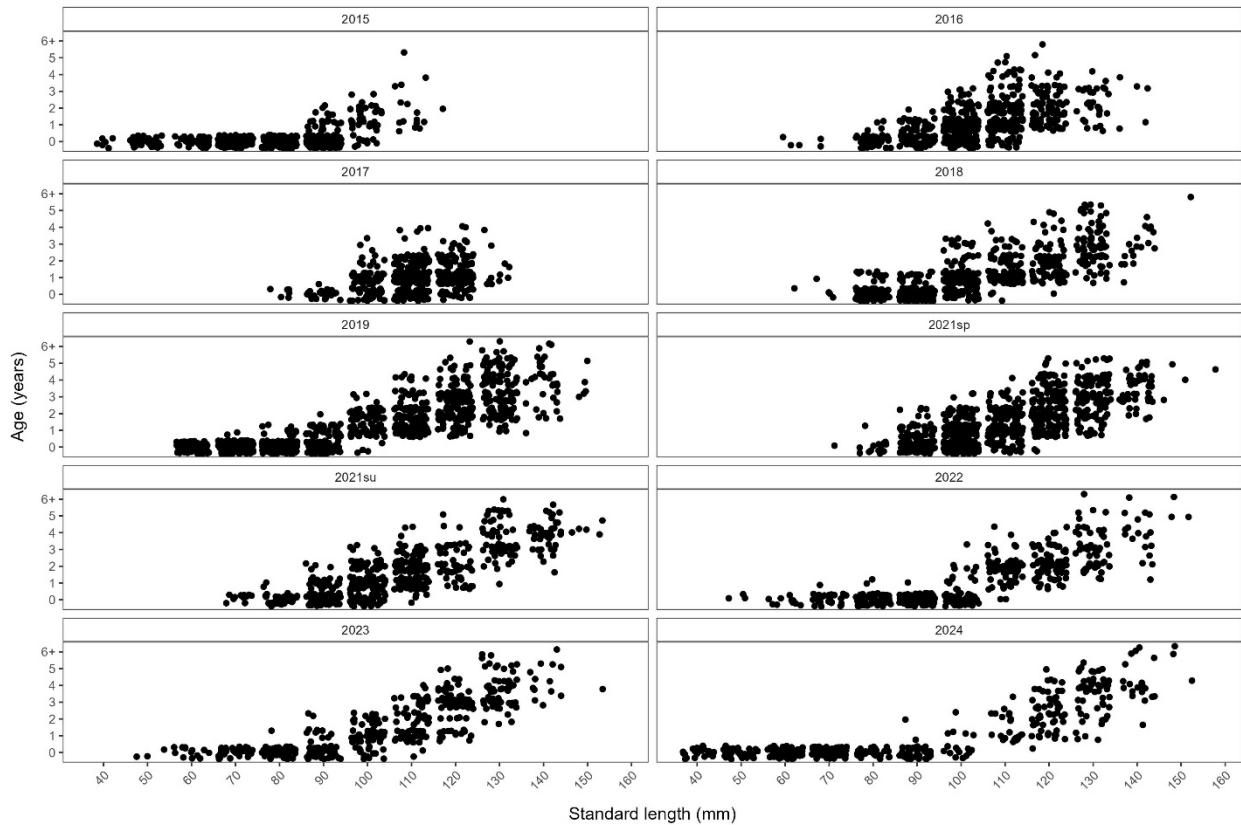


Figure A.4. Jittered age in 10-mm standard length bins of year-specific reference datasets for northern anchovy (*Engraulis mordax*) sampled during CPS acoustic-trawl surveys by the SWFSC during 2015–2024. For the two surveys in 2021, 2021sp refers to the spring survey and 2021su refers to the summer survey.