

REPORT FROM THE PACIFIC SARDINE STOCK STRUCTURE WORKSHOP, NOVEMBER 2022

Edited by Annie Yau

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Southwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic & Atmospheric Administration
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INTRODUCTION

The Southwest Fisheries Science Center (SWFSC), Fisheries Resources Division (FRD) hosted a Pacific Sardine Stock Structure Workshop from November 15-17, 2022, in response to comments received from the Pacific Fishery Management Council's (PFMC's) Scientific and Statistical Committee (SSC) about the 2021 catch-only assessment update of the northern subpopulation of Pacific sardine completed by FRD scientists. That assessment showed that catches from the Mexico (Baja CA) fleet that were attributed to the northern subpopulation were on the same order as the entire estimated biomass of the northern subpopulation, which led to unrealistic changes to the estimates of recruitment and consequently that update assessment was not accepted for use in management. This renewed discussions about Pacific sardine stock structure and its delineation in the stock assessment and hence how survey and catch data are assembled for assessment purposes. Consequently, the SWFSC hosted this workshop as preparation for the early 2024 benchmark stock assessment for the northern subpopulation of Pacific sardine.

There were two major points requested from the SSC. First, that the habitat model (Zwolinski et al. 2011) used to delineate northern subpopulation sardine in the data from CPS surveys (also referred to as Acoustic-Trawl Method (ATM) surveys) be updated with recent years of data that include years of lower sardine stock abundance, to see if the habitat model changes or not. Second, that the method used to delineate northern subpopulation catch (Demer and Zwolinski 2014) be revisited in light of recent years of high catches from the Baja CA fleet being included in the stock assessment.

There are several possibilities for why Mexico catches were being reported on the same order as the entire estimated biomass of the northern subpopulation, and some ideas are (this is not a comprehensive list):

1. Attribution of catch data to stock could be refined (but there may not be detail in the data to do so)
2. Attribution of biomass data to stock from the ATM surveys could be refined, for example decreased inclusion of sardines possibly part of the northern stock and/or recalibrating the habitat model to include more data on years of low sardine abundance (but there may not be detail in the data to do so)
3. Stock structure is changing/different
4. Misreporting of landings, for example misidentification of species

The Pacific Sardine Stock Structure Workshop sought to address those two major points from the SSC and also serve as an opportunity to discuss recent and ongoing research on Pacific sardine stock structure. The Terms of Reference and Agenda for this workshop are provided in Appendix 1.

SWFSC hosted the workshop in a hybrid format, with about 25 in-person participants and 35 virtual participants daily. Many FRD scientists participated. The workshop was open to the public and announced by the PFMC. The SWFSC hosted one member each from the SSC Coastal Pelagic Species (CPS) subcommittee, the CPS Management Team, and the CPS Advisory Subpanel. Persons from the NMFS West Coast Regional Office, PFMC staff, the California Department of Fish and Wildlife (CDFW), and persons from industry and nonprofit organizations were in attendance. A full list of participants is found in Appendix 2, with not all persons attending the entire workshop.

WORKSHOP PROCEEDINGS

The workshop began with introductions, logistics, and covering the Terms of Reference and Agenda. Next came a quick presentation on the current prevailing hypothesis for Pacific Sardine stock structure, defined in the Appendix A-9 of the PFMC’s CPS Fishery Management Plan (PFMC 1998). Then came presentations on the current methods to delineate CPS survey data (Zwolinski et al.2011) and catch (Demer and Zwolinski 2014) for northern subpopulation of sardine.

The current habitat model has been used to delineate northern from southern subpopulation from CPS surveys conducted in the summer. Biomass numbers by stock are reported in the NOAA tech memos produced after every survey, and a table was produced during the workshop summarizing the numbers (Table 1).

Table 1. Amount of biomass from CPS surveys by northern versus southern stock, using the current habitat model (Zwolinski et al. 2011).

Year	Season	Northern stock biomass (t)	Southern stock biomass (t)
2006	Spring	1950000	-
2008	Spring	751075	-
2008	Summer	784000	-
2010	Spring	357006	-
2011	Spring	487871	-
2012	Spring	469480	-
2012	Summer	341000	-
2013	Spring	305145	-
2013	Summer	313745	-
2014	Spring	35330	-
2014	Summer	26270	-
2015	Spring	29048	-
2015	Summer	14795	-
2016	Spring	83037	-
2016	Summer	80902	323
2017	Summer	14155	-
2018	Summer	25148	33093
2019	Summer	35403	14954

Ongoing research related to Pacific sardine stock structure

FRD scientists and participants present were not aware of any recent publications on the topic of Pacific sardine stock structure, so no new published information was presented or considered. Instead, FRD scientists provided 5 presentations on ongoing research related to Pacific sardine stock structure. A short abstract of each presentation follows.

PROGRESS REPORT ON GENETICS STUDY

Matthew Craig¹, Ella Adams^{1,2}, Gary Longo^{1,3}, and John Hyde¹

¹ Fisheries Resources Division, NOAA Southwest Fisheries Science Center

² University of San Diego

³ University of Alaska, Fairbanks

Pacific sardine (*Sardinops sagax*) is currently managed under the assumption of two subpopulations along the west coast of North America. Past genetic research into the genetic architecture of Pacific sardine is based on allozymes, mitochondrial DNA, and microsatellite allele frequency data. These past studies have all demonstrated panmixia for Pacific sardine, however the genetic markers used are not likely to evolve at sufficient rates to reflect ecologically relevant time scales that are useful for fisheries management. More recent work (2022) has used an increased sample size to examine the phylogeography of Pacific sardine using mitochondrial DNA and has again shown a signal of high levels of mixing on an evolutionary time scale. Advances in data generation and analytics allow for the examination of much larger data sets (thousands to hundreds of thousands of loci) primarily using single nucleotide polymorphisms (SNPs). SNPs evolve at time scales of years, making them more suited to time scales relevant to management. Work is currently underway at the SWFSC to evaluate population structure using SNPs across both time and space. The current study design is a two-faceted approach that generates SNPs from low coverage, whole genomes for screening using samples from across the geographic range of Pacific sardine from 2021 to early 2023, while simultaneously collecting samples monthly from a single location to examine potential differences in sardine allocated to putative populations through the year.

PROGRESS REPORT ON SIMULATION STUDY FOR METHOD TO ASSIGN STOCK STRUCTURE

Barbara Muhling^{1,2}

¹ Institute of Marine Sciences, University of California – Santa Cruz

² Fisheries Resources Division, NOAA Southwest Fisheries Science Center

Habitat and temperature-based rules are currently used to separate survey catches and fisheries landings of sardine to subpopulation. In this recently funded study, we aim to 1) compare the current habitat model (developed by Zwolinski et al. 2011) to sea surface temperature-based rules for assigning catch to subpopulation, 2) assess whether marine heatwaves lead to divergence across methods, which may indicate vulnerability of the current rules to climate change and extreme events, and 3) simulate future sardine landings by port and subpopulation using downscaled climate projections. Preliminary results presented here show that sardine captured off San Pedro are typically in northern subpopulation habitat in cooler months, and southern subpopulation habitat in warmer months. However, during the 2014 -2016 marine heatwave, the presence of northern habitat was minimal across all months off southern California. Work in the next 12 months will assess whether heatwave conditions cause habitat and temperature-based rules to diverge, potentially introducing uncertainty into stock assessment and management. We will also use downscaled climate projections to show how future environmental conditions may drive changing availability of sardine subpopulations to US fishers.

RECENT SIZE STRUCTURE AND SPATIAL DISTRIBUTION DATA FROM ATM

Juan Zwolinski^{1,2}, Kevin Stierhoff², David Demer²

¹ Institute of Marine Sciences, University of California – Santa Cruz

² Fisheries Resources Division, NOAA Southwest Fisheries Science Center

The Spring 2021 CPS survey sampled Pacific sardine in the Southern California Bight exclusively in the nearshore region and around the northern Channel Islands. There, the habitat was characterized as unsuitable for the northern stock of Pacific Sardine (Zwolinski et al. 2011) mostly due to excessive chlorophyll-a concentration, resulting in all the Pacific sardine being attributed to the southern stock. This stock delineation was later corroborated when Pacific sardine with lengths compatible to those sampled in the spring were sampled in the Southern California Bight during the Summer 2021 CPS survey. Also during the Spring 2021 CPS survey, there was a spatial gap spanning several hundred miles between the presumed northern stock of Pacific sardine sampled off the US Pacific Northwest and the southern stock observed in Southern California which corresponded to a disjoint size structure that could not occur if the two groups were mixing.

EXPLORATION OF LENGTH AT AGE TO INFORM STOCK STRUCTURE

Kelsey James¹ and Brad Erisman¹

¹ Fisheries Resources Division, NOAA Southwest Fisheries Science Center

Pacific Sardine (*Sardinops sagax*) is currently managed in the U.S. under the assumption of two stocks along the west coast of North America. The delineations of these stocks are based on several historical studies that proposed the possible existence of multiple subpopulations using different criteria (e.g., tagging data, blood groups, vertebral counts, isolated spawning centers, growth rates; reviewed by Smith 2005). Regional differences in length at age is included as a criterion based on one study by Felin (1954) who observed bimodality in length compositions of certain year classes and differences in maximum predicted length (L_{inf}) from measurements of growth increments of scales between sardines landed by fisheries in Canada versus San Pedro, California. Based on these results, it was hypothesized that such differences in growth patterns were suggestive of heterogeneous populations with “limited intermingling”. Sources of uncertainty in the historical study by Felin (1954) included the precision, accuracy, and reliability of age and growth rate estimates from scales; the exclusion of estimates of variance in length at age among individuals within regions; methods used to back-calculate ages; and consideration of alternative hypotheses to explain the results. This uncertainty warrants a reexamination of whether length at age is a viable criterion to inform stock structure in Pacific Sardine. Pacific Sardine otoliths from the California Current Ecosystem Survey from 2004-2021 will be used to examine temporal and geographic differences in length at age. The goal of the study will be to test the null hypothesis of a single population by comparing variations in length at age between and among fish assigned to the northern and southern stock. The dataset includes 9502 otoliths of ages 0-10 from Pacific Sardine 30-292 mm standard length from both Spring (n = 11) and Summer (n = 10) surveys that ranged from Canada to Mexico. The temporal and geographic range of this dataset is large. Therefore, the following factors must be accounted for when examining variability in length at age: year, season, survey extent, and environmental factors. Variability in length at age will be assessed within and among individuals assigned to each stock using the habitat model. Pacific Sardine assigned to the southern stock will be aged and added to the dataset.

A PRELIMINARY REVIEW OF BIOLOGICAL DATA USED TO EVALUATE SUBPOPULATION STRUCTURE IN PACIFIC SARDINE

Matthew Craig¹, Brad Erisman¹, Barbara Muhling^{1,2}, and Andrew Thompson¹

¹ Fisheries Resources Division, NOAA Southwest Fisheries Science Center

² Institute of Marine Sciences, University of California – Santa Cruz

Pacific sardine (*Sardinops sagax*) is currently managed under the assumption of two subpopulations along the west coast of North America. Recently, a renewed interest in stock assessment model assumptions and their associated uncertainties in Pacific sardine has developed. With this renewed interest, we conducted a critical review of early studies that are ubiquitous in the literature in reference to population structure in the species. Among the most commonly cited papers published prior to 1965 were those that examined data on vertebral counts, serological antigen response in erythrocytes, and tagging. In contrast to their often-cited support of the alternative hypothesis of multiple subpopulations along the west coast of North America, our review shows that, in many instances, the authors of these papers concluded that their data could not be used to reject the null hypothesis of a single, well-mixed population of Pacific sardine along the west coast of Baja California, MX, the western USA, and Canada. Additionally, reference to two of these data sources (antigen response and vertebral counts) often failed to consider that, despite having been best practice at the time of publication, these data are no longer used in population studies as they are error-prone and may be driven by environmental processes rather than discontinuity in connectivity among regions.

RESULTS

Delineating data by stock

Much of the workshop time was spent addressing the two major points requested by the SSC. Juan Zwolinski provided a presentation showing a habitat model updated with new years of data, and on changing the temperature inclusion threshold used to delineate catch data. These updated analyses were discussed and details are documented in a separate tech memo (Zwolinski et al. in prep.).

Archetype of northern subpopulation of Pacific sardine

A major product of the workshop was to create an archetype of the northern subpopulation of Pacific sardine as currently used for management. A set of illustrative maps (Figs 1-4) were created showing spring (spawning season) distribution of sardine and another showing summer distribution when the stock is more dispersed. Each map includes some distinction of adult versus juvenile distribution. Maps for spring and summer under both abundant versus low abundance scenarios were created. The intent of these four maps (high abundance-spring, high abundance-summer, low abundance-spring, low abundance-summer) is to jointly illustrate current understanding of northern subpopulation dynamics based primarily on SWFSC data from CPS and CalCOFI surveys. Juveniles are defined as immature individuals. Information about Pacific sardine dynamics in low abundance is only based on a few years of recent data, and those recent years have included several years of warmer summer water temperatures due to marine heat waves.

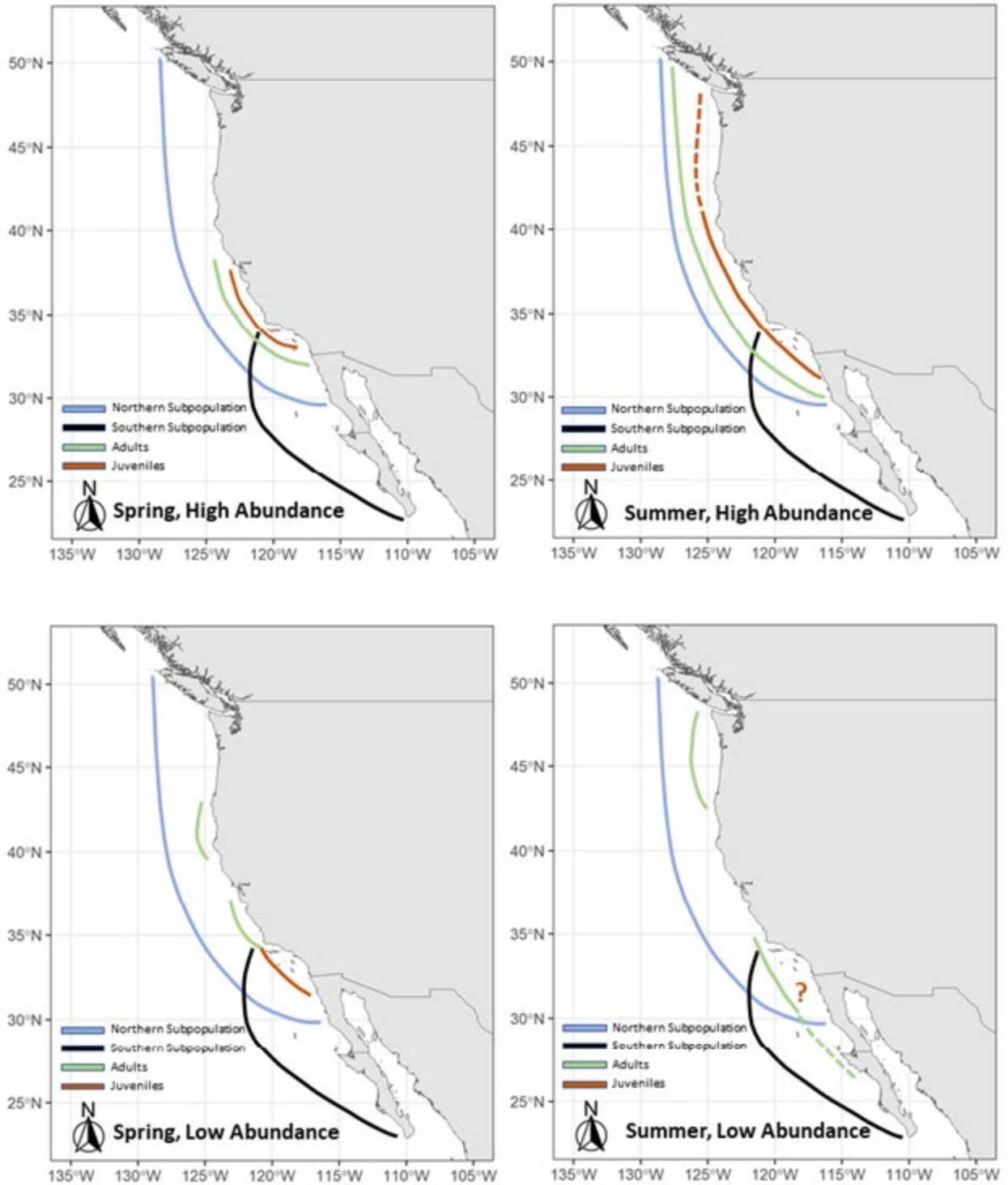


Figure 1. Illustrative archetype of the northern subpopulation of Pacific sardine. Adult distribution in green, juvenile distribution in brownish red, northern subpopulation in blue, southern subpopulation in black. A) (Top, left) Spring at high abundance. Adults aggregate to spawn off Central and Southern California in cold upwelling waters, with juveniles recruiting to areas inshore of spawning. B) (Top, right) Summer at high abundance. Adults disperse and migrate north and inshore all along the US West coast as water temperatures increase, with sporadic spawning off

Washington and Oregon and occasionally off Canada. Juveniles are distributed inshore of adults and are available to Southern and Central California fisheries, sometimes available to Washington and Oregon fisheries. C) (Bottom, left) When found, adults are patchier in distribution and are off Southern Oregon/Northern California with some evidence of spawning, and off Central California but with little evidence of spawning. Juveniles are found inshore in Southern California into Northern Baja California. D) (Bottom, right) When found, adults are off Washington and Oregon, with some found further south off Central and Southern California into Baja California. Juvenile distribution is uncertain.

DISCUSSION

The workshop allowed for focused time discussing the operational details of the prevailing stock structure hypothesis and ongoing research about Pacific sardine stock structure. There were no attempts to jointly define the terms “stock”, “population”, or “subpopulation”, and while such terms were used interchangeably during the workshop it was clear at times that not all participants were using the same definition for each term.

It was widely discussed that there exist alternative hypotheses about Pacific sardine population structure, a primary one being that there is a single stock extending from waters off Canada’s British Columbia south to Baja California in Mexico. SWFSC scientists continue to have discussions about this hypothesis and explore the supporting information for it.

Pacific sardine stock structure remains an important topic from both a science and management perspective. Research efforts on sardine population dynamics and structure continue, and it is envisioned that the topic will be revisited from time to time as new science is published.

REFERENCES

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ACKNOWLEDGEMENTS

The SWFSC would like to thank all participants, some of which traveled from far away, for taking the time and effort to engage and have thoughtful discussions to make this workshop a success. The SWFSC was happy to host Andre Punt, Greg Krutzikowsky, and Mark Fina in their roles representing the SSC and CPS subcommittee, CPS MT, and CPS AS respectively. Many persons from CDFW, industry, and nonprofits, many of which also participate on PFMC bodies, provided helpful context and discussion.

Many SWFSC and FRD staff helped with organizing, leading, and logistics, as well as took the time to prepare materials and participate. As the lead author on the analyses being revisited, Juan Zwolinski prepared numerous presentations and analyses before, during, and after the workshop. Annie Yau organized, led, and facilitated the workshop and authored this report. Matthew Craig created Figure 1. Barbara Muhling and Kelsey James were rapporteurs and provided detailed notes that were essential for writing this report. Brittany Schwartzkopf with help from Brad Erisman monitored and moderated the online participation. Ravi Shiwmandal and Laurie Meyer helped with IT setup and troubleshooting every day. Annie, Brad, Ravi, Lauri, and in-person participants helped break down the room. Stephanie Flores set up and monitored the registration process. Freddie Logan helped with snacks and coffee throughout each day and Brad helped put away snacks at the end of the day.

APPENDIX 1

PACIFIC SARDINE STOCK STRUCTURE WORKSHOP

November 15-17, 2022, hosted by the SWFSC
9:30 AM - 4 PM each day

SWFSC La Jolla
Pacific Room
8901 La Jolla Shores Drive
San Diego, CA 92037

This is a hybrid meeting with both in-person and virtual options.
Information on virtual attendance will be sent out in November to registered persons.

Registration is required by October 31.

For those attending in person, current NOAA guidance states that mask requirements are determined by county-level Covid-19 transmission as updated weekly by the CDC. Under high transmission, masks are required at all times. Under medium transmission, masks are highly encouraged. Regardless of transmission level, personal preferences for mask wearing and distancing will be respected to the extent possible. The meeting will take place indoors in a large room with doors open. Up to date guidance on transmission level and Covid-related protocols will be sent out to registered participants a few days prior to the meeting.

TERMS OF REFERENCE

BACKGROUND:

In 2021, SWFSC scientists conducted a catch-only assessment update of the northern subpopulation of Pacific sardine. That assessment showed that catches from the Mexico (Baja CA) fleet that were attributed to the northern subpopulation were on the same order as the entire estimated biomass of the northern subpopulation, which led to unrealistic changes to the estimates of recruitment and consequently that update was not accepted for use in management. This renewed discussions about Pacific sardine stock structure and its delineation in the stock assessment and hence how survey and catch data are assembled for assessment purposes. Consequently, the SWFSC agreed to revisit this topic in a workshop prior to the next benchmark assessment which is now scheduled for early 2024.

There are several possibilities for why Mexico catches were being reported on the same order as the entire estimated biomass of the northern subpopulation, and some ideas are:

1. Attribution of catch data to stock could be refined (but there may not be detail in the data to do so)
2. Attribution of biomass data to stock from the ATM surveys could be refined, for example decreased inclusion of sardines possibly part of the northern stock and/or recalibrating the habitat model to include more data on years of low sardine abundance (but there may not be detail in the data to do so)

3. Stock structure is changing/different
4. Misreporting of landings, for example landings of *Etrumeus spp* attributed to *Sardinops sagax*

SCOPE:

SWFSC scientists will meet to discuss Pacific sardine stock structure in US waters and catch and survey data delineation methods by doing the following:

1. Present the currently prevailing stock structure hypothesis and catch and survey data delineation methods for Pacific sardine.
2. Identify and evaluate any recent (past 5 years) publications and data relevant to the stock structure of Pacific sardine including but not limited to the species' life history.
3. Recommend the most likely stock structure, considering the current stock structure as null hypothesis.
4. Investigate and present refined methods for stock attribution to existing survey and catch data, following the recommended stock structure.
5. Identify gaps in the literature with respect to Pacific sardine stock structure. Develop a prioritized list of research recommendations to address these gaps. Comment on the feasibility and time horizon of the proposed research recommendations.

This workshop will start with presentations of the current stock structure and catch and survey data delineation methods, and discussions about any changes that may be warranted based on new/recent publications and data. Some explorations and analyses may be completed ahead of time and presented for consideration.

Should the group find that there is insufficient time or data to address this issue during workshop hours, then a plan will be made to collect any required information and complete work. SWFSC scientists will come to a conclusion related to a working stock structure hypothesis and methods to delineate data between stocks, ahead of a methodology review workshop planned for February 2023 that will be used to address any potential changes to the data inputs of the benchmark sardine assessment model. Any final decisions made at this workshop will be made by the SWFSC.

After the conclusion of this workshop, the operational understanding of sardine stock structure may change further as new published information is made available.

PARTICIPANTS:

SWFSC scientists will invite members of the SSC CPS subcommittee and scientific partners from state agencies to discuss the scientific basis and methods for the above topics. The CPS MT, CPS AP, WCRO staff, and industry will be invited to listen and provide fishery and management context. Attendance is open to other members of the public. Registration is required (see above for link).

AGENDA

- 1. Welcome, introductions, ground rules, logistics**
- 2. Current stock structure hypothesis**

From Appendix A-9 of the Pacific Fishery Management Council's Coastal Pelagic Species Fishery Management Plan

<https://www.pcouncil.org/documents/2022/01/appendix-a-description-of-the-coastal-pelagics-fishery.pdf/>

“It is generally accepted that sardine off the West Coast of North America form three subpopulations or stocks. A northern subpopulation (northern Baja California to Alaska), a southern subpopulation (off Baja California), and a Gulf of California subpopulation were distinguished on the basis of serological techniques (Vrooman 1964). A recent electrophoretic study (Hedgecock et al. 1989) showed, however, no genetic variation among sardine from central and southern California, the Pacific coast of Baja California, or the Gulf of California. A fourth, far northern subpopulation, has also been postulated (Radovich 1982). Although the ranges of the northern and southern subpopulations overlap, the stocks may move north and south at similar times and not overlap significantly. The northern stock is exploited by U.S. fisheries and is included in this FMP.”

Note that the terms stock and subpopulation may be used interchangeably.

2.a.) Presentation on current stock structure

- 3. Current delineation methods for survey and catch data**

3.a.) Presentation on ATM habitat-based delineation

3.b.) Presentation on catch temperature-based delineation

- 4. Review new literature/data related to sardine stock structure**

4.a.) Progress report on genetics study

4.b.) Progress report on simulation study for method to assign stock structure

4.c.) Recent size structure and spatial distribution data from ATM

4.d.) Exploration of length at age to inform stock structure

4.e.) A preliminary review of biological data used to evaluate subpopulation structure in Pacific sardine

- 5. Review analyses**

5.a.) Present analyses on different or refined ways to delineate ATM survey data, such as modifying the current habitat model to include less fish that are possibly northern stock (and also the resulting impact on survey estimates)

5.b.) Present analyses on different ways to delineate catch, such as using a different temperature inclusion threshold

6. Conclusion

What do the new literature and analyses tell us about stock structure and delineation methods?

What are the implications to survey data and catch estimates of any new analyses?

Is there agreement on a modification to how we define stock structure and/or delineate catch and survey data?

Define a prioritized list of recommendations on future research ideas for stock structure

APPENDIX 2

List of Participants for the Pacific Sardine Stock Structure Workshop, Nov 15-17, 2022

Name	First Affiliation	Second Affiliation
Alan Byrne	SSC CPS subcommittee	IDFG
Alan Sarich	CPS MT vice chair	Quinault Indian Nation
Andre Punt	SSC CPS subcommittee chair	University of Washington
Annie Yau	SWFSC	-
Barb Muhling	SWFSC	UCSC
Brad Erisman	SWFSC	-
Briana Brady	CDFW	-
Brittany Schwartzkopf	SWFSC	-
Chelsea Protasio	CDFW	-
Dale Sweetnam	SWFSC	-
David Demer	SWFSC	-
David Crabbe	CPS AS Co-chair	-
Desiree Tommasi	SWFSC	UCSC
Diane Pleschner-Steele	California Wetfish Producers Association	-
Dianna Porzio	CDFW	-
Ella Adams	SWFSC	University of San Diego
Emmanis Dorval	SWFSC	Ocean Associates, Inc
Frank Lockhart	WCRO	-
Gary Longo	SWFSC	University of Alaska, Fairbanks
Geoff Shester	Oceana	-
Greg Krutzikowsky	CPS MT	ODFW
Heather Fitch	-	-
James Hilger	SWFSC	-
Jessi Doerpinghaus	PFMC	-
John Budrick	SSC CPS subcommittee	CDFW
John Field	SSC CPS subcommittee	SWFSC
John Hyde	SWFSC	-
Joshua Lindsay	WCRO	-
Josiah Renfree	SWFSC	-
Juan Zwolinski	SWFSC	UCSC
Kelsey James	SWFSC	-
Kerry Griffin	PFMC	-
Kevin Hill	SWFSC	-
Kevin Piner	SWFSC	-
Kevin Stierhoff	SWFSC	-
Kirk Lynn	CPS MT Chair	CDFW
Kym Jacobson	CPS MT	NWFSC
Linnea Flostrand	-	-
Mark Fina	CPS AS	California Wetfish Producers Association
Matthew Craig	SWFSC	-
Matthew Everingham	Everingham Bros Bait Co	-

Michelle Horeczko	CDFW	-
Mike Okoniewski	CPS AS Co-chair	-
Owen Hamel	SSC CPS Subcommittee	NWFSC
Paul Crone	retired NOAA employee	-
Peter Kuriyama	SWFSC	-
Phillip Dionne	WDFW	-
Richard Parrish	-	-
Ryan Wulff	WCRO	-
Taylor Fewell	-	-
Taylor Debevec	WCRO	-
Theresa Labriola	Wild Oceans	-
Theresa Tsou	SSC CPS Subcommittee	WDFW
Trung Nguyen	CPS MT	CDFW
Will Satterthwaite	SSC CPS subcommittee	SWFSC