FEATURE

A Collaborative Aerial Survey of Coastal Pelagic Species in Nearshore California Waters

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A school of Pacific Sardine *Sardinops sagax*. Photo credit: Dana L. Brown.

[Correction added on 30 November 2022, after first print and online publication: An affiliation to NOAA - Southwest Fisheries Science Center has been added for Emmanis Dorval.].

DOI: 10.1002/fsh.10840

Pacific Sardine *Sardinops sagax* and Northern Anchovy *Engraulis mordax* are commercially important West Coast fish stocks managed within the Coastal Pelagic Species (CPS) complex by the Pacific Fishery Management Council and National Marine Fisheries Service. Before 2020, survey indices used in Pacific Sardine stock assessments did not explicitly account for nearshore biomass, which presumably had been relatively small compared to the total biomass of the population, but since 2015, has been a more substantial component of total biomass. During the recent Pacific Sardine stock decline, the California Department of Fish and Wildlife and the California Wetfish Producers Association collaborated on an aerial survey off California to estimate nearshore (within 3,600 m from shore) CPS biomass to inform assessments. This project has also involved federal fisheries biologists and Pacific Fishery Management Council advisory bodies and committees, representing a unique collaborative effort to improve data used in CPS fisheries management. We will discuss successes, issues, and challenges in implementing this nontraditional survey and how these data can continue to inform future stock assessments.

BACKGROUND

West Coast fisheries for Pacific Sardine *Sardinops sagax* (hereafter, sardine) and Northern Anchovy *Engraulis mordax* (hereafter, anchovy) are managed within the Coastal Pelagic Species (CPS) complex by the Pacific Fishery Management Council (PFMC) and the National Marine Fisheries Service (NMFS). In periods of low abundance, sardine and anchovy populations can concentrate in nearshore water depths of <40 m, typically less than about two nautical miles from shore, to seek more favorable feeding or spawning habitats (e.g., MacCall 1990; MacCall et al. 2016; Thayer et al. 2017). The main indices of abundance used in recent sardine and anchovy assessments (Kuriyama et al. 2020, 2022a, 2022b) are derived from the National Oceanic and Atmospheric Administraton (NOAA) Southwest Fisheries Science Center (SWFSC) Acoustic-Trawl Method (ATM) survey (Zwolinski et al. 2012, 2014), which cannot access these shallow nearshore areas. The ATM survey cannot survey in water depths less than 30 m, and nearshore acoustics surveys using industry vessels beginning in 2019 cannot survey in water depths less than 10 m (Stierhoff et al. 2020).

The commercial CPS fisheries off the U.S. Pacific coast originated in California during World War I, as sardine, anchovy, Jack Mackerel *Trachurus symmetricus*, Pacific Mackerel *Scomber japonicus*, and market squid *Doryteuthis opalescens* were processed at canneries centered in Monterey and San Pedro, but also in San Francisco and San Diego. Today these five species are managed by the PFMC under the CPS Fishery Management Plan (PFMC 2019a). They are historically known as "wetfish" because they were moved wet from the ocean to cans at the processing plants (CWPA 2021). Since 1916, the sardine fishery has been one of the largest fisheries in California in terms of volume and value, except during times of fishery closures (1967–1985 and 2015–present; Kuriyama et al. 2020; PFMC 2020a). Recent anchovy landings (since 1983) are much less than historic landings (mid-1960s to early 1980s) due to low market demand and the lower costs of processing fish overseas (PFMC 2020a). Sardine and anchovy caught in the present-day fisheries support a wide variety of commercial uses including bait, feed for aquaculture, and human consumption (PFMC 2020a). To assist vessel catch operations, wetfish fisheries have often employed aerial spotter pilots to locate fish schools that are continually moving in the water column and along the coast (Lo et al. 1992). Biomass estimates by aerial spotter pilots were previously used as an index of relative abundance in stock assessments of anchovy from 1963–1991 and sardine from 1995–2007 (Jacobson et al. 1994; Hill et al. 2007).

The nonprofit California Wetfish Producers Association (CWPA) was established in 2004 to promote sustainable fisheries and foster cooperative research. Voluntary membership includes the majority of wetfish harvesters and processors operating in California (CWPA 2021). Since 2012, the California Department of Fish and Wildlife (CDFW) has partnered with the CWPA to conduct daytime visual CPS aerial surveys (the California Coastal Pelagic Species Survey; CCPSS) to estimate nearshore CPS biomass. As part of these continuing survey efforts, a joint research project in collaboration with the SWFSC began in 2018 to address reviewer recommendations for enhancing the aerial survey's utility in CPS stock assessments and management. This project uses survey biomass estimated by an experienced industry spotter pilot to compute aerial survey variance from replicated flights (Dorval and Lynn 2019; PFMC 2022). In addition, catch data from industry vessels directed by the spotter pilot are used to validate aerial biomass estimates (point sets). The associated biological data from the point sets provide size and age structure of the captured schools. These research efforts allow the collection of data to improve estimates of aerial survey biomass and variance and refine bias correction factors for spotter observations. In the 2020 and 2021 sardine and the 2021 anchovy stock assessments, aerial survey biomass for each species was used as a correction factor to adjust the catchability of the ATM survey, and hence indirectly accounted for nearshore biomass not included in the ATM survey biomass index in the stock assessment model (Kuriyama et al. 2020, 2022a, 2022b).

Providing information on nearshore sardine and anchovy abundance is essential to stock assessments, since distribution of the stock biomass can expand offshore when abundance is high and contracts into nearshore waters when abundance is low (MacCall 1990; MacCall et al. 2016). Both sardine and anchovy experience boom and bust cycles in population levels, on decadal scales (McClatchie et al. 2017). Sardine biomass has been at recent historically low levels, resulting in the closure of the directed commercial fishery in 2015 (USOFR 2015). Although there have been recent efforts to extend acoustic surveys into waters closer to shore using fishing vessels with smaller drafts (Kuriyama et al. 2022b), these surveys cannot reach all the way to the shoreline. Spotter pilot surveys have been used as the basis for indices used in earlier sardine and anchovy stock assessments, e.g., an aerial sardine survey conducted off the West Coast of the United States used in sardine assessments from 2009–2012 (Hill et al. 2012; Jagielo et al. 2012). Continued aerial surveys will require sustaining collaboration in the face of challenging economic times with some CPS fisheries experiencing an ongoing downturn resulting from low stock abundance of sardine and mackerel, and low market demand for anchovy (PFMC 2020a). Recent food web modeling indicates sardine and anchovy are key forage species (Koehn et al. 2016). Aerial surveys will provide critical information on nearshore CPS abundance at low cost to complement data collected from boat surveys. The cost for running the aerial survey can be 1–2

orders of magnitude lower than the on-the-water CPS survey, although it can be difficult to adequately compare costs between these surveys because they operate on different temporal and spatial frames. In addition, the CCPSS has increased attention on the importance of nearshore biomass for CPS. The PFMC advisory bodies have recommended nearshore surveys, such as aerial surveys and SWFSC nearshore acoustics and Saildrone surveys in recent years to address this data need (PFMC 2019b).

The ultimate goal of this aerial survey research project is to estimate CPS abundance in nearshore waters where traditional NOAA survey vessels cannot operate. The project specifically collects nearshore aerial biomass data for improving CPS stock assessments. This work helps to ensure that sustainable management of economically and ecologically important sardine and anchovy stocks is based on the most accurate and complete data possible. These partnerships also build trust in stakeholders regarding the management decisions that regulate their industry.

PROJECT DESCRIPTION

Initially focused on Sardine biomass within the Southern California Bight in 2012, the CCPSS expanded its focus the following year to also include anchovy. Since 2017, the survey has covered nearshore waters off the California coast from the U.S./Mexico border to just south of the California/Oregon border. The aerial survey has typically been flown twice a year, once in the spring and again during the summer or fall. The decision to expand the survey to Northern California (north of Point Conception) in 2017 resulted in increased spatial coverage of the survey, while improving synoptic sampling with the ATM survey as it proceeded in California waters targeting the northern subpopulation of sardine and the central subpopulation of anchovy (PFMC 2019a). Aerial surveys were conducted concurrently (see PFMC 2022, table 1) and flown off the same portions of coastline covered by the ATM survey in August 2017, August 2019, and March–April 2021 (Figures 1–3). The aerial surveys in 2017 and 2019 flew southward from Northern California to the endpoint of the ATM survey at Morro Bay in 2017 and the U.S./Mexico border in 2019 (Zwolinski et al. 2019; Stierhoff et al. 2020). The 2021 aerial survey was coordinated with the ATM survey within the Southern California Bight only, as part of the total ATM survey area extending north to San Francisco.

On a given survey day, the determination of which areas are flown is contingent on (in order): local weather conditions,

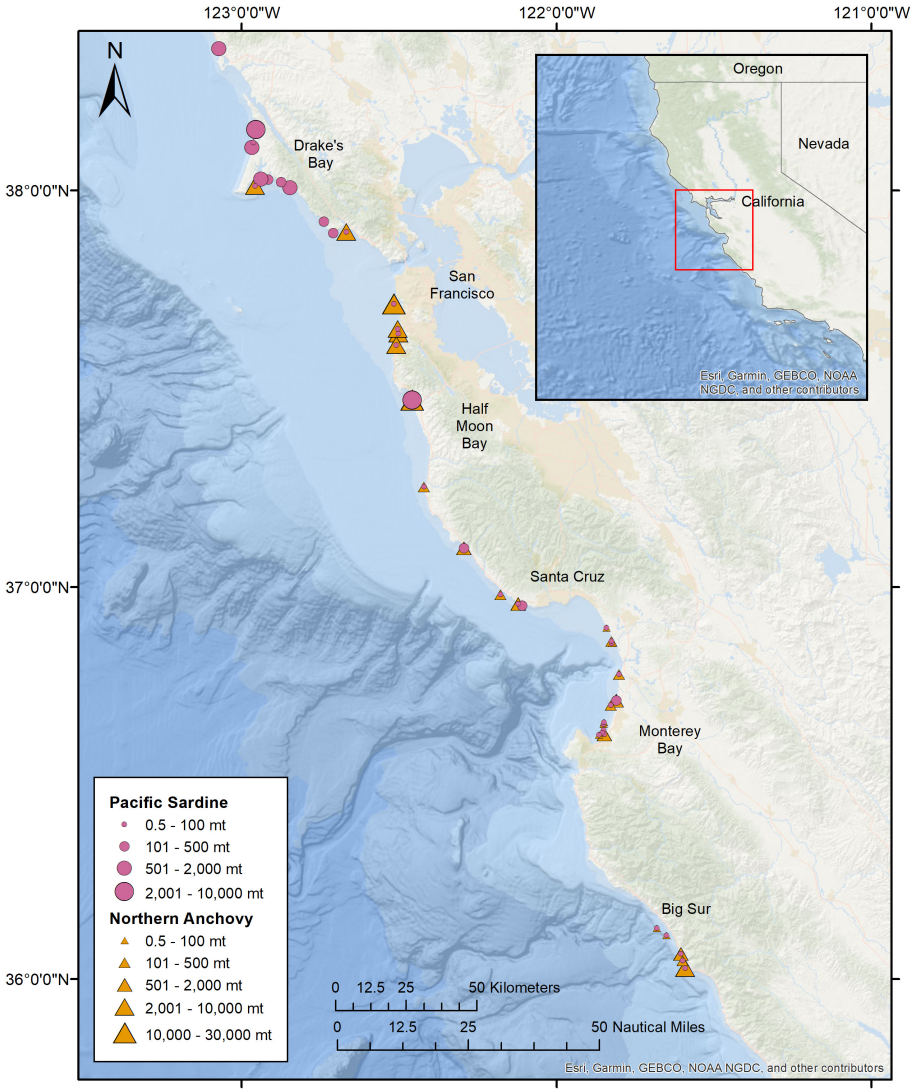

Figure 1. Distribution and size of observed Pacific Sardine and Northern Anchovy schools are shown here from summer 2017 aerial surveys off Northern California.

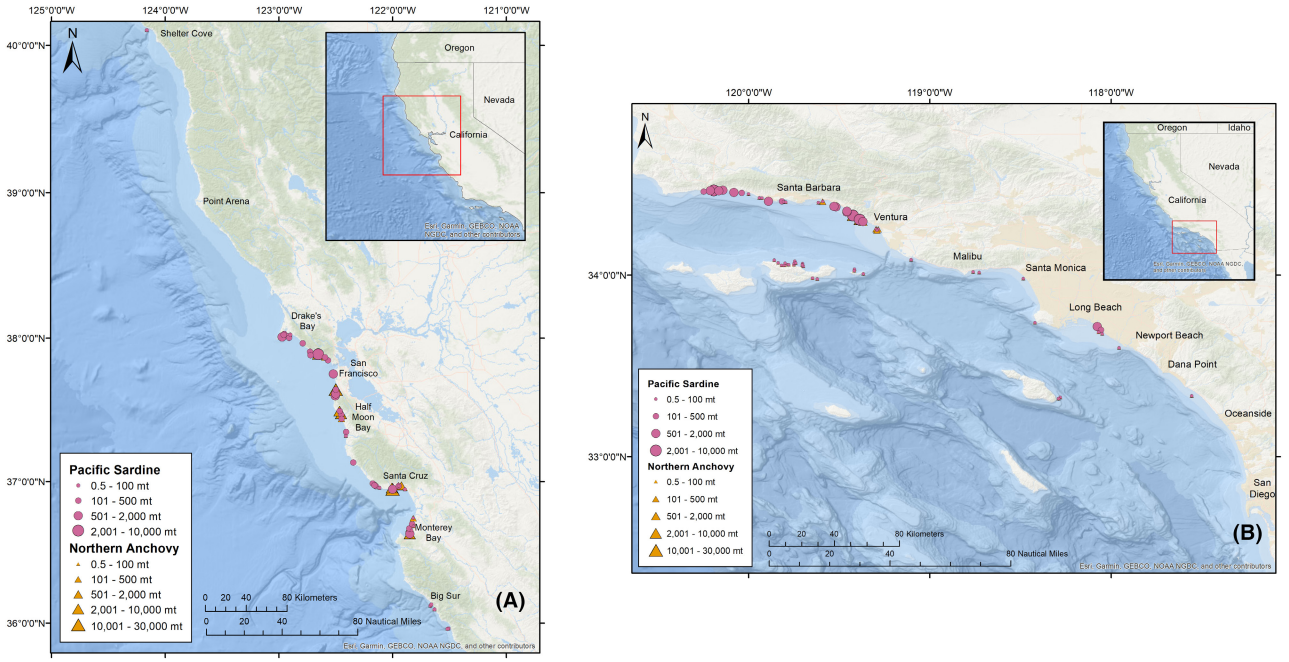

Figure 2. Distribution and size of observed Pacific Sardine and Northern Anchovy schools are shown here from summer 2019 aerial surveys off Northern California (**A**) and Southern California (**B**). Northern Anchovy were seen in much lower abundance in Southern California, clustered primarily off the Santa Barbara–Ventura coast.

coordination with acoustic survey vessels (if any), and random selection within those constraints. For any specific area, acceptable conditions for conducting an aerial survey are maximum wind speed of approximately 10–12 knots, and visibility at least 90% clear of cloud cover. Transects were completed using a CDFW aircraft with an experienced industry spotter pilot and CDFW scientist onboard to record data (Figures 4 and 5). Surveys were flown at 457 m (1,500 ft) altitude. Between 2015–2019, the survey transect design consisted of flying one replicate of two transects covering out to 2.4 km from the coast. Review panel recommendations resulted in design changes for surveys beginning in 2020 to include two replicates and pre-designated strata with an additional transect covering out to 3.6 km from shore (PFMC 2017, 2019b, 2021). Survey transects are spaced 1.2 km apart, and range in length from 28 to 56 nm (PFMC 2022).

When sardine or anchovy are identified along a given transect, the aircraft diverts from the transect to allow the spotter to examine the sighting more closely to identify the species present, obtain species composition, and estimate biomass

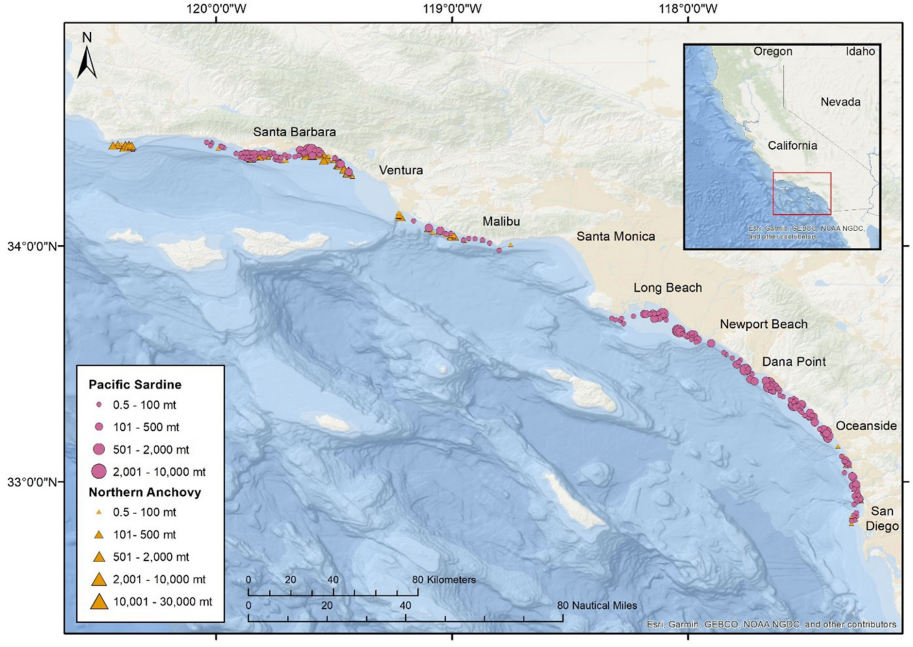

Figure 3. Distribution and size of observed Pacific Sardine and Northern Anchovy schools are shown here from spring 2021 aerial surveys off Southern California.

Figure 4. California Department of Fish and Wildlife used a Partenavia aircraft for 2012–2019 surveys.

tonnage (Figure 6). Once schools are confirmed, photographs are taken to document the observations to the extent possible. The spotter's observations are recorded on field data sheets. Photos and coordinates are captured for data post-processing and spatialization. For additional details on aerial survey methods and data recorded, refer to Lynn et al. (2019).

The joint research project has used two fishing industry spotter pilots and a private aircraft to conduct: (1) replicated transect surveys to obtain information on variance of biomass estimated by aerial survey spotters, and (2) validation of aerial biomass estimates, through "point set" surveys in conjunction with local commercial fishing vessels using purse seine gear. For the point set surveys, the spotter pilots identify CPS schools and then direct the fishing vessels to set on and capture the schools. Information is recorded on aerial estimates of biomass in tons and percent capture of the schools by the vessels.

Capturing schools using purse seine gear is a complex operation, and weather, especially wind and swells, is a much more significant factor to the smaller purse seine fishing vessels transiting and setting gear than for the larger research vessels. Purse seine vessels range in size from 9–27 m (30–90 ft) in length and 20–140 gross registered tons (Figure 7). Purse seine vessels require 5–8 crew to operate, including the skipper (CWPA 2021). Deploying the gear involves launching a smaller skiff vessel off the stern that maneuvers one end of the net while working with the seine vessel to encircle the school (Figure 8). The net is then "pursed" at the bottom to close it and capture the school. Once the spotter pilot has identified a school of fish, the purse seine vessel must follow the school to identify the species, determine size of the school and fish, and discern behavior patterns, taking up to 1 h. Aiming for 100% school capture, the vessel must then get in position to deploy the gear and wrap the school, which usually takes another hour under ideal conditions. Fish inevitably escape or avoid being wrapped and sometimes 100% capture is not achieved. The maximum biomass of schools captured is limited by the purse seine size and vessel hold capacity, about 110 metric tons. The validation efforts to date have included point sets ranging from approximately 2–111 metric tons. After schools are captured, they are brought into the nearest port and offloaded at a licensed fish receiver. When offloaded, the receiver weighs the entire catch and a CDFW biologist conducts bucket sampling to obtain a representative composition of the catch while collecting biological samples (Dorval et al. 2022).

Figure 5. Survey conducted off Santa Catalina Island shown here. On this survey are California Department of Fish and Wildlife warden–pilot Tom Evans (left) and California Wetfish Producers Association spotter pilot Devin Reed (right).

Spotter estimates of school biomass are compared with landed tons to derive a bias correction factor to adjust field CPS biomass estimates using regression analysis. This factor has been established effectively for sardine estimates in Southern California, but more data are needed to develop factors for the second spotter pilot and for sardine estimates in Northern California and anchovy estimates in both regions. These point set data are also used to evaluate aerial species identifications and provide biological information such as length and age from collected samples that can improve the accuracy of aerial survey data and potentially inform stock assessments.

USE IN MANAGEMENT

Comprehensive information on nearshore CPS biomass is an important part of stock assessments. Aerial surveys are uniquely capable of documenting biomass all the way to the water's edge, impossible in any vessel-based survey. This methodology has been used to estimate population size and distribution for a variety of marine taxa, including dolphins (Delphinidae; Slooten et al. 2004), Pacific Bluefin Tuna *Thunnus orientalis*

Figure 6. Pacific Sardine schools are seen off the Southern California coast.

(Bauer et al. 2015), sharks (Elasmobranchii; Cliff et al. 2007), and Bigeye Scad *Selar crumenophthalmus* (Wiley et al. 2021). This is especially important for CPS finfish, because when stocks decline to relatively lower abundance levels, increasingly larger proportions of the total stock biomass can concentrate in nearshore areas (MacCall 1990; MacCall et al. 2016).

The inclusion of aerial survey data to account for nearshore biomass in the 2020 stock assessment increased the final stock biomass estimate (Kuriyama et al. 2020). The NOAA ATM survey biomass is used as the primary survey input in CPS stock assessments as relative indices of abundance, but since these surveys are limited to nearshore waters, aerial survey biomass estimates were used to adjust the ATM catchability (how much of the stock the ATM survey sees) in the sardine stock assessment model (Kuriyama et al. 2020) and can also potentially be used as a separate survey index in the future. For the 2020 sardine benchmark assessment, catchability was estimated at 0.73 for the 2015–2019 period, meaning that aerial survey biomass accounted for 27% of the total sardine biomass (Kuriyama et al. 2020). In addition, aerial survey biomass estimates were also used in the 2022 sardine update assessment (Kuriyama et al. 2022a, table 2) and in a 2021 benchmark anchovy stock assessment (Kuriyama et al. 2022b, table 8). Currently, the inclusion of aerial survey biomass in sardine stock assessments has a greater proportional effect due to the relatively lower overall stock biomass, but it is expected that anchovy nearshore abundance will have a greater impact on stock assessments when its biomass declines since the nearshore concentration of anchovy is believed to be even more pronounced than for sardine at low abundance (MacCall 1990; MacCall et al. 2016).

ADVANTAGES

These surveys represent a complementary approach to collect data on nearshore CPS biomass, variance, and biological information. Using the expertise of a professional spotter pilot has enabled ready identification of observed fish species and estimates of biomass. Without this capability, the surveys would have required costly and time-consuming training of CDFW staff as aerial spotters, and likely resulted in survey data not as accurate and precise as those from a seasoned industry spotter pilot. Validation of spotter identifications and biomass estimates to date has shown them to be highly reliable and accurate for schools ranging from 2–111 metric tons, with spotters underestimating biomass by about 10% compared to landed tonnage (Dorval and Lynn 2019; PFMC 2022). Scientific staff working together with spotter pilots, commercial fishing crews and vessels have the combined knowledge, experience, and gear to efficiently capture CPS schools to collect data on biomass, validation and biological information.

CHALLENGES

Despite significant benefits from these surveys, many challenges remain. The fact that there are only a handful of spotter pilots available that have the necessary expertise in aerial CPS identifications and quantifying biomass, with only two available for these surveys, means that survey work is centered around their limited availability. The aerial survey work is also subject to unpredictable weather conditions, fires and associated smoke in certain areas, airspace restrictions, aircraft maintenance, and other scheduling difficulties. These can all lead to canceled surveys or add pressure to conduct survey work in the limited time when aircraft and survey personnel are available and conditions permit. Attempts at close coordination of aerial surveys with ATM surveys are most affected by weather conditions, and the desired maximum separation of 3 d in temporal coverage of the same latitudinal range between the two surveys (as recommended by review panels) can be difficult to

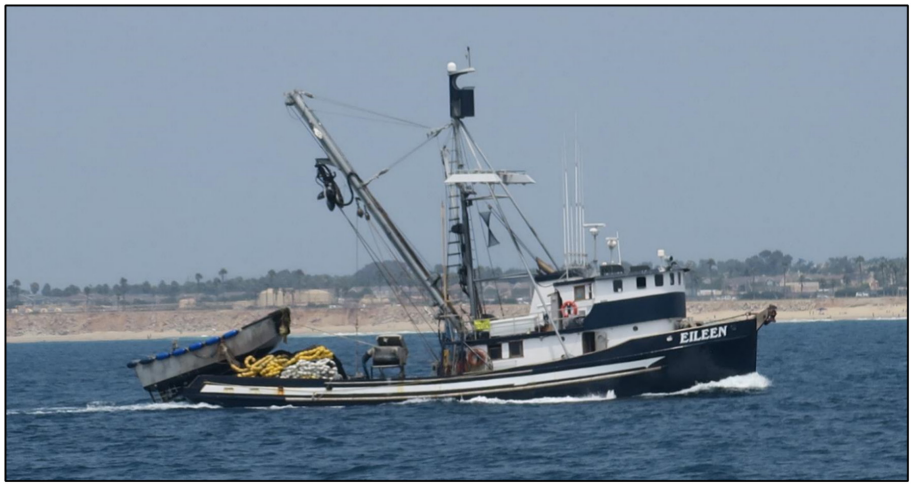

Figure 7. Fishing vessel *Eileen* transits to point set work, August 2018.

Figure 8. Fishing vessel *Trionfo* conducts purse seine operations catching Northern Anchovy within Half Moon Bay, California, August 2017.

achieve, although aerial surveys can cover area relatively faster than ATM. Other factors that affect survey coordination are mechanical and/or logistical issues with ATM survey vessels that may cause delays, which can disrupt predetermined aerial survey schedules. Nevertheless, most aerial surveys have been conducted within 3 d of ATM surveys, but this timing has ranged up to a week or so.

Weighing research and fishery needs remains a difficult balancing act for the fishing industry, given the state of the fishery and scientific work needed to collect data that fully reflects the true status of CPS stocks. The CWPA pilots and fishing crews work full time in other capacities, and the successful design and execution of surveys requires careful planning of survey and research activities with CDFW and SWFSC. Collaboration with research partners from the start has required close coordination involving personnel and equipment, availability and scheduling, funding, and prioritizing when and where to focus efforts.

Incorporating aerial survey data into stock assessments to inform fisheries management is a challenging process. Any use of new data in PFMC stock assessments must first undergo a methodology review that can be proposed to the PFMC once a year. The survey was proposed for such a review three times: in 2013, 2015, and 2016 before being approved for a 2017 review (PFMC 2017). Additional review panel recommendations and other feedback on research needs arose from a 2019 anchovy research meeting (PFMC 2019b). The principal recommendations were: (1) to fly transects synoptically with ATM surveys to align offshore and nearshore biomass estimates, and (2) to replicate transects and further develop a variance estimator. The CCPSS began coordination with ATM surveys in summer 2017 and have continued since then. A revised aerial survey design with replicated transects began with summer 2020 surveys.

Aerial survey data were first used in the sardine assessment in April 2020. Aerial survey data from 2017 and 2019 were presented for use, but only 2019 data were used to adjust catchability, since 2017 data were determined to have an excessively high proportion (83%) of survey tonnage from larger-sized schools greater than the maximum school sizes able to be validated constrained by vessel (total hold capacity) and net size (PFMC 2020b). The 2019 data that were deemed acceptable for use in the stock assessment had ~17% of the total estimated biomass from schools that were >100 metric tons. For recent survey seasons (2020–2021) the percent of tonnage from schools >100 metric tons has varied but were mostly <10% for both species and regions. Ongoing research includes use of unmanned aerial systems to examine their feasibility for use as platforms for photogrammetric validation of spotter pilot biomass estimates of large schools, and as a potential means of automating aerial surveys in the future.

Funding for fishery participants is a key concern. On top of their lack of revenue due to the closure of the directed sardine fishery, fishermen lose revenue when participating in collaborative research, as the costs associated with fuel, crew pay, and reduced fishing opportunity far outweigh those from normal fishing activity. Prior to and during each research season, discussions on survey logistics and design are essential to both maximize the value of the data collected and minimize associated costs. Effective communication of the rationale and details of the design are central to these discussions so that industry participants fully understand the purpose and eventual use of the data collected, and to ensure that field operations are designed and conducted so that data are useful. Close collaboration with CWPA has shown that the fishing industry understands the need for continued data collection to track CPS biomass regardless of stock levels, and even under the current difficult economic circumstances with closure of the directed sardine fishery and historically modest catches of other CPS stocks such as anchovy and Pacific Mackerel.

Recent aerial research projects have been planned on short-term time windows due to budgetary limitations. Securing funds to support industry research time remains a constant challenge. Renewing development of research projects with partners, particularly in seeking more funding sources, will likely continue to be revisited frequently. As more data are collected for observer biomass validation from point sets, that research will eventually be completed, and costs associated with use of industry purse seine vessels will end. All potential

sources of support, including funding from federal and state government research grants and private organizations, will need to be considered to maintain all data time series.

NEXT STEPS

There are several research areas that can benefit the aerial survey moving forward. Given that the current method relies on human spotter availability and is limited to very few individuals with the experience and ability to identify and quantify CPS biomass from the air, the use of manned and unmanned photogrammetric imagery platforms is being explored to automate the process of estimating biomass. Statistical software based on machine learning can be developed and validated, greatly expanding flexibility and effort in conducting surveys and facilitate future surveys much more economically (Terayama et al. 2019; Allken et al. 2021; Joo et al. 2022).

Fisheries management is focused on sustainable harvest of stocks that are available and marketable to the fishery. This may involve specific size, age, or life stages that are taken by a fishery and of interest to managers and useful for stock assessments. One research recommendation for the CCPSS has been to investigate the age proportions of anchovy estimated from surveys, as the California fishery only targets adult fish (PFMC 2019b). Any juvenile anchovy biomass estimated from aerial surveys will need to be accounted for and excluded from the data provided to stock assessors. Determining the proportions of adult and younger anchovy requires sampling, which can only be done with nets capable of capturing all sizes of fish. Industry vessels do not use these types of nets, so we are developing alternative methods to obtain adequate samples and estimate the proportions of juvenile fish in aerial survey biomass.

Two industry spotter pilots have been used to examine variability between and within each spotter pilots' biomass estimates. This has resulted in bias correction factors developed for each spotter pilot so that either can be used to conduct surveys and their observed biomass estimation data can be adjusted appropriately, thus creating more flexibility in planning and conducting future surveys. Additional spotter pilots, or the incorporation of photogrammetric imagery with computer analysis described above, would assist with many logistical and scheduling constraints currently faced.

The inception of the aerial survey began with the goal to use aerial survey biomass estimations with biological sample data to better inform stock assessments of nearshore biomass missed by large research vessels such as those used by ATM surveys. Beyond stock assessments, the CCPSS has contributed to improving the fisheries management process while fostering direct participation of stakeholders. Information provided to managers has increased understanding of the temporal and spatial dynamics of CPS stocks in shallow waters off California and the implications of nearshore biomass on managing sardine during the recent low biomass years. Aerial survey biomass time series are also one of the primary data sources that have informed managers on the recent recovery of the central subpopulation of anchovy after a recent period of low abundance (Kuriyama et al. 2022b). It has been invaluable to work collaboratively with experienced fishing industry spotter pilots to identify and quantify CPS schools, as well as with commercial fishing vessels to catch fish for validating aerial biomass estimates and collecting biological information for CPS management.

The combined expertise from professional spotter pilots and commercial fishermen along with state and federal scientists creates a unique platform to provide nontraditional data for informing CPS stock assessments and management. Collaborative efforts require constant iterative involvement and interactions among research partners for successful outcomes, creating both advantages and challenges. Thus, we will continue seeking better means to strengthen the aerial survey research collaboration, as the partnerships with stakeholders build trust in the stock assessment and management process, and ultimately a more satisfactory result for all.

ACKNOWLEDGMENTS

We are grateful to a number of individuals for their contributions to this survey. We thank the CWPA and their executive director, Diane Pleschner-Steele, for collaboration on this project. Aerial spotters for the CWPA, Devin Reed and Andrew White, were vital in identifying and estimating abundance of fish in the field. We also thank fishing vessel captains Neil Guglielmo, Corbin Hanson, Nick Jurlin, Jamie Ashley, Pete Ciaramitaro, Anthony Russo, and Andy Russo. Vince Torre, Dominic Augello, Lillo Augello, Anthony Tringali and Jenn Cabotage provided processor assistance in receiving point set catch. Tom Evans, Gary Schales, Kevin Kintz, Mike Breiling, and Mike Greenhill of CDFW Air Services ably piloted the survey aircraft. John Ugoretz of CDFW provided support and guidance. We would like to thank Katie Grady, Erica Mills, and Dana Myers of CDFW for designing survey maps and processing survey data. CDFW staff members Chelsea Protasio, Leeanne Laughlin, and Scientific Aid staff participated in point set sampling and in collecting and processing biological samples during the surveys. We thank Andre Punt, John Budrick and members of the Scientific and Statistical Committee of the Pacific Fishery Management Council for reviewing and improving the survey design and analytical methods. Finally, we acknowledge the helpful discussions and comments from the CDFW aerial survey team and staff: Briana Brady, John Budrick, and Michelle Horeczko; and NMFS staff: Kevin Hill, Juan Zwolinski, David Demer, and Kevin Stierhoff. The joint research survey was funded by the NOAA Internal Cooperative Research Program and Fisheries Disaster Relief with substantial indirect funding from CWPA and CDFW, and was conducted under Experimental Fishery Permits (EFP-08/09-2018-2019, EFP-07/08-2019-2020, and EFP-08/06-2020-2021) approved by the Pacific Fishery Management Council and issued by the NMFS West Coast Regional Office. Research activity within the Monterey Bay National Marine Sanctuary was conducted under permits MBNMS-2019-020, MBNMS-2019-023, MBNMS-2020-023, and MBNMS-2021-017. There is no conflict of interest declared in this article.

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