USA-Mexico surveys of transboundary forage fishes in the California Current

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Abstract

In the California Current Ecosystem (CCE), multiple forage fishes are monitored and managed by the United States of America (USA) and Mexico using information from acoustic-trawl method (ATM) surveys that combine information collected with echosounders and nets. Since 2006, the USA National Oceanic and Atmospheric Administration (NOAA) has conducted ATM surveys of Pacific Sardine and other coastal pelagic fish species (CPS) including Northern Anchovy, Pacific Mackerel, Jack Mackerel, Pacific Herring, and Round Herring. During these surveys, the echosounder sampling is done during daytime, when the CPS form schools, and trawling is conducted during nighttime, when they disperse near the surface to feed. The sampling domain is defined at the time of the survey by the modeled potential oceanographic habitat of the northern stock of Pacific Sardine as well as the anticipated distributions of other CPS in the USA and Canadian waters. The ship transects are augmented with interstitial transects sampled by uncrewed surface vehicles (USVS), and extended into shallow waters using smaller fishing vessels. Since 2021, to more accurately assess transboundary CPS stocks, NOAA and the Mexico Research Institute for Sustainable Fishing and Aquaculture (IMIPAS, formerly INAPESCA) standardized sampling instruments and analysis methods to concurrently survey the USA and Mexico waters. These surveys produce annual estimates of the distributions of eight stocks of six CPS, and their biomasses apportioned to lengths and ages. The results may also yield indications of recruitment, and estimates of growth and natural mortality. The results from this IMIPAS-NOAA collaboration collectively yield information for the first observational assessments of multiple transboundary CPS stocks in the CCE, in the context of their changing environment. The central stock of Northern Anchovy presently dominates the forage fish assemblage in the CCE, and the southern stock of Pacific Sardine is increasingly persistent and abundant in the USA waters.

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Introduction

In the California Current Ecosystem (CCE), the forage-fish assemblage is composed primarily of multiple coastal pelagic fish species (CPS; i.e.: Pacific Sardine *Sardinops sagax*, Northern Anchovy *Engraulis mordax*, Jack Mackerel *Trachurus symmetricus*, Pacific Mackerel *Scomber japonicus*, Pacific Herring *Clupea pallasii*, and Round Herring *Etrumeus acuminatus*). Their populations can change by an order of magnitude within a few years. They are prey for marine mammals, birds, and larger migratory fishes (Field *et al.*, 2001), and some are targets of commercial fisheries.

CPS Distributions and migrations

Whether a species remains in an area or migrates depends on its reproductive and feeding behaviors, affinity to certain oceanographic or seabed habitats, its population size, and fish ages and lengths (Zwolinski et al., 2012). Notwithstanding the natural variability in CPS distributions, some generalizations may be made.

The population of Pacific Sardine in the CCE is composed of northern (or cold), southern (or temperate) and Gulf (or warm) stocks (Felix-Uraga *et al.*, 2005; Smith, 2005). When abundant, the northern stock (NSPS) mostly spawns off Southern and Central California in the spring, and feeds as far north as Canada in summer (Demer *et al.*, 2012). Since falling below a critical biomass (Zwolinski and Demer, 2012) circa 2013, the stock has resided and spawned from Central California to Washington (e.g., Stierhoff *et al.*, 2023a, b). The southern stock (SSPS) resides mostly off Baja California, Mexico, but migrates as far north as Central California in summer (Stierhoff *et al.*, 2023a). In the summer, the Gulf stock migrates from the Gulf of California to Southern Baja California (Félix-Uraga *et al.*, 2005).

The population of Northern Anchovy in the CCE is composed of northern (NSNA), central (CSNA), and southern stocks (SSNA; Lecomte *et al.*, 2004). The NSNA remains off Washington and Oregon, the CSNA spans from Central California to Northern Baja California, and the SSNA ranges from Central Baja California to the Gulf of California (Hedgecock *et al.*, 1994) (Figure 1). Northern Anchovy do not migrate as far as Pacific Sardine.

Adult Jack and Pacific Mackerels range throughout the CCE and migrate north in summer. They typically feed, predominantly on smaller fishes, offshore of the coastal upwelling zone (Zwolinski *et al.*, 2014 and references therein) (Figure 1).

In the spring, adult Pacific Herring migrate inshore to spawn in bays and estuaries. In summer, they school on the continental shelf. Pacific Herring range from Central California to Vancouver Island. Round Herring span both coasts of Baja California and mainland Mexico to Guaymas, Sonora (Figure 1).

Acoustic-trawl-method surveys

As early as the 1940s, CPS schools have been detected and mapped in the CCE using single-frequency echosounders (Smith; 1947; Smith and Ahlstrom, 1948). In the 1970s, explosive sound sources were used to measure broad-bandwidth resonance and Doppler shift in CPS echoes, to identify fish species, observe their behaviors, and estimate their sizes, distributions, and abundances (Holliday, 1972, 1974). Sonars and mapping procedures were also used to measure and enumerate CPS schools (Smith, 1970, 1978; Hewitt *et al.*, 1976). Moreover, combined information from echosounder and trawl-catch data was used to estimate the distributions and abundances of multiple fish species (Mais, 1974, 1977; Smith, 1978).

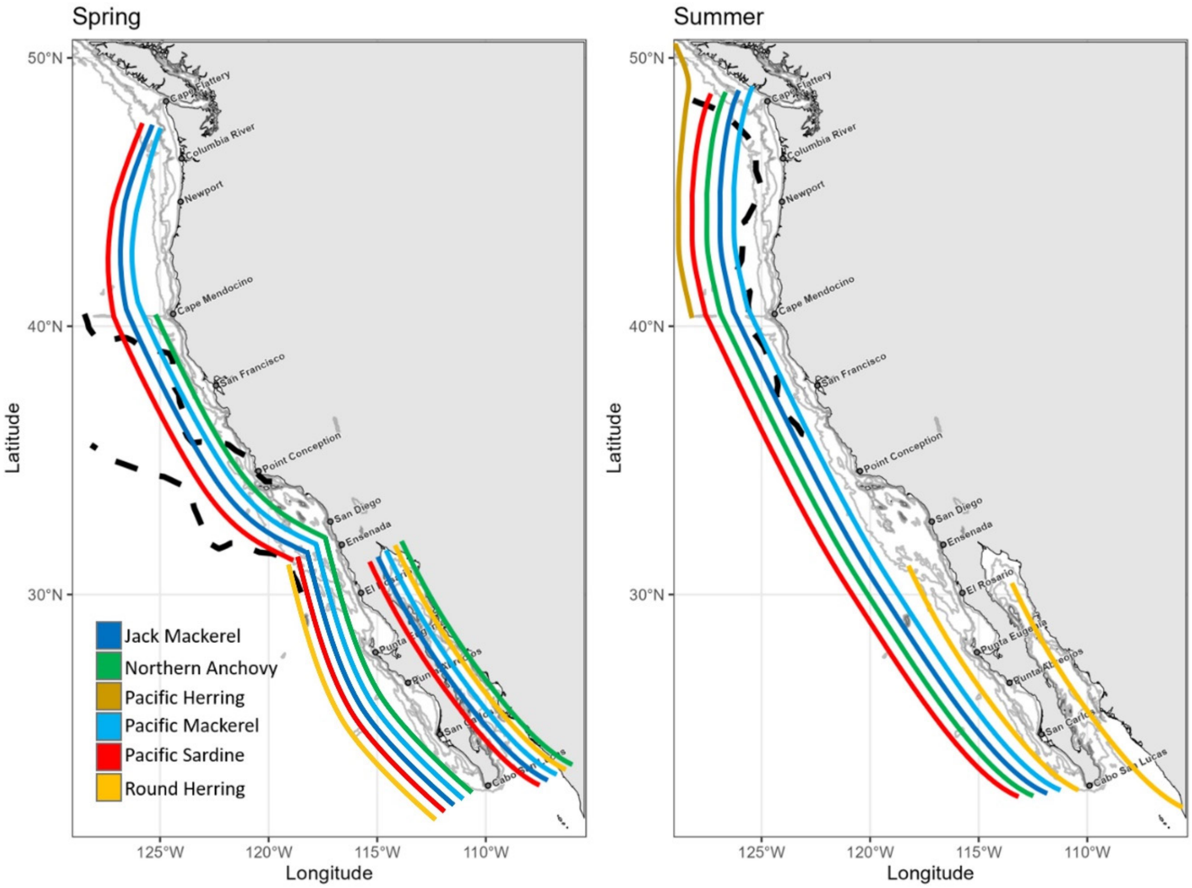

Figure 1. Potential distribution ranges for Pacific Sardine (red), Northern Anchovy (green), Jack Mackerel (dark blue), Pacific Mackerel (light blue), Pacific Herring (dark tan), Round Herring (light tan), and notional NSPS habitat (dashed), during spring (left) and summer (right).

Beginning in the 1980s, principally enabled by advances in computers and data-storage devices, and the creation of a global positioning system, echosounder technology and data-analysis methods evolved, and their use expanded. Equipment developments included multi-frequency and wide-bandwidth echosounders, wide-bandwidth multibeam echosounders, imaging sonars, and scanning sonars (e.g., Demer *et al.*, 2015). Advances in echo classification based on frequency response (e.g., Conti and Demer, 2003; Korneliussen and Ona, 2003; Demer *et al.*, 2009) led to acoustic-trawl-method (ATM) surveys of multiple taxa and trophic levels (e.g., Zwolinski *et al.*, 2016).

In the 1990s and 2000s, information from multi-frequency echosounders and plankton-net catches were combined to study predator-prey interactions between marine mammals, sea turtles, seabirds, and krill (Croll *et al.*, 1998; Fiedler *et al.*, 1998). Beginning in 2000, NOAA added multifrequency echosounder sampling to CalCOFI surveys to estimate the distributions of krill, pelagic and mesopelagic fishes, and their oceanographic habitats (e.g., Davison *et al.*, 2015).

In spring 2006, NOAA added echosounder sampling to an annual daily egg-production survey of Pacific Sardine and expanded the sampling domain to span the west coasts of California (CA), Oregon (OR) and Washington (WA). Since then, NOAA has conducted ATM surveys to observationally assess CPS off the USA west coast, once or twice each year (Cutter and Demer, 2008; Demer *et al.*, 2012; Zwolinski *et al.*, 2014). Beginning in 2011, the ATM estimates of CPS distributions, abundances, and age structures have been incorporated into stock assessment models of the northern stock of Pacific Sardine (NSPS; e.g., Hill *et al.*, 2017; Kuriyama *et al.*, 2020, 2022b), the central stock of Northern Anchovy (CSNA; e.g., Kuriyama *et al.*, 2022a) and Pacific Mackerel (e.g., Crone and Hill, 2015; Crone *et al.*, 2019).

In summer 2012, motivated by the lowest hake-biomass estimate in the survey time series, the CPS survey was combined with the bienniel survey of Pacific hake *Mercluccius productus*. Both surveys use the ATM and sample approximately the same areas at the same time of year. The combined survey was repeated in 2013 and 2015 with the results from each survey used in the respective Pacific hake and CPS stock assessments.

Beginning in summer 2016, to sample CPS in waters too shallow for the fisheries survey vessel (FSVS) to safely navigate, trawl, or both, the ATM surveys were augmented with echosounder and purse-seine sampling from fishing vessels (FVS) (e.g., Stierhoff *et al.*, 2020a, b). Beginning in 2018, the ATM surveys were further augmented with echosounder sampling from uncrewed surface vehicles (USVS; Explorer, Saildrone, Inc.). This was done to improve the accuracy and precision of biomass estimates by sampling farther offshore and closer to shore, and increasing the number of sampled transects and the sampling density (e.g., Stierhoff *et al.*, 2022a, b).

In summer 2021, NOAA and IMIPAS began a historical collaboration by standardizing instruments and methods and concurrently sampling CPS off the coasts of the USA and Mexico. In summer 2022, results from the USA and Mexico surveys were combined to more comprehensively assess transboundary CPS stocks. In summer 2023, to further refine the assessments, Mexico added echosounder sampling from research vessel (RV) *BIP INAPESCA I* in coastal waters that are too shallow for the larger RV *Dr. Jorge Carranza Fraser* (hereafter, Carranza) to safely navigate.

This paper summarizes current protocols for ATM surveys of CPS in the CCE; identifies information that is uniquely obtained from these surveys; and highlights the enhanced information that is garnered from the USA-Mexico collaborative surveys and its utility for managing fisheries. For example, during climate-induced changes in the CCE, these surveys provide observational assessments of multiple transboundary stocks. In summer 2025, NOAA aims to integrate its ATM surveys of CPS and Pacific hake while further expanding the international collaboration to include both Mexico and Canada.

Materials and methods

Sampling platforms

NOAA's ATM surveys have been conducted principally using FSVS. In nearshore areas too shallow to be sampled by the FSV, multifrequency-echosounder and purse-seine net sampling is conducted by charter FVS. To increase sampling precision, the FSV transects are interleaved with echosounder transects conducted by multiple USVS (e.g., Stierhoff *et al.*, 2020a, b; 2022a, b; 2023a, b).

Sampling domain

The sampling domain of spring ATM surveys was originally designed to encompass the NSPS. To optimally apply sampling effort, a probabilistic model of potential habitat for the NSPS was created (Zwolinski *et al.*, 2011) and refined. This is officially Zwolinski and Demer, 2024, as per the journal's website using springtime sardine-egg presence and absence data and concomitant satellite-sensed sea-surface temperature (SST) and chlorophyll-a concentration data. In spring, the potential NSPS habitat is typically offshore of Southern California, and in summer it compresses along the coast and expands northward off OR and WA. The model also predicts the habitat of adult NSPS throughout the year (Zwolinski *et al.*, 2011; Demer *et al.*, 2012; Zwolinski and Demer, 2023). The sampling domain of the current summer surveys (e.g., Stierhoff *et al.*, 2023) extends beyond the NSPS habitat to encompass as much of the historical distributions of eggs, catches, or both, of Northern Anchovy, Pacific Mackerel, Jack Mackerel, Pacific Herring, and Round Herring populations as possible, as time permits (Figure 2), which reduces estimation bias.

Sampling design

Transects in the core sampling region, typically surveyed by FSVS and RVS, extend from the shallowest navigable depth (~20 m) to either a distance of 35 nmi or to the 1,000-ftm (~1830 m) isobath, whichever is farthest (Figure 2a). Compulsory transects, perpendicular to the coast, are spaced 10 nmi apart in areas of historic CPS abundance and off Baja CA, and 20 nmi apart elsewhere. To ensure that the offshore extent of the CPS distribution is identified and sampled, when CPS are observed within the westernmost 3 nmi of a transect, that transect and the next one to the north are extended in 5-nmi increments until no CPS are observed in the last 3 nmi of the extension, to a maximum extension of 50 nmi. Nearshore acoustic sampling, where FSVS, RVS, and USVS cannot safely navigate, is generally to ~5-m depth along 5-nmi-long transects spaced 5 nmi apart, and 2.5-nmi-long transects spaced 2.5 nmi apart around Santa Cruz and Santa Catalina Islands in the Southern California Bight (SCB) (Figure 2b).

Marine mammals, CPS and krill

During summer 2018, the summer survey of CPS was combined with a line-transect survey for cetaceans (Stierhoff *et al.*, 2019; Henry *et al.*, 2020). The coincident observations allowed for a large-scale investigation of humpback whales (*Megaptera novaeangliae*) and their primary prey—Pacific Herring, Northern Anchovy, and krill (Szesciorka *et al.*, 2022).

IMIPAS-NOAA Collaborative Surveys

During January 19 to 22, 2015, representatives of NOAA, IMIPAS (formerly INAPESCA), and the Interdisciplinary Center for Marine Sciences (CICIMAR) first planned collaborative USA-Mexico ATM surveys of CPS. The group presented research on the population structure of Pacific Sardine that emphasized a need to survey the entire distribution of the species. They also discussed common data acquisition and post-processing protocols, personnel exchanges, and jointly prepared survey reports. The collaborative surveys were to commence as early as spring 2015. The plan had NOAA using FSV *Bell M. Shimada* to sample off the west coasts of the USA and Vancouver Island, Canada. Meanwhile, IMIPAS would use FVS *BIP XI* (renamed *Dr. Jorge Carranza Fraser*) and *BIPO-INAPESCA* to survey the west coast of Baja California and within the Gulf of California.

Summer 2021

The first joint NOAA-IMIPAS ATM survey was ultimately conducted in summer 2021, spanning the continental shelf between Punta Abreojos, Mexico and Cape Flattery, Washington (WA). FSV *Reuben Lasker* (hereafter *Lasker)* and RV *Carranza* sampled north and south of Las Flores, Mexico, respectively. In USA waters, three USVS surveyed transects not sampled by *Lasker*, between Cape Flattery, WA to Crescent City, CA, and between Point Arena and Point Conception, CA. In the SCB, to allow FSV *Lasker* to arrive sooner to Mexico, the SCB transects were split into eastern and western portions, and were sampled by FSV *Lasker* and the USVS, respectively. FV *Lisa Marie* surveyed nearshore between Cape Flattery, WA and Bodega Bay, CA, and FV *Long Beach Carnage* sampled between Bodega Bay, CA and the USA-Mexico border, and around Santa Cruz and Santa Catalina Islands. When FSV *Lasker* arrived at Mexico and sampled from the USA-Mexico border to Las Flores, Mexico, RV *Carranza* sampled from Las Flores to Punta Abreojos, Mexico. Also, there was no nearshore sampling off Mexico.

IMIPAS scientists participated in the NOAA survey to provide expertise in trawl-catch, fish-egg, and echosounder-data processing. This participation also served to facilitate cross-training and the adoption of common sampling and analysis protocols.

Summer 2022

In summer 2022, FSV *Lasker*, two USVS, and FV *Lisa Marie* sampled the continental shelf between Cape Flattery, WA and Punta Baja, Mexico. In USA waters, FVS *Long Beach Carnage* and *Lisa Marie* sampled the nearshore region north and south of Bodega Bay, CA, respectively. North of Cape Mendocino, where *Lasker* did not sample, CPS species and length data were from *Lisa Marie's* daytime purse-seine catches, but adjusted for Jack Mackerel escapement (details in Stierhoff *et al.*, 2023b). In the nearshore region south of Bodega Bay, CPS species and length data were from *Long Beach Carnage's* daytime purse-seine catches or *Lasker*'s nighttime surface-trawl catches, whichever was nearest to the acoustically sampled CPS. IMIPAS scientists again participated in the NOAA survey, aboard FSV *Lasker*, to provide expertise in trawl-catch, fish-egg, and echosounder-data processing.

RV *Carranza* sampled the Gulf of California, May to early July, from northern Nayarit to the Great Islands, and West Baja CA Peninsula from the end of July to mid-August, from the Gulf of Ulloa to the USA-Mexico border (Vallarta-Zárate *et al.*, 2023). Off Northern Baja CA, sampling from FSV *Lasker* and RV *Carranza* overlapped, but the sampling was not coincident in time. Also, there was no nearshore sampling off Mexico.

Summer 2023

In summer 2023, FSV *Lasker* sampled from San Diego to Cape Mendocino and FSV *Bell M. Shimada* sampled between Florence, OR and Cape Flattery, WA. Between Point Conception and Cape Flattery, three USVS sampled transects not sampled by an FSV. FVs *Long Beach Carnage* and *Lisa Marie* sampled the nearshore region off the USA.

RV *Carranza* sampled the Gulf of California, April to early June, and West Baja CA, mid-June to mid-July, from Cabo San Lucas, Mexico to the USA-Mexico border. RV *BIP INAPESCA I* sampled nearshore regions in the same areas (Figure 2b). Prior to the survey, scientists from Mexico trained at NOAA on the calibration and operation of echosounder equipment installed on RV *BIP INAPESCA I*.

Sampling equipment

Along transects, the echosounders transmitted sound pulses downward beneath the ship and received echoes from animals and the seabed. Software (EAL; Renfree and Demer, 2016) was used to synchronize the echosounder transmissions, avoid noise from aliased seabed echoes, and reduce file sizes. Typically, at two or three locations along each transect, measurements were also made of seawater salinity and temperature versus depth. These were used to calculate the time-averaged sound speed (Demer *et al.*, 2015) for estimating ranges to the sound scatterers, and sound-absorption coefficients for compensating signal attenuation of the sound pulses between the transducers and the fishes (Simmonds and MacLennan, 2005). The temperature profiles were also used to identify the mixed-layer depth (see *Echo classification,* below).

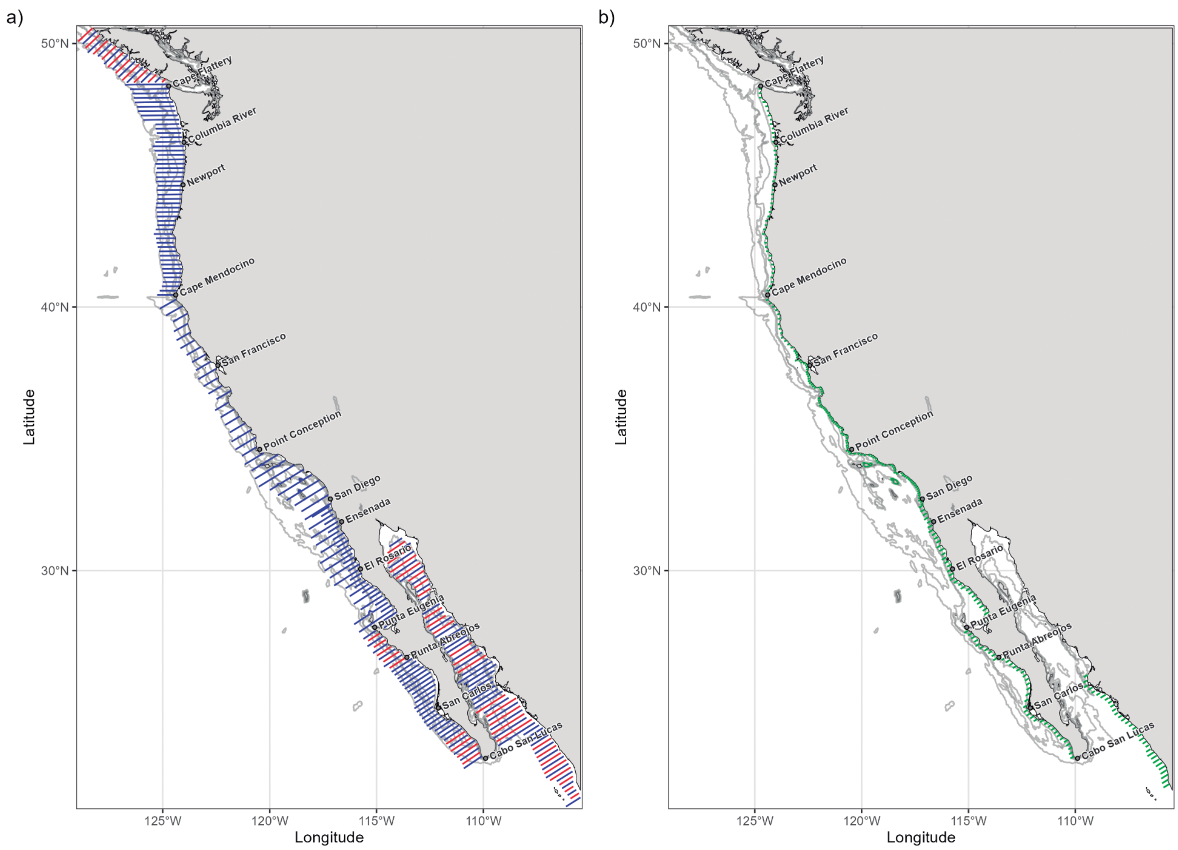

Figure 2. Example core (a) and nearshore (b) area transect plans from NOAA and IMIPAS surveys, from northern Vancouver Island to Cabo San Lucas, including the Gulf of California, during summer 2023. Blue and red lines in (a) are compulsory and adaptive transects, respectively. Isobaths (light gray lines) are 50, 200, 500, and 2,000 m.

Fish eggs sampled along each transect indicated the locations of actively spawning fish, and were used in combination with CPS echoes to identify stock boundaries (see *Sampling domain)*, adaptively extend transects (see *Sampling design)*, and select trawl locations (see *Echo classification* and *Stock Separation)*. Surface trawls from FSVs were conducted during nighttime to capture CPS and other fish that ascended and dispersed after sunset (Mais, 1977). The trawl catches provided regional information about species composition, lengths, weights and ages of CPS sampled acoustically during the day. This combination of daytime echosounder transects and nighttime trawling is efficient and reduces sampling uncertainty compared to daytime-only sampling. In the nearshore area, where CPS-school depth is constrained by the seabed, and CPS vision is obscured by turbidity, purse-seine sampling during daytime generally provided similar biological information. In the nearshore area, where CPS-school depth is constrained by the seabed and CPS vision is obscured by turbidity, purse-seine sampling during daytime generally provided similar biological information. Offshore, where the water is clearer purse-seine exhibited species selectivity, particularly under-sampling larger, faster swimming Jack Mackerel (see Stierhoff *et al.*, 2023).

Echo classification

CPS, with highly reflective swim bladders, create high intensity echoes of sound pulses at all echosounder frequencies (e.g., Conti and

Demer, 2003). The echo energy attributed to CPS, based on the characteristic frequency response (Demer *et al.*, 2012), was apportioned to species and their lengths and ages using catch proportions and demographics (Zwolinski *et al.*, 2014) in the nearest cluster of up to three nighttime trawls. To reject echoes from other species with similar frequency response, e.g., rockfishes, the CPS echoes were overlaid on isotherms calculated from the temperature-depth data, and seabed lines, to evaluate their position below the mixed layer and above rocky seabed.

Stock separation

For Pacific Sardine, a model of NSPS potential habitat (Zwolinski and Demer, 2024), computed for the sampling times (e.g., Renfree *et al.*, 2023), was used to attribute survey observations and fishery landings to the NSPS or SSPS (Felix-Uraga *et al.*, 2004; Felix-Uraga *et al.*, 2005; Garcia-Morales *et al.*, 2012; Demer and Zwolinski, 2014a, b; Hill *et al.*, 2014). The attribution accuracy depended on the temporal and spatial coincidence of the environmental data, and survey or landings data. The separations were corroborated with differences in the distributions of standard length (L_S), maximum L_S, L_S at age, and distances between agglomerations of Pacific Sardine biomass (Zwolinski and Demer, 2024). For Northern Anchovy, Cape Mendocino (40.8 ∘N) separated the northern and central stock (NSNA and CSNA, respectively) (see Figure 1).

Biomass Estimation

Along the acoustic transects, densities for each species and stock were estimated by dividing its depth-summed and distance-averaged intensities by its length-weighted average echo intensity (e.g., see MacLennan *et al.*, 2002; Demer *et al.*, 2012). Because each species or stock did not generally span the entire survey area (Demer and Zwolinski, 2017; Zwolinski *et al.*, 2014), transects with similar densities were grouped into post-sampling strata (Johannesson and Mitson, 1983; Simmonds *et al.*, 1992). This approach also accounts for the spatial heterogeneity in sampling effort, and tracks the patchiness of each species and stock (e.g., Zwolinski *et al.*, 2014, 2016). Abundance was estimated for each species and stratum by multiplying the average density in the stratum by the stratum area (Demer *et al.*, 2012). The sampling variance in each stratum was estimated using non-parametric bootstrap of the mean transect densities. The estimated total abundance of each species in the survey area was computed as the sum of abundances in all strata. The estimated total variance was computed as the sum of the variance in each stratum.

The numerical densities by length class were averaged for each stratum, and multiplied by the stratum area to obtain abundance per length class (e.g., Stierhoff *et al.*, 2023b). Time series of stock abundance apportioned to length and age were used to identify recruitment events, model growth, and estimate natural mortality (Zwolinski and Demer, 2013).

Recruitment

Predicated on catch selectivity (Demer *et al.*, 2013) and the survey time and area, which is estimated in the stock assessment model, recruitment may be inferred from the abundance of age-0 fish in survey time series of stock abundances by length and cohort. Recruitment success, the logarithmic ratio of recruitment and spawning stock biomass, may also be obtained from the results of analytical assessments based on ATM-survey observations (Zwolinski and Demer, 2014, 2019). The latter correlates with indices of the Pacific Decadal Oscillation (Zwolinski and Demer, 2014, 2019).

Growth

In the ATM analysis, fish lengths were weighted by the nearest density estimates. Cohorts were identified annually using contemporaneous age-to-length keys (details in Kuriyama *et al.*, 2020). Their respective growths can be estimated by fitting a growth equation, e.g., von Bertalanffy, to time-series of ages and density-weighted length distributions (e.g., Zwolinski and Demer, 2013). Variations in cohort growth could also be evaluated, e.g., in relation to stock, stock biomass, and environmental conditions.

Natural mortality

When recruitments are sporadic and cohorts can be unambiguously tracked through the abundance time series and fishery landings can be subtracted, time series of natural mortality, *M*, may be estimated by bootstrap (Zwolinski and Demer, 2013). *M* may vary between cohorts and throughout the life of each cohort.

Species Alternations

The ATM surveys simultaneously estimate the biomasses and distributions for at least seven stocks of five CPS in the CCE. The results indicate the dominant species or stocks in the forage fish assemblage and their cumulative biomass (e.g., Stierhoff *et al*. 2023b). This information is monitored because the dominant species may differ regionally and the cumulative biomass may change interannually by orders of magnitude.

Results and Discussion

Distributions and migrations

NOAA conducted ATM surveys of CPS in the CCE during spring, summer, or both during most years, 2006 to 2023. Composite maps of CPS catches show the historical distributions of each species (Figure 3). These distributions, however, conflate the interannual variation of the species distributions e.g., due to changes in oceanographic habitat, stock biomass, demographics, and intra-guild dynamics.

In spring, NSPS were mostly caught between San Diego, CA and San Francisco, CA, to 300 nmi from shore (Figure 3). During spring 2015 and 2016, after the stock collapsed and its migration ceased (Zwolinski *et al.*, 2014), Pacific Sardine were also caught between Cape Mendocino, CA and Newport, OR in the spring (Figure 3). In the summer, Pacific Sardine, potentially from the NSPS and the SSPS, were caught closer to shore, from Central Baja CA to the north end of Vancouver Island (See *Stock differentiation,* below). Also in summer, the Gulf stock of Pacific Sardine was caught in the Southern Gulf of CA (GoC) to Southern Baja CA.

In both spring and summer, the NSNA and CSNA were separated geographically at Cape Mendocino. In spring, the NSNA were caught off WA, and catches of CSNA ranged from San Diego to Monterey Bay, CA. In summer, catches of NSNA spanned from Cape Mendocino to Central Vancouver Island. Catches of CSNA ranged from Central Baja CA to Cape Mendocino.

In spring, Pacific Mackerel and Jack Mackerel were caught off of the continental shelf and between San Diego and Newport, OR. During summer, catches of both Mackerels were mostly on the continental shelf, from Cabo San Lucas, Baja, CA to Northern Vancouver Island.

In spring, no Pacific Herring were caught. In summer, Pacific Herring were caught, mostly close to shore, north of Cape Mendocino. In spring, Round Herring were caught mostly close to shore near Cabo San Lucas. In summer, more Round Herring were caught between Cabo San Lucas and Punta Eugenia.

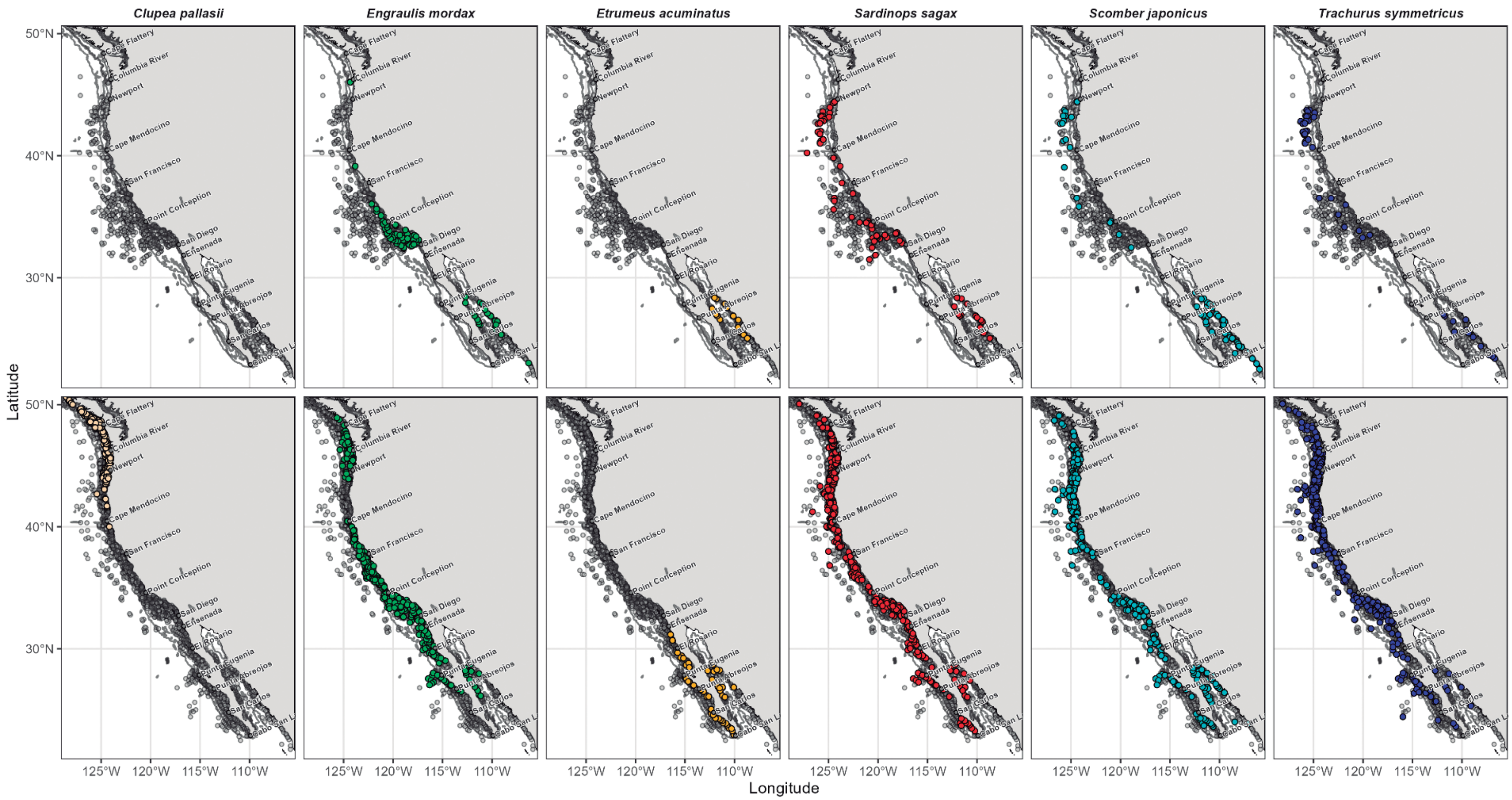

Figure 3. Composite distributions of nighttime catches >0.1 kg of Pacific Herring, Northern Anchovy, Round Herring, Pacific Sardine, Pacific Mackerel and Jack Mackerel (left to right) in ATM-survey areas during spring (March - May; top) and summer/fall (June - October; bottom). Data are from the NOAA and IMIPAS surveys, 2006-2023 and 2021-2023, respectively. Also shown are the locations of trawls without CPS catch (gray points), and the 50, 200, 500, and 2,000-m isobaths (gray lines).

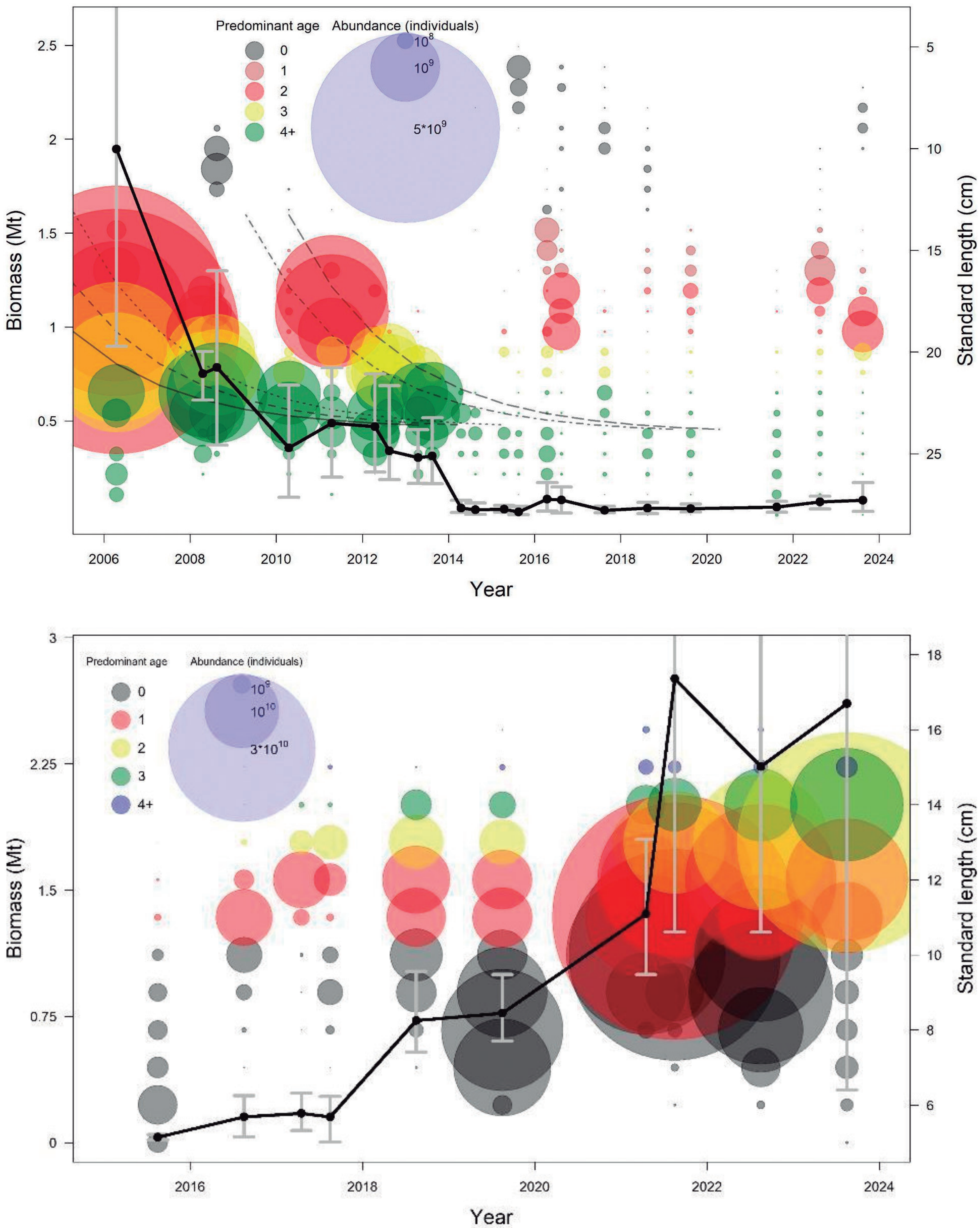

Figure 4. Abundance apportioned to length and age versus year for the NSPS (top) and CSNA (bottom). The NSPS data are overlaid with ATM-estimates of stock biomass (black line) and growth curves for the 2003 to 2005 and 2009 to 2010 cohorts (dashed lines, left to right). Note the consistency of spring and summer NSPS biomass estimates within the same year; and the roughly 15-fold increase in CSNA biomass from 2017 to 2022. These data are used to infer recruitment variability, model growth, and estimate natural mortality.

Recruitment

The estimated NSPS biomass declined between 2006 and 2014, and the stock was composed primarily of 2003 to 2005 and 2009 and 2010 year-classes (Figure 4). The paucity of recruitment observed during this period was linked to unfavorable oceanographic conditions (Zwolinski and Demer, 2014). Although there have been subsequent periods with environmental conditions favorable to recruitment success (Zwolinski and Demer, 2019), notably during 2015 and 2016, the residual population has not recruited sufficiently to recover (Stierhoff *et al.*, 2023a, b).

Between 2006 and 2015, the biomass of the CSNA was too low to be estimated using the ATM sampling design (Zwolinski et al., 2014). However, beginning in 2015, the survey results showed recruitments and growth of the stock and, since 2016, it has dominated the forage fish assemblage in the CCE. The CSNA biomass continued to grow through at least 2022, when it peaked at over 2.7 Mt (Figure 4).

Without significant recruitments, the Pacific Mackerel biomass declined from its peak in 2012. Meanwhile, Jack Mackerel exhibited multiple significant recruitment events and its biomass increased. As a result, Jack Mackerel has dominated the CPS community off OR and WA since 2011 (Stierhoff *et al.*, 2023 and references therein).

Growth

Cohort growth is generally evident in time series of density-weighted lengths (Figure 4). For example, the ATM estimates of NSPS abundances by length between 2006-2011 indicated that the stock was dominated by the 2003, 2004, and 2005 year classes between 2006 and 2010, and by a mixture of 2009 and 2010 year classes in 2011 (Figure 4a).

A von Bertalanffy growth model was fit to the data from multiple cohorts (Figure 5) using a non-linear least-squares algorithm (e.g., Zwolinski and Demer, 2013).

Natural mortality

Insignificant recruitments to the NSPS during 2006–2010 allowed the 2003–2005 cohort to be tracked, compensated for fishery landings, and *M* to be estimated (Zwolinski and Demer, 2013). The bootstrapped estimates suggest that *M* is high for a new cohort, declines during mid-life, and increases as the fish approach their longevity. The mean *M* for this period was 0.52, 30% higher than 0.4, assumed for the assessment (Hill *et al.*, 2012). More than 10 years later, the analytical stock assessment estimated that an average *M* for the NSPS is between 0.5 and 0.6 (Kuriyama, *et al.*, 2024).

Prediction

By 2011, results of the CPS surveys revealed or corroborated a number of characteristics of the NSPS, its environment, and the fishery that resembled those in the mid-1900s when the stock and fishery collapsed (Zwolinski and Demer, 2012). The stock no longer dominated the forage fish assemblage in the CCE and the residual NSPS were increasingly caught with Mackerels, theoretically creating a negative-feedback mechanism, accelerating a population decline and opposing recovery (Zwolinski and Demer, 2012). Meanwhile, exploitation of the NSPS peaked (Demer and Zwolinski, 2014a, b), and the stock biomass steeply declined (Figure 4a). All indicators predicted an imminent stock collapse (Zwolinski and Demer, 2012; Demer and Zwolinski, 2012). Three years later, in 2015, the directed fishery was closed and, in 2018, the stock was deemed overfished (Kuriyama *et al.*, 2020; PFMC, 2021).

Stock differentiation

The ATM observations of NSPS and SSPS are geographically separated and differentiated by modeled potential habitat, spawning seasons and areas, and stock demographics and growth (Zwolinski and Demer, 2023; Stierhoff *et al.*, 2023a, b). Compared to the original NSPS habitat model (Zwolinski *et al.*, 2011), the updated model (Zwolinski and Demer, 2023) more accurately attributes survey biomass and fishery landings to the SSPS, notably in the SCB and at Ensenada, Mexico, respectively. In these areas, the SSPS has been resident and its biomass has increased since 2019 (Stierhoff *et al.*, 2023a, 2023b). SSPS are significantly smaller for the same ages (*L*s<210 versus <280 mm) and have shorter longevity (~4 *versus* ~8 yr) (Zwolinski and Demer, 2023), compared to the NSPS (Figure 5). These results comport with the long-standing hypothesis of two stocks, and earlier observations of their differing characteristics, off the Pacific Coast of the USA and Mexico (Felix-Uraga *et al.*, 2005).

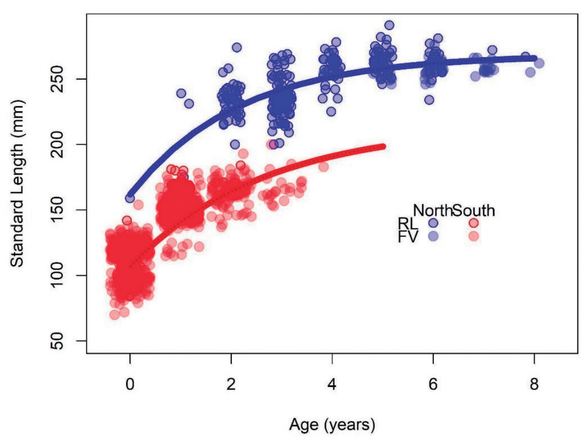

Figure 5: Lengths versus age for NSPS (blue, n=283) and SSPS (red, n=935) (Zwolinski and Demer, 2023) sampled using FSV Lasker (RL) and two fishing vessels (FV), during summer 2021 (Renfree et al., 2022). The lower growth curve (red) was derived for SSPS by Enciso-Enciso et al., (2022). The upper growth curve (blue; *L*s = 268.4*(1- exp (-0.463*(age+2.0))) was fit to the data using a non-linear regression.

Marine mammals, CPS and krill

In 2018, the ATM survey of CPS was combined with a survey of marine mammals and seabirds (Stierhoff *et al.*, 2019; Henry *et al.*, 2020). Although the humpback whale distribution resembled the collective distributions of Pacific Herring, Northern Anchovy, and krill, the variation in whale abundance was related more to prey hotspots than biomass density (Szesciorka *et al.*, 2022). The humpback whales were typically observed on the periphery of hotspots, possibly due to predation avoidance or a prey-density threshold. Also, the three segments of the humpback whale population were associated with different prey species and densities (Szesciorka *et al.*, 2022). The study highlighted a need to consider multiscale trophic interactions for ecosystem-based fisheries management.

Observational stock assessments

The collaborative USA-Mexico surveys of transboundary stocks use common ATM protocols to provide information needed for observational stock assessments of multiple CPS that are unobtainable from the individual surveys (Demer and Zwolinski, 2017). Provided that the combined sampling domains span entire stocks, the results can provide time series of stock distributions, biomasses, abundances at age, recruitment events, and estimates of their growth and mortality.

Beginning in summer 2021, the combined survey efforts of NOAA and IMIPAS sampled the area from Cape Flattery, WA to Cabo San Lucas, Mexico and into the Gulf of California. The results provided information needed to more accurately assess the SSPS and CSNA, evaluate their distributions and demographics, quantify the proportions of each stock in the USA and Mexico waters, and characterize the total biomasses of the predominant species in the forage fish assemblage in the CCE (Table 1).

Table 1
Biomass estimates for the proportions of each stock off each country during 2021-2023, including confidence intervals. Also tabulated are the ranges of length, *L*, which is fork length for Clupea pallasi and standard length for the other species

Year	*Species*	*Stock*	*Country*	*Proportion* (%)	*Biomass* (t)	*CI (Lower)* (t)	*CI (Upper)* (t)	*Ls (max)* (cm)	*Ls (max)* (cm)
2021	*Clupea pallasii*		USA	100	67,920	14,913	134,879	8	24
	Engraulis mordax	Central	USA	72	2,691,174	1,216,430	3,299,334	10	17
			Mexico	28	1,057,223	465,405	1,322,438	8	14
		Northern	USA	100	8,031	1,624	15,893	7	16
	Etrumeus acuminatus		Mexico	100	18,848	5,071	32,421	14	30
	Sardinops sagax	Northern	USA	100	47,721	14,016	90,475	7	27
		Southern	USA	18	45,333	7,044	84,936	8	21
			Mexico	82	201,201	46,280	115,048	8	14
	Scomber japonicus		USA	35	7,796	7,052	9,277	9	38
			Mexico	65	14,202	8,315	25,023	11	36
	Trachurus symmetricus		USA	100	569,793	310,939	941,151	4	51
2022	*Clupea pallasii*		USA	100	50,718	14,461	99,701	13	17
	Engraulis mordax	Central	USA	87	2,235,996	1,248,956	3,051,863	10	17
			Mexico	13	347,146	158,259	536,033	5	15
		Northern	USA	100	16,432	5,646	27,680	7	16
	Etrumeus acuminatus		Mexico	100	4,649	3,480	5,818	10	27
	Sardinops sagax	Northern	USA	100	69,506	30,484	99,021	7	27
		Southern	USA	53	107,092	47,926	178,273	8	21
			Mexico	47	96,515	46,102	146,918	9	20
	Scomber japonicus		USA	15	7,968	3,741	12,662	9	38
			México	85	44,743	21,250	68,236	9	24
	Trachurus symmetricus		USA	98	807,090	515,560	1,145,812	4	51
			Mexico	2	16,891	6,894	26,887	8	22
2023	*Clupea pallasii*		USA	100	106,732	33,364	149,722	8	23
	Engraulis mordax	Central	USA	83	2,689,200	297,242	4,932,949	5	15
			Mexico	17	565,392	188,987	914,347	6	15
		Northern	USA	100	11,356	438	30,038	9	16
	Etrumeus acuminatus		Mexico	100	14,099	7,163	21,035	12	27
	Sardinops sagax	Northern	USA	100	77,252	17,856	171,829	7	28
		Southern	USA	8	82,132	44,039	133,290	8	22
			Mexico	92	946,853	642,272	1,251,434	15	24
	Scomber japonicus		USA	3	7,289	3,305	11,394	8	31
			Mexico	97	240,774	128,284	353,264	10	40
	Trachurus symmetricus		USA	100	159,354	51,323	270,757	2	52

Summer 2021

In summer, 2021, the forage fish assemblage was dominated by Jack Mackerel between Westport, WA and Cape Mendocino, CA; Northern Anchovy between Cape Mendocino and El Rosario, Mexico; and Pacific Sardine between Punta Eugenia, Mexico and Punta Abreojos, Mexico. Pacific Sardine were virtually absent from catches between Cape Blanco, OR and Monterey Bay, CA, a distance of over 700 km.

The total biomass of the SSPS was 294,255 t, located principally between Point Conception, CA and Punta Eugenia, Baja California, mostly close to shore. This included 63,208 t in the core region sampled by FSV *Lasker* (40% was observed in Mexican waters), 31,490 t sampled nearshore between Bodega Bay and San Diego by FV *Long Beach Carnage*, and 101,911 t sampled by RV *Carranza* (Stierhoff *et al.*, 2023a). There was no nearshore sampling off Mexico. Of the total SSPS biomass, 23% was off the USA and 77% was off Mexico. *L*s ranged from 8 to 21 cm.

The total biomass of the CSNA was 3,756,428 t, located principally between Point Conception, CA and Punta Eugenia, Baja California. This included 2,691,174 t in the core region sampled by FSV *Lasker,* 102,642 t sampled by FV *Long Beach Carnage* nearshore between Bodega Bay and San Diego, and 1,057,223 t sampled by RV *Carranza* (Stierhoff *et al.* 2023a). There was no nearshore sampling off Mexico. Of the total CSNA biomass, 72% was off the USA and 28% was off Mexico. *L*s ranged from 8 to 17 cm, and the largest specimens were caught north of the USA-Mexico border.

The biomass of Pacific Mackerel was 21,998 t, located between Punta Eugenia and Central Baja CA. *L*s for Pacific Mackerel ranged from 9 to 38 cm.

The biomass of Jack mackerel was 569,793 t, located mostly nearshore between Punta Eugenia and Punta Abreojos. *L*s ranged from 4 to 51 cm.

The biomass of Round Herring was 18,848 t, located mostly between Punta Eugenia and the Gulf of Ulloa. Their *L*s ranged from 14 to 30 cm, with the largest specimens near El Vizcaíno.

Summer 2022

In summer 2022, FSV *Lasker* surveyed offshore, north to south, from Cape Mendocino to the USA-Mexico border. RV *Carranza* surveyed from the USA-Mexico border to the Gulf of Ulloa. Compared to the previous summer, Jack Mackerel dominated the forage fish assemblage between Cape Mendocino and Punta Arena. Northern Anchovy dominated from Punta Arena to Punta Eugenia. Farther south, the assemblage was composed of a mix of Round Herring, Pacific Sardine, Jack Mackerel and Pacific Mackerel.

The total biomass of the SSPS was 203,606 t, located principally between Point Conception, CA and Punta Eugenia, Baja California, mostly close to shore. This included 40,206 t in the core region sampled by FSV *Lasker*, 67,262 t sampled nearshore between Bodega Bay and San Diego by FV *Long Beach Carnage*, and 96,139 t (95% CI = 46,034 - 146,244 t), sampled by RV *Carranza* (Vallarta-Zárate *et al.*, 2023a). There was no nearshore sampling off Mexico. Of the total SSPS biomass, 53% was off the USA and 47% was off Mexico. SSPS were caught predominantly with Northern Anchovy in Central Baja CA, and with Round Herring in the Gulf of Ulloa. Their *L*s ranged from 8 to 21 cm, increasing from El Vizcaíno to Punta Eugenia, and between the Gulf of Ulloa and El Vizcaíno.

The total biomass of the CSNA was 2,583,142 t, located principally between Point Conception, CA and Punta Eugenia, Baja California. This included 2,197,812 t in the core region sampled by FSV *Lasker*, 38,184 t sampled nearshore between Bodega Bay and San Diego by FV *Long Beach Carnage* (Stierhoff et al. 2023a), and 347,146 t (95% CI = 158,259 - 536,033 t) sampled by RV *Carranza* (Vallarta-Zárate *et al.*, 2023a). There was no nearshore sampling off Mexico. Of the total CSNA biomass, 87% was off the USA and 13% was off Mexico. *L*s ranged from 5 to 17 cm, and the largest specimens were caught northwest of Puerto San Carlos. Catches of CSNA, which comprised the largest catch volumes, were predominantly north of Central Baja California.

Pacific Mackerel were caught with Pacific Sardine and Round Herring off Southern Baja California. Their biomass totaled 52,710 t with 44,743 t (95% CI = 21,250 - 68,236 t) sampled by RV *Carranza* (Vallarta-Zárate *et al*., 2023a). Their *L*s ranged from 9 to 38 cm. Near the USA-Mexico border, Pacific Mackerel were caught with Jack Mackerel.

The biomass of Jack Mackerel was 823,981. Catches were generally monospecific, greater than 40 nmi from shore in Central and Northern Baja California, and closer to shore off Southern Baja California. Their *L*s ranged from 4 to 51 cm, and the largest were caught off the USA.

The biomass of Round Herring was 4,649 t (95% CI = 3,480 - 5,818 t) sampled by RV *Carranza* (Vallarta-Zárate *et al*., 2023a). They were located between Central Baja CA and the Gulf of Ulloa, where most were caught. Their *L*s ranged from 10 to 27 mm.

Summer 2023

The summer 2023 survey spanned the area from the Canada-WA border to the USA-Mexico border, by NOAA; and from the Gulf of CA to the USA-Mexico border by IMIPAS. Off the USA, the sampling was conducted in the core region by FSV *Lasker* and *Shimada*, USVS and, in the nearshore including around Santa Cruz and Santa Catalina Islands, by FVS *Lisa Marie* and *Long Beach Carnage*. Off Mexico, sampling was done in the core region by RV *Carranza* and nearshore by RV *INAPESCA I*.

In summer, 2023, the forage fish assemblage was dominated by Pacific Herring off WA and OR; Northern Anchovy between Cape Mendocino and El Rosario, Mexico; Pacific Sardine between Punta Eugenia and Punta Abreojos; and Round Herring farther south to Cabo San Lucas.

The total biomass of the SSPS was 1,028,985 t, located principally near the coast, between Point Conception, CA and Punta Eugenia, Baja CA. This included 6,448 t (CI95% = 646 - 17,940 t) in the core region sampled by FSV *Lasker*, 75,686 t (CI95% = 43,393-115,350 t) sampled nearshore between Bodega Bay and San Diego by FV *Long Beach Carnage* (Stierhoff *et al*. 2023a), and 946,853 t (642,272 – 1,251,434 t) sampled by RV *Carranza* (Vallarta-Zárate *et al*., 2023b) and by RV *INAPESCA I* in the region off the west coast of Baja CA. Of the total SSPS biomass, 8% was off the USA and 92% was off Mexico. Pacific Sardine were commonly caught with Round Herring, but also at times with Northern Anchovy, Pacific Mackerel and Jack Mackerel. *L*s ranged from 15 cm off Northern Baja CA to 24 cm farther south, in the Gulf of Ulloa.

The total biomass of the CSNA was 3,254,592 t, located principally between Point Conception, CA and Punta Eugenia, Baja CA. This included 2,689,200 t (CI95% = 297,242 - 4,932,949 t) in the core region sampled by FSV *Lasker*, 241,822 t (CI95% = 91,071 - 192,544 t), sampled nearshore between Bodega Bay and San Diego by FV *Long Beach Carnage* (Stierhoff et al. 2023a), 565,392 t (CI95% =188,987 – 914,347 t) t sampled by RV *Carranza* (Vallarta-Zárate *et al*., 2023b) and by RV INAPESCA I in the region off the west coast of Baja CA. Of the total CSNA biomass, 83% was off the USA and 17% was off Mexico. CSNA was commonly caught with Pacific Sardine and Jack Mackerel. *L*s ranged from 5 to 15 cm, with the largest specimens caught north of El Vizcaino.

Total biomass of Pacific Mackerel was 248,063t, located throughout the survey area, from Cabo San Lucas to the US-Mexico border. Of this, 7,289 (3,305-11,330) t (CI95% = 4,358 - 86,886 t) were in USA waters (13%) and 240,774 t (CI95% = 128,284 – 353,264 t) were in Mexico waters. Their *L*s ranged from 10 to 40 cm, and the largest were north of the Gulf of Ulloa.

The total biomass of Jack Mackerel was 159,354 t (CI95% = 51,323 - 270,757 t), located mostly in USA waters. Off Mexico, they were nearshore, mostly between Punta Eugenia and Punta Abreojos. *L*s ranged predominantly

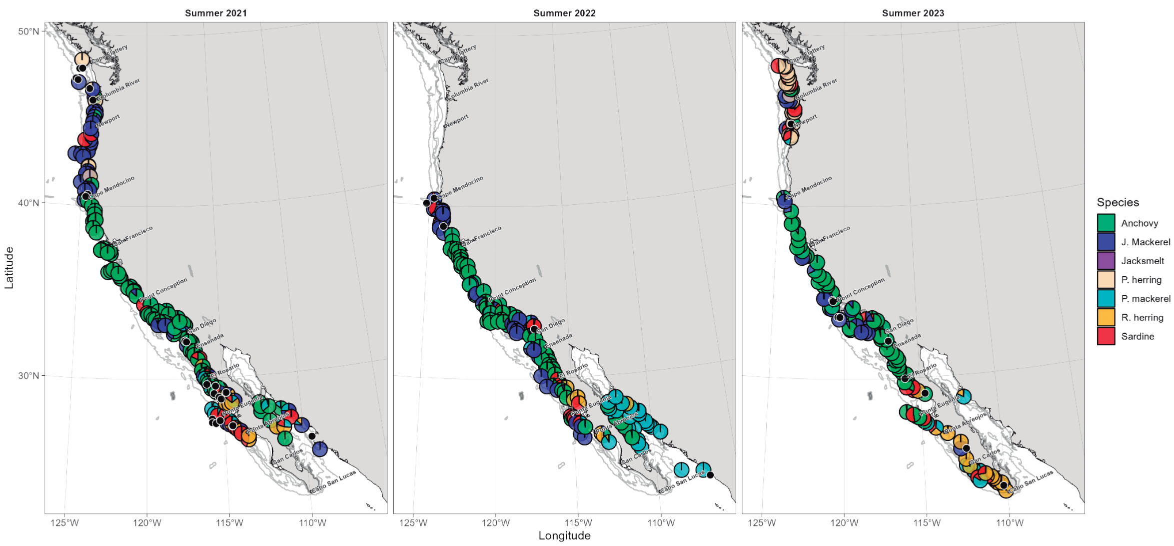

Figure 6. Species proportions, by weight, of CPS species in each nighttime trawl catch off the USA and Mexico during summer 2021, 2022 and 2023 (left to right). Also shown are the locations of trawls that did not catch CPS (black points) and the 50, 200, 500, and 2,000 m isobaths (light gray lines). Species with low catch proportions may not be visible at this scale.

from 2 to 52 cm with the largest specimens off the USA.

The total biomass of Round Herring was 14,099 t (7,163 - 21,035 t), sampled by RV *Carranza* and BIP INAPESCA I. They were located near the coast between Cabo San Lucas and El Vizcaino. Their *L*s ranged from 12 to 27 cm, and the largest specimens were caught farthest south.

Forage fish assemblage

Between 2008 and 2023, the total biomass of the forage fish assemblage off the west coast of the USA fluctuated by roughly 25 fold (Figure 7). From 2006 through 2013, NSPS dominated the CPS assemblage in the CCE, but since then their biomass declined (Demer and Zwolinski, 2012; Zwolinski and Demer, 2012) and their seasonal migration contracted (Zwolinski *et al.*, 2014). Meanwhile, harvest rates for the declining stock increased (Demer and Zwolinski, 2017), and the total forage-fish biomass decreased to less than 200 kt, dominated by Jack Mackerel, in 2014 and 2015 (Figure 7). The biomass of the CSNA off the USA then grew from an almost undetectable level in 2014 to a peak of ~2.6 Mt in summer 2021. The CSNA remained the dominant CPS through summer 2023 (Stierhoff *et al.*, 2023a; Stierhoff *et al.*, in prep.). Including the portion of the CSNA off Mexico, the stock biomass peaked at ~3.6 Mt in summer 2021. In 2023, as it was a half century ago (Mais, 1974, 1977), the CPS assemblage in the CCE consisted mostly of CSNA and SSPS (Figure 7).

Since 2019, the SSPS biomass has been present and increasing north of the USA-Mexico border, primarily nearshore. Between the summers of 2018 and 2021, the biomass of the SSPS in USA waters increased from ~33,000 t to over 107,000 t. During summer 2022, the total estimated biomass of SSPS was 203,607 t. However, in summer 2023, IMIPAS began sampling nearshore off Baja CA and estimated a SSPS biomass of almost 1 Mt, just off Mexico.

Since the resurgence of the CSNA, beginning in 2015, there has been consistency in the regional distributions of the three dominant species: Northern Anchovy, Jack Mackerel and

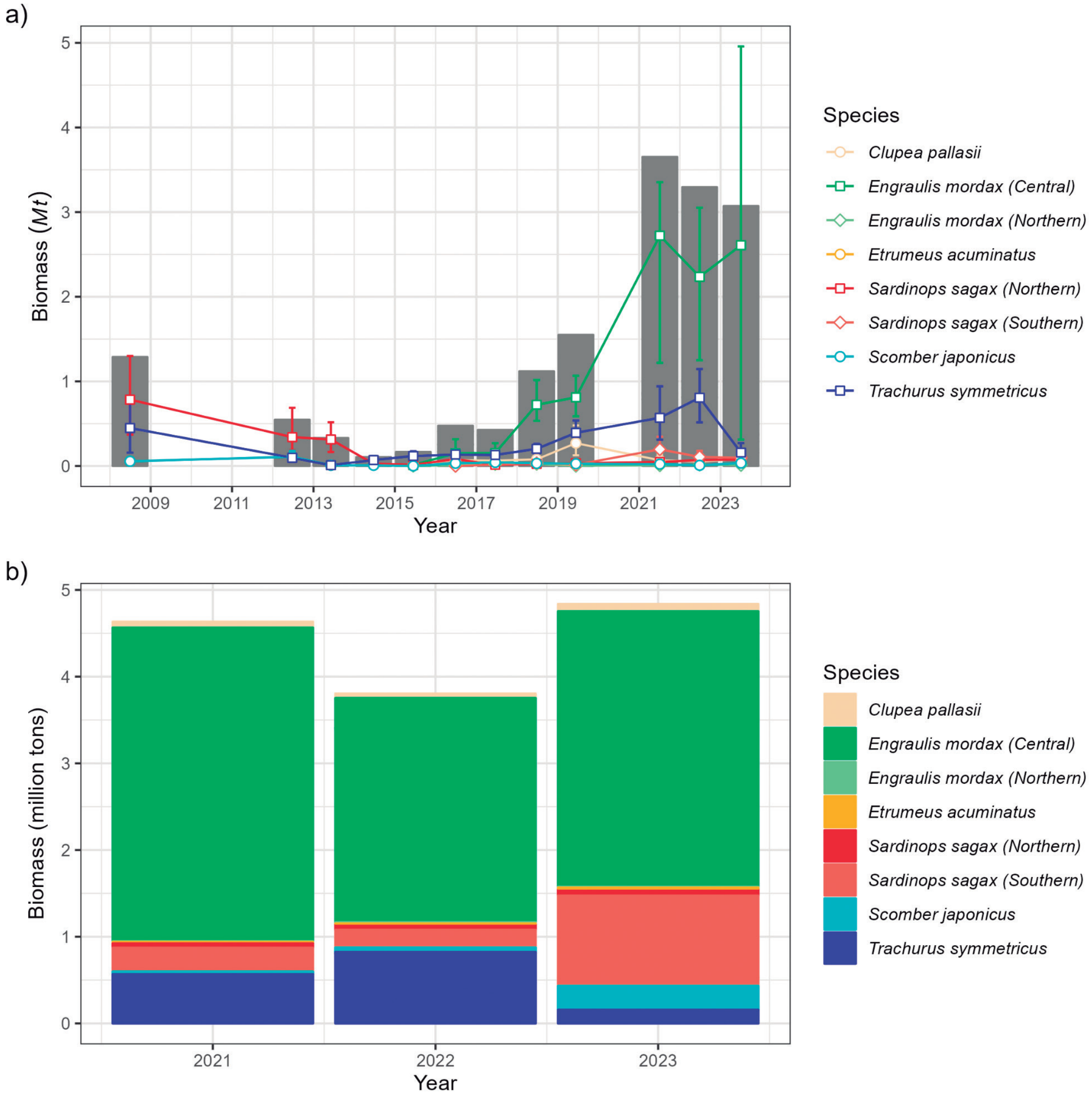

Figure 7. Time series of the individual stock (colored lines and points) and cumulative biomass (gray bars) for the NSPS (red), Jack Mackerel (dark blue), Pacific Mackerel (light blue), Pacific Herring (tan), CSNA (green), and Round Herring (orange) in us waters from 2009-2023 (a), and the cumulative stock biomasses for the same species in USA and Mexican waters from 2021-2023 (b).

Pacific Herring (Figure 6). Pacific Herring are caught mostly north of Central WA. Lower biomasses of the NSPS and the NSNA are resident off OR and Northern CA. Jack Mackerel are caught between central WA and Cape Mendocino and often, in recent years, along with fewer NSPS. CSNA are caught south of Cape Mendocino and, with the exception of summer 2021, mostly south of Bodega Bay. The smaller NSNA is resident from Central WA to Northern CA. Relative to summer 2021, the summer 2022 distribution of CSNA shifted south, better aligning with its distributions during 2015-2019.

Conclusion

ATM *efficiency and accuracy*

In 2006, the SWFSC's ATM survey in the CCE commenced in the general form and frequency in which it occurs today. The 2006 survey focused on Pacific Sardine (Cutter and Demer, 2008), but evolved to assess the five most abundant CPS (Zwolinski *et al.*, 2014). As the ATM surveys have evolved, their efficiencies have improved. Modeled potential habitat is used to optimally allocate sampling effort. The echosounder and catch data is used to estimate the biomasses and distributions of multiple stocks. Concurrent satellite- and ship-based measures of their biotic and abiotic habitats are used to provide an ecosystem perspective. Also, the surveys may be joined with observations of other functional groups in the ecosystem, to investigate intra- and inter-guild competition, and predator-prey interactions.

The accuracy of survey results have improved by sampling the entire stock domains, e.g., by additionally sampling nearshore using FVS, farther offshore using USVS, and in international waters through collaboration. Accuracy has also improved by adding more transects and trawls in areas of high abundance and species diversity. Precision has increased by interleaving FSV and USV transects, resulting in increased sampling density.

Forage Fish Assemblage

The IMIPAS-NOAA ATM survey now produces biomass and composition estimates of at least six species and eight stocks. Collectively, the results allow the biomass and dominant species of the forage fish assemblage, a fundamental functional group in the CCE, to be tracked. This provides information on the productivity and resilience of the ecosystem. The information can indicate resource surpluses and optimal harvest rates; and it can warn of food web deficiencies. For example, in 2014 and 2015, when the cumulative biomass of CPS in the CCE was below ~200,000 t, and the USA fishery for NSPS was closed (NMFS, 2015), there were reports of mass strandings, deaths, and reproductive failures in Brown Pelicans *(Pelecanus occidentalis)*, Common Murres *(Uria aalge)*, Brandt's Cormorants *(Phalacrocorax penicillatus)*, and California sea lions *(Zalophus californianus)* (McClatchie *et al.*, 2016), all of which depend on these forage species. Conversely, since 2018, the CPS assemblage has been dominated by CSNA with a biomass exceeding 3 Mt, suggesting an underexploited surplus (Kuriyama *et al.*, 2022a).

Observational assessments

The ATM surveys of CPS provide information needed to apportion the observations to species, their lengths, ages, and sub-populations, and to simultaneously assess multiple CPS stocks. The results include most or all of the components needed for population assessments, including: stock distributions, abundances at age, indications of recruitment, and estimations of cohort-specific growth and mortality. Collectively, these observational assessments provide data on the forage-fish assemblage and track species alternations, which can indicate the state of the ecosystem.

Generally, however, CPS stocks under the US jurisdiction using information from analytical stock assessments. Instead of using the observations directly for managing fisheries, the results of ATM surveys are used as the primary or, since the closure of CPS fisheries, sole input to these stock assessment models, and the model parameters are adjusted to fit the ATM observations. This is not always the case, however. For the management of some fisheries, the quality and frequency of observational assessments is preferred information to set catch limits (Uriarte *et al.*, 2023).

Acknowledgments

The NOAA ATM surveys represent the culmination of more than a half century of development efforts by researchers from around the world. Each survey requires effort by many people, particularly those in the SWFSC's Advanced Survey Technologies group; CalCOFI and Ship Operations group; Life History Group; and Stock Assessment group; as well as administrative staff; and volunteers. Also vital to the contemporary surveys are the efforts of the captains and crews of FVs *Long Beach Carnage* and *Lisa Marie*; and the scientists and staff from the California Wetfish Producers Association, Ocean Gold Seafoods, the Washington Department of Fish and Wildlife, and the California Department of Fish and Wildlife. The participation of scientists and staff from IMIPAS has been critical to the NOAA surveys in 2021 and 2022 as well as the USA-Mexico collaboration since 2021.

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