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SAMPLING METHODOLOGY FOR ESTIMATING LIFE HISTORY PARAMETERS OF COASTAL PELAGIC SPECIES ALONG THE U.S. PACIFIC COAST

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Sampling Methodology for Estimating Life History Parameters of Coastal Pelagic Species Along the U.S. Pacific Coast

NOAA Technical Memorandum

By

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EXECUTIVE SUMMARY

Historically, life history data such as age-at-length, maturity-at-length, and fecundity-at-length have been important demographic information for developing stock assessment models and for monitoring and managing coastal pelagic species (CPS) along the U.S. Pacific Coast. The CPS assemblage is managed under the federal CPS Fishery Management Plan (FMP) and comprises five exploited marine species: Pacific Sardine (*Sardinops sagax*), Pacific Mackerel (*Scomber japonicus*), Jack Mackerel (*Trachurus symmetricus*), Northern Anchovy (*Engraulis mordax*) and Market Squid (*Doryteuthis opalescens*). The Magnuson-Stevens Fishery Conservation and Management Act (MSA), enacted in 1976 and reauthorized in 2007, requires that all U.S. fisheries be managed sustainably and use the best scientific data, assessment models, and information available on each exploited fish population. To this end, both state and federal agencies have developed various research programs to collect life history data from CPS populations, depending on assessment and management priorities and critical issues affecting the status of exploited populations and their environment. Accordingly, sampling methodologies under these programs have evolved in response to ongoing changes in assessment and management priorities, population status associated with environmental conditions, and budget or sampling effort constraints. In this report, we summarize the evolution of sampling methods mostly developed by the California Department of Fish and Wildlife (CDFW) and the Southwest Fisheries Science Center (SWFSC) to collect life history data. The goal is to provide a reference document that describes the methodologies used to sample CPS from fishery-independent surveys in the California Current Ecosystem and fishery port landings. Sampling methods are broadly categorized as historical methods used from 1920 to 1995 and contemporary methods developed since 1996. Future research to improve important components of CPS sampling surveys is also proposed.

1. INTRODUCTION

1.1. Background

Coastal pelagic species (CPS) constitute one of the most ecologically and economically important marine species assemblages in the California Current Ecosystem (CCE). Under the CPS Fishery Management Plan (FMP), this assemblage comprises five exploited species, Pacific Sardine (*Sardinops sagax*), Pacific Mackerel (*Scomber japonicus*), Jack Mackerel (*Trachurus symmetricus*), Northern Anchovy (*Engraulis mordax*), and Market Squid (*Doryteuthis opalescens*); two ecosystem component species, Pacific Herring (*Clupea pallasii*) and Jacksmelt (*Atherinopsis californiensis*); and eight krill species (*Euphausia pacifica, Thysanoessa spinifera, Nyctiphanes simplex, Nematoscelis difficilis, T. gregaria, E. recurva, E. gibboides, E. eximia*) for which harvest is prohibited. In addition, to prevent future development of directed fisheries on specific taxa until or unless they are assessed, the CPS FMP includes a category named “shared ecosystem component species” (Table 1) (PFMC 2020). The CPS assemblage ranges from Alaska to the southern tip of Baja California, Mexico, providing food for marine mammals, seabirds, and other apex predators (Morejohn et al. 1978; McClatchie et al. 2016; Robinson et al. 2018). Several CPS are structured into multiple subpopulations, and the ranges of some subpopulations span transboundary waters and are managed by multiple nations (e.g., central subpopulation of Northern Anchovy: Mexico and U.S.; northern subpopulation of Pacific Sardine: Mexico, U.S., and Canada). In the U.S., CPS support some of the most productive commercial fisheries off Washington, Oregon, and California, and they contribute significantly to their economies. During 1981-2018, landings by the CPS fishery ranged from 57,000 to 225,000 mt, corresponding to ex-vessel values of $15 to $99 million (PFMC 2020). The CPS Fishery Management Plan (FMP) as amended through Amendment 17 (PFMC 2019) covers all the aforementioned CPS, although surveys conducted by both federal and state agencies have historically focused on collecting data to assess and monitor stock status of the five exploited species.

The Magnuson Stevens Fishery Conservation and Management Act (MSA), enacted in 1976 and reauthorized in 2007, requires that all U.S. fisheries be managed sustainably and use the best scientific data, assessment models, and information available on each exploited fish stock. Under the MSA, the CPS FMP divides the five exploited CPS stocks into two distinct categories: actively managed and monitored species. Pacific Sardine and Pacific Mackerel are actively-managed species and are assessed annually or biennially. In contrast, Northern Anchovy [formerly an actively managed species from 1981-1997, see Amendment 8 (PFMC 1998)], Jack Mackerel, and Market Squid are monitored to control fishing impacts and maintain stock productivity (Table 1). Monitored stocks are not regularly assessed, and harvest levels are not adjusted on an annual or biennial cycles. The primary function of the Active and Monitored management categories has been to use available agency resources in the most efficient and effective manner, recognizing that not all CPS stocks require intensive management, e.g., frequent assessment and changes to harvest levels. Seasonal trawl (fishery-independent) surveys conducted from National Oceanic and Atmospheric Administration (NOAA) ships and monthly port-sampling (fishery-dependent) implemented by the California Department of Fish and Wildlife (CDFW; formerly the California Department of Fish and Game) are the key means that have ensured the collection of the best available data and the estimation of fisheries parameters for the sustainable management of CPS from Washington to California over the past three decades.

Table 1. Management categories of coastal pelagic species (CPS) as described in the Fishery Management Plan as amended through 2019 (Amendment 17)

Management Category	Common Name	Family	Scientific Name
Actively Managed Species	Pacific Sardine	Clupeidae	*Sardinops sagax*
	Pacific Mackerel	Scombridae	*Scomber japonicus*
Monitored Species	Jack Mackerel	Carangidae	*Trachurus symmetricus*
	Northern Anchovy	Clupeidae	*Engraulis mordax*
	Market Squid	Loliginidae	*Doryteuthis opalescens*
Ecosystem Component Species	Pacific Herring	Clupeidae	*Clupea pallasii*
	Jacksmelt	Atherinopsidae	*Atherinopsis californiensis*
Shared Ecosystem Component Species	Round Herring	Clupeidae	*Etrumeus teres*
	Thread Herring	Clupeidae	*Opisthonema libertate, O. medrastre*
	Mesopelagic fishes	Myctophidae	
		Bathylagidae	
		Paralepididae	
		Gonostomatidae	
	Pacific Sand Lance	Ammodytidae	*Ammodytes hexapterus*
	Pacific Saury	Scomberesocidae	*Cololabis saira*
	Silversides	Atherinopsidae	
	Smelts	Osmeridae	
	Pelagic squids	Cranchiidae	
		Gonatidae	
		Histioteuthidae	
		Octopoteuthidae	
		Ommastrephidae except Humboldt squid (*Dosidicus gigas*)	
		Onychoteuthidae	
		Thysanoteuthidae	
Prohibited Harvest Species	Krills	Euphausiidae	*Euphausia pacifica*
			Thysanoessa spinifera
			Nyctiphanes simplex
			Nematoscelis difficilis
			T. gregaria
			E. recurva
			E. gibboides

1.2. Goal and Objectives

The goal of this report is to provide a reference document that describes the history of methodologies applied to the sampling of CPS from the CCE and fishery port landings. Surveys have always involved many research components, but in this report, we focus on the sampling methods that produced biological samples and associated life history data and parameters in support of stock assessments, management, and monitoring of CPS populations. Various research programs have also been implemented by state and federal agencies, depending on assessment and management priorities and critical issues affecting the status of exploited populations and their environment. Thus, sampling methods for life history data have evolved in response to ongoing changes in assessment and management priorities, population status associated with environmental conditions, and budget or effort constraints.

For this report, we defined historical surveys as those which occurred prior to 1996. Conversely, contemporary surveys are those that started in 1996, a period when CDFW began focusing primarily on sampling CPS catches from port landings and when the Southwest Fisheries Science Center (SWFSC) started implementing all fishery-independent surveys to collect data for life history research, stock assessments, and management. The primary objectives of both historical and contemporary surveys were to: (1) provide demographic and biological data and parameters to stock assessments; (2) monitor stock status based on species biological characteristics; (3) improve the understanding of CPS population structure and dynamics; (4) contribute to achieving the missions of NOAA-SWFSC and CDFW to assess and monitor CPS and provide the best available data for their sustainable management.

2. FISHERY-DEPENDENT SURVEYS

2.1. Historical Fishery-Dependent Surveys

The development of a CPS fishery off the U.S. Pacific coast originated in California during World War I with the commercial exploitation of Pacific Sardine (BCF 1936). Since 1916, Pacific Sardine has dominated the CPS fishery; landings in California have far exceeded all other species, except during directed sardine fishing moratoria in the past (1967-1985) and present (2015-present), as well as since the late 1990s with increased landings from the Market Squid fishery. The dominance of Pacific Sardine in the fishery has historically influenced port sampling methodologies to collect life history data and to monitor and assess stocks. In November 1919, CDFW began a Sardine Investigation Program to sample the commercial fishing fleet to “contribute to the understanding of the natural changes that occur in sardine abundance so that those could be distinguished from the effects of overfishing” (Scofield 1926; Thompson 1926). The main fishing ports were located in Monterey, Los Angeles, and San Diego, and sampling effort was determined based on the number of CDFW fisheries biologists available to collect samples and analyze the data (Thompson 1926). The daily catch landed from a given boat at a processing plant was considered the sampling unit. From each individual boat, a 1-bucket subsample was randomly taken from the deck or from the fish conveyor belt as the fish were carried into the cannery. During the 1919-1920 fishing season, all days were surveyed, and five boats were sampled daily, consisting of 20 fish per vessel in Monterey and Los Angeles. However, during the 1923-1924 season, bi-weekly sampling occurred due to a lack of staff, and these procedures were applied until 1926 when sample size was increased to 40-50 fish based on new variance component analyses (Sette 1926). This sampling method was extended to the San Diego area during the 1927–1928 season (Clark 1930). In July of 1929, CDFW inaugurated an investigation of Pacific Mackerel in addition to the Sardine Investigation Program (Fitch 1951).

The Sardine Investigation Program further expanded to include other states, federal, and national agencies. The Canadian Research Board began participating in 1926, the U.S. Fish and Wildlife Service (USFWS) in 1928, and the Washington and Oregon fisheries agencies were participating in this program by the mid-1930s. From 1936 through 1942, these agencies participated in a formal tagging study to determine the extent of the migration of the Pacific Sardine population along the Pacific Coast of North America. The state agencies' objectives were to monitor changes in Pacific Sardine abundance and "if serious declines occurred to recommend suitable regulatory measures," while the USFWS primary focus was on studying Pacific Sardine biology and its relation to the environment and on developing new methods for assessing CPS populations (Clark and Janssen 1945a, b; Ware 1999). This more inclusive and formal research became the California Cooperative Sardine Research Program, which lasted from 1937 to 1949 (NOAA 2020).

In the late 1940s, biomass of Pacific Sardine rapidly declined and the fishery collapsed along the U.S. Pacific Coast (McHugh and Ahlstrom 1951). In response, the California fishing industry instigated and financially supported additional research with a Marine Research Committee, representing industry, scientists, and citizens, set up to administer the new funds (McHugh and Ahlstrom 1951). The California Academy of Sciences and Stanford University's Hopkins Marine Station joined the program to study environmental effects on population dynamics of Pacific Sardine. Thereafter, the University of California's Scripps Institution of Oceanography (SIO) set up a full-scale study of the physical, chemical, and planktonic conditions to relate variations in population abundance, recruitment, and availability of Pacific Sardine to its fishery (Clark 1953; McClatchie 2014).

During the 1965-1966 fishing season, port sampling of the reduction fishery for Northern Anchovy was conducted using the same design established for Pacific Sardine, in which random days and individual boats were used as sampling units. However, beginning with the 1966-1967 season, a multi-stage sampling program based on tonnage was established by CDFW to improve data collection and estimation of life history parameters from the reduction fishery. This sampling plan was implemented differently in Southern and Central California. In Southern California, a stratified (multi-stage) sampling design was implemented as follows: (1) stratification of landings into 5,000 short tons strata; (2) categorization of each stratum into first-stage units (i.e., boat loads of unequal tonnage) and a total of 20 units selected with replacement so that the probability of selecting a boat's load was proportional to its tonnage; (3) two clusters of 500^+ g were randomly selected from each primary-stage unit; and (4) each cluster was further split into two subsamples of 250 g and only one subsample was processed for biological characteristics. In Central California, a month was selected as the stratum within which a two-stage sampling plan was used: (1) the primary units (boat load of unequal size) were selected randomly with equal probability and replacement; and (2) the secondary units consisted of a single sample of 1,000 g (± 1 fish) randomly selected from each boat load with equal probability but without replacement (Collins 1969). Landing observations and sample collections from the reduction fishery ceased in 1982 (CDFW 2020a).

The finfish sampling program used from 1978 to 1995 was based on a stratified, random ton method with each stratum consisting of a certain tonnage, and the sampling unit was a sample of fish, each selected randomly and without replacement, from one vessel. If a landing consisted of more than just the targeted CPS, Pacific Sardine, Pacific Mackerel, and Jack Mackerel were sampled if they exceeded five percent of the volume of the targeted species. CDFW staff became overwhelmed due to the sampling method (i.e., large sample size), the expansion of the Pacific Sardine population, and reductions in budgets and staff. Therefore, in 1996 the finfish sampling program was significantly revised, and the current sampling regime was implemented using a random day method for Pacific Sardine and Pacific Mackerel; while sampling of Jack Mackerel was suspended. Also in 1996, monthly sampling restarted in Monterey, as samples had previously been taken only occasionally. In 2014, CDFW observed an increase in commercial landings of Northern Anchovy and began collecting samples. CDFW also restarted collecting Jack Mackerel samples, with both species collected according to the finfish sampling protocols established in 1996.

Age and growth studies for Pacific Sardine formally began in 1938 with the USFWS South Pacific Fishery Investigations, which developed into a comprehensive program for ageing Pacific Sardines undertaken jointly by the USFWS and CDFW (McHugh and Ahlstrom 1951). The Fisheries Research Board of Canada, the Washington State Department of Fisheries (WSDF [now known as the Washington Department of Fish and Wildlife (WDFW)]), and the Fish Commission of Oregon (FCO [now the Oregon Department of Fish and Wildlife (ODFW)]) participated in the program by ageing scales of Pacific Sardine collected in the U.S. Pacific Northwest and British Columbia (Felin and Phillips 1948). This program continued through the 1965-1966 season, when the collapse of the Pacific Sardine fishery ended the need for extensive analyses of age compositions (Yaremko 1996). Age determinations of Pacific Mackerel have been made since the 1940s using otoliths as the only hard structure (Fitch 1951). Age-at-length estimates of the Northern Anchovy population have been generated from live bait and commercial catches, initially using scales during the 1952–1953 season, and then switching to otoliths starting with the 1967-1968 fishing season (Collins and Spratt 1969). When CDFW's finfish sampling programs were unified and revised after 1985, otoliths were selected for analysis of all species (Yaremko 1996).

CDFW began collecting gonads from female Pacific Sardine in 1986 with the resurgence of the directed fishery. Ovaries were extracted and weighed at the CDFW laboratory and then used to develop a gonadosomatic index (GSI) by dividing ovary weight (g) by total weight (g) of each individual fish. In 1996, sampling was limited to one GSI sample (i.e., all females out of 25 fish) per week as time allowed. GSI data are currently collected on freshly collected samples of female Pacific Sardine and Northern Anchovy. Although important information on spawning dynamics could be derived from GSI data (e.g. extent and annual variability in spawning seasonality), the existing index has not been used to inform stock assessment, mostly because gonad tissues are collected and histologically analyzed from most SWFSC survey cruises, providing more accurate data to develop maturity ogives for assessment models.

The fishery for Market Squid in California has existed since at least 1863 with Chinese immigrants fishing at night with light torches near Monterey (Recksiek and Frey 1978). Annual landings remained low (i.e., below 18,144 mt) and at a nominal value until 1985 when the fishery began expanding rapidly due to increasing global demand (CDFW 2020b). Concerns over increases in landings of Market Squid and participation in the fishery from out-of-state vessels led to legislative actions in 1997 and 2001 that provided for the management of the fishery by the California Fish and Game Commission (FGC) and required the FGC adopt a Market Squid Fishery Management Plan (MS FMP) under the 1999 Marine Life Management Act (MLMA). The MS FMP was adopted by the FGC in March 2005 and implemented in April 2005 for management fishing seasons that start April 1 and end March 31 of the following year (CDFW 2005, CDFW 2020b, CDFW 2020c). Market Squid is included under Pacific Fishery Management Council's CPS FMP; however, this fishery is principally managed by the State of California under the MS FMP.

Since the late 1990s, Market Squid has consistently been one of the largest commercial fisheries in California in terms of volume (tons) and ex-vessel value (Sweetnam 2011; Porzio 2015). Measures put in place to ensure long term conservation include a restricted access permit program, a weekend closure, a seasonal catch limit, a network of marine protected areas, and the establishment of a mandatory logbook program in 1999 to replace voluntary logbooks (CDFW 2020b). Since 1998, CDFW has collected information on the Market Squid fishery from three different data sources: (1) landings receipts; (2) commercial fishing logbooks; and (3) dockside sampling. These data are collected to monitor changes in the biological characteristics of Market Squid in the fishery, to track landings, and to characterize the commercial fishery. Samples have also been collected for various research projects to address fecundity, genetics, and stock identification (CDFW 2020b).

2.2. Contemporary Fishery-Dependent Surveys

2.2.1 Port Sampling of Finfish

The modified finfish sampling plan that has been in place since 1996 is based on a stratified random daily method, in which each month represents one stratum. Twelve days are randomly chosen to sample within each month for each port area where the majority of landings occurs. The first boat that begins offloading after the CDFW sampler arrives at the port is selected for sampling.

For each vessel, a total of 25 fish per species are randomly selected during the offload. Hence, the sampling unit is the vessel, and a maximum of 12 sampling units are collected per month. If a sample is not collected on the designated sampling day, the next day is designated a carry-over sampling day, and attempts are made to collect missing samples. If missing samples are still not collected, the samples still needed are carried over to the next sampling day. A sampling day that falls on a Friday does not carry over to the next Monday and samples left at the end of a month are not carried over to the next month.

The design and protocols are applied similarly to each port area where landings occur. Sampling efforts are currently concentrated in three major port complexes: Monterey/Moss Landing (Monterey); Ventura/Port Hueneme (Santa Barbara); and San Pedro/Terminal Island (Los Angeles) (Figure 1). The objectives are to: (1) collect 12 random samples, per port complex, of each species (Pacific Sardine, Pacific Mackerel, Jack Mackerel, and Northern Anchovy) that constitutes at least one percent of the total catch landed; and (2) estimate species composition by volume.

As stated above, a sample is collected by selecting the first vessel that begins offloading after the sampler arrives at the port. The vessel captain is interviewed to collect information on the estimated tonnage caught, fishing location (reported as fishing block, Figure 1), and whether a spotter pilot was used. Other information recorded by the sampler includes the sampling date, landing and sample numbers, vessel name and ID, a landing receipt number or an electronic landing (E-tix) number, incidental species observed, and any other anecdotal information (CDFW 2020a). E-tix is an electronic reporting system, established and maintained in cooperation with the Pacific States Marine Fisheries Commission (PSMFC), that allows fish receivers to record both federal and state managed fishery landings through one application (CDFW 2018; PSMFC 2021). Electronic reporting using E-tix has been required of specific federal fisheries since 2011, but as of 1 July 2019, all California commercial fishery landings were required to be recorded and submitted electronically using E-tix, usually within 3 business days of landing (California Code of Regulations Title 14, section 197). This system has increased efficiency by eliminating paper landing receipts (that have been processed and managed by CDFW since 1933) and by allowing CDFW's Data and Technology Division to replace the outdated Commercial Fisheries Information System previously used to house and manage landings data with the Marine Landings Data System (MLDS). All data submitted using PSMFC's E-Tix are automatically transferred to CDFW's MLDS on a nightly basis (CDFW 2021).

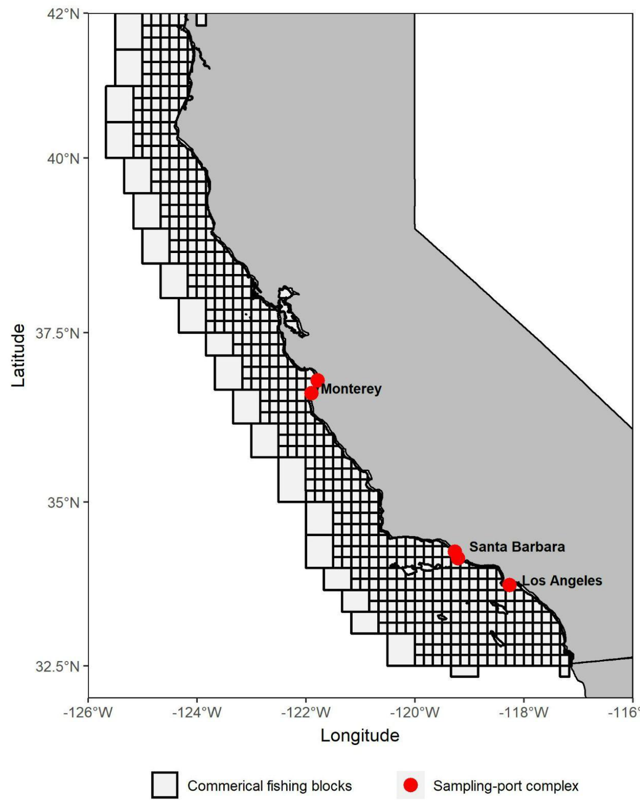

Figure 1. CDFW fishing blocks and locations of the three major port complexes (Monterey, Santa Barbara, and Los Angeles) where samples are collected.

Each sample consists of 25 fish that are pulled randomly from throughout the entire landing as fish are offloaded and moved on a conveyor system or in bins. Only one sample of each species can be collected from one vessel. Visual observations for species composition by volume are made by observing the entire offloading process, and an overall total estimation of CPS percent composition of each species is recorded. Quantitative bucket sampling, a method traditionally used to estimate species composition in landings, ceased in 1993 due to staff reductions. However, it has been used occasionally since 1997, only when a sampler is unable to make an accurate visual percent composition estimation due to dockside sampling logistics (CDFW 2020a). Quantitative bucket sampling requires a sampler to randomly fill a five-gallon bucket with fish every 10-minutes until the entire vessel's catch is unloaded. The fish are then separated by species, and individual fish are counted and weighed collectively to the nearest ounce (CDFW 2020a).

Once a sample is collected, it is processed for biological information in the lab. The entire sample is weighed to the nearest gram and the remaining blood in the pan is weighed after processing the sample. Individual fish are weighed to the nearest gram and a length measurement is taken to the nearest millimeter - fork length (FL) for Pacific and Jack Mackerels and standard length (SL) for Pacific Sardine and Northern Anchovy. Sex is determined, a macroscopic maturity stage is assigned, using codes 1 - 4 (Standard Maturity Guide for Finfish – Appendix CDFW 2020a;

Macewicz et al. 1996), and the otoliths are extracted and stored in labeled gel capsules for ageing by CDFW. Biological, age, and landings data are shared with the stock assessment team at the SWFSC as components for inclusion in models that generate biomass estimates (e.g., Schwartzkopf et al. 2022).

2.2.2. Port Sampling of Market Squid

Initial statistical analyses to determine the number of landings to sample and the optimal number of individual squid to select per fishing boat were conducted by Chun (1999). Due to a limited amount of scientific data available for Market Squid, port sampling data gathered in Monterey from 1989 to 1994 (except 1993) were used by Chun (1999) to represent landings for all ports and years (CDFW 2020b). Chun (1999) recommended that a single sample should be taken from one landing or boatload and should consist of 30 squid randomly sampled from different bins or different parts of the vessel's hold. Length-frequency distributions in 5 mm increments were developed for selected years having sufficient samples and for all years combined, with each sex considered separately as well as combined. The mode from each distribution was used to calculate the number of landings necessary to accurately characterize the length distributions for the fishery. Based on these results, CDFW and SWFSC concluded that each port where the majority of landings occur (e.g., Monterey, Santa Barbara, and Los Angeles) would need to collect a minimum of 160 samples per season to obtain a CV of 10% for length frequency. The optimal number of squid per sample ranged from 23 to 29 when the sexes were combined (CDFW 2020b). In October 1999, another analysis on the number of samples needed to characterize the fishery was conducted using data collected in Southern California in 1998 and 1999 rather than the Monterey data, and the new analysis yielded similar results. As more biological data (e.g., existence of monthly cohorts, Butler et al. 1999) and fishery data (e.g., high variability of fishing effort among months) became available, in January 2000 CDFW decided to use month as the sampling stratum rather than season. Hence, a monthly goal of 25 samples per port was adopted for Southern California and Monterey (CDFW 2020b). In January 2004, staff reductions in all offices made it necessary to reduce the number of samples from 25 to 12 per month, following the established stratified random sampling protocols used for sampling other CPS (CDFW 2020b).

The Market Squid sampling design and protocols are applied similarly to each port area where the majority of landings occur. Sampling efforts are currently concentrated in three major port complexes: Monterey/Moss Landing; Ventura/Port Hueneme; and San Pedro/Terminal Island (Figure 1). The goal is to collect 12 random samples of squid per port-complex each month. Like the finfish protocols, a squid sample is collected by selecting the first vessel that begins offloading after the sampler arrives at the market. Each sample consists of 30 squid that are randomly selected from throughout the entire landing as squid are offloaded and moved on a conveyor system or in bins. Only one sample can be collected from one vessel. Visual observations for species and squid egg case composition by volume are made throughout the entire offloading process and an overall total estimation is recorded (CDFW 2020b). The vessel captain is interviewed to collect information on the estimated tonnage landed, vessel set locations, the number of sets made, gear used, and if a light boat was used. Other information recorded by the sampler includes the sampling date, landing and sample numbers, vessel name and ID, an E-tix or landing receipt number, incidental species observed including Market Squid egg cases, and any other pertinent, anecdotal information (CDFW 2020b).

During the 2007-2008 season, a net disturbance project was initiated to determine how often Market Squid nets interact with squid egg beds (masses of squid egg cases that are laid on the ocean floor) during fishing activities. To achieve this, egg cases are collected during port sampling whenever possible, and boat captains are required to provide information on fishing gear (e.g., squid net vs finfish net, mesh size, leadline type) used and the average fishing depth for all purse seine sets. When egg cases are seen in a landing they are either laid in the net or scraped off the ocean floor. Samplers take note throughout the offload if egg cases appeared fouled or attached to mud or of any other abiotic evidence the net may have touched the bottom. If egg cases are collected, they are examined in the lab to determine the developmental stage of the most mature embryos in the sampled egg cases (CDFW 2020b).

Once a sample is collected, it is processed for biological information in the lab. Individual squid are weighed to the nearest gram and a Dorsal Mantle Length (DML) measurement is taken to the nearest millimeter. Sex is determined, and maturity is determined by recording the presence or absence of spermatophores in the male's spermatophoric sac or duct, and the presence or absence of large clear oocytes in the female ovary. In addition, statoliths are removed and stored in gel capsules, gonads are weighed to the nearest 0.1 g, and a mantle punch is taken from the first five females of every sample. The statoliths and a mantle punch are also taken from the first male of every sample (CDFW 2020b). Mantle punches collected by each port are frozen and later processed by CDFW in Monterey by drying thawed punches in an oven at 60°C for 3 days and recording the dry weight to the nearest 0.0001 g. Statoliths are extracted for ageing later.

The original methods and protocols used by CDFW and SWFSC for collecting gonad and mantle weights (see Macewicz et al. 2004) were revised in 2010 and 2014 after resources and laboratory processing time were identified as critical areas of concern for the egg escapement model to be applied successfully (McDaniel et al. 2015; CDFW 2020b). In July 2010, CDFW switched from preserving gonads in 10% neutral buffered formalin for SWFSC to weigh at a later date, to weighing and recording the fresh gonad weight while processing a sample (CDFW 2020b). In 2014, to account for this change and to reduce laboratory processing time by SWFSC for mantle punches, CDFW and SWFSC conducted experiments to determine the relationship between fresh and preserved gonads and re-evaluate protocols for drying mantle tissues of female Market Squid (McDaniel et al. 2015). These changes led to the adoption of the revised methods now used by CDFW since August 2014, allowing for new data to be combined with historical data. Biological, maturity, and landings data are shared with SWFSC as components for inclusion in egg escapement model estimates, which are used as a proxy for maximum sustainable yield or optimum yield (MSY/OY) (PFMC 2020).

2.2.3 Port Sampling by ODFW and WDFW

Biological samples are taken from vessels that make landings of CPS in Oregon and Washington. Landing information is collected from the dealer purchasing catch from each sampled vessel, including sample date, dealer name, fish ticket (landing receipt) number, vessel name, port of landing, and landed pounds for all species landed. Sample data for all species including CPS are recorded into ODFW's SQL database of commercial fisheries. Washington similarly records sample data into a WDFW database (i.e., BDS). The biological sampling data from both are then sent to PacFIN.

Pacific Sardine landed in Oregon and Washington have typically been harvested in the same geographic areas. Therefore, these two states have agreed to coordinate their sampling programs in order to increase sampling efficiency and random selection of vessels (Wiedoff and Smith 2006) and to ensure that sampling coverage is evenly distributed throughout the Pacific Northwest (Wargo and Hinton 2016). Originally designed for Pacific Sardine, the current sampling program started in 1999 (McCrae 2001; Krutzikowsky and Smith 2012). Sampling occurs from June through September primarily in Astoria, Oregon and Ilwaco and Westport, Washington. The objectives of this sampling survey are: (1) to improve the coast-wide assessment of Pacific Sardine; (2) collect size, age, and maturity data to monitor stock status; and (3) document the extent of bycatch in the CPS fishery. The collection of biological samples is proportional to the number of tons landed in a given port. ODFW collects four samples (of 25 fish each) for every 1,000 mt landed (Krutzikowsky and Smith 2012); whereas WDFW targets 3 samples (of 25 fish each) per 1,000 mt (Wargo and Hinton 2016). Data recorded for each individual fish include body weight (g), standard length (SL, mm), sex, and maturity phase. Macroscopic inspections of gonads are performed to assess sex and maturity, based on the same maturity code system used during port sampling in California and SWFSC CPS surveys. All otoliths collected during sampling are sent to WDFW for ageing (Krutzikowsky and Smith 2012; Wargo and Hinton 2016).

Due to a lack of directed fisheries targeting Pacific Mackerel or Jack Mackerel off Washington and Oregon, systematic state sampling programs for these species have not been developed. Prior to 2016, directed landings of Pacific Mackerel were prohibited in Washington. Pacific Mackerel samples were collected from incidental catches in the Pacific Sardine fishery, and in the North Pacific Hake fishery, and to a lesser extent from Washington recreational fishery catches (Wargo and Hinton 2016). Most landings of Jack Mackerel in Oregon and Washington occur as bycatch in the North Pacific Hake fishery. Jack Mackerel lengths and weights are recorded in the Pacific Northwest from incidental catches in the North Pacific Hake fishery by the Northwest Fisheries Science Center via the NOAA Observer Program, and upon request otoliths and gonad samples are often collected (Pers. comm. Vanessa Tuttle NWFSC). Should a directed fishery or landings with CPS gears occur for either of these two species, sampling protocols similar to those for Pacific Sardine would be followed and evaluated for consistency among states.

WDFW systematically samples Northern Anchovy landed in commercial bait fisheries that operate at Ilwaco and Westport, Washington. Routine sampling began in 2014. Sampling is conducted weekly when there is active fishing, which may occur as early as May, but is more typical in June through September and rarely into October. The goal is to collect at least 1000 individual fish per season. Each sample consists of 100 fish per landed catch (Wargo and Hinton 2016). In addition to length and weight data, otoliths are collected for ageing. In 2014, otoliths were only extracted from the first 10 fish collected in each landing, but since 2015 otoliths have been taken from all 100 fish collected per landed catch. These data are reported to PacFIN. Compared to Washington, landings of Northern Anchovy in Oregon are sporadic and too few across years to support systematic sampling.

In recent years, ODFW has developed a sampling program for Market Squid similar to that of California, as the abundance of this species has increased off Oregon since 2016. Sampling targets single commercial fishery landings, and 30 squid are randomly selected from each landing. Individual squids are measured for DML (mm) and weight (g), and sex is determined by visual inspection of gonads following the same criteria as CDFW. Absent a fishery, WDFW has not developed a specific sampling program for Market Squid.

3. FISHERY-INDEPENDENT SURVEYS

3.1 Historical Fishery-Independent Surveys

Since the 1950s, three broad categories of fishery-independent surveys have been conducted by CDFW and SWFSC. The first category includes quarterly surveys conducted by the California Cooperative Oceanic Fisheries Investigations (CalCOFI) and the annual Juvenile Rockfish Survey. The CalCOFI survey began in 1949 and focuses on monitoring oceanographic conditions and the early life stages (i.e., eggs and larvae) of all species, including CPS in the CCE (McClatchie 2014) while also providing data to develop ecosystem indicators (Thompson et al. 2019), time series of relative abundance (e.g., Lo et al. 1996), spawning stock distributional range (Weber et al. 2012), and environmental parameters for management regulations (e.g., CalCOFI Temperature index in Pacific Sardine Harvest Guideline, PFMC 2020). The Juvenile Rockfish Survey began in 1983 to monitor long term trends in the abundance of young-of-the-year (YOY) rockfish (*Sebastes* spp.), Pacific Hake (*Merluccius productus*), and other groundfish stocks off Central California (Ralston et al. 2015) and has since expanded into Southern California, providing time series of relative abundances for juvenile Pacific Sardine, Northern Anchovy, and Market Squid (Field and Sakamura 2015; Ralston et al. 2018). The second survey category samples fish from the late juvenile stage (i.e., immature recruits) to mature adults (Table 2), including the Sea Survey Program (SSP) conducted by CDFW (Mais 1974; Show and Hill 2021) and the SWFSC spring and summer CPS trawl surveys. The SSP began in 1966 after the collapse of the Pacific Sardine fishery and conducted acoustic surveys using mid-water trawls to estimate CPS school biomass in the CCE using a transect-based design (Mais 1974; Parrish et al. 1985). The SWFSC acoustic trawl survey began in 2006, employing new acoustic technologies to estimate biomass of CPS schools in the CCE, sampling off California in the spring and from British Columbia to the US-Mexico border in summer (Cutter and Demer 2008; Stierhoff et al. 2019) and will be discussed in detail below. The third category includes the Daily Egg Production Method (DEPM) survey that samples all life stages of Northern Anchovy and Pacific Sardine, from eggs to mature adult fish. The DEPM was originally developed to estimate spawning stock biomass of Northern Anchovy in the late 1970s and early 1980s (Parker 1980; Picquelle and Hewitt 1983; Lasker 1985), and thereafter was expanded to Pacific Sardine off California (Lo et al. 1996) and other CPS around the world (Somarakis et al. 2006; Ward et al. 2015; Steer et al. 2017; McGarvey et al. 2021). The DEPM has produced relative abundance indices of spawning stock biomass to assess the central subpopulation of Northern Anchovy (1979-1994, 2017) and the northern subpopulation of Pacific Sardine (2001-2016) off the U.S. Pacific coast (Jacobson et al. 1995; Lo 2001; Lo and Macewicz 2005; Lo et al. 2005, 2013; Dorval et al. 2014, 2016, 2018).

The first DEPM surveys for Pacific Sardine were conducted by CDFW in 1986-1988 off California (Wolf 1988a, b; Scannell et al. 1996), following the methods described in Lasker (1985) for Northern Anchovy. In 1994, an international collaborative survey between the U.S. and Mexico was conducted by CDFW, SWFSC, and the Instituto Nacional de Pesca (INP; now INAPESCA) of Mexico, with the involvement of the fishing industry of both countries. The survey covered the existing CalCOFI grid, from San Ignacio Lagoon, south of Punta Abreojos, Baja California Sur, Mexico to just south of San Francisco, U.S. (Arenas et al. 1996; Deriso et al. 1996; Lo et al. 1996). In total the survey covered 380,000 km^2, and as such, this project remains one of the largest and most comprehensive surveys conducted by Mexico and U.S. on CPS. The *RVs McArthur* and *El Puma* collected ichthyoplankton samples at 4-mile intervals for Pairovet nets (also known as CalVET; Smith et al. 1985; Figure 2a), and 20-mile intervals for Bongo nets (Lo et al. 1996; Figure 2b) between stations and with 40-mile intervals between lines, respectively in U.S. (lines 63.3 - 93.3, https://calcofi.org/field-work/station-positions/113-station-pattern.html) and Mexican (lines 96.7 to 130) waters. The mesh size of the Pairovet net body and the codend are 150 µm and the frame opening is 25 cm (Figure 2a). The Bongo net is made of paired 71 cm rings connected by a central swivel, and the paired nets have a mesh size of 505 µm and the codends have a 333 µm mesh (Figure 2b). This net can fish down to a depth of 210 m at an oblique (~45°) trajectory.

Adult fish samples were randomly collected from either trawl or purse seine catches (Macewicz et a. 1996). The *RV BIP XII* sampled from San Ignacio Lagoon (~ 26.88°N) to Ensenada (~31.87°N), Mexico; the *RV David Starr Jordan* collected fish from San Diego (~32.72°N), US, to Punta Eugenia (~27.85°N), Mexico; and the *RV Mako* sampled from Point Conception (~34.45°N) to San Diego, US. Sonar or spotter planes were used to determine the location of fish schools during daylight, and this information was provided to fishing and research vessels to determine the location of trawling at night. The *RVs David Starr Jordan and Mako* used a high-speed mid-water trawl, with an opening of approximately 15 m x 20 m that was towed through the target area at an average of 4 knots. The *RV BIP XII* used a mid-water trawl with a mouth opening of 4.5 m x 25 m that was towed at 4 - 4.5 knots (Lo et al. 1996; Lo et al. 2005). The duration of trawling varied with school density but did not exceed 30 minutes per haul. Fish samples were taken "quasi-randomly" using a scoop net or a scoop shovel from different portions of the nets into 2-3 buckets. The first 50 fish from the subsample buckets (or all if less than 50) were processed and measured for length and weight, and sex and maturity stage were determined visually. Ovaries from the first 25 mature females of Pacific Sardine and the first 20 mature females of Northern Anchovy, both collected randomly, were extracted and preserved in 10% neutral buffered formalin. Following the random selection process, additional fish were then selected based on their size (small and large) or if they were females with hydrated ovaries. These fish were used to increase length-class ranges for ageing or sample sizes of mature females used to estimate batch fecundity (Macewicz et al. 1996). Histological slides were developed from these preserved ovaries and then used for final assignment of maturity stages. Otoliths from all selected female Pacific Sardine and Northern Anchovy were extracted and preserved in gelatin capsules, but only the first 5 males of each species were processed for otolith collections.

The Larval Census Survey (Picquelle and Hewitt 1983) and the DEPM-Light method (Fissel et al. 2011; MacCall et al. 2016) are similar to the DEPM. In the Larval Census Method, the abundance of eggs and larvae are predicted from both daily egg and larval production, and mortality rates of both eggs and larvae. Assumptions under this method are that the spawning stock biomass is proportional to the average standing stock of larvae summed over four quarters of the year, and that both the reproductive output per unit ton of spawning adults and the survival of juvenile fish are constant parameters. In the DEPM-Light method, the total number of eggs and larval abundance-at-stages are used to back calculate egg production, which is then used to estimate spawning stock biomass, assuming adult parameters (e.g., daily specific fecundity, spawning fraction) stay constant since the last implementation of a DEPM survey.

Starting in the early 2000s, a more formal research separation was agreed upon among the state agencies and SWFSC for the US, in which the state agencies collect and age fish from fishery-dependent port sampling surveys for stock assessments while SWFSC conducts coastwide or seasonal fishery-independent surveys in the CCE to collect samples for age and growth studies and for estimating spawning stock biomass based on DEPM or total stock biomass based on acoustic surveys.

3.2 Contemporary Fishery-Independent Surveys

3.2.1 SWFSC Spring DEPM Survey

The primary objective of the contemporary spring DEPM surveys is to collect eggs, larvae, and adults and estimate adult parameters (weight, fecundity, maturity, sex ratio, spawning frequency) to assess the spawning stock biomass of the northern subpopulation of Pacific Sardine or the central subpopulation of Northern Anchovy off California. A secondary objective is to collect ichthyoplankton data to develop relative abundance indices for assessing species such as Pacific Mackerel (e.g. Lo et al. 2010), and for monitoring the trends in the variability of other managed species such as Jack Mackerel and Market Squid. A third objective of the survey is to collect length and age data for CPS stock assessments. The time frame of these surveys (March-May) has varied little since the mid-1990s, but their spatial frame has changed over time, varying with the abundance of Pacific Sardine and Northern Anchovy and the resources (financial, logistical and/or human) available to support their implementation and completion.

From 1996 to 2002, SWFSC led all DEPM survey efforts, with these surveys occurring from San Diego to San Francisco, the region typically called the DEPM standard area (CalCOFI Line 90 to 60, https://calcofi.org/field-work/station-positions/113-station-pattern.html). During this period, egg and larval samples were collected from the CalCOFI survey using Pairovet and Bongo nets. Additionally, eggs were also collected from the newly developed Continuous Underway Fish Egg Sampler (CUFES). The CUFES was applied to the DEPM survey in 1996 and became a tool to conduct adaptive sampling in 1997 (Checkley et al. 1997, 2000; Lo et al. 2001) based on an egg-density threshold. More Pairovet tows are performed when egg density is greater than the threshold, allowing a more cost-effective sampling and better estimation of variance for egg production. Based on this threshold the spatial frame of the survey is post-stratified into low and high egg-density areas, allowing better estimation of variance for egg production. Juvenile and adult fish were obtained either from trawling during the CalCOFI survey (1997, 2001, 2002) or from commercial fishing vessels (2002). Similar to the 1994 survey, research vessels used a high-speed, mid-water trawl (Lo and Macewicz 2005) to capture fish, and samples were selected from each haul using basket sampling, followed by a random sample of 50 fish from 2-3 baskets. Only U.S. fishing vessels participated in these surveys, collecting fish with various gear types such as gillnets and purse seines (Lo et al. 1996).

Table 2. List of spring DEPM surveys conducted from 1994 to 2021.

Survey Type	Year	Season	Period[1]	Vessel[2]	Sample type	Sample gear
DEPM	1994	Spring	April 18 - May 11	*RV El Puma* (INP, Mex)	Eggs, Larvae	Pairovet, Bongo
			April 18 - May 12	*RV* BIP XII (INP, Mex)	Adults	mid-water trawl
			April 18 - May 11	*RV McArthur* (NOAA, US)	Eggs	Pairovet, Bongo
			April 14 - May 4	*RV* David *Starr Jordan* (NOAA, US)	Adults	High speed-mid water trawl
			April 11 - May 6	*RV Mako* (CDFW, US)	Adults	High speed-mid water trawl
			April 21 - May 14	Mexican *FV* (Ensenada, Mex)	Adults	Purse seine
			April 4- May 3	*FV Pacific Leader* and *Sea-Wave* (Monterey Bay and San Pedro, US)	Adults	Purse seine
CalCOFI/DEPM[3]	1996	Spring	April 15 -May 1	*RV David Starr Jordan* (NOAA, US)	Eggs, Larvae, Juveniles, Adults	Pairovet, CUFES, Bongo, High speed-mid water trawl
	1997		March 11- April 7			
	1998		April 2 - 24			
	1999		April 1 - 23			
	2000		April 3 - 29			
	2001		April 4 - May 3			
	2002		March 27-April 19	*RV McArthur* (NOAA, US)		
DEPM[4]	2003			*RV David Starr Jordan* (NOAA, US) and RV *Roger Revelle* (SIO, US)		
	2004		April 22 - April 27	*RV David Starr Jordan* and *New Horizon* (SIO, US)		
	2005			*RV David Starr Jordan* (NOAA, US)		
	2006		April 6 - May 8	*RV David Starr Jordan* and FSV *Oscar Dyson* (NOAA, US), and *RV New Horizon* (SIO, US)		
	2007		March 27 - May 2007	*RV David Starr Jordan* (NOAA, US) and FV *LB*[5] (CA,US)		
	2008		March 24 -May 1	*RV David Starr Jordan* and *Miller Freeman* (NOAA, US)		
	2009		April 3 -21	*RV Miller Freeman* (NOAA, US) and *FV Frosti* (US)		
	2010		March 23 - May 17			
	2011		March 17 - April 27	*FSV Bell M. Shimada* (NOAA, US) and *FV Frosti* (US)		
	2012		March 17 - April 29	*RV Ocean Starr* and *FSV Bell M. Shimada* (NOAA, US)		
	2013		April 8 - May 3			
	2014		April 15 - May 8			
	2015		March 28 - May 1	*FSV Bell M. Shimada* (NOAA, US)		
	2016		March 22 - April 23	*RV Reuben Lasker* (NOAA, US)		
	2017		March 21 - April 22			
	2021		July 2- October 15			
Growth & Reproductive Biology	1998	Winter	January 7 - 15	*RV David Starr Jordan* (NOAA, US)	Market Squid Paralarvae, Juveniles and Adults	Mid-water and bottom trawls, and Jigging

Notes:

[1]Abbreviations1 preceding vessel names are defined as follows: RV = research vessel; FSV =Fishery survey vessel; and FV= fishing vessel

[2] Indicates that period does not always reflect the number of effective days surveyed.

[3] Indicates that CalCOFI and DEPM surveys were conducted simultaneously on the same research vessel.

[4] Indicates that in years with 2 research vessels, one vessel only conducted DEPM, whereas the other one from CalCOFI conducted trawling for DEPM during at least one leg of the CalCOFI spring survey.

[5] Indicates samples were collected by CPS observers (under contract with Frank Orth and Associates) on board of commercial fishing vessels off Seal Beach, CA.

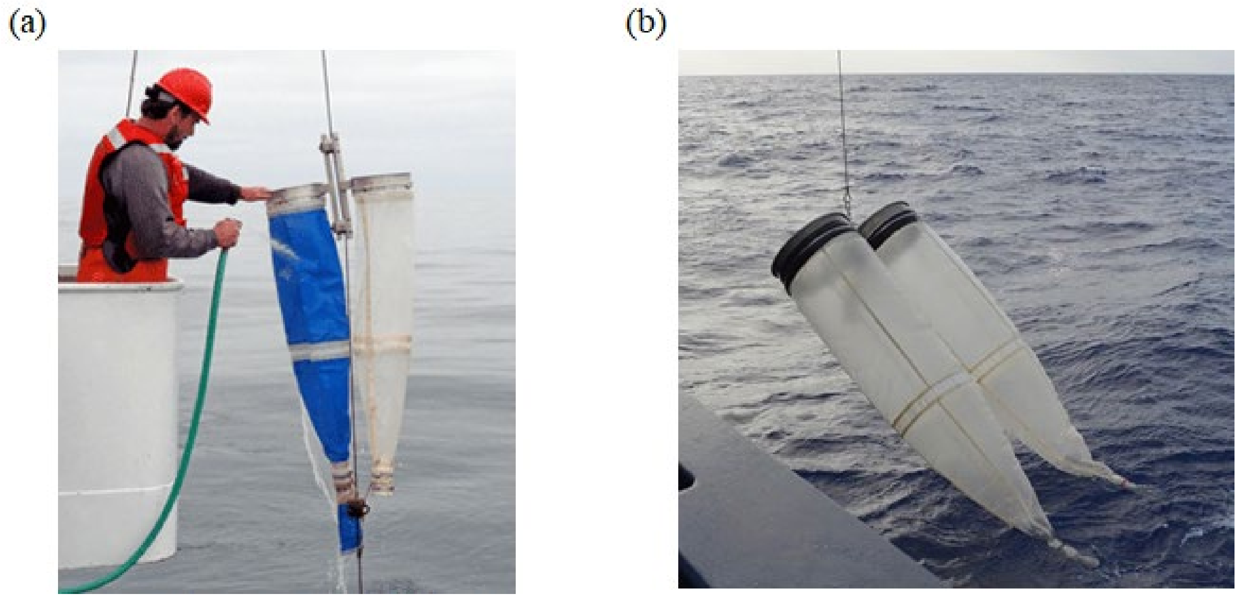

Figure 2. Primary ichthyoplankton gears used during spring and summer surveys: (a) 25 cm diameter Pairovet, and (b) 71 cm diameter Bongo

Starting in 2003, more standardized sampling methods were developed for the DEPM survey, and these methods were consistently applied to each spring survey up to 2014, when spawning stock biomass (SSB) of Pacific Sardine declined markedly and was mostly located off Northern California and Southern Oregon. Surveys were conducted primarily within the DEPM standard area, although in some years the sampling frame was extended up to Vancouver Island, Canada (2006), Washington (2004, 2005, 2008, 2010) or Southern Oregon (2015, 2016; see Appendix Figure A1-A3). In most years (2005, 2008, and 2010-2014), two NOAA research vessels sampled the standard area. Effort was often made for one vessel to start sampling from south of San Francisco and moving southward, and the other starting off San Diego and moving northward; but in years (e.g., 2011-2014) when DEPM surveys were extended into the Pacific northwest, sampling in different directions could not be realized due logistical constraints. During this period, Pairovet and Bongo nets and CUFES were used to collect ichthyoplankton data following the methods developed by the CalCOFI program. CUFES data were also used to develop models of relative abundance of pelagic eggs in relation with temperature and other oceanographic parameters. The Pairovet and Bongo nets were used to collect eggs and larvae in the water column (SWFSC 2003).

Pairovet net tows are cast vertically from 70 m depth to the surface at a retrieval rate of 70 m per minute. Prior to each spring survey, a threshold rate of eggs/min was determined to allow adaptive allocation of Pairovet samples. Threshold rates varied from year to year as a function of expected egg and larval abundances. When the rate of eggs collected exceeded the threshold in 2 consecutive CUFES samples, adaptive Pairovet samples were taken every 4 nautical miles. Adaptive Pairovet tows ceased when 2 consecutive CUFES samples were below the threshold and sampling reverted to standard station sampling. Note that only eggs collected from Pairovet tows and yolk sac larvae collected from Pairovet and Bongo tows were used in estimating egg production for DEPM. More detailed descriptions of both Pairovet and Bongo nets can be found in Smith and Richardson (1977), Lasker (1985), and McClatchie (2014).

Beginning in 2004, NOAA vessels collected Pacific Sardine samples using a Nordic 264 rope trawl (NET Systems, Bainbridge Island, WA), which remains the primary gear used during all CPS surveys. This trawl has a working opening of 300 m^2 when towed at 3.5 knots and a cod-end fitted with an 8 mm mesh liner to retain adult and juvenile fish (Figure 3). The trawl was modified for surface trawling with Polyform floats attached to the head rope and trawl wings. In 2009, a marine mammal excluder device (MMED) comprised of an aluminum grate angled towards an escape panel was built into the net to prevent capture of marine mammals (e.g., dolphins, seals) sea turtles, sharks, and other large-bodied animals (Dotson et al 2010). Details on the characteristics of this trawl are provided by Griffith (2008).

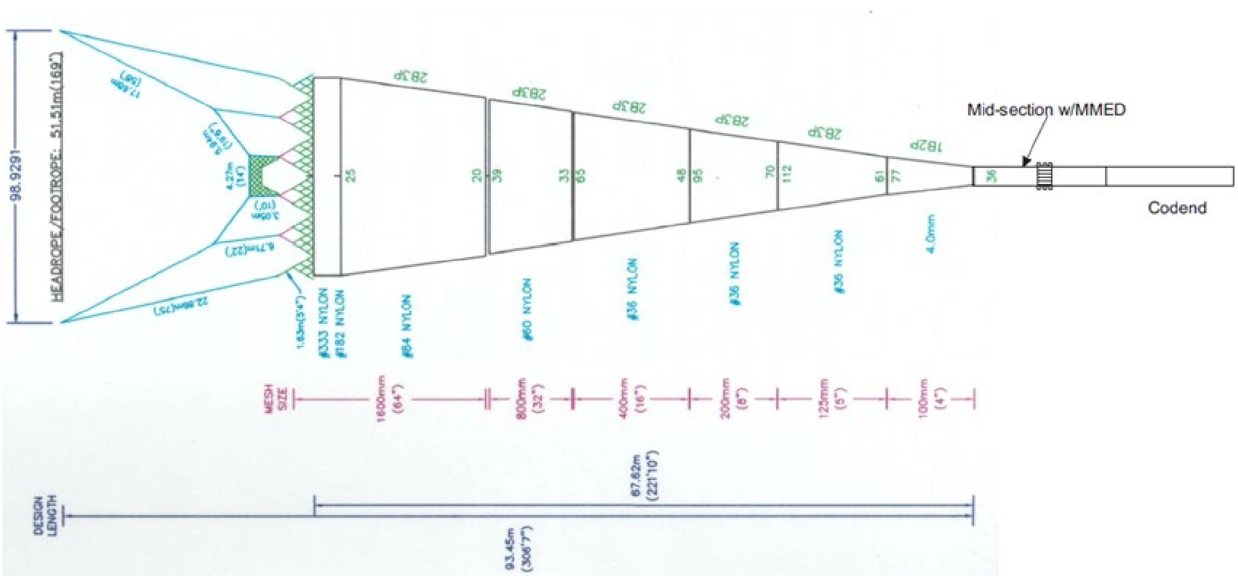

Figure 3. Nordic 264 trawl net with marine mammal excluder device (MMED)

From 2004 to 2021, trawls were allocated based on detections of CPS schools from echosounders or egg densities from CUFES samples (Lo et al. 2005; Stierhoff et al. 2019). As active acoustic technologies have evolved, several different types of echosounders have been used for acoustic detection of CPS schools during daylight. Recent acoustic instruments used during CPS surveys are listed and described in Stierhoff et al. (2019). CPS schools typically migrate from the upper-mixed layer of the water column to the surface after sunset and disperse into a scattered layer (Mais 1974). For this reason, surface trawl sampling was performed from one hour after sunset to sunrise. Up to 50 Pacific Sardine were randomly selected from each positive trawl with more than 75 Pacific Sardine (starting in 2012), or all were sampled if less than 76 Pacific Sardine. During this period, all 50 or 75 fish were measured and weighed, visually sexed and staged for maturity, and then otoliths were removed for ageing. Additional non-random samples were collected for estimating reproductive biological parameters. For example, whole ovaries of hydrated females were extracted, weighed, and preserved in 10% neutral buffered formalin for later use in analyses to estimate batch fecundity.

During the 2015-2016 period, a habitat model developed by Zwolinski et al. (2011) was used to predict the probable location of spawning for Pacific Sardine, and hence the starting line and overall DEPM sampling area. During this period, the Age-1^+ biomass of Pacific Sardine decreased below the management harvest cutoff of 150,000 mt level (Hill et al. 2016), and the spawning biomass (65,118 mt) was mostly located northward outside of the DEPM standard area (Dorval et al. 2016, Dorval et al., unpublished data). Similar to previous years, ichthyoplankton sampling was conducted adaptively, and trawling at night was conducted in areas where the density of Pacific Sardine eggs from CUFES or the acoustic backscatter observed during daylight were the highest. Beginning in 2016, biomass estimates generated by the DEPM method were no longer used in stock assessments (Hill et al. 2017), and hence the SWFSC stopped conducting annual spring surveys. In spring 2017, a Northern Anchovy DEPM was conducted from San Diego to south of San Francisco (Stierhoff et al. 2017; Dorval et al. 2018). For spring 2021, an acoustic trawl survey aimed at collecting data to estimate the biomass of Northern Anchovy was conducted over the same area, but a planned DEPM survey was not completed due to resource, time, and staff limitations associated with the COVID-19 pandemic.

3.2.2 SWFSC Summer CPS Survey

The summer CPS survey spans the CCE from British Columbia, Canada to the US-Mexico border and is conducted from June to September or October. The objective of the survey is to continue building a time series of age and growth and reproductive biology for use in estimating fish biomass (from the acoustic trawl method) and generating life history parameters (e.g. age composition, length at maturity) for use in stock assessments during a period when most CPS managed stocks are distributed within U.S. or Canadian waters. The first summer CPS surveys were conducted in July 2003, 2004, and 2007 off Washington and Oregon, and targeted mostly Pacific Sardine (Table 3; see also Appendix: Figure A4). Combined with DEPM data in those three years, these short summer surveys provided coast-wide distribution of the northern population of Pacific Sardine (e.g., Lo et al. 2010) from April to July. Beginning in 2008 the summer CPS survey extended its temporal frame to sample during 3-4 summer months, included acoustic sampling, and has been conducted annually since 2012 as shown in Table 3 (see also Appendix: Figures A5-

A6). These surveys have occurred under different names (e.g., SaKe, CCES) but the primary objective remains the same for CPS sampling. The data collected are used to assess Pacific Sardine, Pacific Mackerel, and Northern Anchovy stocks. Length and weight data are also generated to monitor the status of Jack Mackerel, Pacific Herring, and Market Squid. Jack Mackerel otoliths and gonad samples are collected to produce age and reproductive data for potential use in future assessment models for this population. No surveys occurred in 2020 due to the COVID-19 pandemic.

Table 3. List of summer CPS surveys from 2003-2021

Survey	Year	Period[1]	Vessel
Washington and Oregon Sardine survey	2003	Jul 06 – Jul 25	*FV Frosti*
Washington and Oregon Sardine survey	2004	Jul 06 – Jul 25	*FV Frosti*
Washington and Oregon Sardine survey	2007	Jul 05 – Jul 10	*RV Miller Freeman*
California Current Ecosystem survey, (CCES)	2008	Jun 30 – Aug 20	*RV David Starr Jordan*
SaKe[2]	2012	Jun 24 – Aug 30	*FSV Bell M. Shimada*
California Current Ecosystem survey, (CCES)	2012	Jul 02 – Aug 31	*RV Ocean Star*
SaKe[3]	2013	Jun 06 – Aug 30	*FSV Bell M. Shimada*
SaKe[4]	2014	Jun 24 – Sep 14	*FSV Bell M. Shimada*
SaKe[5]	2015	Jun 15 – Sep 10	*FSV Bell M. Shimada*
California Current Ecosystem survey, (CCES)	2016	Jun 28 – Sep 23	*FSV Reuben Lasker*
West Coast Pelagic Fish Survey	2017	Jun 19 – Aug 11	*FSV Reuben Lasker*
California Current Ecosystem survey, (CCES)	2018	Jun 26 – Sep 23	*FSV Reuben Lasker*
California Current Ecosystem survey, (CCES)	2019	Jun 13 – Sep 9	*FSV Reuben Lasker*
California Current Ecosystem survey, (CCES)	2021	Jul 02 – Oct 15	*FSV Reuben Lasker*

Notes:

[1]Period does not always reflect number of effective days at sea;

[2]Joint U.S. – Canada Pacific Hake-Sardine Integrated Acoustic Trawl Survey;

[3] Joint U.S. – Canada Integrated Acoustic and Trawl Survey of Pacific Hake and Pacific Sardine;

[4] California Current Ecosystem (CCE14): Acoustic-Trawl Survey of Coastal Pelagic Fishes; and Investigations of hake survey methods, life history, and associated ecosystem;

[5] Joint U.S. – Canada Integrated Acoustic and Trawl Survey of Pacific Hake and Coastal Pelagic Species.

Similar to the DEPM survey, trawl sampling is performed from one hour after sunset to sunrise, using a Nordic 264 rope trawl (NET Systems, Bainbridge Island, WA). From 2008 to 2015, trawl duration was mostly 30 minutes during summer surveys, but varied up to 45 minutes in some years (e.g., 2013 and 2014). Since 2016, the standard trawling time has been 45 minutes, but the duration of the tow could be reduced at the discretion of the trawl lead to avoid protected species or to ensure safety of the ship and the ship's crew (e.g., during poor weather conditions or when a large catch is obtained). The total catch from each trawl is sorted to species or species groups, counted when possible, and weighed using an electronic, motion-compensated scale. In the event of a large catch (i.e., greater than 5 standard fish baskets ~ 17”D x 14”T), a random subsample of 5 fish baskets is taken and the remaining unsorted catch is weighed and discarded. The unsorted portion of large catches is characterized through the species composition, counts, and weights of the 5-basket subsamples. Subsamples of management and ecosystem component species are randomly selected for individual length and weight measurements (managed and monitored species) or to generate a length frequency and group weight (ecosystem component species; Table 1). Depending on the species and year, up to 75 specimens are measured and weighed (Tables 4 and 7). Managed and monitored species are measured to the nearest millimeter for either SL (Pacific Sardine and Northern Anchovy), FL (Pacific Mackerel and Jack Mackerel), or DML (Market Squid). Ecosystem component species are measured for FL using length frequency measurements to a 10-centimeter grouping. Over the years, there was interest in taking lengths on additional species that were commonly caught when time permitted; a list of species was compiled and termed ‘minor target’ (Table 5). For the ‘minor target’ species length frequencies of up to 50 individuals were taken for teleosts and individual lengths and weights were taken for chondrichthyans.

From 2008 through 2015, the subsamples of management species that were processed for length and weight measurements and biological samples varied. In 2008, only Pacific Sardine and Northern Anchovy were individually measured and weighed and biologically sampled, and only ovaries from Pacific Sardine were collected and preserved. Pacific Mackerel and Jack Mackerel were measured using length frequency and group weights with no additional biological sampling except sex determination and maturity stage. Market squid were measured using length frequency and group weights and biologically sampled (ovaries or oviducts were preserved; heads frozen). Beginning in 2012, all four finfish managed and monitored species were individually measured for length and weight and were all biologically sampled. This is also when Market Squid specimens were no longer biologically sampled. In 2013, Market Squid began being individually measured for length and weight.

During the period of 2016-2019, a binning system was utilized for managed and monitored fish species. These specimens were apportioned over twelve predetermined length-bins based on their expected minimum and maximum sizes in trawl catches (Table 6) and a subset randomly selected for biological sampling. The intention of the binning system was to ensure that all length-classes present in each trawl catch were accounted for when estimating the length and age compositions of acoustic biomass. For Pacific Sardine and Northern Anchovy, length-bins were divided into 20 mm increments (Table 6a), while Pacific Mackerel and Jack Mackerel length-bins were in 50 mm increments (Table 6b). Sex and maturity stage were recorded for up to 50 specimens, depending on species, with up to 25 ovary samples per species preserved for further histological analysis. Otoliths for up to 50 specimens were removed for each species to determine age. Pacific Sardine was the only exception to this system: all measured Pacific Sardine specimens were sexed, assigned a maturity stage, and had their otoliths removed (Table 4). In 2016, fin clips were removed from 20 Northern Anchovy and 20 Pacific Sardine for use in studies on population genetics, which changed to 25 fin clips per species in 2017. Beginning in 2018, five designated geographic regions across the survey track were devised for fin clip sampling. The five regions span from Canada to the Columbia River, Columbia River to Cape Mendocino, Cape Mendocino to San Francisco Bay, San Francisco Bay to Point Conception, and Point Conception to the U.S.-Mexico border. Fin clips are now collected from 50 Pacific Sardine and 50 Northern Anchovy specimens from each region and preserved for genetic analysis.

Table 4. Biological processing chart of target species (no larval stages) during the 2019 summer Acoustic Trawl Method (ATM) survey

Species (codes)	**Length frequency**	**Group weight (kg)**	**Length (mm)**	**Individual weight (g)**	**Sex Maturity**	**Ovary saved**	**Otolith**	**DNA**	**Remainder weight (kg)**
Pacific sardine (161729)	N/A	N/A	50 SL	50	50	10	50	50	Yes
Northern Anchovy (161828)	N/A	N/A	50 SL	50	25	10	25	50	Yes
Pacific Mackerel (172412)	N/A	N/A	50 FL	50	25	10+H[1]	25	N/A	Yes
Jack Mackerel (168586)	N/A	N/A	50 FL	50	25	10	25	N/A	Yes
Market Squid[2] (82371)	N/A	N/A	50 ML	50	N/A	N/A	N/A	N/A	Yes
Pacific Herring (551209)	N/A	N/A	50 FL	50	N/A	N/A	N/A	N/A	Yes
Minor target	50	50	N/A	N/A	N/A	N/A	N/A	N/A	Yes

[1]H indicates that all observed hydrated ovaries must be collected

[2]Market Squid should be a random mixture (both large and small sizes);

- Market Squid >= 75mm – individually bag and freeze 10 (>= 75mm) if available in the 50, discard the rest >= 75mm in the 50
- Market Squid < 75mm – individually bag and freeze 10 (< 75mm) if available in the 50, discard the rest <75mm in the 50

In 2021, the summer CPS survey resumed with a geographic extension, sampling from British Columbia, Canada south into Baja California, Mexico, and a temporal extension into October (Table 3). This extension in Mexican waters allowed sampling of a larger portion of the central subpopulation of Northern Anchovy and the southern subpopulation of Pacific Sardine for the first time since 1994 (Deriso et al. 1996; Lo et al. 1996). Minor changes were made to the biological sampling. For this survey, totals of 75 Pacific Sardine and 75 Northern Anchovy were subsampled from each trawl for lengths, weights, sex, and visual maturity. Conversely, only 50 Jack Mackerel and 50 Pacific Mackerel were subsampled (Table 7). In 2021, ovaries were preserved in 10% neutral buffered formalin for a smaller subset of specimens than previous cruises. To determine the accuracy of visual maturity estimates, one or two members of the trawl team for each cruise leg were assigned to visually assess maturity of the managed and monitored fish species. For this study, 10 ovaries of each maturity phase were collected and preserved for each species. Otoliths were removed from 50 Pacific Sardine and 25 individuals from the other three species (Table 7). To increase efficiency, the binning system was no longer used to select individuals for otolith extraction; instead, samples were chosen with a combination of direct selection and randomization. This new method is detailed in Schwartzkopf et al. (2022), but briefly, several of the smallest and largest individuals from the 75 random subsamples were first selected, and then additional fish from the random subsample were chosen to reach either 25 or 50 samples. Plots were then continually generated throughout the survey to make sure that a large enough sample size was being obtained for each length-class, and additional samples were targeted for otolith extraction if a certain length-class was undersampled. This method was found to increase sampling efficiency and was effective in collecting a sufficient number of otolith samples across the entire length distribution relative to previous years (Schwartzkopf et al. 2022). DNA fin clips were taken from up to 50 Pacific Sardine and 50 Northern Anchovy for each of the five geographic regions described above; two additional regions were added off Baja California, Mexico, from the US-Mexico border south to San Quintin, Mexico, and San Quintin to Punta Eugenia, Mexico, for a total of seven geographic regions. Up to 50 Pacific Herring were sampled for lengths and weights only. As time allowed, Market Squid were divided into two length categories (<75 and ≥75 mm DML), and up to 5 per night per category were frozen for further spatial distribution analyses, ageing studies, stock structure, and feeding ecology based on stable isotopes analyses at SWFSC. Due to limited resources in 2021, 'minor target' species (Table 5) were not sampled for length frequencies (except Pacific Herring, *Mola mola*, and sharks). There is also concern that data collected on 'minor target' species has been opportunistic and inconsistent among previous survey years. Therefore, length data for these species will not be collected moving forward. Individual lengths and weights were collected on *Mola mola* and sharks in 2021, but not rays and non-target teleosts; this sampling is expected to continue in future years.

Table 5. List of minor target species collected during summer and spring CPS surveys

Scientific Name	Common Name
FISH	
Alosa sapidissima	American Shad
Atherinopsis californiensis	Jacksmelt
Brama japonica	Pacific Pomfret
Cololabis saira	Pacific Saury
Hypomesus pretiosus	Surf Smelt
Mallotus villosus	Capelin
Merluccius productus (>110mm)	North Pacific Hake or Whiting
Mola mola	Ocean Sunfish
Peprilus simillimus	Pacific Butterfish or Pompano
Sarda chiliensis	Pacific Bonito
Sphyraena argentea	Pacific Barracuda (CA barracuda)
Symbolophorus californiensis	California Lanternfish
Tarletonbeania crenularis	Blue Lanternfish
Thunnus alalunga	Albacore
Triphoturus mexicanus	Mexican Lampfish
(Sebastes spp.[1])	Rockfish
Alopias vulpinus	Thresher Shark
Prionace glauca	Blue Shark
Squalus suckleyi	Pacific Spiny Dogfish
Torpedo californica	Pacific Torpedo Ray
Pteroplatytrygon (*Dasyatis*) *violacea*	Pelagic Stingray
Myliobatis californica	Bat Ray
Hydrolagus colliei	Spotted Ratfish
INVERTEBRATES[2]	
Phacellophora camtchatica	Eggyolk Jelly
Aurelia	Moon Jellys Unident
Chrysaora	Chrysaora Jellyfish
Dosidicus gigas	Humboldt Squid
Onychoteuthis borealijaponicus	Boreal Clubhook Squid

Notes:

[1] Indicates that the identification of all adult Rockfish is required.
[2] Indicates that lengths are not measured for invertebrate species.

Table 6. Bin charts for processing target species bin charts during the 2019 summer Acoustic Trawl (ATM) Method survey

A) Bin Processing Chart for Northern Anchovy and directions (●). Except for Bin 1, all bin sizes were 20 mm

Bin #	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Bin Start	40	51	71	91	111	131	151	171	191	211	231	>=251
Bin End	50	70	90	110	130	150	170	190	210	230	250	
● Divide 25 fish over the 12 bin sizes												
● Record sex and maturity, and take otoliths for the 25 bin selected fish												
● Up to 10 ovaries (any maturity code) will be removed from the 25 bin selected fish (max n=10; if no females in 25 then # ovary save = 0)												
● DNA: take DNA sample for 50 fish from the designated 5 geographic zones												

B) Bin Processing Chart for Mackerels and directions (●). Except for Bin 1, all bin sizes were 50 mm

Bin #	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Bin Start	31	51	101	151	201	251	301	351	401	451	501	>=551
Bin End	50	100	150	200	250	300	350	400	450	500	550	
● Divide 25 fish over the 12 bin sizes												
● Record sex and maturity, and take otoliths for the 25 bin selected fish												
● Up to 10 ovaries (any maturity code) will be removed from the 25 bin selected fish (max n=10; if no females in 25 then # ovary save = 0)												
● Pacific mackerel: additionally, preserve any other hydrated ovaries whole												

Table 7. Target species biological processing chart from the summer 2021 trawl survey

Species (code)	Length (mm)	Individual weight (g)	Sex Maturity	Ovary Saved	Otolith	DNA	Remainder weight (kg)
Pacific sardine (161729)	75 SL	75	75	10+H[1]	50+	50	Yes
Northern Anchovy (161828)	75 SL	75	75	10+H	25+	50	Yes
Pacific Mackerel (172412)	50 FL	50	25	10+H	25+	N/A	Yes
Jack Mackerel (168586)	50 FL	50	25	10+H	25+	N/A	Yes
Pacific Herring (551209)	50 FL	50	N/A	N/A	N/A	N/A	Yes

Note: [1] H indicates that all hydrated ovaries must me collected.

3.2.3 Nearshore CPS Surveys

NOAA research vessels, such as the *Reuben Lasker*, are unable to operate in waters less than 20-30 m depth and therefore unable to sample any CPS aggregations in the shallower, nearshore areas. To address this data gap, a research collaboration with the California Wetfish Producers Association (CWPA) and state agencies (WDFW and CDFW) began in 2012 to estimate biomass in nearshore waters and quantify any sampling bias from offshore NOAA ship surveys. This collaborative effort has since evolved into the California Coastal Pelagic Species Survey (CCPSS) and the Acoustic Trawl Method-Nearshore Survey (ATM-NS).

The CCPSS is an aerial survey of Pacific Sardine and the central stock of Northern Anchovy in California nearshore waters (< 40 m depth) conducted since 2012 (Lynn et al., 2019). The aerial survey is usually conducted aboard a spotter plane (Cessna 175A or 185) or a CDFW aircraft (e.g., Partenavia P.68) in spring and summer off California. During flights an experienced industry spotter estimates CPS school biomass on predetermined transects covering waters from the shoreline to 3600 m offshore. Since 2018 the SWFSC has collaborated with CDFW and CWPA to standardize the aerial survey design and develop methods to estimate bias and variance for aerial biomass. Bias of aerial survey biomass is estimated by conducting purse seine sampling and aerial surveys simultaneously, which is known as point set sampling. During point set sampling, the pilot ("Spotter 1") and an additional observer ("Spotter 2") flies ahead of the fishing boats to determine the distribution of CPS schools over the survey area. The pilot then communicates the location of observed schools and directs the purse seine fishing vessels to wrap selected individual schools. Calibration curves are then developed from school biomass estimated by each spotter and the adjusted purse seine catch taken from each school (Dorval and Lynn 2019; Lynn et al. 2021). Additionally, biological sampling is conducted on each set to determine the species, length, and age composition of captured Pacific Sardine and Northern Anchovy schools. Variance of aerial survey biomass is estimated from replicated flights, during which transects are flown two or three times during daily surveys (Dorval and Lynn 2019; Lynn et al. 2021). In 2020 and 2021, spring and summer aerial surveys were conducted based on a stratified sampling design in two regions, northern and southern California. In each region daily flights were conducted in each stratum. Three transects spaced at 1,200 m from the shoreline were flown at 457 m altitude, with two replicated flights on each transect in a given stratum and a given day (Lynn et al. 2021). Whenever possible, aerial surveys are conducted synoptically with the *FSV Reuben Lasker*, and aerial biomass estimated during these synoptic surveys has been used to adjust the catchability of the acoustic trawl survey for Pacific Sardine and Northern Anchovy, respectively in the 2020 and the 2021 stock assessments of these species (Kuriyama et al. 2020; Kuriyama et al. 2021).

The ATM-NS is a small vessel survey that began in 2019 to extend sampling into nearshore waters off Oregon, Washington, and quantify any potential sampling bias in acoustic biomass (Stierhoff et al. 2020). In 2021, this survey was extended into nearshore waters off California. Off Oregon and Washington, the survey is implemented by SWFSC in collaboration with the West Coast Conservation Group (WCCG) and ODFW; whereas off California the survey is conducted by SWFSC, CDFW and CWPA. Two fishing vessels (*FV*s *Lisa Marie* and *Long Beach Carnage*) have been involved in conducting acoustic surveys and in collecting biological samples in nearshore waters. The *FV Lisa Marie* with WDFW staff onboard sampled CPS in nearshore waters off Washington and Oregon and the *FV Long Beach Carnage* sampled in nearshore waters off southern California, with both *FVs* using purse seines. On the *FV Long Beach Carnage*, CDFW staff are not on board due to space limitations. During sampling from both *FV*s, up to three purse seine sets are made for approximately 60 minutes per set during daytime or nighttime hours, and during each set, three dip net samples are collected. On the *FV Lisa Marie*, after each dip net set, the CPS are sorted, counted, and weighed per species by WDFW staff. Next, the three dip nets are combined and lengths and weights are measured for up to 50 specimens from each species. From these specimens, otoliths are extracted for ageing and maturity is visually assessed for up to 25 or 50 specimens. On the *FV Long Beach Carnage* in 2019, samples from the three dip nets were immediately frozen and later sorted, counted, weighed by species, and 50 fish of each species were processed ashore by CDFW staff. The weights, lengths, maturity codes, and ages from extracted otoliths were recorded for all fish sampled. In 2021, purse seine sampling in nearshore waters was conducted similarly to the sampling conducted in 2019. For spring 2021, the *FV Long Beach Carnage* sampled CPS in nearshore waters from the US-Mexico border to Point Conception, California. For summer 2021, the *FV Lisa Marie* sampled CPS in nearshore waters off Oregon, Washington, and Northern California, and the FV *Long Beach Carnage* sampled from Central to Southern California. The processing methods were the same as those in 2019, with one exception.

In both spring and summer 2021, a biologist from the California Wetfish Producers Association (CWPA) led the nearshore biological sampling on board the *FV Long Beach Carnage*. Dip net sets were sorted, counted, weighed, and 50 fish of each species were frozen on board, and then processed by CDFW staff ashore. Length and age data collected during ATM-NS sampling are used to derive length and age composition for both the nearshore acoustic and aerial biomass estimates.

3.2.4 Disclaimers of data

The methods and data collected during fishery-independent surveys have changed incrementally over time as a result of changing priorities and resources of SWFSC and its partners. With this in mind, the data available from these surveys are not necessarily a continuous time series for all collected data, particularly data collected for non-target species (not managed or monitored fish species). Every effort has been made to collect presence and group weight data of other species in the catch, specifically ecosystem component species. However, when large catches (>5 baskets) occur, only a random subsample of the catch is sorted and identified to the lowest taxon possible. Therefore, the presence of some species may be missed. Furthermore, data on non-target species should be regarded as opportunistic, in which the absence of weight, number, or length data may reflect a lack of time available to record those data or shifts in data collection priorities among years. Every year, there are cruise-specific sampling requests by external scientists, and these collections can lead to data collections for a specific species or group in a specific year and/or specific area that occur only once in the time series. Finally, the configuration and design (e.g., mesh size; depth of trawl) of the trawl net may limit species or sizes of species caught. Consequently, the presence, weight, number, or lengths may not be reflective of what was present in the ocean but rather only reflective of what was caught. Under the 2013 Office of Management and Budget's Memorandum M-13-13: "Open Data Policy—Managing Information as an Asset" Act, the trawl catch data are being shared with the scientific communities and the general public in the National Ocean and Atmospheric Administration's Environmental Research Division's Data Access Program (ERDDAP) database system. Three data tables are currently available, namely the CPS Trawl Life History Haul Catch Data, the CPS Trawl Life History Length Frequency Data, and the CPS Trawl Life History Specimen Data. Metadata describe all components of each data table, but it is important to note that while the contemporary fishery-independent survey dataset is an extensive resource, its main purpose is to produce biological samples for assessing and monitoring commercially important CPS and may have limited use in other capacities.

4. FUTURE RESEARCH

One future research priority is to implement targeted surveys that specifically address data gaps and priorities related to generating life-history parameters of target CPS that are used in stock assessments (PFMC 2018). For example, updating specific parameters related to reproductive biology of CPS (e.g., length- and age-based patterns in maturity, batch fecundity, and spawning frequency) is a worthy investigation, because such information improves the accuracy and precision of estimates of annual reproductive output that can be used to generate biological reference points used to set harvest rates (Hunter and Macewicz 1985a, b; Hunter and Macewicz 2003; Erisman et al. 2014; Barneche et al. 2018). The summer survey runs anywhere from June to October along the entire U.S. west coast, starting off British Columbia, Canada, and usually ending at the US-Mexico border. As a result, this survey does not coincide with the peak spawning season for multiple CPS. For example, the central subpopulation of Northern Anchovy has its peak spawning season from January through April with the main spawning area occurring in the Southern California Bight (Brewer 1978; Hunter and Leong 1981; Richardson 1981; Reiss et al. 2008; Dorval et al. 2018). For the northern subpopulation of Pacific Sardine, spawning peaks off California in April and is typically concentrated offshore and in regions north of Point Conception, although the location of spawning biomass can vary from year to year (Lo et al. 1996, 2005; Dorval et al. 2016, Hill et al. 2019). For Pacific Mackerel, spawning primarily occurs late April through August off California in areas south of Point Conception (Knaggs and Parrish 1973; Dorval et al. 2007; Crone et al. 2019). Surveys designed to collect reproductive data (e.g. maturity, fecundity, spawning frequency) during the peak spawning season and within the main spawning areas for each CPS are necessary to produce the most robust, accurate information on their reproductive biology. As a more efficient and cost-effective complementary survey to collect reproductive data on managed species aboard government vessels, targeted surveys could also be developed on chartered fishing vessels in collaboration with CWPA or directly through port sampling in partnership with CDFW. The implementation of targeted surveys could help overcome many constraints that often prevent the collection of adequate reproductive data from NOAA research vessels. For example, Pacific Sardine and Northern Anchovy tend to concentrate more in nearshore waters during low population biomass and expand into offshore waters as their abundance increases (MacCall 1990). There is also ontogenetic distribution with smaller and younger fish occurring in nearshore shallower waters; and larger and older fish in offshore deeper waters. These spatial differences in biomass, length and age composition of these populations represent significant challenges to adequately estimate parameters such as maturation-at-age and at-length from CPS spring surveys. The use of purse seine vessels could allow simultaneous sampling of both nearshore and offshore areas in order to obtain more representative samples for developing length-based and aged-based maturity ogives.

Although effort has been made to improve the design of the CPS trawl survey, it is not well understood how optimal the process of sampling is for various components of this survey. The process of developing optimal designs for collecting life history data and acoustic data is substantially different. Consequently, conflict of objectives and/or data can occur in surveys that are targeting both data types. For example, increasing the trawl duration from 30 to 45 minutes has increased the number of length and weight samples collected per trawl and species, likely producing better data for estimating acoustic biomass. However, this change may have also reduced the number of trawls per night and the quality of age data that are produced to proportion the acoustic biomass by age. There is evidence that increasing the number of sampling units (i.e., trawls) would increase the precision of proportion-at-age estimates, whereas sampling more CPS from each trawl improves precision of estimated proportion-at-age only slightly (Aanes and

Volstad 2015). Sampling across more trawls improves precision, because fish caught close together tend to be more similar than the overall population (Helle and Pennington 2004). More trawls would potentially give access to more, separate schools of CPS, which would thus provide a more representative dataset of the age and length composition of the population as a whole. But yet, more trawls may not result in better biomass estimates, because sampling unit for biomass estimates is a night rather than a trawl, and therefore trawls from the same night are assigned to a trawl cluster (Stierhoff et al. 2020). Therefore, sampling more trawl clusters may be more effective in increasing precision than sampling more trawls within a cluster (Helle and Pennington 2004). Consequently, developing research to evaluate trade-offs between the different survey objectives in order to optimize sampling is warranted. Along with directed research surveys, simulation-based research should also be considered as stock biomass and associated length and age composition are now available for a total of 21 CPS spring and summer surveys (Tables 2 and 3). This research could help address important questions such as the optimal number of: fish samples that can be taken per trawl; trawls per night and trawls per cluster for estimating CPS biomass and age compositions.

The addition of nearshore sampling in 2012 began to address a big data gap for sampling of CPS for biomass estimates, but more comparative work needs to be conducted to examine how to incorporate these data into stock assessments. Specifically, as a different sampling methodology is completed, the best methods to combine biological samples from multiple sources need to be determined. Additionally, it needs to be determined if estimated life history parameters from nearshore surveys are valid for assessments. One important piece of information that is missing from nearshore sampling in Central and Southern California is reproductive data, which is due to the inability to analyze gonad samples from frozen specimens. Although visual analysis is a quick method to assess maturity, the accuracy of visual maturity data may be low when fish are collected outside the peak spawning season or main spawning area (Hunter and Macewicz 1985a; Murua et al. 2003; Lowerre-Barbieri et al. 2011). Additionally, assessing maturity visually after freezing may cause errors in visual maturity assignment (Lasker 1985). The nearshore sampling that occurs off California during the summer survey is outside the peak spawning season of many CPS, so the ability to collect and analyze gonad samples would contribute to the understanding of reproductive potential and spawning patterns of CPS, especially as all of the contemporary (and most of the historical) fishery-independent surveys were conducted on ships unable to trawl in nearshore waters.

The port sampling of finfish conducted by CDFW collects a large number of biological samples with the objective of accurately representing fishery landings. There is an opportunity to examine how many otoliths need to be aged in order to be representative of the landings. This could be explored through simulations to assess the effect, if any, of ageing fewer samples. Similar research could be conducted to ensure that sufficient samples are being collected during port sampling to accurately represent the landings. While weight, length, and ages are included in the stock assessments for CPS (Kuriyama et al. 2020), the reproductive data have not been used traditionally.

Therefore, there is an interest in conducting research that can make reproductive data from the fishery more useful for stock assessments. For example, the large time-series of data collected by CDFW may be useful for assessing annual variations in the spawning season, which in turn, could affect annual estimates of reproductive output (Lasker 1985; Fitzhugh et al. 2012; Erisman et al. 2014; Barneche et al. 2018). Additionally, a specific collaboration between SWFSC and CDFW to perform histological examinations of maturity on samples collected from the fishery could validate the CDFW visual maturities and improve the overall quality and accuracy of these reproductive data for use in future assessments.

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6. REFERENCES

Aanes, S., and J.H. Volstad. 2015. Efficient statistical estimators of sampling strategies for estimating the age composition of fish. Canadian Journal of Fisheries and Aquatic Sciences 72:938–953.

Arenas, P.R., J.R. Hunter, and L.D. Jacobson. The 1994 Mexico-U.S. Spawning biomass survey for Pacific Sardine (*Sardinops sagax*) and the 1995 CalCOFI Symposium. CalCOFI Reportts, 37: 129-133.

Barneche, D.R., D.R. Robertson, C.R. White, and D.J. Marshall. 2018. Fish reproductive-energy output increases disproportionately with body size. Science 360:642–645.

BCF (Bureau of Commercial Fisheries). 1936. The commercial fish catch of California for the year of 1935. Fish Bulletin No. 49.

Brewer, G.D. 1978. Reproduction and spawning of the northern anchovy, *Engraulis mordax*, in San Pedro Bay, California. California Fish and Game Bulletin 64:175–184.

Butler, J., D. Fuller, and M. Yaremko. 1999. Age and growth of Market Squid (*Loligo opalescens*) off California during 1998. California Cooperative Oceanic Fisheries Investigative Reports 40:191–195.

CDFW (California Department of Fish and Wildlife). 2005. Final market squid fishery management plan. Available online: http://www.dfg.ca.gov/marine/msfmp/ (accessed on 21 November 2014).

CDFW (California Department of Fish and Wildlife). 2018. CDFW Launches Electronic Reporting System for Commercial Fish Landings. CDFW News. https://cdfgnews.wordpress.com/2018/07/06/cdfw-launches-electronic-reporting-system-for-commercial-fish-landings/. (accessed on 11 November 2021).

CDFW (California Department of Fish and Wildlife). 2020a. Coastal Pelagic Species Project, Pelagic Fish Monitoring: A Guide to Port Sampling, Laboratory Sample Processing, and Databases for the CPS Finfish Fishery. Available upon request.

CDFW (California Department of Fish and Wildlife). 2020b. A guide to port sampling, laboratory sampling procedures, and databases for the market squid fishery. State of California – The Resources Agency. Department of Fish and Game, Marine Region, Los Alamitos, CA.

CDFW (California Department of Fish and Wildlife). 2020c. Market Squid, *Doryteuthis (Loligo) opalescens*, Enhanced Status Report. K. Grady, S. Valencia, and D. Porzio (Contributors). https://marinespecies.wildlife.ca.gov/market-squid/management/ (accessed 11 November 2021).

CDFW (California Department of Fish and Wildlife). 2021. Procedures and Resources for Commercial Landings. CDFW Landings Resources. https://wildlife.ca.gov/Fishing/Commercial/Landing-Resources. (accessed on 11 November 2021).

Checkley, Jr., D.M., P.B. Ortner, L.R. Settle, and S.R. Cummings. 1997. A continuous, underway fish egg sampler. Fisheries Oceanography 6:58–73.

Checkley, Jr., D.M., R.C. Dotson, and D.A. Griffith. 2000. Continuous, underway sampling of eggs of Pacific sardine (*Sardinops sagax*) and northern anchovy (*Engraulis mordax*) in spring 1996 and 1997 off southern and central California. Deep Sea Research Part II: Topical Studies in Oceanography 47:1139–1155.

Chun, C. 1999. Sample sizes for market squid sampling. *In* A guide to port sampling, laboratory sampling procedures, and databases for the market squid fishery. pp. 54-62. California Department of Fish and Game, Marine Region, 2020.

Clark, F.N. 1930. Fishing localities off San Pedro from 1919 to 1929 for the California sardine (*Sardina caerulea*). California Fish and Game Bulletin 25:28–39.

Clark, F.N. 1953. *Sardine Investigations*. Internal CDFW report: unpublished. Available upon request.

Clark, F.N., and J.F. Jr. Janssen. 1945a. Movement and abundance of sardine as measured by tag returns. California Fish and Game Bulletin 61:7–43.

Clark, F.N., and J.F. Jr. Janssen. 1945b. Measurement in the losses of sardine tag returns. California Fish and Game Bulletin 61:63–93.

Collins, R.A. 1969. Size and age composition of northern anchovies (*Engraulis mordax*) in the California anchovy reduction fishery for the 1965-66, 1966-67, and 1967-68 seasons. California Fish and Game Bulletin 147:56–74.

Collins R.A., and J.D. Spratt. 1969. Age determination of northern anchovies, *Engraulis mordax*, from otoliths. California Fish Game Bulletin 147:39–55.

Crone, P.R., KT. Hill, J.P. Zwolinski, and M.J. Kinney. 2019. Pacific mackerel *(Scomber japonicus*) stock assessment for U.S. management in the 2019-20 and 2020-21 fishing years. Pacific Fishery Management Council, Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, OR 97220. 112 p.

Cutter, G.R., and D.A. Demer. 2008. California Current Ecosystem Survey 2006. Acoustic cruise reports for NOAA FSV Oscar Dyson and NOAA *FRV David Starr Jordan*. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-SWFSC-415. 98 pp.

Deriso, R.B., J.T. Barnes, L.D. Jacobson, and P.R. Arenas. 1996. Catch-at-age analysis for Pacific sardine (*Sardinops sagax*). California Cooperative Oceanic Fisheries Investigative Reports 37:175–187.

Dorval, E. K. T. Hill, N.C.H. Lo, and J.D. McDaniel. 2007. Pacific mackerel (*Scomber japonicus*) stock assessment for U.S. Management in the 2007-08 fishing season. Pacific Fishery Management Council June 2007 Briefing Book, Agenda Item F.2b. Attachment 1. http://www.pcouncil.org/cps/cpsback.html

Dorval, E. and K. Lynn. 2019. Accuracy and precision of Pacific sardine (*Sardinops sagax)* and northern anchovy (*Engraulis mordax*) biomass estimated from aerial surveys in nearshore waters off California. Progress report. ftp://ftp.pcouncil.org/pub/CPS/CPSMtgOct2019/Documents%20for%20November%202019%20Council%20meeting/

Dorval E., B.J. Macewicz, D.A. Griffith, N.C.H. Lo, and Y. Gu. 2014. Spawning biomass of Pacific sardine (*Sardinops sagax*) estimated from the daily egg production method off California in 2013. U.S. Dep. Commer., NOAA Tech. Memo., NMFS-SWFSC-535. 40 pp.

Dorval E., B.J. Macewicz, D.A. Griffith, N.C.H. Lo, and Y. Gu. 2016. Spawning biomass of Pacific sardine (*Sardinops sagax*) estimated from the daily egg production method off California in 2015.U.S. Dep. Commer., NOAA Tech. Memo., NMFS-SWFSC-560. 41 pp.

Dorval, E., B.J. Macewicz, D.A. Griffith, and Y. Gu. 2018. Spawning biomass of the central stock of northern anchovy (*Engraulis mordax*) estimated from the daily egg production method off California in 2017. U.S. Dep. Commer., NOAA Tech. Memo., NMFS-SWFSC-607. 31 pp.

Dotson, R.C., D.A. Griffith, D.L. King, and R.L. Emmett. 2010. Evaluation of a marine mammal excluder device (MMED) for a Nordic 264 midwater rope trawl. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-SWFSC-455. 19 pp.

Erisman, B.E., A.M. Apel, A.D. MacCall, M.J. Román, and R. Fujita. 2014. The influence of gear selectivity and spawning behavior on a data-poor assessment of a spawning aggregation fishery. Fisheries Research 159:75–87.

Felin, F.E., and J.B. Phillips. 1948. Age and length composition of the Sardine catch off the Pacific coast of the United States and Canada, 1941–42 through 1946–47. California Fish and Game Bulletin 69:1–122.

Field, J., and K. Sakuma. 2015. Ecosystem indicators for the Central California Coast. Fisheries Ecology Division, SWFSC Report.

Fissel, B.E., N.C.H. Lo, and S. Herrick Jr. 2011. Daily egg production, spawning biomass and recruitment for the central subpopulation of northern anchovy 1981–2009. California fishing season. California Cooperative Oceanic Fisheries Investigative Reports 52:116–128.

Fitch, J.E. 1951. Age composition of the southern California catch of Pacific mackerel 1939–40 through 1950–51. California Fish and Game Bulletin 83:1–73.

Fitzhugh, G.R., K.W. Shertzer, G.T. Kellison, and D.M. Wyanski. 2012. Review of size-and age-dependence in batch spawning: implications for stock assessment of fish species exhibiting indeterminate fecundity. Fishery Bulletin 110:413–425.

Griffith, D. A. 2008. Collecting Adult Coastal Pelagic Fish Using the Nordic 264 Rope Trawl: A Guide to Deployment and Sample Processing. Available upon request.

Helle, K., and M. Pennington. 2004. Survey design considerations for estimating the length composition of the commercial catch of some deep-water species in the northeast Atlantic. Fisheries Research 70:55–60.

Hill, K.T., P.R. Crone, E. Dorval, and B.J. Macewicz. 2016. Assessment of the Pacific sardine resource in 2016 for U.S. management in 2016-17. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-SWFSC-501. 562. 171 pp.

Hill, K.T., P.R. Crone, and J. Zwolinski. 2017. Assessment of the Pacific sardine resource in 2017 for U.S. management in 2017-18. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-SWFSC-576. 46 pp.

Hill, K.T., P.R. Crone, and J.P. Zwolinski. 2019. Assessment of the Pacific sardine resource in 2019 for U.S. management in 2019-20. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-SWFSC-615. 130 pp.

Hunter, J.R., and R. Leong. 1981. The spawning energetics of female northern anchovy, *Engraulis mordax*. Fishery Bulletin 79:215–230.

Hunter, J.R., and B.J. Macewicz. 1985a. Measurement of spawning frequency in multiple spawning fishes. In An egg production method for estimating spawning biomass of pelagic fish: application to the northern anchovy, *Engraulis mordax*. Ed. by R. Lasker. NOAA Technical Report NMFS 36:67–77.

Hunter, J. R., and B.J. Macewicz. 1985b. Rates of atresia in the ovary of captive and wild northern anchovy, *Engraulis mordax*. Fishery Bulletin 83:119–136.

Hunter, J.R. and B.J. Macewicz. 2003. Improving the accuracy and precision of reproductive information used in fisheries. Pages 57-68 *in* O.S. Kjesbu, J.R. Hunter and P.R. Witthames, editors. Modern Approaches to Assess Maturity and Fecundity of Warm- and Cold-Water Fish and Squids. Fisken og Havet, Bergen, Norway.

Jacobson, L.D., N.C.H. Lo, S.F. Jr. Herrick, and T. Bishop. 1995. Spawning biomass of the northern anchovy in 1995 and status of the coastal pelagic fishery during 1994. National Marine Fisheries Service, Southwest Fisheries Science Center Admin. Rep. LJ-95-11. 49 pp.

Knaggs, E.H. and R.H. Parrish. 1973. Maturation and growth of Pacific mackerel population, *Scomber japonicus* houttuyn. California Fish and Game Bulletin 59:114–120.

Krutzikowsky, G., and J. Smith. 2012. Oregon's sardine fishery, 2009 summary. Oregon Department of Fish and Wildlife, Newport, OR, 20 pp. Available online: https://www.dfw.state.or.us/mrp/publications/docs/Sardine_fishery_2009.pdf (accessed on 06 October 2021).

Kuriyama, P.T., J.P. Zwolinksi, K.T. Hill, and P.R. Crone. 2020. Assessment of the Pacific Sardine resource in 2020 for U.S. management in 2020-2021. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-SWFSC-628. 171 pp.

Kuriyama, P.T., J.P. Zwolinksi, S.L.H. Teo, and K.T. Hill. 2021. Assessment of the Northern Anchovy (*Engraulis mordax*) central subpopulation in 2021 for U.S. management in 2022. https://www.pcouncil.org/documents/2021/11/anchovy-assessment-draft-11-23-21.pdf/

Lasker, R. 1985. An egg production method for estimating spawning biomass of pelagic fish: application to the northern anchovy, *Engraulis mordax*. U.S. Department of Commerce, NOAA Technical Memorandum NMFS 36. 99 pp.

Lo, N.C.H. 2001. Daily egg production and spawning biomass of Pacific sardine (*Sardinops sagax*) off California in 2001. National Marine Fisheries Service, Southwest Fisheries Science Center Admin. Rep. La Jolla, LJ-01-08. 32 pp.

Lo, N.C.H., and B. Macewicz. 2005. Spawning biomass of Pacific sardine (*Sardinops sagax*) off California in 2004 and 1995. Southwest Fisheries Science Center, National Marine Fisheries Service, SWFSC Admin. Rep. La Jolla, LJ-04-08. 30 pp.

Lo, N.H., Y.A.G. Kuiz, M.J., Cervantes, H.G. Moser, and R.J. Lynn. 1996. Egg production and spawning biomass of Pacific sardine (*Sardinops sagax*) in 1994, determined by the daily egg production method. California Cooperative Oceanic Fisheries Investigative Reports 37:160–174.

Lo, N.C.H., J. R. Hunter, and R. Charter. 2001. Use of a continuous egg sampler for ichthyoplankton survey: application to the estimation of daily egg production of Pacific sardine *(Sardinops sagax*) off California. Fishery Bulletin 99:554–571.

Lo, N.C.H., B.J. Macewicz, and D.A. Griffith. 2005. Spawning biomass of Pacific Sardine from 1994-2004 off California. California Cooperative Oceanic Fisheries Investigative Reports 46:93–112.

Lo, N.C.H., B.J. Macewicz, and D.A. Griffith. 2010. Biomass and reproduction of Pacific sardine off the Pacific northwestern United States, 2003-2005. Fishery Bulletin 108:174–192.

Lo, N.C.H., B.J. Macewicz, and D.A. Griffith. 2013. Spawning biomass of Pacific sardine (*Sardinops sagax*) off U.S. in 2012. U.S. Dep. Commer., NOAA Tech. Memo., NMFS-SWFSC-505. 38 pp.

Lowerre-Barbieri, S.K., N.J. Brown-Peterson, H. Murua, J. Tomkiewicz, D. Wyanski, and F. Saborido-Rey. 2011. Emerging issues and methodological advances in fisheries reproductive biology. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 3:32–51.

Lynn, K., E. Dorval, D. Porzio, and T. Nguyen. 2019. California nearshore aerial survey biomass estimates for Pacific sardine (*Sardinops sagax*) and northern anchovy (*Engraulis mordax*). Draft Report. ftp://ftp.pcouncil.org/pub/CPS/CPSMtgOct2019/Documents%20for%20November%202019%20Council%20meeting/

Lynn, K., E. Dorval, D. Porzio, T. Nguyen, and D. Myers. 2022. Nearshore Aerial Survey Biomass for the 2021 Northern Anchovy Stock Assessment. https://www.pcouncil.org/events/central-subpopulation-of-northern-anchovy-stock-assessment-review-panel-to-be-held-online-december-7-10-2021/

MacCall, A.D. 1990. Dynamic geography of marine fish populations. University of Washington Press, Seattle, Washington. 153 p.

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.

Macewicz, B.J., J.J. Castro-Gonzalez, C.E. Cotero-Altamrano, and J.R. Hunter. 1996. Adult reproductive parameters of Pacific sardine (*Sardinops sagax*) during 1994. California Cooperative Oceanic Fisheries Investigative Reports 37:140–151.

Macewicz, B.J., J.R. Hunter, N.C.H. Lo, and E.L. LaCasella. 2004. Fecundity, egg deposition, and mortality of market squid (*Loligo opalescens*). Fishery Bulletin 102:306–327.

Mais, K. F. 1974. Pelagic fish surveys in the California Current. California Fish and Game Bulletin 162:1–79.

McClatchie, S. 2012. California Ecosystem Survey (CCE) Survey. Final Project Instructions,

submitted June 18, 2012. Available upon request.
McClatchie, S. 2014. Regional fisheries oceanography of the California current system, the CalCOFI program. Springer Netherlands, First ed. 235p.
McClatchie S, J. Field, A.R. Thompson, T. Gerrodette, M. Lowry, P.C. Fiedler, W. Watson, K.M. Nieto, and R.D. Vetter. 2016. Food limitation of sea lion pups and the decline of forage off central and southern California. Royal Society Open Science 3:150628.
McCrae, J. 2001. Oregon's sardine fishery, 2000. Oregon Department of Fish and Wildlife, Newport, OR, 10 pp. Available online: https://www.dfw.state.or.us/MRP/publications/docs/sardine_1.pdf (accessed on 06 October 2021).
McGarvey, R., M.A. Steer, J.J. Smart, D.J. Matthews, and J.M. Matthews. 2021. Generalizing the Parker equation of DEPM: Incorporating the size dependence of population number and reproductive inputs to estimate spawning biomass and female population by size. Fisheries Research. doi: 10.1016/j.fishres.2021.105992
McHugh, J.L., and E.H. Ahlstrom. 1951. Is the Pacific Sardine Disappearing? The Scientific Monthly, 72(6): 377-384.
McDaniel, J., E. Dorval, J. Taylor, and D. Porzio. 2015. Optimizing biological parameterization in the egg escapement model of the Market Squid, (*Doryteuthis opalescens*), population off California. U.S. Dep. Commer., NOAA Tech. Memo., NMFS-SWFSC-551. 23 pp.
Morejohn, V.G., J.T. Harvey, and L.T. Krasnow. 1978. The importance of *Loligo opalescens* in the food web of marine vertebrates in Monterey Bay, California. California Fish and Game Bulletin 169:67–98.
Murua, H., G. Kraus, F. Saborido-Rey, A. Thorsen, P. Witthames, and S. Junquera. 2003. Procedures to estimate fecundity of wild collected marine fish in relation to fish reproductive strategy. Journal of Northwest Atlantic Fishery Science 33:33–54.
NOAA (National Oceanic and Atmospheric Administration). 2020. History of the California Cooperative Oceanic Fisheries Investigations (CalCOFI) program. https://www.fisheries.noaa.gov/west-coast/science-data/history-california-cooperative-oceanic-fisheries-investigations-calcofi (accessed 11 November 2021).
Parker, K. 1980. A direct method for estimating northern anchovy, *Engraulis mordax*, spawning biomass. Fishery Bulletin 78:541–544.
Parrish, R.H., D.L. Mallicoate, and K.F. Mais. 1985. Regional variations in the growth and age composition of northern anchovy, *Engraulis mordax*. Fishery Bulletin 83:483–496.
PFMC (Pacific Fishery Management Council). 1998. Amendment 8 (To the Northern Anchovy Fishery Management Plan) incorporating a name change to: The Coastal Pelagic Species Management Plan. Available at https://www.pcouncil.org/documents/1998/12/cps-fmp-amendment-8-feis.pdf/
PFMC (Pacific Fishery Management Council). 2018. Research and Data Needs. https://www.pcouncil.org/documents/2018/09/research-data-needs-document-september-2018.pdf/. (accessed 03 December 2021).
PFMC (Pacific Fishery Management Council). 2019. Coastal Pelagic Species Fishery

Management Plan as Amended through Amendment 17.
PFMC (Pacific Fishery Management Council). 2020. Status of the Pacific Coast Coastal Pelagic Species Fishery and Recommended Acceptable Biological Catches. Stock Assessment and Fishery Evaluation for 2019-20. Available at https://www.pcouncil.org/documents/2021/01/2020-cps-safe-december-2020.pdf/.
Picquelle, S.J., and R.P. Hewitt. 1983. The northern anchovy spawning biomass for the 1982-1983 California fishing season. California Cooperative Oceanic Fisheries Investigative Reports 24:16–28.
Porzio, D. 2015. Review of Selected California Fisheries for 2014. California Cooperative Oceanic Fisheries Investigative Reports 56:1–30.PSMFC (Pacific States Marine Fisheries Commision). 2021. E-Tix Portal. https://etix.psmfc.org/Account/Login. (accessed 11 November 2021).
Ralston, S., J.C. Field, and K.M. Sakuma. 2015. Long-term variation in a central California pelagic forage assemblage. Journal of Marine Systems 146:26–37.
Ralston, S., E. Dorval, L. Ryley, K.M. Sakuma, and J.C. Field. 2018. Predicting market squid (*Doryteuthis opalescens*) landings from pre-recruit abundance. Fisheries Research 199:12–18.
Recksiek, C.W., and H.W. Frey. 1978. Background of market squid research program, basic life history, and the California fishery. In Biological, oceanographic, and acoustic aspects of the market squid, *Loligo opalescens* Berry, C.W. Recksiek, and H.W. Frey, eds. California Fish and Game Bulletin 169, 185 pp.
Reiss, C.S., D.M. Checkley Jr., and S.J. Bograd. 2008. Remotely sensed spawning habitat of Pacific sardine (*Sardinops sagax*) and Northern anchovy (*Engraulis mordax*) within the California Current. Fisheries Oceanography 17:126–136.
Richardson S.L. 1981. Spawning biomass and early life of northern anchovy, *Engraulis mordax*, in the northern subpopulation off Oregon and Washington. Fishery Bulletin 78:855–876.
Robinson, H., J. Thayer, W.J. Sydeman, and M. Weise. 2018. Changes in California sea lion diet during a period of substantial climate variability. Marine Biology 65. https://doi.org/10.1007/s00227-018-3424-x.
Scannell, C.L., T. Dickerson, P. Wolf, and K. Worcester. 1996. Application of an egg production method to estimate the spawning biomass of Pacific Sardines off southern California in 1986. Southwest Fisheries Science Center, National Marine Fisheries Service, SWFSC Admin. Rep. La Jolla, LJ-96-01. 37 pp.
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. Dep. Commer., NOAA Tech. Memo., NOAA-SWFSC-659
76 pp.
Scofield 1926. The Sardine at Monterey: Dominant size-classes and their progression, 1919-1923. California Fish and Game Bulletin 11:191–222.
Sette, O.E. 1926. Sampling the California Sardine: a study of the adequacy of various systems at

Monterey. California Fish and Game Bulletin 11:67–190.

Show, C., and K.T. Hill. 2021. Overview of pelagic fish surveys, 1950-1989, in the California Current region and documentation of the legacy database. U.S. Dep. Commer., NOAA Tech. Memo., NOAA-SWFSC-650. 62 pp.

Smith, P.E., and S.L. Richardson. 1977. Standard techniques for pelagic fish egg and larva surveys. FAO Fisheries Technical Paper No. 175: 100 pp.

Smith, P.E., W. Flerx, and R. Hewitt 1985. The CalCOFI vertical egg tow (CalVET) net. R. Lasker (editor), An egg production method for estimating spawning biomass of pelagic fish: application to the northern anchovy, *Engraulis mordax*. U.S. Department of Commerce, NOAA Technical Memorandum NMFS 36:27–32.

Somarakis, S., K. Ganias, A. Siapatis, C. Koutsikopoulos, A. Machias, C. Papaconstantinou, 2006. Spawning habitat and daily egg production of sardine (*Sardina pilchardus*) in the eastern Mediterranean. Fisheries Oceanography 15:281–292.

Steer, M.A, R. McGarvey, A. Oxley, A.J. Fowler, G. Grammer, T.M. Ward, E. Westlake, D. Matthews, and J. Matthews, J. 2017. Developing a fishery independent estimate of biomass for Snapper (*Chrysophrys auratus*). South Australian Research and Development Institute (Aquatic Sciences), Adelaide (Australia); FRDC Project 516 2014/019. 97 pp.

Stierhoff, K.L., J.P. Zwolinski, J.S. Renfree, and D.A. Demer. 2017. Report on the collection of data during the acoustic-trawl and Daily Egg Production Methods survey of coastal pelagic fish species and krill (1704RL) within the California Current Ecosystem, 21 March to 22 April 2017, conducted aboard fisheries survey vessel *Reuben Lasker*. U.S. Dep. Commer., NOAA Tech. Memo., NMFS-SWFSC-582. 26 pp.

Stierhoff, K.L., J.P. Zwolinski, and D.A. Demer. 2019. Distribution, biomass, and demography of coastal pelagic fishes in the California Current Ecosystem during summer 2018 based on acoustic-trawl sampling. U.S. Dep. Commer., NOAA Tech. Memo., NMFS-SWFSC-613. 83 pp.

Stierhoff, K.L., J.P. Zwolinski, and D.A. Demer. 2020. Distribution, biomass, and demography of coastal pelagic fishes in the California Current Ecosystem during summer 2019 based on acoustic-trawl sampling. U.S. Dep. Commer., NOAA Tech. Memo., NMFS-SWFSC-626. 87 pp.

Sweetnam, D. 2011. Review of selected California Fisheries for 2010. California Cooperative Oceanic Fisheries Investigative Reports, Fisheries Review 52:13–35.

SWFSC (Southwest Fisheries Science Center). 2003. Southwest Regional Standard Operating Protocols for: CalCOFI Surveys, Cowcod Conservation Area Surveys, DEPM Sardine Biomass Surveys. *In NOAA Fisheries Protocols for Ichthyoplankton Surveys*. Available upon request.

Thompson, W.L. 1926. The California sardine and the study of the available supply. California Fish and Game Bulletin 11:5–66.

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 Investigative Reports 60:1–65.

Ward, T.M., G. Grammer, A. Ivey, J. Carroll, J. Keane, J. Stewart, and L. Litherland. 2015. Egg distribution, reproductive parameters and spawning biomass of Blue Mackerel, Australian Sardine and Tailor off the east coast during late winter and early spring. South Australian Research and Development Institute (Aquatic Sciences), Adelaide (Australia); FRDC Project 2014/033. 77 pp.

Ware, D.M. 1999. Life history of Pacific sardine and a suggested framework for determining a BC catch quota. Canadian Stock Assessment Secretariat Research Document, 99/204. 19 pp.

Wargo, L., and K. Hinton. 2016. Washington review of commercial fisheries, 2014-2015 sardine and mackerel and 2014 anchovy. Washington Department of Fish and Wildlife, Montesano, WA, 25 pp. Available online: https://wdfw.wa.gov/sites/default/files/publications/01883/wdfw01883.pdf (accessed 06 October 2021).

Weber, E.D., and S. McClatchie. 2012. Effect of environmental conditions on the distribution of Pacific mackerel (*Scomber japonicus*) larvae in the California Current system. Fishery Bulletin 110:85–97.

Wiedoff, B., and J. Smith. 2006. Oregon's sardine fishery, 2006 summary. Oregon Department of Fish and Wildlife, Newport, OR, 20 pp. Available online: https://www.dfw.state.or.us/mrp/publications/docs/sardine_7.pdf (accessed on 06 October 2021).

Wolf, P. 1988a. Status of the spawning biomass of the Pacific sardine, 1987-88. Calif. Dep. Fish Game, Mar. Res. Div., Rep. to the legislature, 9 pp.

Wolf, P. 1988b. Status of the spawning biomass of the Pacific sardine,1988-1989. Calif. Dep. Fish Game, Mar. Res. Div., Rep. to the legislature, 8 pp.

Yaremko, M.L. 1996. Age determination in Pacific sardine, *Sardinops sagax*. U.S. Dep. Commer., NOAA Tech. Memo., NMFS-SWFSC-223. 33 pp.

Zwolinski, J.P., R.L. Emmett, and D.A. Demer. 2011. Predicting habitat to optimize sampling of Pacific sardine (*Sardinops sagax*). ICES Journal of Marine Science 68:867–879.

7. APPENDIX: Map of trawling locations for the SWFSC spring and summer surveys

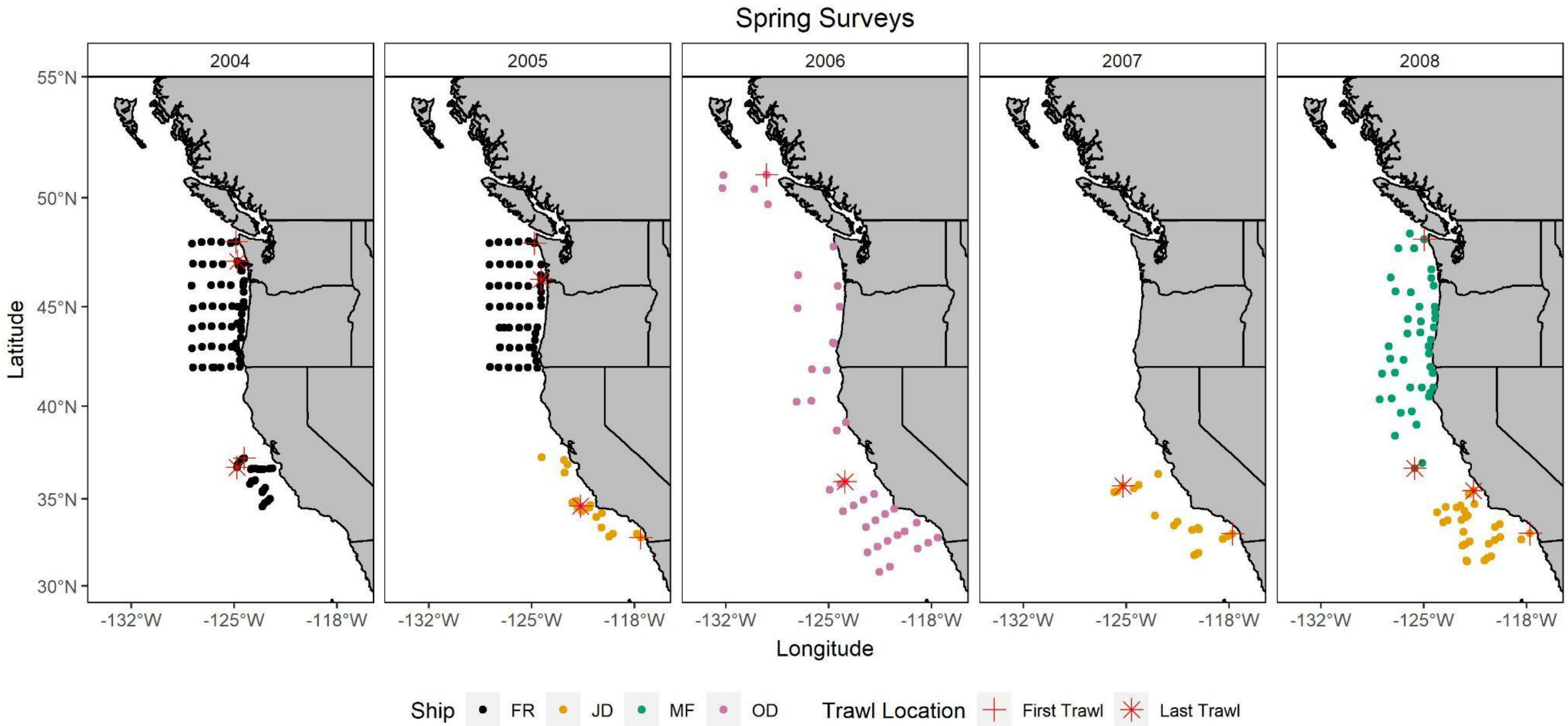

Figure A1. Map of the trawling locations and ships used during the SWFSC spring trawl surveys from 2004 to 2008. The ships used include the *FV Frosti* (FR), and NOAA *RVs David Star Jordan* (JD), *Miller Freeman* (MF), and *FSV Oscar Dyson* (OD). Also included are the first (red plus symbol) and last (red asterisk symbol) trawl locations for each survey. In 2008, sampling using purse seines was conducted by commercial fishing vessels, but were not included on the map as there was no associated longitude or latitude.

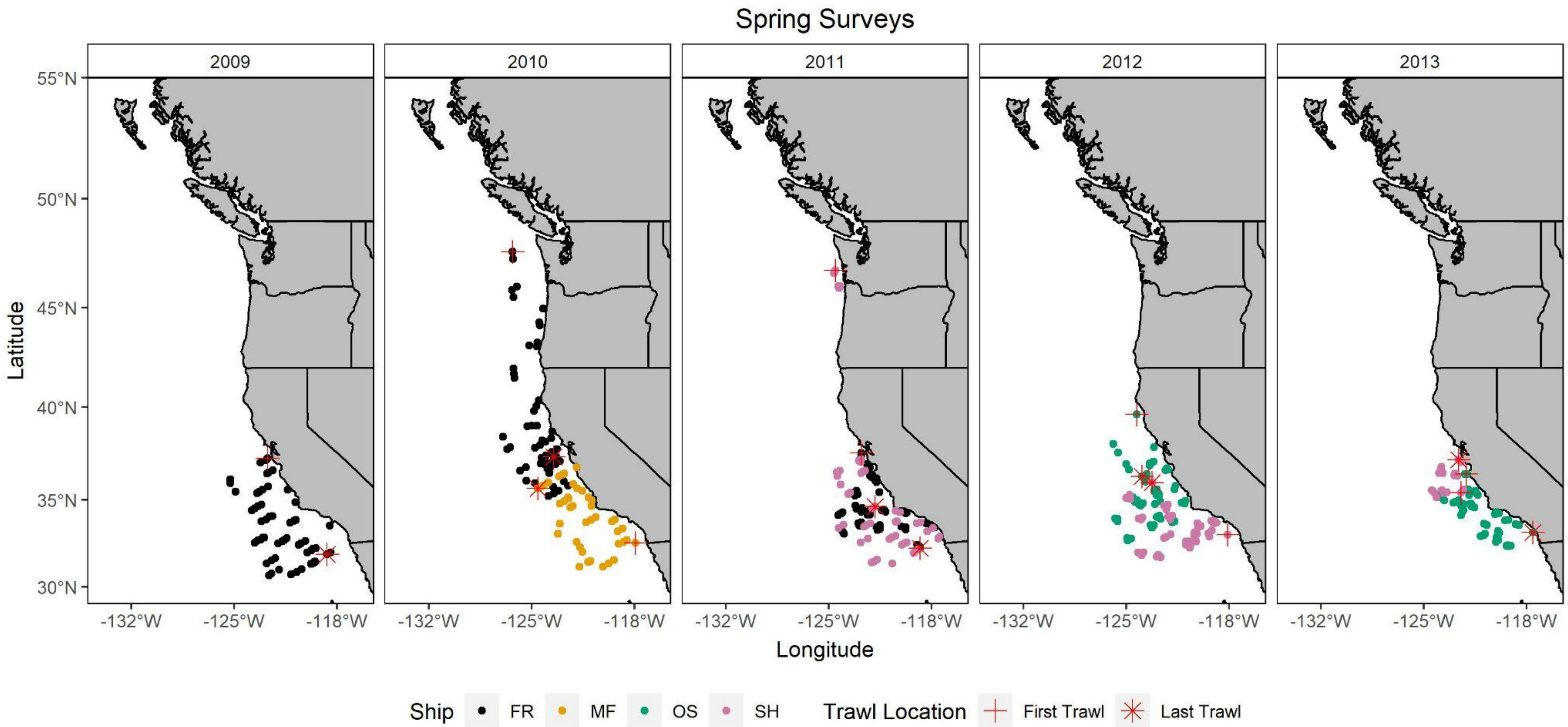

Figure A2. Map of the trawling locations and ships used during the SWFSC spring trawl surveys from 2009 to 2013. The ships used include the *FV Frosti* (FR), *RV Ocean Star* (OS), and NOAA *RVs Miller Freeman* (MF), and *Bell M. Shimada* (SH). Also included are the first (red plus symbol) and last (red asterisk symbol) trawl locations for each survey.

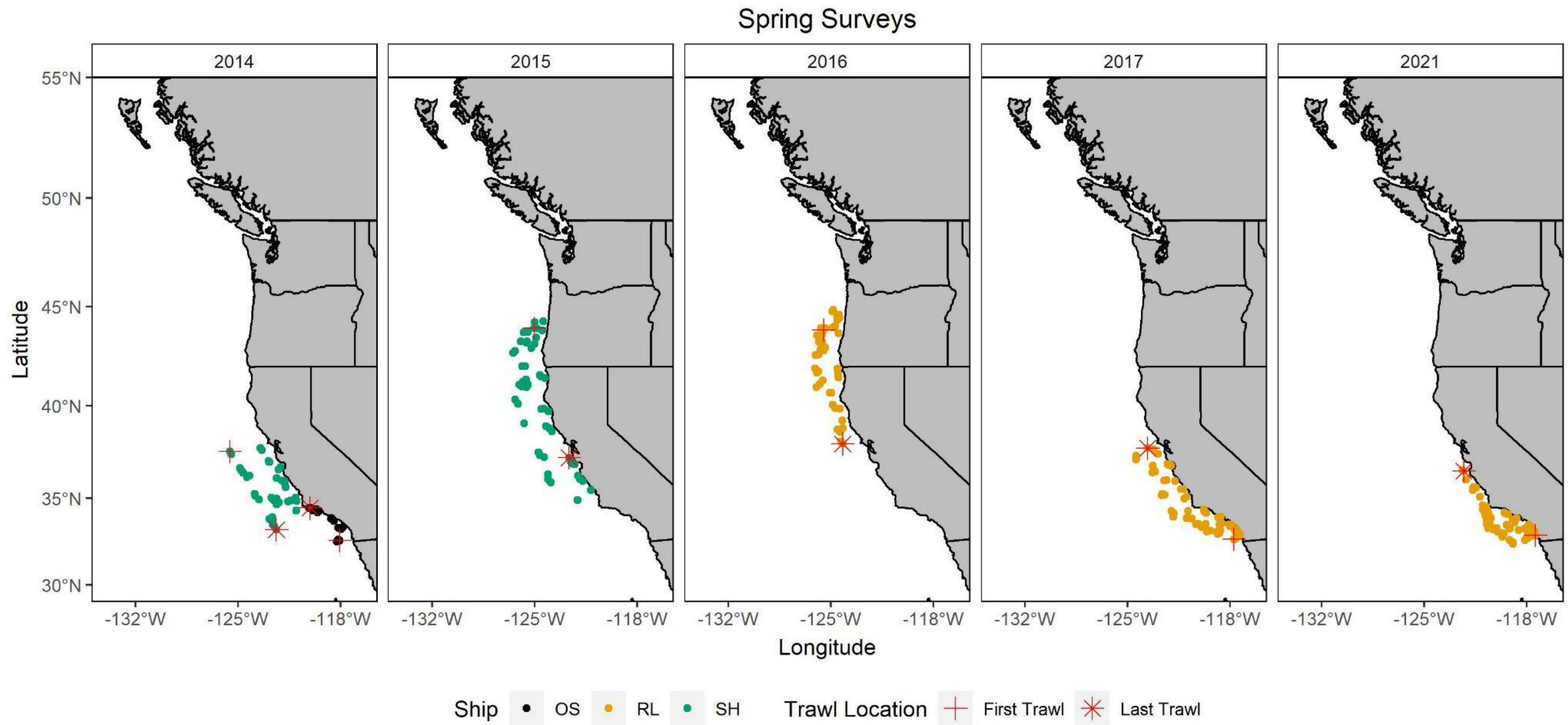

Figure A3. Map of the trawling locations and ships used during the SWFSC spring trawl surveys from 2014 to 2021. The ships used include the RV Ocean Star (OS), and NOAA RVs *Reuben Lasker* (RL) and *Bell M. Shimada* (SH). Also included are the first (red plus symbol) and last (red asterisk symbol) trawl locations for each survey.

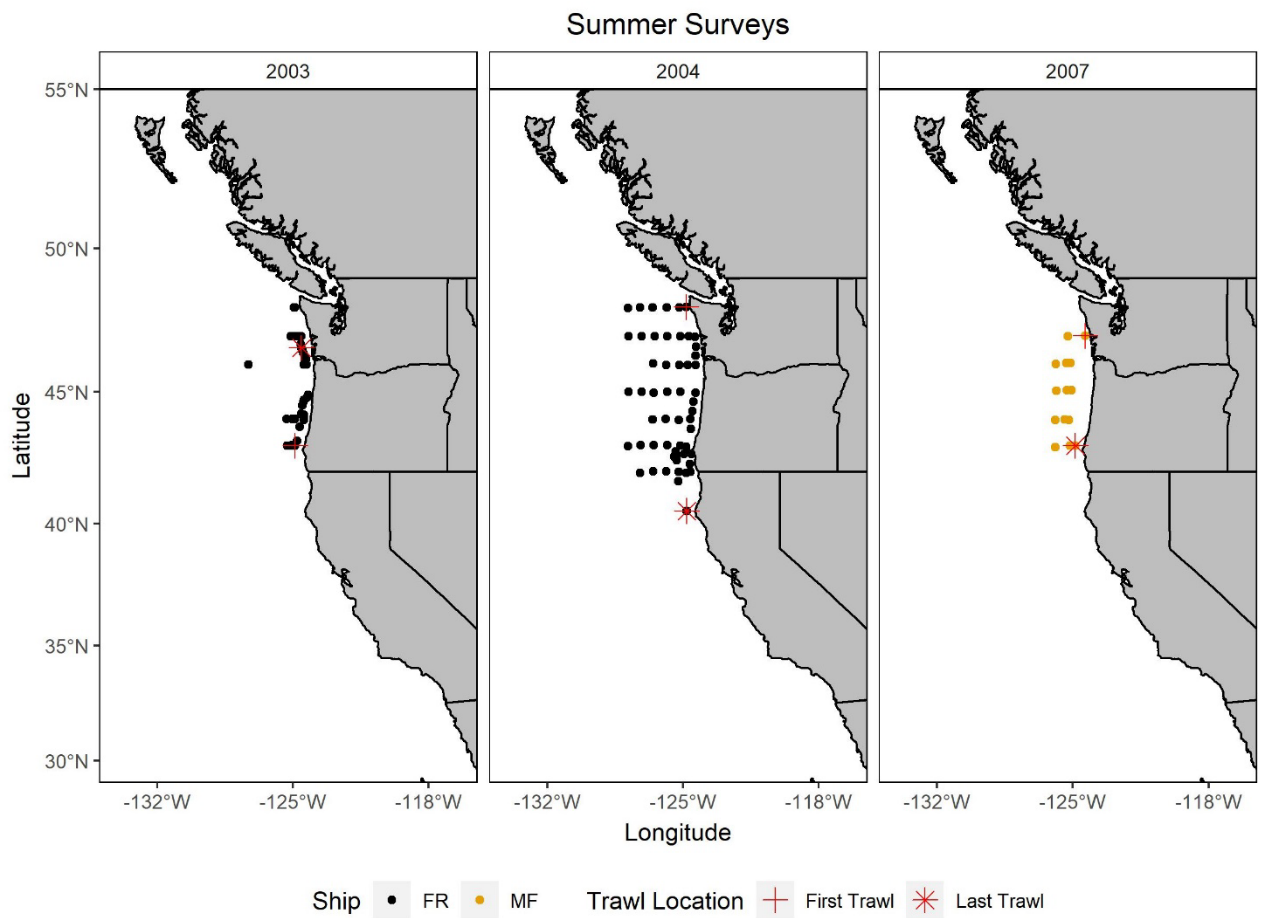

Figure A4. Map of the trawling locations and ships used during the SWFSC Washington and Oregon Sardine summer survey from 2003 to 2007. The ships used include the *FV Frosti* (FR) and NOAA RV *Miller Freeman* (MF). Also included are the first (red plus symbol) and last (red asterisk symbol) trawl locations for each survey.

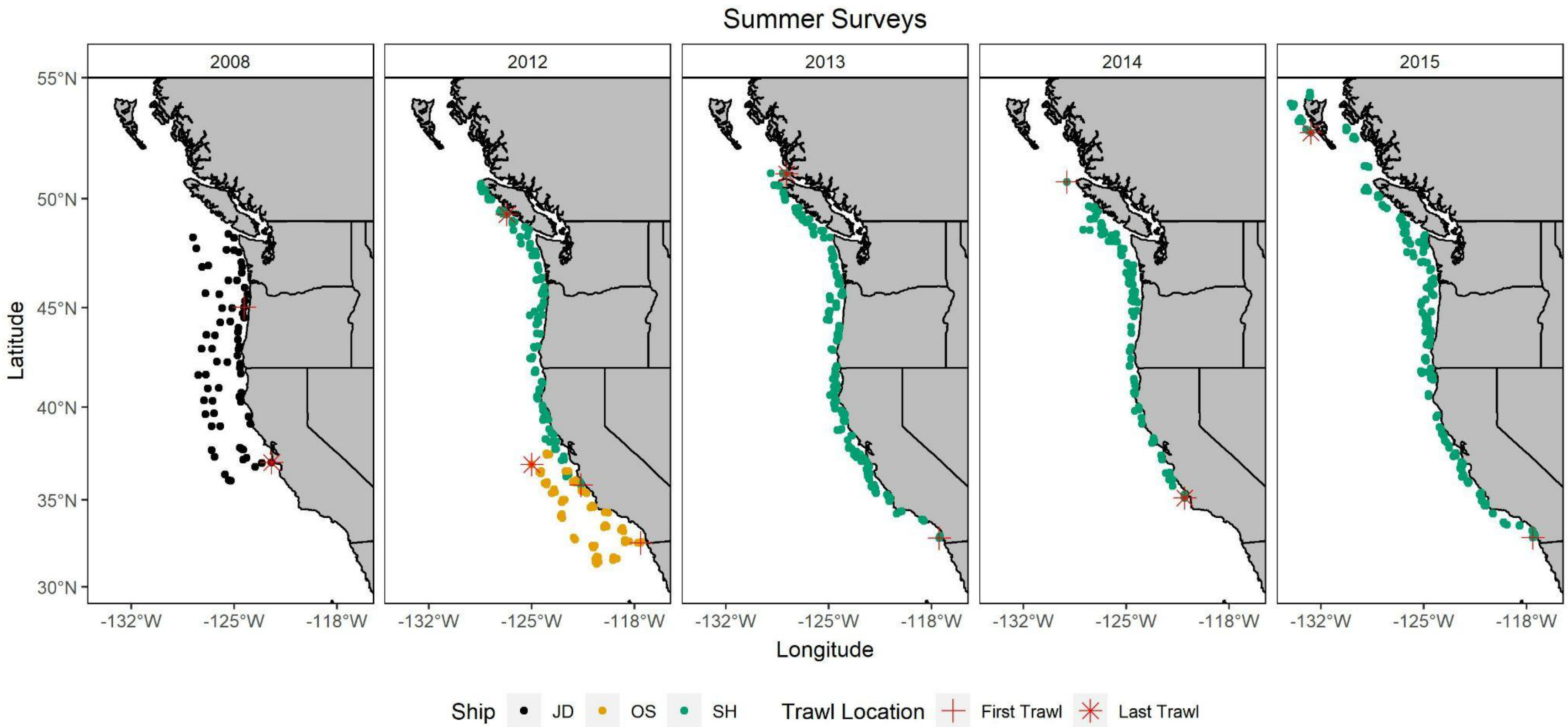

Figure A5. Map of the trawling locations and ships used during the coastwide SWFSC summer trawl surveys from 2008 to 2015. The ships used include the *RV Ocean Star* (OS) and NOAA *RV David Star Jordan* (JD) and *FSV Bell M. Shimada* (SH). Also included are the first (red plus symbol) and last (red asterisk symbol) trawl locations for each survey.

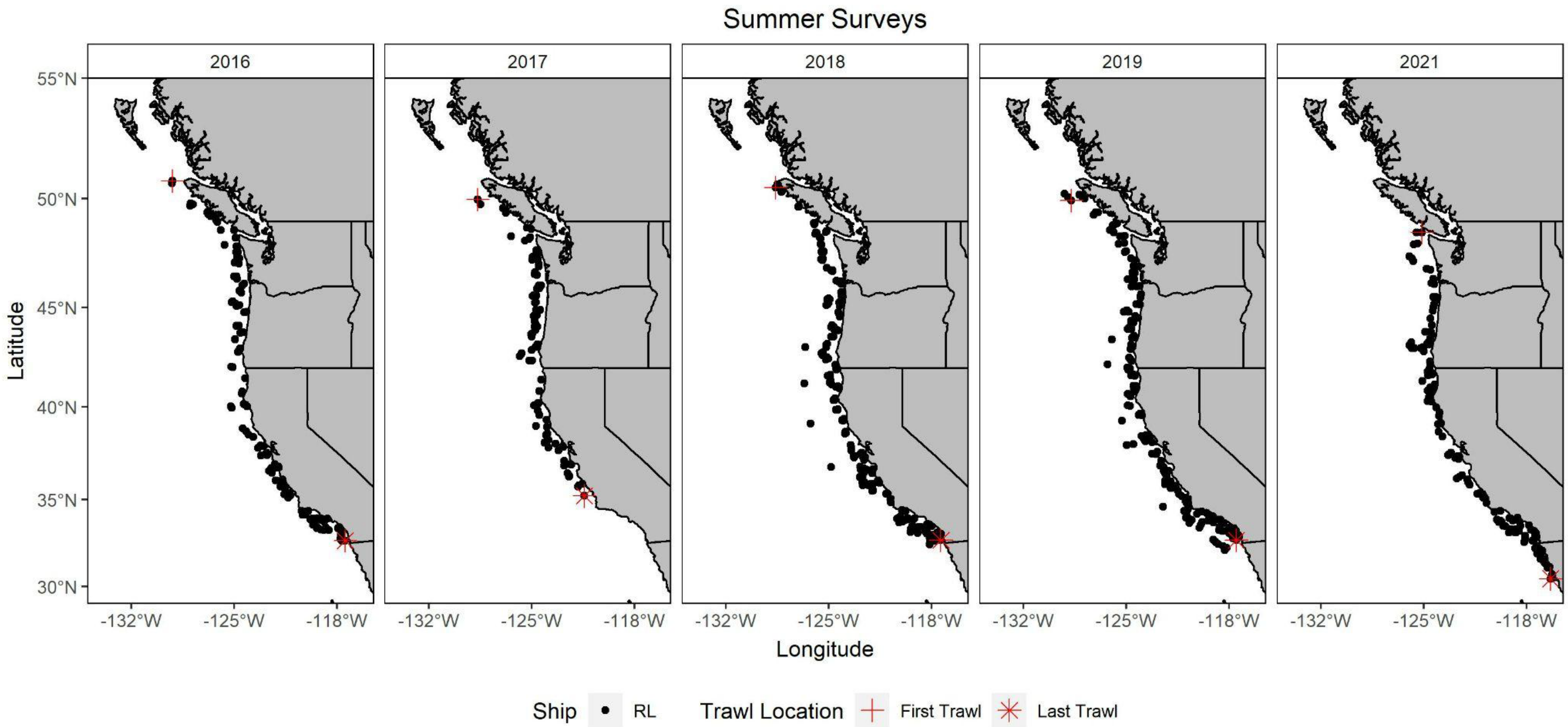

Figure A6. Map of the trawling locations during the coastwide SWFSC Summer trawl surveys from 2016 to 2021 on the NOAA FSV *Reuben Lasker* (RL). Also included are the first (red plus symbol) and last (red asterisk symbol) trawl locations for each survey.