Summary of a U.S. Stakeholder Meeting on North Pacific Albacore Management
May 21, 2026
Virtual

Pacific Islands Regional Office and West Coast Region

Meeting summary: On May 21, 2026, National Marine Fisheries Service (NMFS) Pacific Islands Regional Office (PIRO) and West Coast Region (WCR) staff hosted a webinar to gather input from U.S. stakeholders on North Pacific albacore (NPALB) management for upcoming international meetings (*e.g.*, the Western and Central Pacific Fisheries Commission (WCPFC) Northern Committee (NC)). Seventy participants registered to attend the meeting representing the federal government, state governments, fishery management councils, industry, and non-governmental organizations. Drew Lawler, the National Oceanic and Atmospheric Administration's (NOAA) Principal Deputy Assistant Secretary (PDAS) for International Fisheries, delivered opening remarks. During the meeting, scientists from the Southwest Fisheries Science Center (SWFSC) presented results of the 2026 NPALB stock assessment and the Shiny app that the International Scientific Committee for Tuna and Tuna-Like Species (ISC) developed to provide estimates of the historical impact of fleet groups. NMFS posed a series of focus questions to participants, specifically related to translating fishing intensity to management measures in the harvest strategies adopted by the Inter-American Tropical Tuna Commission (IATTC) and the WCPFC. Meeting materials, including the preliminary executive summary for the 2026 NPALB stock assessment, preliminary science advice on interpreting historical impacts of fleets fishing for NPALB in terms of fishing intensity, and slides presented during the webinar, are included in Appendices I, II, and III, respectively. Also attached in Appendix IV is a paper stakeholders requested that looks at the behavior of different sized albacore vessels. In general, participants had questions about enforcement of existing regulations and data requirements by foreign vessels, emphasized a need to reiterate the 2002-2004 reference period for future discussions regarding compliance, and agreed that the harvest strategy should apply to the full range north of the equator. While some participants stated a need for explicit linkage between the harvest strategy and the implementing measure, others questioned the need for increased specificity since the stock is healthy and fishing effort has declined in recent years.

Below is a summary of the preliminary results of the 2026 NPALB stock assessment, discussions by meeting participants on presentations by NMFS, and feedback on focus questions posed by NMFS on refining the NPALB harvest strategy and management measures.

Preliminary 2026 North Pacific Albacore Stock Assessment

SWFSC began the presentation on the preliminary stock assessment results by showing updated catch data. NPALB catch has generally declined since the early 2000s. Catches since 2021 have been around 45,000 tons.

For NPALB, the target reference point (TRP) is $F45\%_{\text{Spawning Potential Ratio (SPR)}}$, which is the fishing intensity that results in the stock producing a SPR of approximately 45%. The threshold (ThRP) and limit reference (LRP) points are 30% Spawning Stock Biomass $(SSB)_{\text{current, F=0}}$ and $14\%SSB_{\text{current, F=0}}$, which are 30% and 14%, respectively, of the current, dynamic SSB under zero fishing, and hence fluctuate with changes in recruitment.

The average fishing intensity during 2021-2023 was estimated to be $F66_{\%SPR}$ (95% CI: $F74_{\%SPR}$-$F57_{\%SPR}$), which resulted in a population with an SPR of approximately 66%. Juvenile albacore aged 2 to 4 years comprised approximately 76% of the annual catch-at-age in number between 1994 and 2024 due to the larger fishery impact of surface fisheries (primarily troll and pole-and-line), which remove juvenile fish, relative to longline fisheries, which primarily remove adult fish.

The SSB_{2024} was estimated to be approximately 60% (95% CI: 38-83%) of $SSB_{\text{current, F=0}}$ and 2.01 (95% CI: 1.26-2.76) times greater than the estimated ThRP. The estimated current fishing intensity ($F_{2021\text{-}2023}$) was estimated to be $F66_{\%SPR}$ (95% CI: $F74_{\%SPR}$-$F57_{\%SPR}$) and was lower than both the $F45_{\%SPR}$ TRP and the average fishing intensity during 2002-2004.

Based on these preliminary findings, the following information on the preliminary status of the North Pacific albacore stock is provided:

1. The stock is likely not overfished relative to the ThRPs ($30\%_{\text{SSBcurrent, F=0}}$) and LRPs ($14\%_{\text{SSBcurrent, F=0}}$) adopted by the WCPFC and IATTC, and

2. The stock is likely not experiencing overfishing relative to the TRP ($F45_{\%SPR}$).

Participants had multiple questions about the completeness and accuracy of the data used in the stock assessment. SWFSC answered that the data used in the assessment are self-reported by members to the ISC, WCPFC and IATTC, and that the data include all catches of NPALB (no distinction between targeted and non-target catch). A participant asked whether any efforts to compare catch data with consumption-side numbers had been done (*e.g.*, volume of fish processed). SWFSC replied that that is not currently done, but could be something to consider going forward.

In response to a question on whether certain datasets are weighted more heavily within the stock assessment, SWFSC responded that catch from different fleets are not treated differently, but the stock assessment does rely on specific indices of abundance, and specifically on the Japanese longline index in the primary spawning area. SWFSC also noted that some juvenile indices of abundance used in the stock assessment as sensitivity runs include those developed for the Eastern Pacific Ocean (EPO) surface fleet and the Taiwan longline fleet.

A participant asked about what signs scientists might see in the stock assessment if there were problems with some catch data not being reported. SWFSC answered that the indices of

abundance should decline in that case. This participant noted that 2021 and 2023 were not great fishing years for the U.S. fleet and asked if there were recruitment signs that may explain those poor fishing years. SWFSC replied that recruitment in those years was not estimated to be poor, and it is unclear why the fish did not come to the West Coast, but speculated it could be due to movement dynamics related to changing environments.

ISC Estimates of Historical Impact of Fleet Groups

SWFSC demonstrated a Shiny app for NPALB that ISC developed in response to a WCPFC NC request to provide estimates of historical impact by fleet groups, and took questions and comments from participants.

SWFSC also confirmed that the "EPO Surface" fleet includes various surface gears from Mexico, Canada, and U.S. trollers, as well as the U.S. recreational fleet. One participant noted that they would also like to see the number of vessels included as a metric in the app, to which SWFSC replied the U.S. would need to get the NC to request the ISC to include that variable. SWFSC noted that the number of vessel days is typically considered the best measure of effort for the surface fleet, and alternative measures of effort should be explicitly stated if that is the U.S. preference.

Another participant asked if this tool could help them think through what cuts would be needed if the SSB drops too low. SWFSC answered that is correct and what the Shiny app tool is intended for and then showcased various "what if" scenarios and how fishing intensity would correspondingly be reduced for catch or effort limits of various fleets.

A participant asked what the Catch Per Unit Effort (CPUE) of juveniles might imply about the biomass of adult fish and vice versa. SWFSC noted that juvenile CPUE may provide a signal of what one might expect adult CPUE about several years later, but the response depends on how much juvenile movement rates have influenced the juvenile CPUE and the response for larger fish might be more muted from what is observed in younger fish.

A participant was concerned that the analysis might be impacted by the fact that different fisheries catch different age classes of fish. SWFSC responded that this concern is understandable, and the differences in age classes of fish caught is the reason that the analysis was based on fishing intensity and SPR. By doing so, the impact of each fishery is expressed in the same way that accounts for these differences (i.e., SPR is the proportion of SSB per recruit that remains after fishing relative to an unfished population) and is hence comparable. SWFSC stated that spawning biomass is important as they contribute to the production of albacore recruits. In general, it was stated that, based on the MSE results and the adopted harvest strategy, as long as SSB is above the ThRP (30% Dynamic SSB_0), there is a very low risk of the population collapsing. It was also noted that the changes observed in CPUE in the U.S. troll fleet are likely more dependent on movement rates because an unknown and likely variable

proportion of recruits swim to the West Coast while some also stay in the Western and Central Pacific Ocean (WCPO).

A participant noted that if vessel days are used, it may be useful to consider a "standard vessel" as there have been previous discussions at the Pacific Fishery Management Council that the CPUE of a vessel days may be very different depending upon vessel length and whether vessels are long-term commercial vessels or are relatively more recreational, but entering the commercial fishery for various reasons.

Implementing the Harvest Strategy for North Pacific Albacore Fisheries

NMFS posed a series of focus questions related to potentially refining the harvest strategy and management measures for NPALB.

FOCUS QUESTIONS

1) ***What if any changes to the harvest strategy should be considered to help define fishing intensity?***

A participant asked whether catch levels are determined by fishing intensity and whether the reference period is only used to determine the Total Allowable Catch (TAC) levels by relative fishing intensity from 2002-2004. NMFS noted that the current harvest strategy does not explicitly reference a baseline period nor does it include a specific formula for dividing the TAC, but only says that it should consider historical participation and source of increased fishing mortality. Another participant noted that 2002-2004 is a familiar baseline period, and cautioned that using a different baseline might be difficult to negotiate. This participant also stated that he felt it would be important to have some explicit linkage between the harvest strategy and implementing the measure in the future. Another participant supported having a linkage, and also supported proposing the current harvest strategy in the WCPFC for NPALB as a Conservation Management Measure (CMM) to make it binding.

A participant questioned the need for increased specificity to the harvest strategy, particularly since the stock is healthy, and the fishery has been declining. He cautioned against developing additional rules that might limit the U.S. fleet's ability to regrow or increase in the future, noting that other international fleets may be looking to grow. He acknowledged that the fleet already has limits under the current regime, and worried that adding details to the harvest strategy will result in the U.S. needing to make cuts with no assurances that others internationally would face similar reductions. NMFS responded that the U.S. has effort limits under the current international management frameworks, and the goal is to align the implementation measures with the harvest strategy while protecting historical interests and catch levels.

2) ***Do you have suggestions on how to address incidental catch of NPALB from fisheries not targeting albacore (e.g., catch limit for 0-10° N, de minimis clause for***

non-targeting vessels)? Is there a need to define targeting? If so, how?

A participant stated that there is a need to define targeting, and that fisheries and gears that incidentally catch NPALB should be managed under a TAC.

3) ***What feedback do you have to offer about the impact of other harvest strategies (i.e., WCPO skipjack, WCPO BET, EPO BET, or South Pacific albacore (SPALB) on the further development of harvest strategies and/or management measures for NPALB?***

A participant noted that WCPFC had recently held a workshop to discuss development of a management procedure for WCPO bigeye tuna where the U.S. initially took a position that it preferred a spatial range of the bigeye Management Procedure (MP) from 10° S to 10° N. He noted that the 20° N boundary for the NC was heavily negotiated originally, and there have been warnings in the past by some Pacific Island nations that if the NPALB measure was revised that the management area would be shifted from north of the equator to north of 20° N. This participant cautioned that there are a lot of discussions surrounding the development and implementation of MPs for bigeye tuna and SPALB, and that precedent set by any of those other negotiations might limit our decision making for NPALB.

Another participant asked how management approaches for different stocks are layering upon one another and if latitude or targeting/non-targeting could be used to help define different management options. NMFS noted that there have been a couple of approaches to harvest strategy/management development, and that it may be a philosophical versus a practical approach. Philosophically, management for bigeye tuna has historically been for the range of the stock no matter whether vessels were targeting or incidentally catching bigeye tuna. However, for SPALB, some feel that it is more practical to focus the area of management control to the temperate area of the South Pacific. NMFS noted that the discussion on spatial range for bigeye is ongoing and it is unlikely we would know what the spatial range will be until the bigeye tuna MP is adopted in December.

Another participant responded that he feared the potential impacts from the implementation measure being developed for the South Pacific, in that any constraints put on that fishery may incentivize vessels to move to the North Pacific. This participant stated that he felt it very important to explicitly reference the 2002-2004 reference period in order to prevent effort shift from the South Pacific to North Pacific.

4) ***Expansion and contraction of fishing opportunities – Do stakeholders understand how the U.S. fleet would and would not be affected if the harvest strategy were fully implemented? When might the U.S. troll fleet expand from its 2002-2004 baseline period? What guardrails should be in place if other countries expand from their 2002-2004 baseline?***

A participant noted that if stock biomass declined and reductions were necessary, it might be

difficult to negotiate those reductions, and that the 2002-2004 baseline is favorable to the United States, but wondering if other countries would be supportive especially if current allocations are somewhat different from what historical allocations were.

A participant noted that the recreational catch of NPALB is small in comparison to commercial catches, but that the recreational fleet is economically important to many communities on the West Coast and supports opportunities to promote economic stability. NMFS noted that the United States does report on its recreational catch of NPALB and is not aware of other countries that similarly report on recreational catch of NPALB.

A participant asked whether there might be a path to exempt the surface fisheries from any potential future reductions, particularly since the fleet has been in decline for a number of years. NMFS responded that it would always advocate for the best possible outcome for its stakeholders. NMFS acknowledged that the United States had unsuccessfully tried to exempt the troll fishery from MP control in the South Pacific where impacts are small, but warned that the impact of the fleet in the North Pacific is much larger, and a proposal to exempt the surface fleet in the North Pacific was unlikely to be favorably received internationally.

Another participant noted that the current management measures contain effort controls, and that it is very important to enforce their effort controls. He noted that last year, China changed the metric it used from number of vessels to vessel days. He asked if there were a way to ensure that if effort limits were exceeded in the future, if they could benefit from a payback mechanism similar to that in the Pacific bluefin tuna management measure (C-24-02; *i.e.,* if effort relative to 2002-2004 is exceeded by a country in one year, it would be subtracted from their effort limit the following year).

NMFS noted that in past meetings, there has been a focus on potential consequences for limiting the fishery if stock biomass were to decline, but it may also be appropriate to discuss scenarios of when the stock is healthy, and whether the fishery could expand. Current U.S. effort is significantly below the 2002-2004 baseline, and it might be difficult to rebuild to those levels in the short term. NMFS has previously heard that fuel prices and market factors play a role in where vessels are fishing and that there is significantly less fishing on the high seas in recent years relative to historical levels. NMFS also noted that while the U.S. fleet may be interested in expansion, that practically speaking, it might be a long-term goal, and cautioned that other fleets might also be interested in expanding their fishing opportunities for NPALB. NMFS noted that a potential guard rail that could be considered might be for increased electronic monitoring coverage on longline vessels to increase compliance with CMMs and Resolutions.

5) ***What would stakeholders like to see in order to better address compliance and enforcement concerns?***

In response to past inquiries about enforcement and compliance with RFMO resolutions, NMFS

gave an overview of the IATTC and WCPFC compliance committees, High Seas Boarding and Inspection (HSBI) operations in the Pacific Ocean, and what steps the U.S. is currently taking to make further improvements in these areas. For example, while the WCPFC has an HSBI scheme in place, the IATTC currently lacks one despite the U.S. putting forward proposals for adoption in 2016 and 2025.

The United States Coast Guard (USCG) annually participates in Operation North Pacific Guard with international partners (*i.e.*, Canada, Japan, and South Korea) to counter Illegal, Unreported, and Unregulated (IUU) fishing. Many of the boardings that take place during this operation are done under the WCPFC HSBI scheme. The WCPFC HSBI website provides summary statistics of how many boardings are performed of tuna fishing vessels in the WCPO each year. For example, from 2016-2025, 916 HSBIs occurred on tuna vessels in the WCPO.

NOAA frequently coordinates with the USCG to advise them of ongoing issues in the WCPFC and IATTC fisheries. Additional information on how the U.S. works to combat IUU fishing can be found on NOAA's IUU webpage.

6) ***What types of data would be useful to have more readily available? How frequently should those data be updated?***

NMFS detailed how they are already working with the scientific staff at the WCPFC and IATTC to make improvements to NPALB related data that are publicly available. Additionally, they noted they intend to discuss at NC improvements to the annual "Updated information on North Pacific albacore fishing effort" paper to make it easier to read and ensure it more fully encompasses effort by all countries fishing for NPALB. Finally, NMFS noted it is also exploring how to expand the number of countries submitting catch data in the ISC's annual catch table.

A participant voiced support for these improvements, and in particular they would like to see the ISC catch table expanded as well as an interactive tool showing not just catch and effort (in days and vessels), but also transshipment data for NPALB.

7) ***Are there any other management considerations stakeholders would like to raise?***

Discussion on this item was all related to the enforcement conversation detailed in question #5 above.

8) ***As a way to encourage improved and more frequent data reporting from vessels that incidentally catch albacore, would stakeholders be in favor of requiring electronic logbook reporting in the EPO (e.g., similar to CMM-2022-06)?***

A participant noted that while the EPO does not have as much incidentally caught NPALB as the WCPO, it is always good to acquire more accurate and timely information, thus they supported this concept.

Electronic Logbooks

NMFS provided an overview of current electronic logbook offerings for West Coast fleets. One electronic logbook is available and another is anticipated to be available in the coming days. NMFS will update the West Coast Highly Migratory Species Logbooks as new options emerge.

NOAA Changing Ecosystems and Fisheries Initiative (CEFI) Project: Albacore Tuna CPUE Outlooks

Scientists from the SWFSC gave a presentation on NOAA's Changing Ecosystems and Fisheries Initiative. The project aims to develop predictive models of NPALB tuna CPUE on the U.S. West Coast with the goal of providing stakeholders with actionable insights for improved operational efficiency. Participants had some general questions about what years of data were in the model, whether or not prey dynamics (*i.e.*, for anchovy and sardines) were included, and if the models can help fishermen determine why certain years were below average for CPUE. SWFSC responded they are still working to incorporate certain data and dynamics into their models and thanked participants for their inquiries and suggestions.

Next Steps

NMFS intends to continue to solicit input from the Permanent Advisory Committee (PAC) to the U.S. Section to the WCPFC. Based on input received from the June 2026 Council meeting and the PAC, the United States will consider its positions and potentially any proposals for meetings of the WCPFC Northern Committee (July 13-14, 2026) and the IATTC (September 1-5, 2025).

APPENDIX I

INTER-AMERICAN TROPICAL TUNA COMMISSION

SCIENTIFIC ADVISORY COMMITTEE

17TH MEETING

La Jolla, California (USA)
08-12 June 2026

DOCUMENT SAC-17 INF-I

Subject to change and approval by the ISC26 Plenary

List of Acronyms

$14\%SSB_{current,\ F=0}$	14% of the current, dynamic SSB under zero fishing. Current limit reference point for North Pacific albacore tuna.
$30\%SSB_{current,\ F=0}$	30% of the current, dynamic SSB under zero fishing. Current threshold reference point for North Pacific albacore tuna.
ALBWG	Albacore Working Group of the ISC
ASPM	Age-structured production model, which is used for model diagnostics
ASPM-R	Age-structured production model with recruitment deviation estimates
CPUE	Catch-per-unit-effort
EPO	Eastern Pacific Ocean
IATTC	Inter-American Tropical Tuna Commission
ISC	International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (https://isc.fra.go.jp/)
F-at-age	Instantaneous fishing mortality at age
$F_{\%SPR}$	Fishing intensity in %SPR
$F45_{\%SPR}$	Fishing intensity that results in the population reaching an SPR of 45% at equilibrium. Current target reference point for North Pacific albacore tuna.
JPLL	Japan longline
JPPL	Japan pole-and-Line
MSY	Maximum Sustainable Yield
RFMO	Regional Fisheries Management Organization
SPR	Spawning Potential Ratio, which is the ratio of the equilibrium SSB per recruit that would result from an F-at-age relative to that of the unfished population.
SSB	Spawning Stock Biomass
USA	United States of America
WCPFC	Western and Central Pacific Fisheries Commission
WCPO	Western and Central Pacific Ocean

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EXECUTIVE SUMMARY

Stock Identification and Distribution: For stock assessment purposes, North Pacific albacore tuna (*Thunnus alalunga*) are assumed to constitute a single stock distributed throughout the Pacific Ocean north of the equator to 55°N. The assessment incorporates all available fishery data from this area and uses a fleets-as-areas modeling approach. Population dynamics are represented under the assumption that there is instantaneous mixing of albacore across the modeled stock area on a quarterly time step, i.e., a single, well-mixed population with no explicit internal spatial structure.

Major changes from the 2023 assessment: There were four main changes to the base case model compared to the previous assessment in 2023. 1) The F10 JPLL index was recalculated with data from 1996-2024 and an expanded area that matched the spatial definitions in the stock assessment rather than that defined in the historical Japanese longline data. 2) Two JPLL fleets for juvenile and adult fleets (i.e., F1 and F2) in the 2023 assessment were combined into one fleet here (F1 in 2026 assessment) and modelled with time-varying age-based selectivity because having two fleets in the 2023 assessment did not improve fits to the size data and did not remove the need for time-varying selectivity. 3) Time-varying age-based selectivity was estimated with two-dimensional autoregressive selectivity patterns rather than assuming arbitrary time blocks, due to improved fits to length composition data and improved model stability. 4) Size composition data from China longline (CNLL) and Vanuatu longline (VULL) were included and fitted in this assessment. However, selectivity was only estimated for one CNLL fleet (CNLL Area 3 and 5), while CNLL Area 2 and 4 and VULL selectivities were mirrored to Taiwan longline (TWLL) selectivity. As a model sensitivity, the 2023 assessment model was updated with 2026 data (to the extent possible) to illustrate the impact of these structural changes (Table ES1).

Catches: During the modeling period (1994-2024), the total reported catch of north Pacific albacore reached a peak of about 119,000 t in 1999 and then declined since the early 2000s, Catches since 2021 have been about 45,000 t, although catches in 2020 were roughly 75,000t (Fig. ES1). Surface gears (e.g., troll, pole-and-line), which primarily harvest juvenile albacore, have typically accounted for the majority of the albacore catch (Fig. ES2).

Data and Assessment: All north Pacific albacore catch and size composition data from ISC member (Canada, China, Chinese-Taipei, Japan, Korea, Mexico, and the USA) and non-member countries (e.g., Vanuatu, Kiribati) were compiled for the assessment. The fleet structure was similar to that of the 2020 assessment, which differs from the fleet structure in the 2023 assessment. Specifically, the 2023 assessment had JPLL fleets operating in Areas 1 and 3 (A13) during Quarter 1 (Q1) separated into juvenile and adult fleets. The 2026 assessment reverts to the 2020 fleet structure with just one fleet for JPLL A13 Q1. The fleet structure was revisited during the development process, as the fits to the length composition data were not notably improved when juveniles and adults were modeled separately. Four relative abundance indices (standardized CPUE) were provided by Japan, the USA, and Chinese-Taipei. Based on a thorough review of all fishery data and preliminary model runs, the ALBWG fitted the base case model to one abundance index: the standardized CPUE of the JPLL fleet operating in Area 2 during Quarter 2 (F10 index; 1996 – 2024). This index was chosen because it represented the best information on trends for adult age-classes of female albacore, had good contrast, and ASPM analyses indicated the index was informative on both population trends and scale. Previous assessments have used an index from the JPLL fleet in the same area but from Quarter 1, which is the primary albacore-targeting season. However, a re-examination of the data indicated that trends in the adult age-classes of female albacore were likely better represented by the CPUE in Quarter 2, which is also the primary spawning season.

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The north Pacific albacore tuna stock was assessed using a length-based, age-, and sex-structured Stock Synthesis (SS; Version 3.30.24) model over the 1994-2024 period. Biological parameters like growth and natural mortality (M), were the same as for the 2017, 2020, and 2023 assessments. Sex-specific growth curves were used because of sexually dimorphic growth, with adult males attaining a larger size-at-age than females after maturity. Sex-specific M-at-age vectors were developed from a meta-analysis, with a sex-combined M that scaled with size for ages 0-2, and sex-specific M fixed at 0.48 and 0.39 y^{-1} for age-3+ females and males, respectively. The steepness of the Beverton-Holt stock-recruitment relationship was assumed to be 0.9, based on two prior analyses. The base case model was fitted to the F10 index and all representative size composition data in a likelihood-based statistical framework.

All but one fleet (USA longline in Areas 2 and 4) were assumed to have dome-shaped length selectivity patterns. Some fleets had high year-to-year variability in the size composition data. For these fleets, age-based selectivity was estimated in addition to length-based selectivity. The goal was to account for age-based changes in juvenile albacore availability and movement. Time-varying age-based selectivities were estimated for four surface fleets (JPPL and EPO surface) in order to further improve fits to the size composition data. The base model converged on a maximum likelihood estimate with a positive, definite Hessian matrix and had good ASPM diagnostics.

Maximum likelihood estimates of model parameters, derived outputs, and their variances were used to characterize stock status. Several sensitivity analyses were conducted to evaluate changes in model performance or the range of uncertainty resulting from changes in model parameters, including growth, natural mortality, stock-recruitment steepness, selectivity patterns, and data weighting.

An ASPM diagnostic analysis showed that the estimated catch-at-age and fixed productivity parameters (growth, mortality and stock-recruitment relationships with and without annual recruitment deviates) were able to explain trends in the primary index. Based on these findings, the ALBWG concluded that the base case model was able to estimate the stock production function and the effect of fishing on the abundance of the north Pacific albacore stock. Similar to the 2020 and 2023 assessments, the link between catch-at-age and the primary index adds confidence to the data used and the results of the assessment. Due to the moderate exploitation levels relative to the productivity, the production function was weakly informative about north Pacific albacore stock size. It is important to note that the primary aim of estimating the female SSB in this assessment was to determine if the estimated SSB was lower than the adopted limit and threshold reference points. Since the lower bound is better defined, it adds confidence to the ALBWG's evaluation of stock condition relative to these reference points.

Conservation and Management: The WCPFC and IATTC are the tuna RFMOs that manage the north Pacific albacore stock in the WCPO and EPO, respectively, and have adopted similar harvest strategies and biological reference points for this stock (WCPFC HS 2022-01; IATTC Resolution C-22-04). These harvest strategies include target, threshold, and limit reference points. The target reference points are $F45_{\%SPR}$, which is the fishing intensity that results in the stock producing a SPR of approximately 45%. The threshold and limit reference points are $30\%SSB_{current,\ F=0}$ and $14\%SSB_{current,\ F=0}$, respectively, which are 30% and 14% of the current, dynamic SSB under zero fishing, and hence fluctuates with changes in recruitment. Importantly, three of the management objectives in the harvest strategies are to: 1) maintain SSB above the limit reference point, with a probability of at least 80% over the next 10 years; 2) maintain depletion of total biomass around historical (2006 – 2015) average depletion over the next 10 years; and 3) maintain fishing intensity at or below the target reference point with a probability of at least 50% over the next 10 years. In addition, both

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RFMOs have current management measures (WCPFC CMM 2019-03; IATTC Resolution C-05-02) that maintain albacore fishing effort at or below the average effort levels during 2002 – 2004.

Stock Status: Estimated summary biomass (males and females at age-1+) declined at the beginning of the time series until 2004 (Fig. ES3A). Subsequently, the summary biomass fluctuated without a trend until 2018, after which the biomass increased to values higher than those at the beginning of the model time period. It should be noted that the high summary biomass estimates since 2018 also had increasing uncertainty (Fig. ES3A). These high summary biomass estimates were due to historically high recruitment estimates in 2017 (~297 million fish; 95% CI: 215– 381million fish), 2019 (~292 million fish; 95% CI: 187 to 396 million fish), and 2022 (~314 million fish; 95% CI: 93-536 million fish) (Fig. ES3C). However, it should be noted that the recruitment estimates in the last 5 years (2020-2024) were highly uncertain and should be treated with caution. Estimated female SSB exhibited a similar population trend to the summary biomass, albeit with a lag of several years, and showed an initial decline until 2007 followed by fluctuations without a clear trend through 2020 (Fig. ES3B).

The average fishing intensity during 2021 – 2023 was estimated to be $F66_{\%SPR}$ (95% CI: $F74_{\%SPR}$ – $F57_{\%SPR}$), which was relatively moderate and resulted in a population with an SPR of approximately 66%. Instantaneous fishing mortality at age (F-at-age) was similar in both sexes through age-5, peaking at age-4 and declining to a low at age-6, after which males experienced higher F-at-age than females up to age 14 (Fig. ES4). Juvenile albacore aged 2 to 4 years comprised approximately 76% of the annual catch-at-age in numbers between 1994 and 2024 (Fig. ES5) due to the larger fishery impact of surface fisheries (primarily troll, pole-and-line), which remove juvenile fish, relative to longline fisheries, which primarily remove adult fish (Fig. ES6).

Stock status is depicted in relation to the target ($F45_{\%SPR}$,), threshold ($30\%SSB_{current,\ F=0}$), and limit ($14\%SSB_{current,\ F=0}$) reference points (Fig. ES7A; Table ES1). The estimated female SSB has never fallen below the threshold and limit reference points since 1994, albeit with large uncertainty in the terminal year (2024) estimates. The historical fishing intensity was estimated to have exceeded the target reference point for most years between 1997-2018. However, the estimated fishing intensity has been declining since 2019 and has been below the target reference point for the last six years. Even when alternative hypotheses about key model uncertainties such as growth were evaluated, the point estimate of female SSB in 2024 (SSB_{2024}) did not fall below the threshold and limit reference points (Fig. ES7B). Estimated average fishing intensity during 2021-2023 ($F_{2021\text{-}2023}$) did not exceed the target reference point under the alternative hypotheses. (Fig. ES7B; Table ES1). Average fishing intensity from 2021-2023 also did not exceed the average fishing intensity during 2002-2004 (Table ES1).

The SSB_{2024} was estimated to be approximately 60% (95% CI: 38 – 83%) of $SSB_{current,\ F=0}$ and 2.01 (95% CI: 1.26 – 2.76) times greater than the estimated threshold reference point (Table ES1). The estimated current fishing intensity ($F_{2021\text{-}2023}$) was estimated to be $F66_{\%SPR}$ (95% CI: $F74_{\%SPR}$ – $F57_{\%SPR}$) and was lower than both the $F45_{\%SPR}$ target reference point and the average fishing intensity during 2002 – 2004 (Table ES1).

Based on these findings, the following information on the status of the north Pacific albacore stock is provided:

1. The stock is likely not overfished relative to the threshold ($30\%SSB_{current,\ F=0}$) and limit ($14\%SSB_{current,\ F=0}$) reference points adopted by the WCPFC and IATTC, and
2. The stock is likely not experiencing overfishing relative to the target reference point ($F45_{\%SPR}$).

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Future Projections: A new version of the SSfuture C++software package (ssfcpp version 2.0.4) was developed to perform future projections for this assessment. Two 10-yr projection scenarios, constant F2021-2023 and randomly resampled F2005-2019 scenarios, were used to evaluate the impacts of fishing on the management objectives of IATTC and WCPFC. Each projection scenario consisted of 160,000 (400 x 400) runs, starting in 2025 and continuing for 10 years through 2034. For each scenario, 400 initial populations, together with their stock-recruitment relationships, were simulated by sampling from the estimated N-at-age distributions in 2021. Each initial population was in turn projected using 400 runs with an F-at-age and random recruitment. Most of the uncertainties from the base case model, except for estimation uncertainties of the selectivities and recruitment deviates, were incorporated into the projections. The ALBWG considered these projections to be an improvement over projections from previous assessments but more improvements will still be needed in the future. Depending on the scenario, the F-at-age used was either based on the average F-at-age during 2021 – 2023, or randomly resampled from 2005 – 2019. Both projection scenarios showed similar trends. The constant fishing intensity scenario showed that the current fishing intensity (F2021-2023) is expected to result in female SSB increasing to 109,384 t (95% CI: 82,915–136,573 t) by 2034. Over the next 10 years, there was: 1) a 100.0% probability of the female SSB remaining above the $14\%SSB_{current,\ F=0}$ LRP for all 10 years; 2) a 86.5% probability of the total biomass (age-1+) being above the average of 2006 – 2015 for any year; and 3) a 95.3% probability of the fishing intensity remaining at or below the $F45_{\%SPR}$ TRP for any year (Fig. ES9). Similarly, the randomly resampled fishing intensity scenario showed that if future fishing intensity is similar to the 2005 – 2019 period, it is expected to result in female SSB increasing to 67,340 t (95% CI: 47,082 – 87,597 t) by 2034. Over the next 10 years, there was: 1) a 99.1 % probability of the female SSB remaining above the $14\%SSB_{current,\ F=0}$ LRP for all 10 years; 2) a 79.9 % probability of the total biomass (age-1+) being above the average of 2006 – 2015 for any year; and 3) a 48.8% probability of the fishing intensity remaining at or below the $F45_{\%SPR}$ TRP for any year (Fig. ES10).

Conservation Information: Two harvest scenarios were projected to evaluate impacts on the management objectives of IATTC and WCPFC for this stock: 1) maintain SSB above the limit reference point, with a probability of at least 80% over the next 10 years; 2) maintain depletion of total biomass around historical (2006 – 2015) average depletion over the next 10 years; and 3) maintain fishing intensity at or below the target reference point with a probability of at least 50% over the next 10 years (WCPFC HS 2023-01; IATTC Resolution C-23-02). As a larger cohort is estimated in the latest period of the assessment, all projections show a steep increase of SSB in the first year.

The constant fishing intensity scenario showed that the current fishing intensity (F2021-2023) is expected to result in female SSB increasing to 109,384 t (95% CI: 82,915 – 136,573 t) and a $SSB/SSB_{current,\ F=0}$ ratio of 0.83 by 2034. Over the next 10 years, there was: 1) a 100.0% probability of the female SSB remaining above the $14\%SSB_{current,\ F=0}$ LRP for all 10 years; 2) a 86.5% probability of the total biomass (age-1+) being above the average of 2006 – 2015 for any year; and 3) a 95.3% probability of the fishing intensity remaining at or below the $F45_{\%SPR}$ TRP for any year. The randomly resampled fishing intensity scenario showed that if future fishing intensity is similar to the 2005 – 2019 period, it is expected to result in female SSB increasing to 67,340 t (95% CI: 47,082 – 87,597 t) and a $SSB/SSB_{current,\ F=0}$ ratio of 0.52 by 2034. Over the next 10 years, there was: 1) a 99.1 % probability of the female SSB remaining above the $14\%SSB_{current,\ F=0}$ LRP for all 10 years; 2) a 79.9 % probability of the total biomass (age-1+) being above the average of 2006 – 2015 for any year; and 3) a 48.8% probability of the fishing intensity remaining at or below the $F45_{\%SPR}$ TRP for any year.

Based on these findings, the following conservation information is provided:

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1. If fishing intensity over the next 10 years is maintained at the current fishing intensity ($F_{2021-2023}$), then female SSB is expected to increase to around 83% of $SSB_{current,F=0}$ (109,384 t) by 2034, with a 100.0% probability that female SSB will remain above the 14%$SSB_{current, F=0}$ LRP for all 10 years and the harvest strategy management objectives of the IATTC and WCPFC (IATTC Resolution C-23-02; WCPFC Harvest Strategy 2023-01) will likely be met; and

2. If fishing intensity over the next 10 years is similar to the 2005 – 2019 period, then female SSB is expected to decrease to around 52% of $SSB_{current, F=0}$ (67,340 t) by 2034, with a 99.1 % probability that female SSB will remain above the 14%$SSB_{current, F=0}$ LRP for all 10 years and the harvest strategy management objectives of the IATTC and WCPFC (IATTC Resolution C-23-02; WCPFC Harvest Strategy 2023-01) will likely be met.

Key Uncertainties: The ALBWG notes that the uncertainty in growth and natural mortality and the simplified treatment of the spatial structure of north Pacific albacore population dynamics are important sources of uncertainty in the assessment.

Exceptional Circumstances: The adopted harvest strategies of the WCPFC and IATTC for North Pacific albacore tuna include provisions for the identification and evaluation of exceptional circumstances that may warrant suspension or modification of the current strategies. Consistent with this requirement, the ALBWG evaluated the adopted criteria for identifying exceptional circumstances for North Pacific albacore tuna, including indicators related to stock and fleet dynamics, application of the stock assessment, and implementation of management measures. Based on the information available and the evaluation criteria, the ALBWG found no evidence to indicate that exceptional circumstances were present with respect to the conservation and management of the stock.

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Table ES1. Estimates of maximum sustainable yield (MSY), female spawning stock biomass (SSB), fishing intensity (F), and reference point ratios for north Pacific albacore tuna for: 1) the base case model; 2) one important sensitivity model due to uncertainty in growth parameters; 3) a model representing an update of the 2023 base case model to 2026 data; and 4) a model representing uncertainty in the specification of initial fishing mortality. SSB_0, $SSB_{current,\ F=0}$ and SSB_{MSY} are the expected female SSB of a population in the equilibrium, unfished state; in the current, dynamic, unfished state; and at MSY, respectively. The Fs in this table are indicators of fishing intensity based on spawning potential ratio (SPR) and calculated as %SPR. SPR is the ratio of the equilibrium SSB per recruit that would result from the estimated F-at-age relative to that of an unfished population. Depletion is calculated as the proportion of the age-1+ biomass during the specified period relative to an unfished age-1+ equilibrium biomass. The model representing an update of the 2023 base case model is similar to but not identical to the 2026 base case model due to changes in data preparation and model structure. †A value of >1 for the depletion ratio indicates higher age-1+ biomass in 2024 relative to the 2006 – 2015 period. §Higher %SPR values indicate lower fishing intensity levels. ¶Values of >1 for ratios of $F_{\%SPR}$ to $F_{\%SPR}$-based reference points indicate fishing intensity levels lower than the reference points.

Quantity	Base Case	Growth CVold = 0.06	Update of 2023 base case model to 2026 data	Initial Conditions initF F20 F24
MSY (t)	106,578	86,675	113,793	100,322
SSB_{MSY} (t)	19,360	15,878	20,524	18,316
SSB_0 (t)	139,466	113,685	147,874	131,221
SSB_{2024} (t)	84,209	49,547	96,362	73,236
$SSB_{current,\ F=0}$ (2024 estimate)	139,777	107,072	151,193	129,224
$SSB_{2024}/SSB_{current,\ F=0}$	0.60	0.46	0.64	0.57
$SSB_{2024}/30\%SSB_{current,\ F=0}$	2.01	1.54	2.12	1.89
$SSB_{2024}/14\%SSB_{current,\ F=0}$	4.30	3.31	4.55	4.05
† $Depletion_{2024}/Depletion_{2006\text{-}2015}$	1.45	1.40	1.61	1.45
§ $F_{\%SPR,\ 2021\text{-}2023}$ (%SPR)	65.6	51.9	68.0	62.2
§ $F_{\%SPR,\ 2013\text{-}2023}$ (%SPR)	50.3	36.7	53.6	46.6
¶ $F_{\%SPR,\ 2021\text{-}2023}/F_{\%SPR,\ MSY}$	4.03	3.17	4.18	3.80
¶ $F_{\%SPR,\ 2013\text{-}2023}/F45_{\%SPR}$	1.12	0.82	1.19	1.04
¶ $F_{\%SPR,\ 2021\text{-}2023}/F45_{\%SPR}$	1.46	1.15	1.51	1.38
¶ $F_{\%SPR,\ 2021\text{-}2023}/F_{\%SPR,\ 2002\text{-}2004}$	1.87	2.13	1.78	1.95

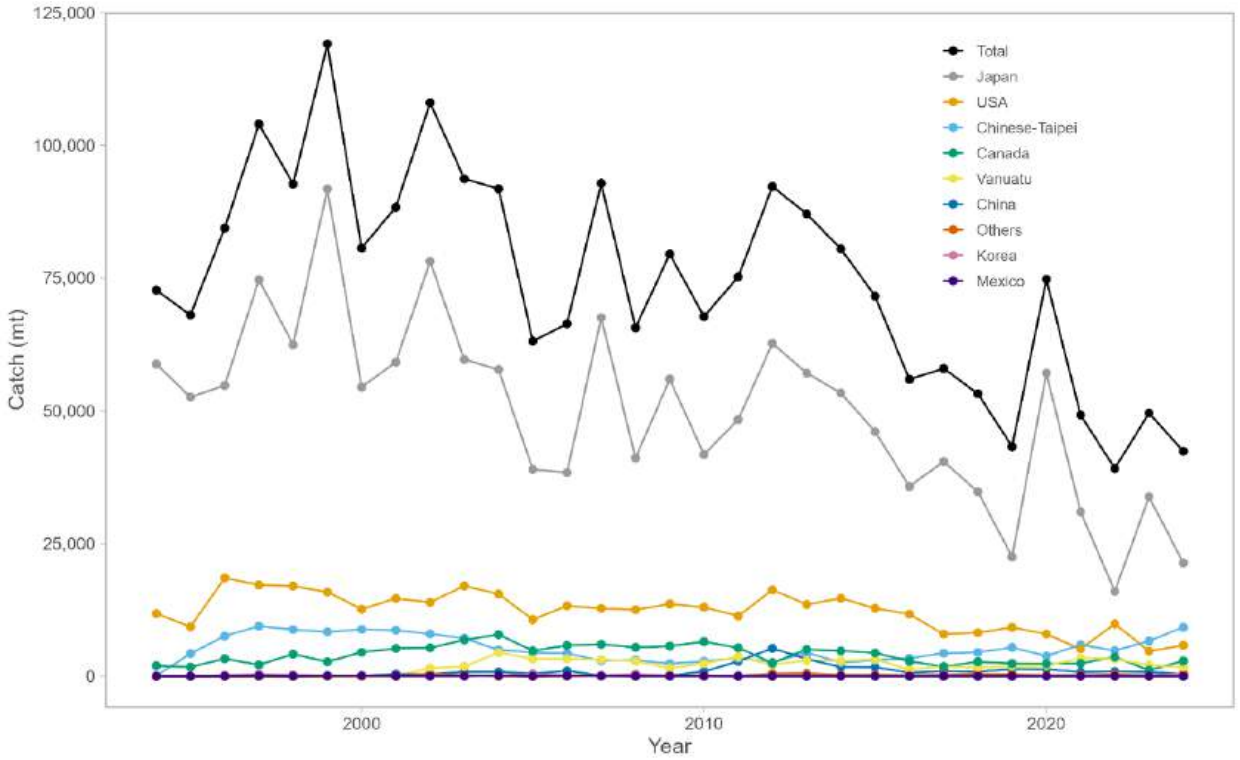


Figure ES1. Estimated total annual catch of north Pacific albacore (*Thunnus alalunga*) by all countries harvesting the stock, 1994-2024. Catches in the "Others" categories includes small amount of catch by other countries such as Kiribati, Belize, Panama, and Marshall Islands.

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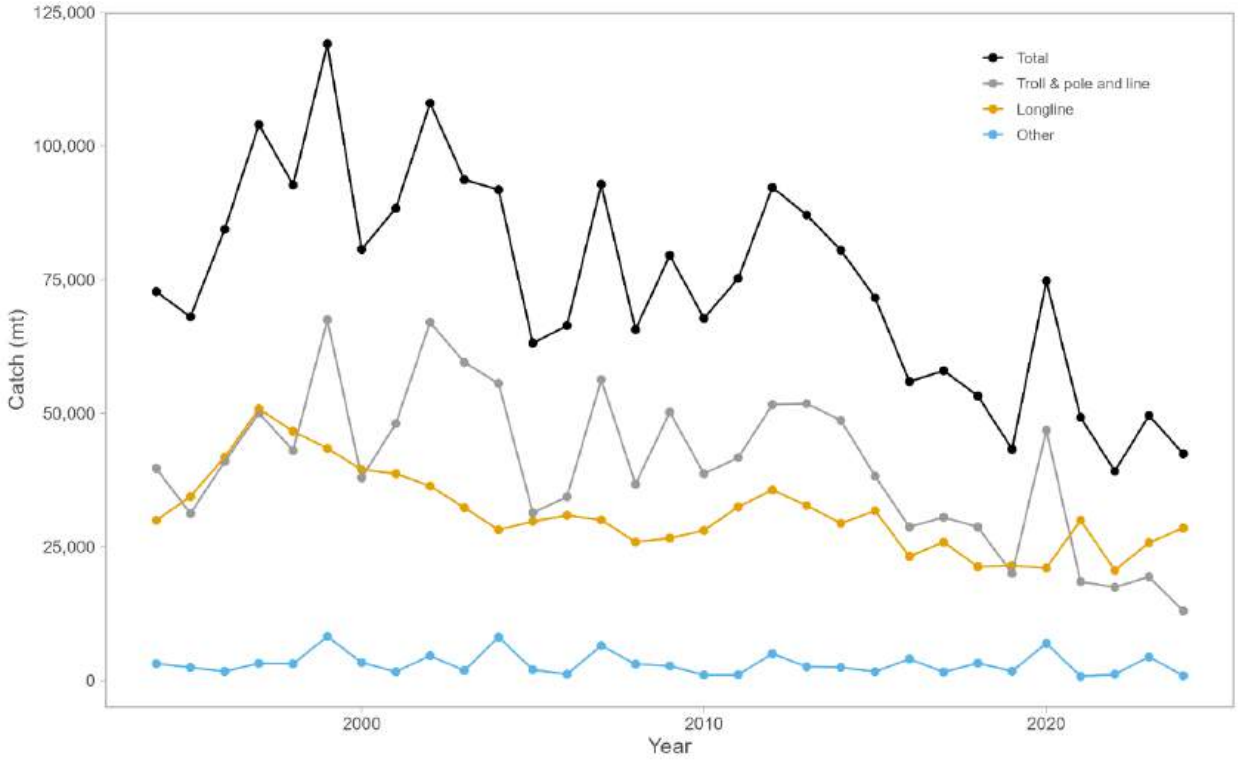


Figure ES2. Estimated catches of north Pacific albacore (*Thunnus alalunga*) by major gear types, 1994-2024. The Other gear category includes catches with purse seine, gillnet, hand lines, and harpoons.

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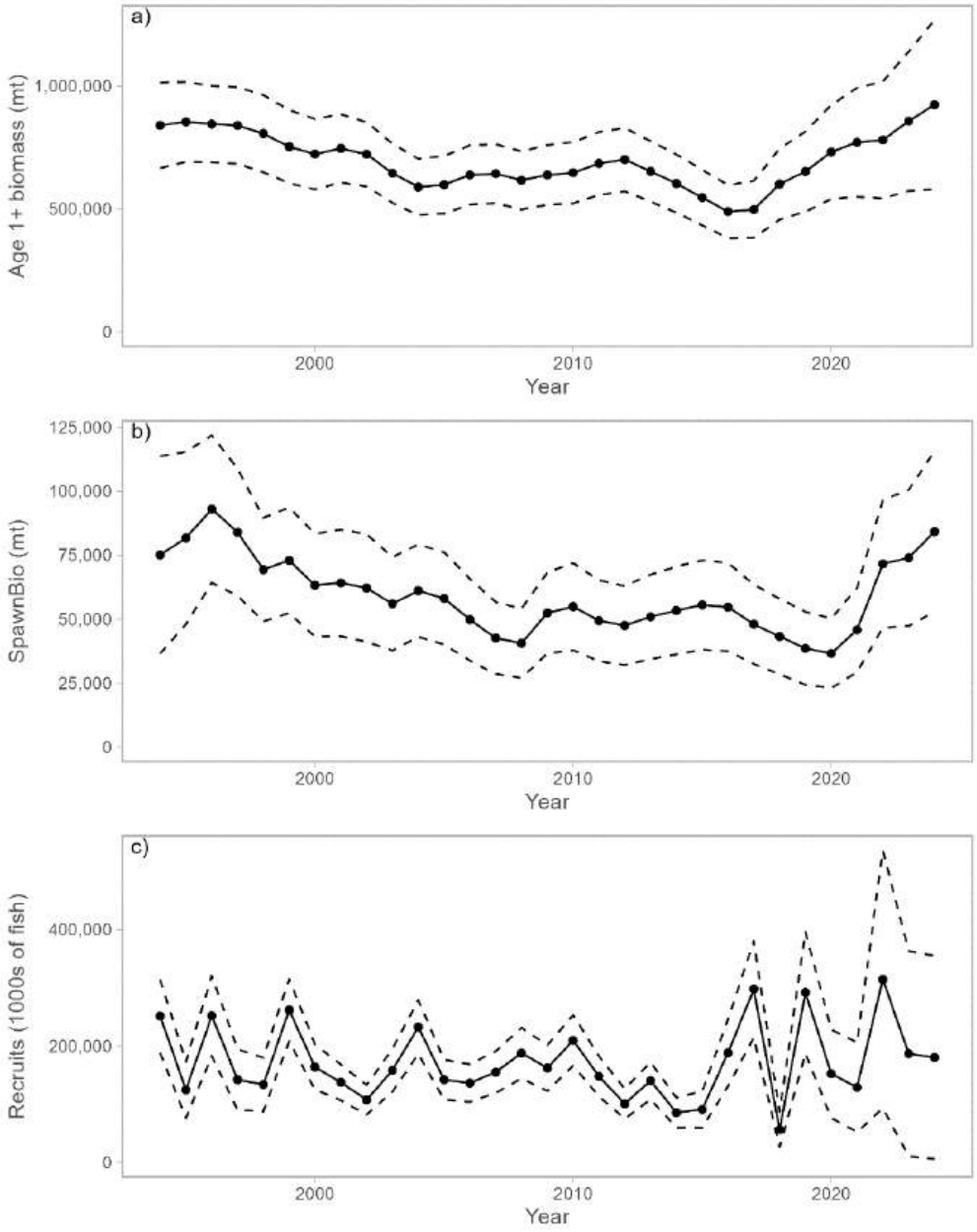


Figure ES3. Maximum likelihood estimates of (A) age-1+ biomass (B), female spawning biomass (SSB), and (C) age-0 recruitment of north Pacific albacore tuna (*Thunnus alalunga*). Dashed lines indicate 95% confidence intervals.

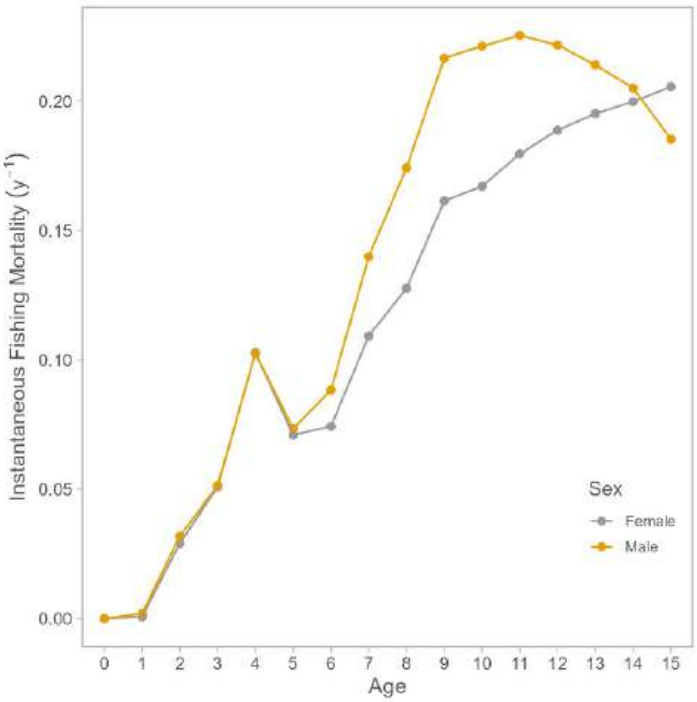


Figure ES4. Estimated sex-specific instantaneous fishing mortality-at-age (F-at-age) for the 2026 base case model, averaged across 2021-2023.

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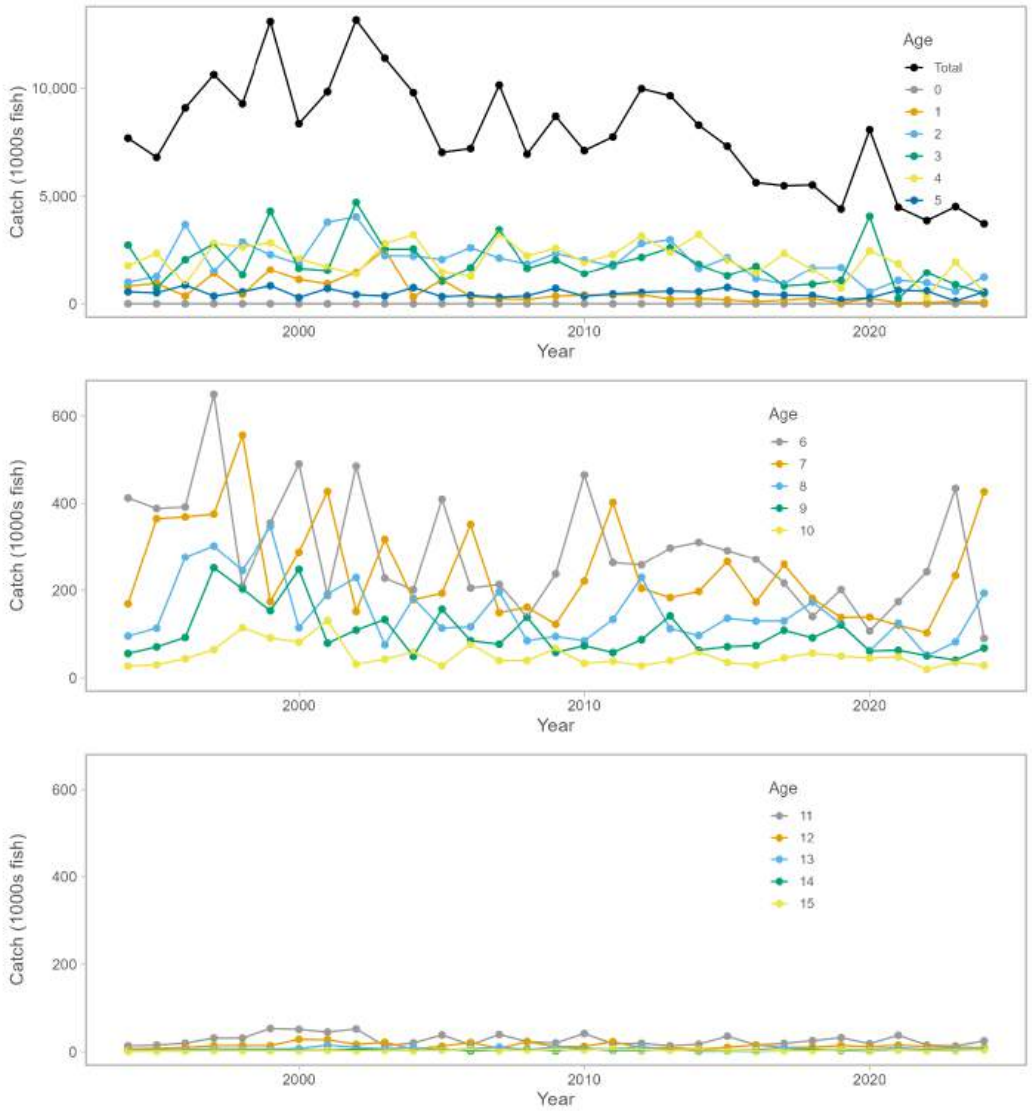


Figure ES5. Historical catch-at-age of north Pacific albacore (*Thunnus alalunga*) estimated by the 2026 base case model. Panels are arranged for the total catch and ages 0-5 (top), 6-10 (middle), and 11-15 (bottom). Note the difference in y-axis scale between the top panel and middle and bottom panels.

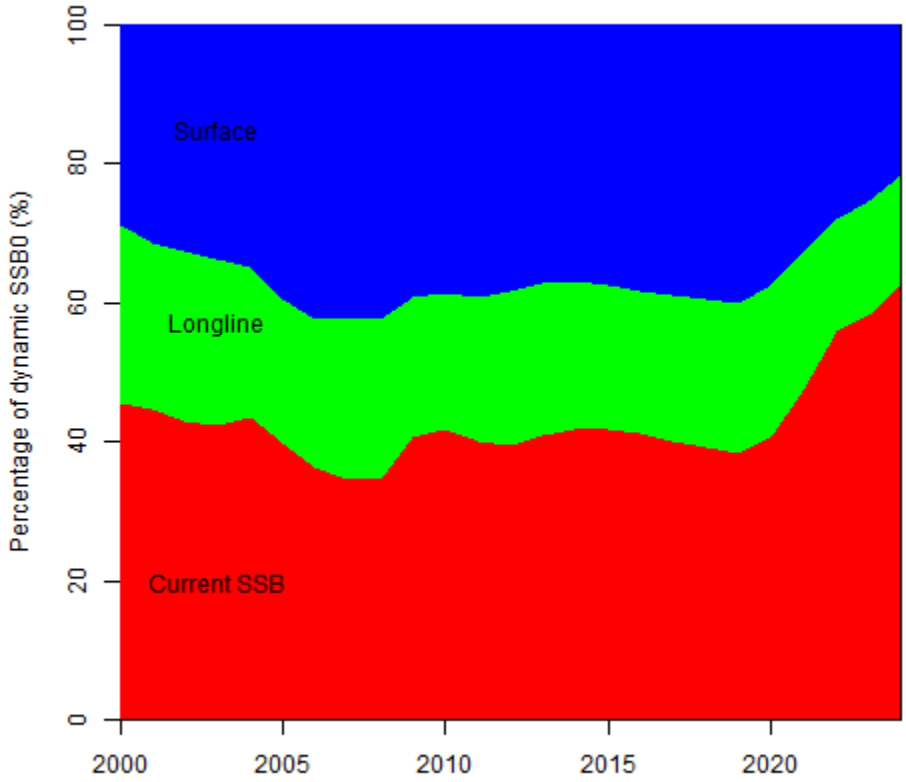


Figure ES6. Fishery impact analysis on north Pacific albacore (*Thunnus alalunga*) showing female spawning biomass (SSB) (red) estimated by the 2026 base case model as a percentage of dynamic, unfished female SSB ($SSB_{current,\ F=0}$). Colored areas show the relative proportion of fishing impact attributed to longline (green) and surface (blue) fisheries (primarily troll and pole-and-line gear, but including all other gears except longline).

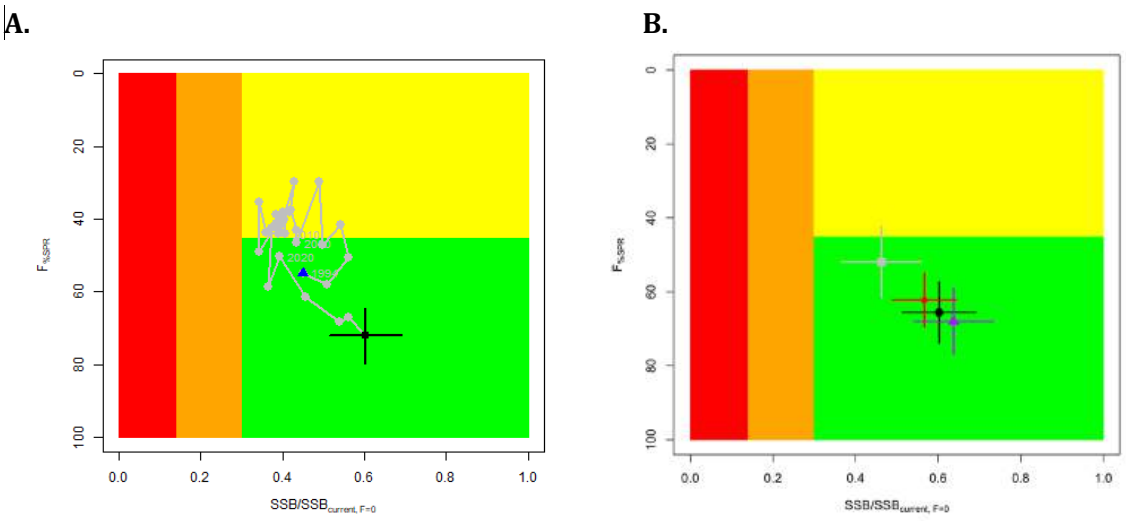


Figure ES7. (**A**) Stock status phase plot showing the status of the north Pacific albacore (*Thunnus alalunga*) stock relative to the biomass-based threshold (30%$SSB_{current, F=0}$) and limit (14%$SSB_{current, F=0}$) reference points, and fishing intensity-based target reference point ($F45_{\%SPR}$) over the modeling period (1994 – 2024). Blue triangle indicates the start year (1994) and black circle with 95% confidence intervals indicates the terminal year (2024). (**B**) Stock status plot showing current stock status and 95% confidence intervals of the base case model (black circle), a sensitivity run an important sensitivity run of CV = 0.06 for L_{inf} in the growth model (gray), an important sensitivity run with two initial fishing mortality parameters (red), and a model representing an update of the 2023 base case model to 2026 data (purple). Red zones in both panels indicate female SSBs falling below the limit reference point while the orange zones indicate female SSBs between the threshold and limit reference points. Green zones indicate female SSBs above the threshold reference point and fishing intensity levels below the target reference point. Yellow areas indicate female SSBs above the threshold reference point and fishing intensity levels above the target reference point. The Fs in this figure are indicators of fishing intensity based on spawning potential ratio (SPR) and calculated as %SPR. SPR is the ratio of the equilibrium SSB per recruit that would result from the estimated F-at-age relative to that of an unfished population. A higher %SPR indicates lower fishing intensity. Current fishing intensity values and $SSB/SSB_{current,F=0}$ ratios in (B) were calculated as the average during 2021-2023 ($F_{\%SPR, 2021-2023}$) and 2024 ($SSB_{2024}/SSB_{current, F=0}$), respectively. The model representing an update of the 2023 base case model is similar to but not identical to the 2023 base case model due to changes in data preparation and model structure.

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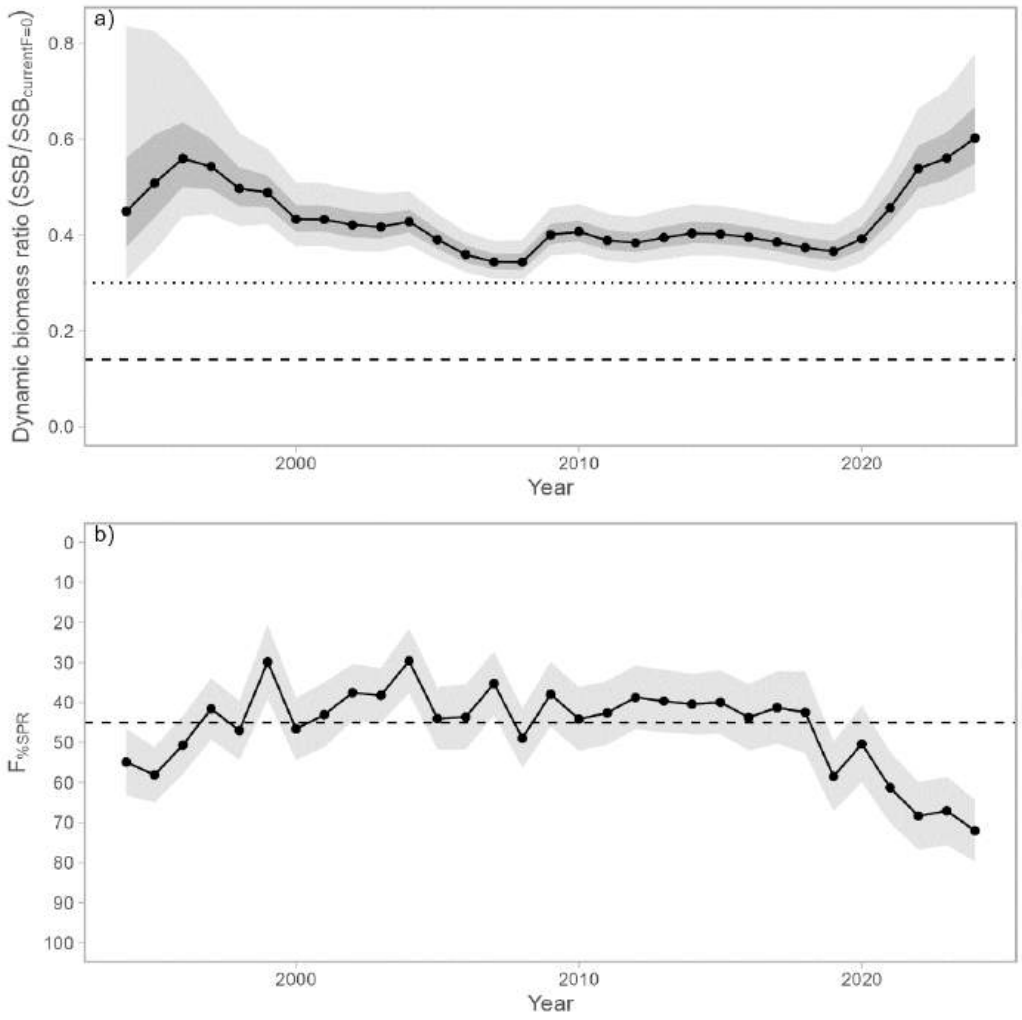


Figure ES8. (**A**) Estimated dynamic biomass ratio (SSB/SSB$_{current,\ F=0}$) of north Pacific albacore relative to biomass-based threshold (30%SSB$_{current,\ F=0}$; dotted line) and limit (14%SSB$_{current,\ F=0}$; dashed line) reference points over the modeling period (1994 – 2024). 95% confidence intervals are indicated by the lighter gray bands and 60% confidence intervals are indicated by the darker gray bands. **(B)** Estimated fishing intensity relative to the fishing intensity-based target reference point ($F45_{\%SPR}$) over the modeling period (1994 – 2024). The gray area indicates the 95% confidence intervals. The limit reference point is considered to be breached if the lower bound of the 60% confidence intervals overlaps the limit reference point.

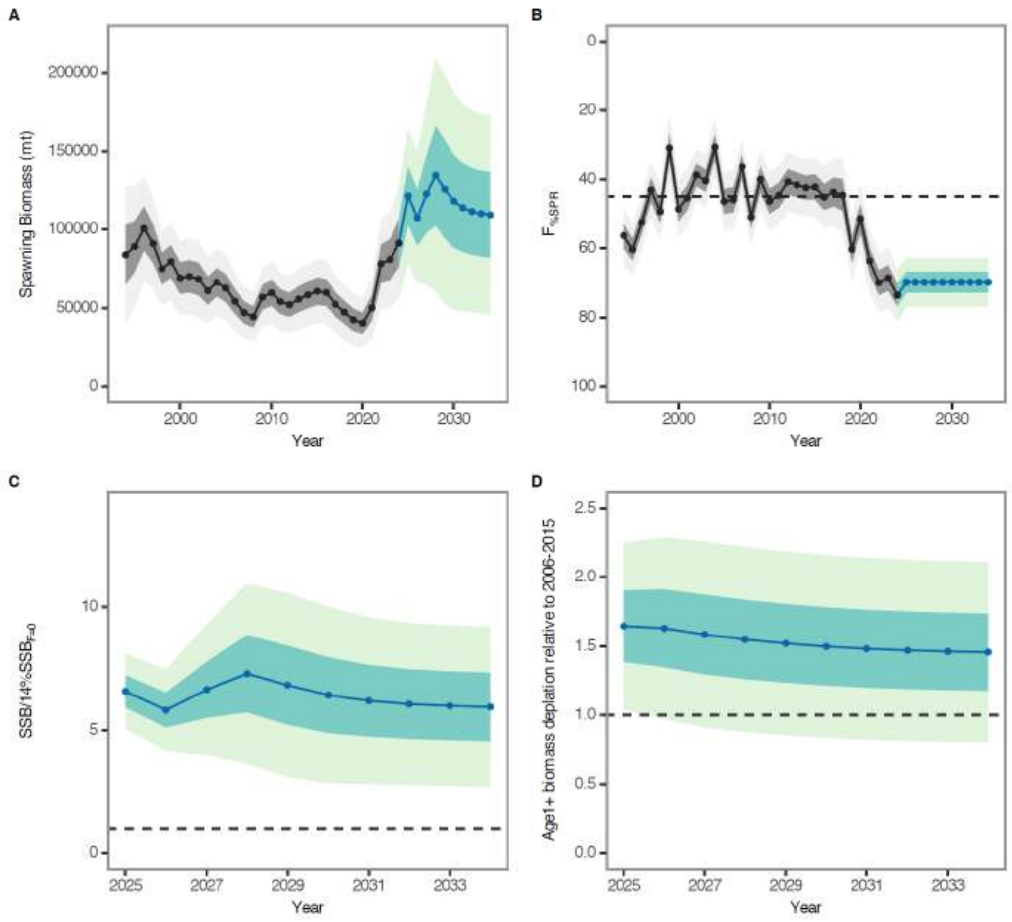


Figure ES9. Future projection results under a constant fishing intensity ($F_{2021\text{-}2023}$) harvest scenario. Solid lines indicate mean values, uncertainty ranges indicate 60% and 95% confidence intervals, and the dashed line is the reference point, respectively. (A) Annual changes in spawning biomass; (B) Interannual changes in fishing mortality ($F_{\%SPR}$); (C) Projected ratios to the limit reference point thresholds; and (D) Projected ratios to management targets for the total biomass.

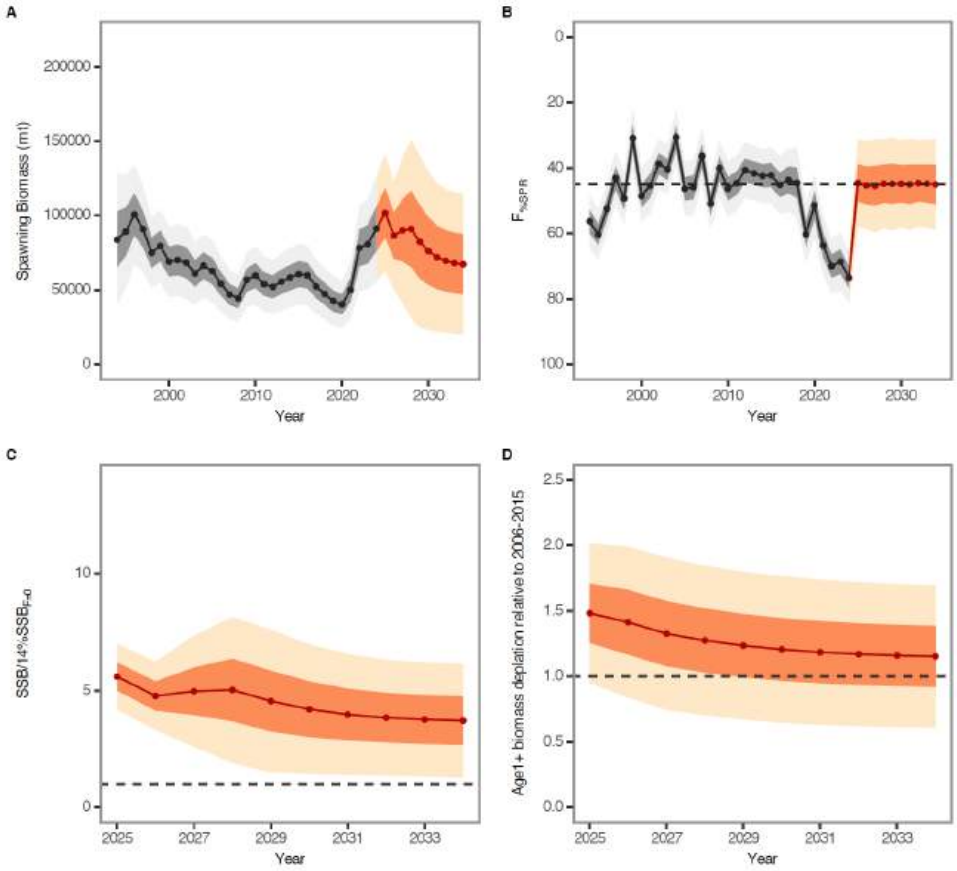


Figure ES10. Future projection results under a randomly F (2005-2019) scenario. Solid lines indicate mean values, and uncertainty ranges indicate 60% and 95% confidence intervals, and the dashed line is the reference point, respectively. (A) Annual changes in spawning biomass; (B) Interannual changes in fishing mortality ($F_{\%SPR}$); (C) Projected ratios to the limit reference point thresholds; and (D) Projected ratios to management targets for the total biomass.

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APPENDIX II

INTER-AMERICAN TROPICAL TUNA COMMISSION

SCIENTIFIC ADVISORY COMMITTEE

17TH MEETING

La Jolla, California (USA)
08-12 June 2026

DOCUMENT SAC-17 INF-U

Subject to change and approval by the ISC26 Plenary

Attachment 5

Science advice on interpreting historical impacts of fleets fishing for north Pacific albacore tuna in terms of fishing intensity

BACKGROUND

The Western and Central Pacific Fisheries Commission (WCPFC) Northern Committee (NC) and the Inter-American Tropical Tuna Commission (IATTC) harvest strategies for north Pacific albacore (NPALB; WCPFC NC Harvest Strategy 2023-01; IATTC Resolution C-23-02) include harvest control rules that mandate reductions in fishing intensity ($F_{\%SPR}$) if the female spawning stock biomass (SSB) falls below the adopted reference points. The Albacore Working Group (ALBWG) of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) provided scientific advice translating fishing intensity into traditional management controls, such as catch and effort (ISC/25/ANNEX/10). The analyses supporting this advice separated the annual total fishing intensity estimated in the 2023 stock assessment into fleet-specific fishing intensities, and demonstrated strong relationships between fleet-specific fishing intensities and catch, and moderate relationships with effort for some fleet groups, indicating that fishing intensity can be managed by these traditional measures. In order for this advice to be implemented, the ALBWG recognized that allocation rules needed to be provided by the WCPFC and IATTC to guide the calculations of fleet-specific fishing intensities according to the harvest strategies. In response, WCPFC NC members requested that the ISC provide estimates of the historical impact of each fleet group on the North Pacific albacore tuna (NPALB) stock expressed in terms of fishing intensity ($F_{\%SPR}$). Specifically, the NC requested that these estimates be calculated for the historical reference periods: 2002–2004 and 1999–2015. It was also requested by NC that the fleet groupings used in the previous advice for translating fishing intensity into catch and effort be reevaluated and slightly altered to accommodate requests from some countries.

Overall, the purpose of this request is to ensure that, should the NPALB stock decline below the threshold reference point, management bodies have the necessary information to support

potential fleet-specific allocation of reductions in fishing intensity, and to inform harvest strategy implementation discussions.

SUMMARY OF ANALYSES

The ALBWG applied analytical methods previously developed to estimate the annual proportional historical impacts of each fleet group on the NPALB stock. The annual fleet-specific spawning potential ratios (SPRs) for each fleet group were first estimated using outputs from the updated 2026 NPALB stock assessment (ALBWG 2026) and applying the methods from Teo et al., 2024 (Table 2). The annual proportional impact of each fleet group was then calculated using the annual fleet-specific SPRs and the annual total SPR from the stock assessment, applying methods in Teo and Kuriyama (2025; Table 3). The average proportional impact of each fleet group during the 2002 – 2004 and 1999 – 2015 time periods was then calculated using the arithmetic means of the fleet-specific SPRs and the total SPR for the two time periods (Tables 4).

SCIENTIFIC ADVICE AND RECOMMENDATIONS

The ALBWG advises that the fleet-specific fishing intensity estimates presented in this document provide a biologically consistent and transparent characterization of the historical impacts of major NPALB fleet groups on the stock. By expressing fleet-specific impacts in terms of spawning potential ratio ($F_{\%SPR}$), these estimates account for differences in selectivity, age composition, and biological contribution to female SSB, allowing impacts across diverse gears and fisheries to be compared on a common scale. These metrics are therefore more appropriate than catch or effort alone for evaluating relative historical fishing impacts and informing harvest strategy implementation.

The average fleet-specific proportional impacts estimated for the requested historical reference periods, 2002–2004 and 1999–2015 (Table 4) represent suitable indicators of each fleet group's relative contribution to total fishing pressure during those periods. These averaged values are particularly appropriate for informing discussions on proportional reductions in fishing intensity, should the harvest control rules be triggered by the stock falling below the threshold reference point. However, the interpretation and use of these estimates should recognize that fleet-specific fishing intensity is conditional on historical stock and fishery conditions, including recruitment, availability, and selectivity patterns.

The ALBWG therefore notes that the historical fleet-specific proportional impact estimate values are likely to change slightly with updated stock assessment outputs. The ALBWG recommends using the 2026 stock assessment results to inform the upcoming discussions around allocation rules required should the SSB fall below the threshold reference point. The ALBWG does not recommend recalculating the fleet specific proportional impacts for the historical periods for subsequent stock assessments unless there is a specific need related to an identified exceptional circumstance.

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The ALBWG reiterates that while this scientific advice provides quantitative estimates of historical fleet-specific fishing intensity, the development and application of explicit allocation rules for translating total fishing intensity targets into fleet-specific fishing intensities remain the responsibility of the RFMOs.

Once allocation rules are agreed upon, the ALBWG's previous scientific advice on interpreting fleet-specific fishing intensity in terms of catch and effort management measures can be applied. The ALBWG is prepared to provide further technical support or updated analyses as requested to facilitate transparent and effective implementation of the NPALB harvest strategy.

ADDITIONAL RESOURCES

In addition, the ALBWG has also developed an online tool to help discussions by the WCPFC NC and IATTC on allocation rules and harvest strategies for north Pacific albacore (https://connect.fisheries.noaa.gov/NPALB_harvest_strategy_tool).

REFERENCES

Teo, S. L. H., H.-H. Lee, D. Tommasi, S. Hawkshaw, Y.-J. Chang, Y. Tsuda, and Y. Kwon. 2024. Relationships between fleet-specific spawning potential ratios and measures of catch and effort for North Pacific albacore tuna. ISC/24/ALBWG-01/07. Working document submitted to the ISC ALBWG, 11-18 March, 2024, Institute of Ocean Sciences, Fisheries and Oceans Canada, Sidney, British Columbia, Canada.

Teo, S. L. H. and Kuriyama, P. 2025. Estimating fleet-specific allocations of spawning potential ratios. ISC/25/ALBWG-01/11. Working document submitted to the ISC ALBWG, 10-14 March 2025, held at the National Taiwan University, Institute of Oceanography in Taipei, Taiwan.

TABLES

Table 1. Fleet groups are from the 2026 North Pacific albacore (NPALB) stock assessment.

Fleet Group	Fleet Group Name	Fleet ID	Units of Effort	Fleet Group Description
1	JPLLalbtgt (NPALB targeting)	F1/F2/F9/F12/ F13/F16	Hooks, Vessels, Days	Japan longline; targeting NPALB (A13_Q1/2 & A2_Q1/4)
2	JPLLnontgt (NPALB Non-targeting)	F3 to F8 & F10/F11 & F14/F15 & F17/F18	Hooks, Vessels, Days	Japan longline; all areas; all seasons; (except A13_Q1/2 and A2_Q1/4)

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3	JPPL	F19 to F23	Vessels, Days, Poledays, Avg poles, SKJ catch	Japan pole-and-line; all areas; all seasons
4	USLL	F24/F25	Hooks, Vessels, Sets	US longline; all areas; all seasons
5	TWLL	F26/F27	Hooks, Vessels, Days	Taiwan longline; all areas; all seasons
6	KRLL	F28	Hooks	Korea longline; all areas; all seasons
7	CNLL	F29/F30	Hooks	China longline; all areas; all seasons
8	VULL	F31/F32	Hooks	Vanuatu longline; all areas & seasons
9	OTHLL	F33	Hooks	Others longline; all areas & seasons
10	EPOSF	F34	Vessels, Days	EPO Surface fleet (primarily US and Canada); all seasons
11	PSDNMISC	F35	NA	Purse seine and miscellaneous fleets from Japan and Taiwan

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Table 2. Estimated fleet-specific spawning potential ratios (SPRs) for each fleet group described in Table 1 using estimates from the 2026 North Pacific albacore (NPALB) stock assessment.

Year	Fleet Group Name										
	JPLL albtgt	JPLL nontgt	JPPL	USLL	TWLL	KRLL	CNLL	VULL	OTHLL	EPOSF	PSDN Misc
1994	0.861	0.867	0.814	0.994	0.999	1.000	1.000	1.000	1.000	0.903	0.985
1995	0.866	0.878	0.866	0.993	0.963	1.000	1.000	1.000	1.000	0.921	0.978
1996	0.849	0.874	0.827	0.991	0.931	0.999	1.000	1.000	1.000	0.875	0.990
1997	0.801	0.862	0.750	0.989	0.918	0.997	1.000	1.000	1.000	0.859	0.982
1998	0.817	0.861	0.833	0.993	0.916	0.998	1.000	1.000	1.000	0.861	0.977
1999	0.840	0.844	0.557	0.989	0.910	0.999	0.998	1.000	1.000	0.839	0.955
2000	0.819	0.882	0.835	0.993	0.900	1.000	1.000	1.000	1.000	0.848	0.972
2001	0.831	0.868	0.746	0.990	0.902	0.999	0.994	1.000	0.999	0.866	0.988
2002	0.817	0.904	0.666	0.996	0.902	0.999	0.995	0.979	0.993	0.862	0.974
2003	0.833	0.927	0.694	0.996	0.914	0.998	0.989	0.975	0.998	0.800	0.984
2004	0.866	0.920	0.611	0.997	0.934	0.999	0.988	0.936	1.000	0.742	0.924
2005	0.807	0.916	0.834	0.997	0.933	0.995	0.992	0.946	1.000	0.807	0.977
2006	0.807	0.895	0.786	0.998	0.933	0.998	0.981	0.942	1.000	0.864	0.992
2007	0.806	0.881	0.661	0.997	0.957	0.998	0.998	0.947	0.999	0.836	0.962
2008	0.844	0.896	0.843	0.996	0.956	0.994	0.997	0.957	0.999	0.842	0.975
2009	0.822	0.886	0.667	0.997	0.964	0.999	0.998	0.976	0.999	0.828	0.977
2010	0.820	0.893	0.786	0.995	0.958	0.998	0.986	0.962	0.998	0.820	0.992
2011	0.841	0.875	0.761	0.991	0.951	0.999	0.956	0.942	0.999	0.857	0.993
2012	0.800	0.899	0.727	0.990	0.963	0.998	0.921	0.967	0.993	0.864	0.966
2013	0.848	0.889	0.734	0.996	0.940	0.998	0.952	0.956	0.992	0.824	0.984
2014	0.854	0.884	0.745	0.997	0.964	0.998	0.975	0.959	0.996	0.792	0.978
2015	0.806	0.899	0.744	0.997	0.955	0.999	0.974	0.951	0.996	0.823	0.983
2016	0.843	0.917	0.767	0.997	0.949	0.999	0.988	0.978	0.997	0.818	0.962
2017	0.813	0.929	0.725	0.998	0.939	0.997	0.981	0.965	0.994	0.839	0.979
2018	0.855	0.925	0.691	0.999	0.931	0.999	0.981	0.965	0.992	0.886	0.965
2019	0.871	0.920	0.890	0.999	0.922	0.999	0.969	0.961	0.994	0.933	0.990
2020	0.880	0.928	0.762	0.998	0.946	0.999	0.976	0.970	0.998	0.913	0.967
2021	0.839	0.920	0.931	0.997	0.921	0.996	0.990	0.958	0.997	0.952	0.993
2022	0.928	0.945	0.944	0.998	0.944	0.998	0.989	0.962	0.995	0.915	0.995
2023	0.908	0.941	0.920	0.995	0.934	0.999	0.992	0.979	0.998	0.956	0.969
2024	0.904	0.951	0.962	0.998	0.922	0.996	0.997	0.983	0.995	0.954	0.994

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Table 3. Estimated annual historical fleet-specific proportional impact (%) on North Pacific albacore (NPALB) stock using estimates from the 2026 North Pacific albacore (NPALB) stock assessment. Fleet groups described in Table 1. The proportional impact can also be thought of as the fleet-specific share of the SPR shown in Table 2. Each row sums to approximately 100%.

Year	Fleet Group Name										
	JPLL albtgt	JPLL nontgt	JPPL	USLL	TWLL	KRLL	CNLL	VULL	OTHLL	EPOSF	PSDN Misc
1994	24.1	23.0	33.0	0.9	0.1	0.0	0.0	0.0	0.0	16.5	2.4
1995	25.3	22.8	25.4	1.3	6.8	0.0	0.0	0.0	0.0	14.5	3.9
1996	22.9	18.9	26.5	1.2	10.1	0.2	0.0	0.0	0.0	18.8	1.4
1997	23.8	16.0	30.8	1.2	9.3	0.4	0.0	0.0	0.0	16.4	2.0
1998	25.1	18.6	22.7	0.9	11.0	0.2	0.0	0.0	0.0	18.5	2.9
1999	14.1	13.8	45.4	0.9	7.7	0.1	0.1	0.0	0.0	14.2	3.8
2000	24.5	15.5	22.2	0.9	13.0	0.0	0.0	0.0	0.0	20.3	3.5
2001	20.7	15.8	32.4	1.1	11.6	0.1	0.7	0.0	0.1	16.1	1.4
2002	19.7	9.9	39.1	0.4	10.2	0.1	0.5	2.1	0.7	14.6	2.6
2003	18.4	7.7	36.2	0.4	9.1	0.2	1.1	2.5	0.2	22.5	1.7
2004	11.7	6.9	38.7	0.2	5.6	0.1	1.0	5.4	0.0	23.9	6.5
2005	24.8	10.3	21.1	0.3	8.1	0.6	0.9	6.5	0.0	24.8	2.7
2006	24.5	12.8	27.4	0.3	8.0	0.2	2.3	6.9	0.0	16.8	1.0
2007	20.1	11.8	37.8	0.3	4.1	0.2	0.2	5.1	0.1	16.6	3.7
2008	22.6	14.7	22.7	0.6	6.0	0.8	0.4	5.9	0.1	22.9	3.4
2009	19.7	12.2	39.9	0.3	3.7	0.1	0.2	2.5	0.1	18.9	2.4
2010	22.9	13.1	27.8	0.6	5.0	0.2	1.7	4.6	0.2	22.9	0.9
2011	19.0	14.8	29.9	1.0	5.6	0.1	5.0	6.6	0.1	17.0	0.8
2012	22.2	10.7	31.5	1.0	3.8	0.2	8.3	3.4	0.7	14.7	3.5
2013	17.0	12.2	31.5	0.4	6.5	0.3	5.1	4.6	0.8	19.9	1.7
2014	16.8	13.1	31.0	0.3	3.9	0.2	2.8	4.5	0.4	24.7	2.4
2015	22.4	11.2	30.5	0.3	4.8	0.1	2.8	5.2	0.4	20.3	1.9
2016	20.0	10.2	30.8	0.3	6.2	0.1	1.5	2.6	0.3	23.4	4.6
2017	22.3	8.0	34.4	0.2	6.9	0.3	2.1	3.9	0.7	19.0	2.3
2018	17.5	8.8	40.7	0.2	8.1	0.2	2.1	4.0	1.0	13.6	4.0
2019	23.9	14.4	20.1	0.2	14.0	0.2	5.4	7.0	1.1	12.0	1.7
2020	17.9	10.5	37.9	0.3	7.8	0.1	3.4	4.4	0.3	12.8	4.7
2021	32.8	15.7	13.5	0.5	15.5	0.8	2.0	8.0	0.5	9.3	1.4
2022	18.8	14.1	14.5	0.6	14.3	0.6	2.8	9.7	1.1	22.2	1.3
2023	22.7	14.4	19.8	1.1	16.0	0.3	1.9	5.1	0.4	10.7	7.5
2024	28.4	14.3	11.0	0.6	22.8	1.2	1.0	4.7	1.3	13.1	1.6

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Table 4. Estimated average historical fleet-specific spawning potential ratio (SPR) and proportional impact (%) on North Pacific albacore (NPALB) stock for the requested historical time periods 2002-2004 and 1999-2015. Estimates are from the 2026 stock assessment and fleet groups are described in Table 1. The proportional impact can also be thought of as the fleet-specific share of the SPRs. The total SPR is the product of the fleet-specific SPRs.

Fleet Group	Average SPR 2002-2004	Average proportion of SPR 2002-2004 (%)	Average SPR 1999-2015	Average proportion of SPR 1999-2015 (%)
JPLLalbtgt	0.839	16.3	0.827	19.8
JPLLnontgt	0.917	8.1	0.892	12.0
JPPL	0.657	38.1	0.729	32.6
USLL	0.996	0.4	0.995	0.6
TWLL	0.917	8.1	0.938	6.8
KRLL	0.999	0.1	0.998	0.2
CNLL	0.990	0.9	0.982	1.9
VULL	0.964	3.5	0.965	3.8
OTHLL	0.997	0.3	0.998	0.2
EPOSF	0.801	20.5	0.830	19.4
PSDNMisc	0.961	3.8	0.975	2.7
Total	0.337	100.0	0.383	100.0

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APPENDIX III

U.S. Stakeholder Meeting on North Pacific Albacore Management

May 21, 2026

Meeting Logistics

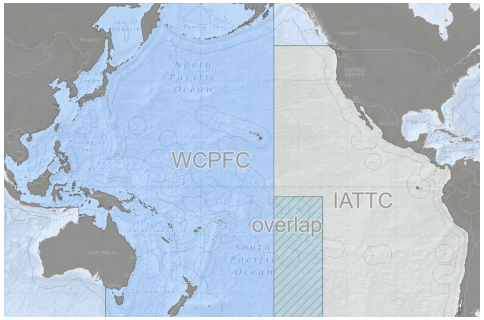
- Please mute when not speaking
- Raise your hand if you would like to speak
- Please state your name and affiliation when speaking
- We will solicit comment after specific sections.
  - Focus questions are contained within the background paper for this meeting.

Meeting Overview

1. Overview of NPALB management
2. Recap of February webinar
3. Preliminary results of the 2026 NPALB stock assessment and ISC estimates of the historical impact of fleet groups
4. Discussion on options to potentially revise the WCPFC/IATTC harvest strategy/management
5. Electronic logbook update
6. Bonus: CEFI project

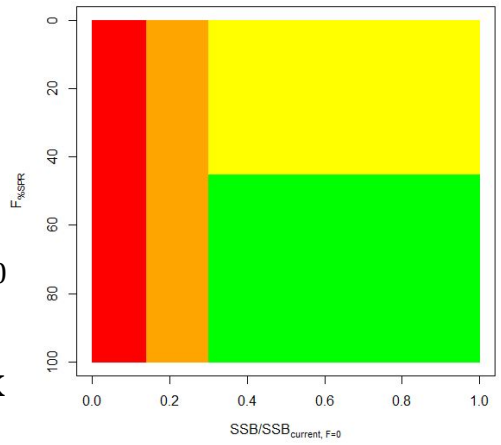
International management

- IATTC and WCPFC first adopted management measures for NP ALB in 2005
- Current versions are IATTC Resolution C-18-03 and WCPFC CMM 2019-03
- WCPFC and IATTC adopted harvest strategies for NP ALB in 2023



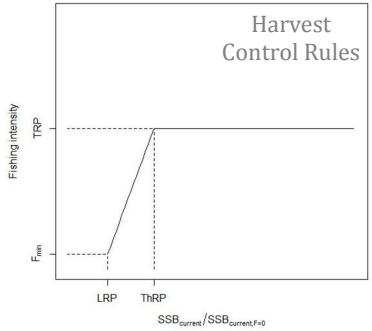
NPALB Harvest Strategy

- Reference Points
  - Target: F45%
  - Threshold: 30%$SSB_{current,F=0}$
  - Limit: 14%$SSB_{current,F=0}$
  - Fmin: F87%
- Acceptable Levels of Risk
  - <20% Risk



NPALB Harvest Strategy

- Monitoring Strategy
  - Stock Assessment
  - ISC evaluate for exceptional circumstances
- Harvest Control Rules
  - Apply to all fisheries harvesting NPALB
  - Produce a relationship between stock status and fishing intensity



NPALB Harvest Strategy

- Harvest Control Rules (continued)
  - Fishing intensity is not explicitly defined
  - Footnote re: reductions states "*When adopting proposed revisions to the conservation and management measures proposed, which may include inter alia reductions in fishing effort, CPCs will take into account historical fishing activity and the source of increased fishing mortality in reference to the average effort referenced in Resolution C-05-02.*"

NPALB Harvest Strategy

- Other Provisions
  - Performance Review of Harvest Strategy in 2030 and 2033

Recap from February 2026 Webinar

- Improve catch and effort data from other countries
- The harvest strategy should apply north of the equator, and should not be modified to only apply north of 20° N
- Per the current harvest strategy guidelines, U.S. troll effort would only be impacted in specific situations.
  - Foreign fleets would be impacted commensurately.
- Preference to see the results of the 2026 stock assessment before making further decisions on potentially revising the harvest strategy.

Recommendations from the PFMC and HMS Advisory Subpanel (March 2026)

- Continuation of the 2002–2004 baseline
- Continued stakeholder engagement with the fleet in advance of this summer's international meetings
- Need to better understand the potential impact(s) to the U.S West Coast fleet

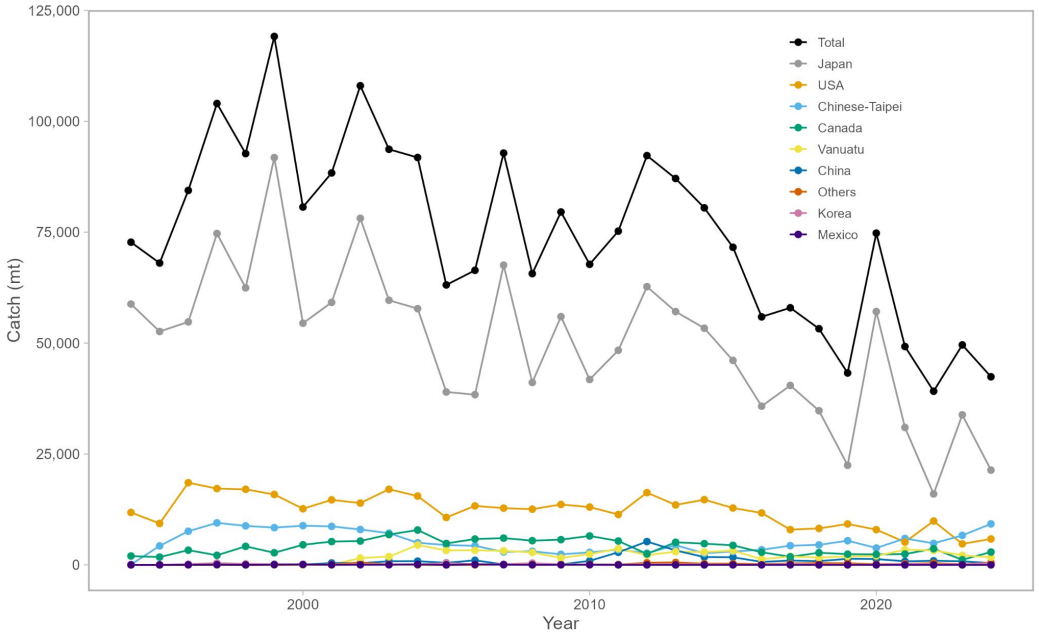
Meeting Objectives

1. Present preliminary results of the 2026 NPALB stock assessment and ISC estimates of the historical impact of fleet groups
2. Solicit feedback on options to potentially revise the WCPFC/IATTC harvest strategy

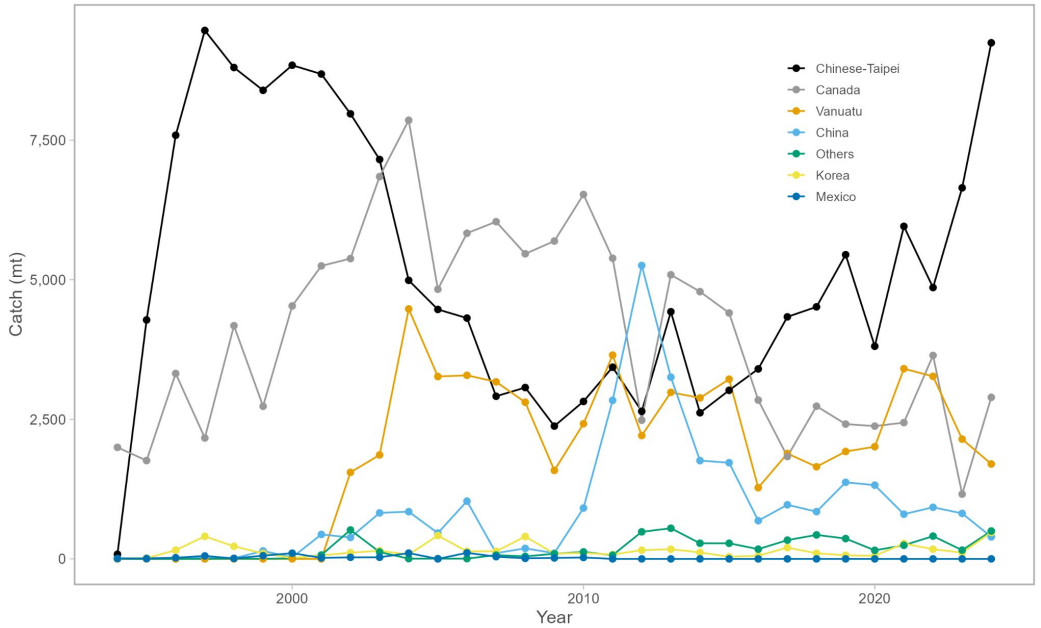
2026 North Pacific Albacore Stock Assessment

(Preliminary - Subject to Change)

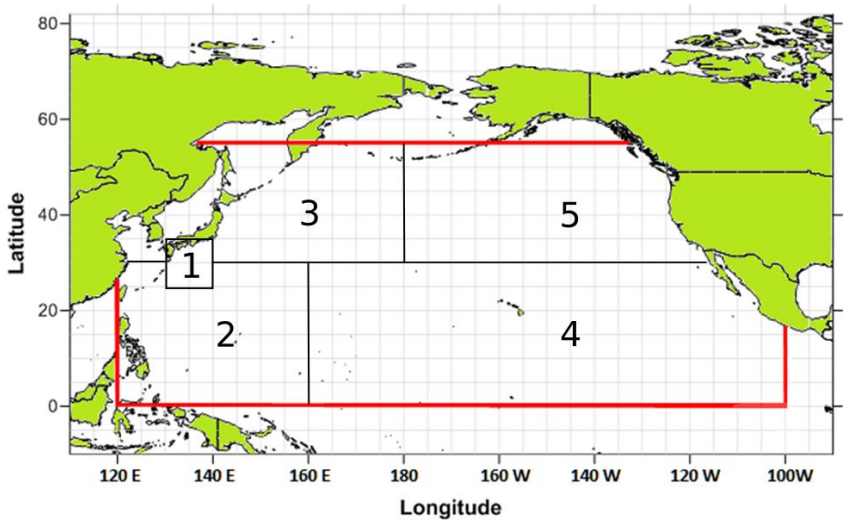
Updated catch data



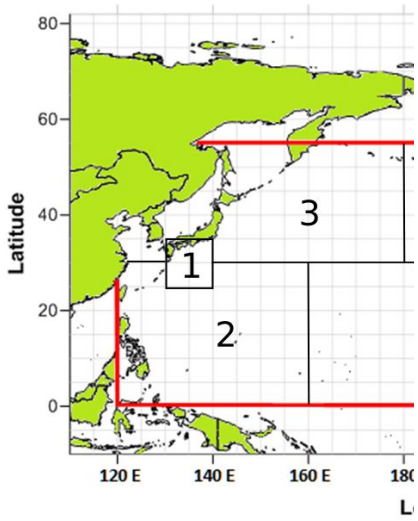
Updated catch data - no Japan, no USA



Index of abundance (Japan longline, April-June, Area 2)

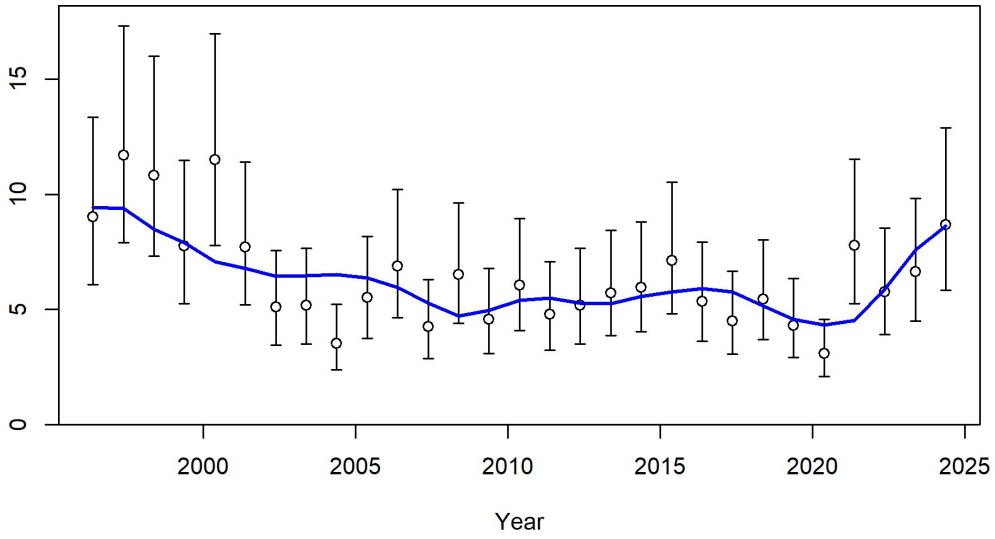


Index of abundance (Japan longline, April-June, Area 2)

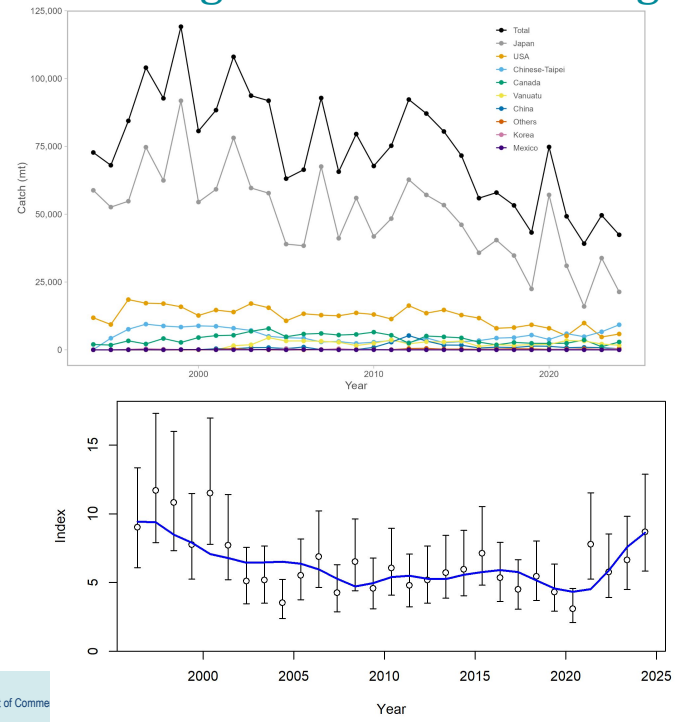


- Highest proportion of adult female albacore in Area 2 from April-June
- Main spawning area and season
- Considered other indices of abundance but this one had the best model diagnostics

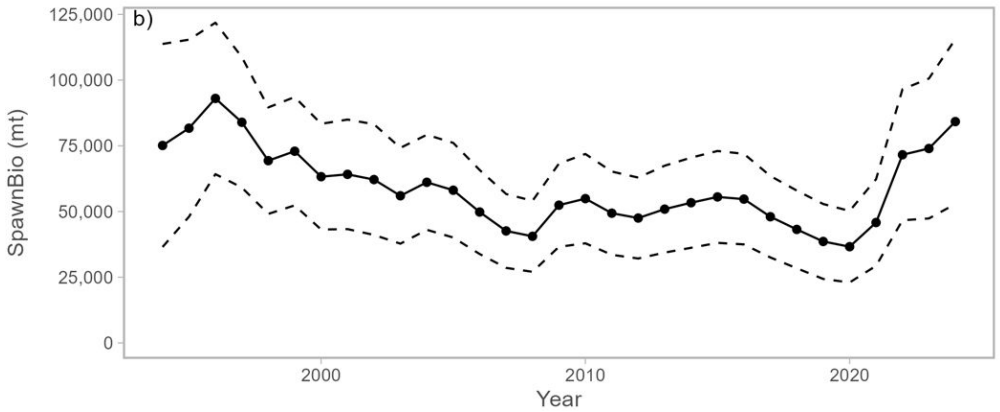
Index of abundance (Japan longline, April-June, Area 2)



Catch decreasing and index increasing

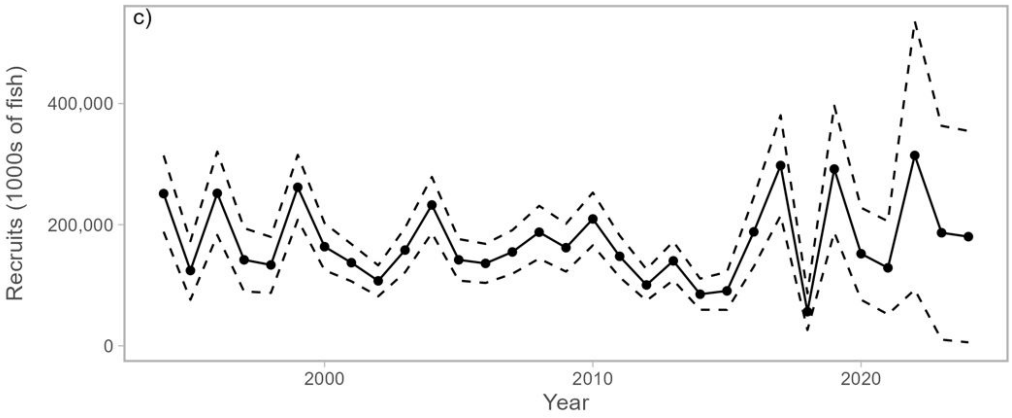


Preliminary estimated female spawning stock biomass (mt)



- Increase in early years, followed by relative decline, then somewhat constant, increasing since 2020
- Higher uncertainty at beginning and end of model time period
- Increase seen in other data sets (Taiwan small-scale longline and Japan longline indices of abundance)

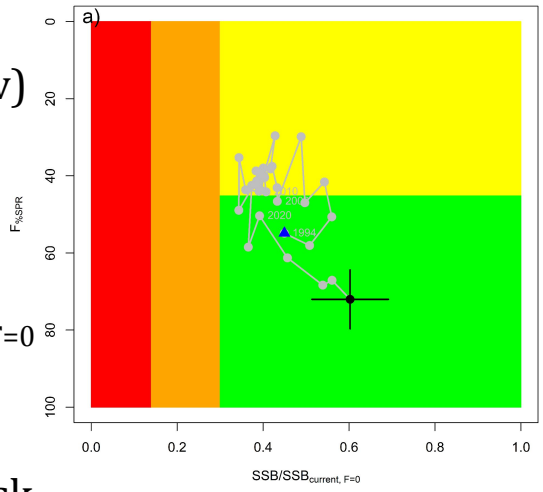
Preliminary estimated recruitment (1000s of fish)



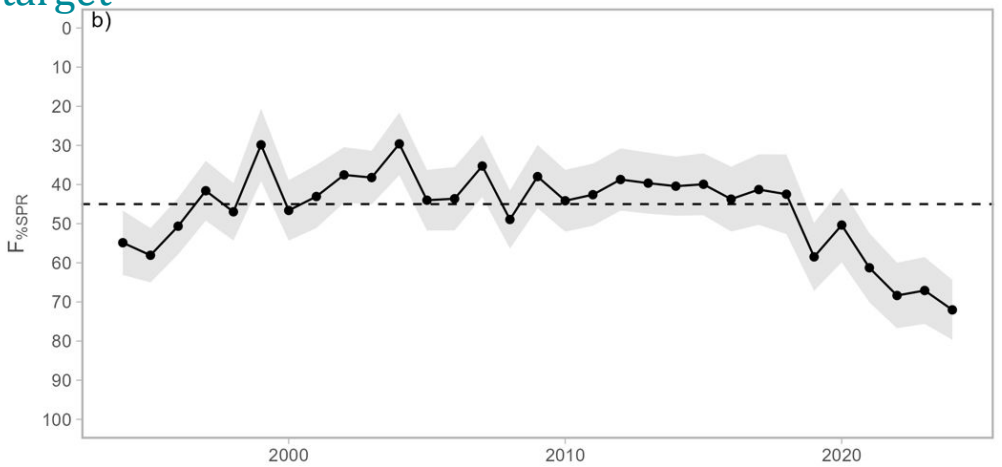
- Strong recruitment in 2017, 2019 and 2022
- Higher uncertainty at end of model time period

Preliminary 2026 NPALB Results

- Reference Points
  - Target: F45% (yellow)
  - Threshold: $30\%SSB_{current,F=0}$ (orange)
  - Limit: $14\%SSB_{current,F=0}$ (red)
  - Fmin: F87%
- Acceptable Levels of Risk
  - <20% Risk

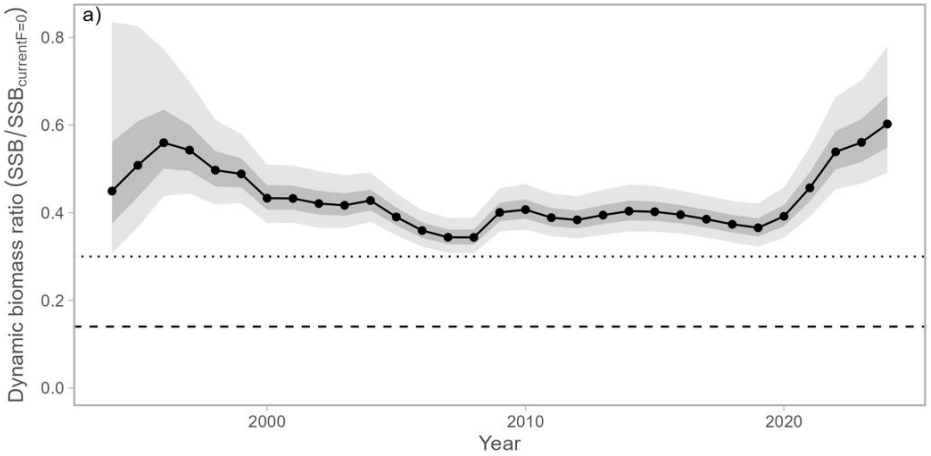


Preliminary estimated fishing intensity relative to target



- Most years 1999-2018 above target fishing intensity reference point (dashed line; $F45_{\%SPR}$), recent years below ref. point
- Preliminary population scale (R_0) estimate is lower than in 2023, likely due to updated index of abundance

Preliminary estimated dynamics biomass ratio



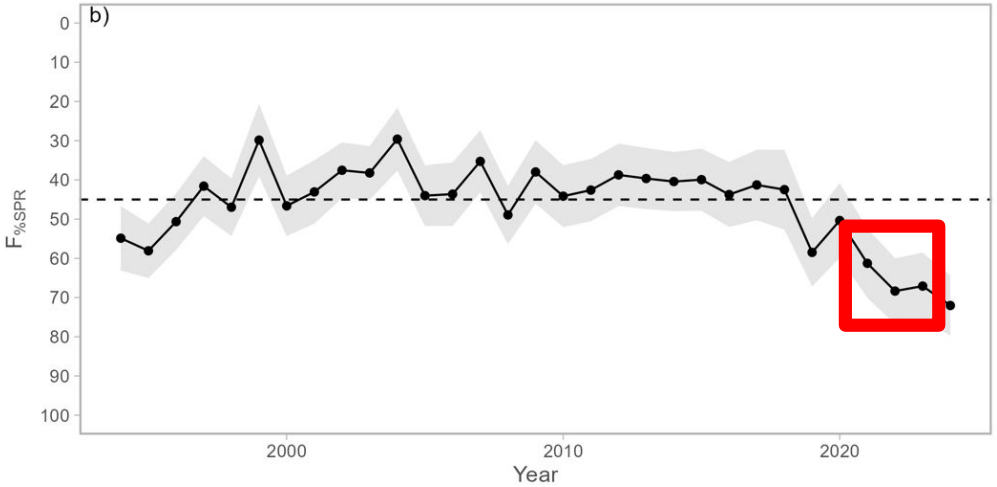
- Biomass above threshold reference point ($30\%SSB_{current, F=0}$) and limit reference point ($14\%SSB_{current, F=0}$) for time period

Preliminary Stock Status

1. The stock is likely not overfished relative to the threshold (30%SSBcurrent,F=0) and limit (14%SSBcurrent,F=0) reference points adopted by the WCPFC and IATTC

2. The stock is likely not experiencing overfishing relative to the target reference point (F45%SPR).

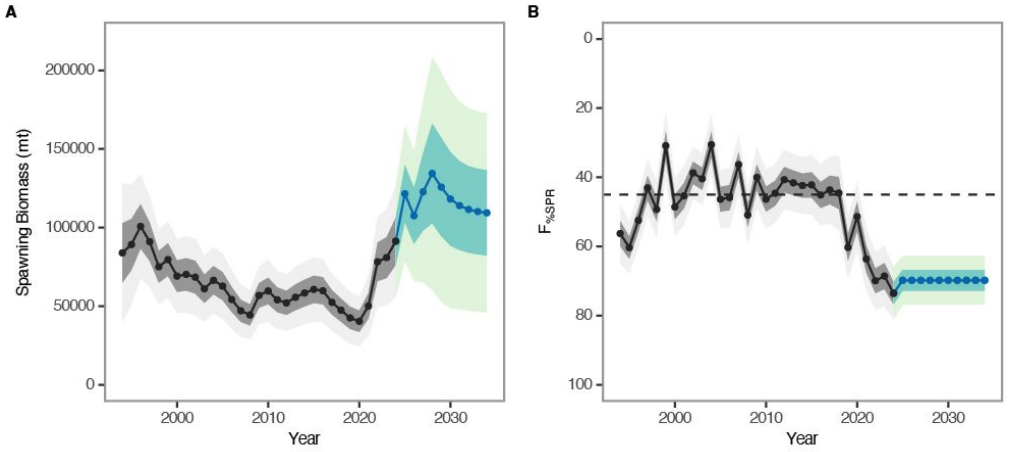
Preliminary future projections



- Under current fishing intensity (F2021-F2023)
  - Averaged

NOAA FISHERIES

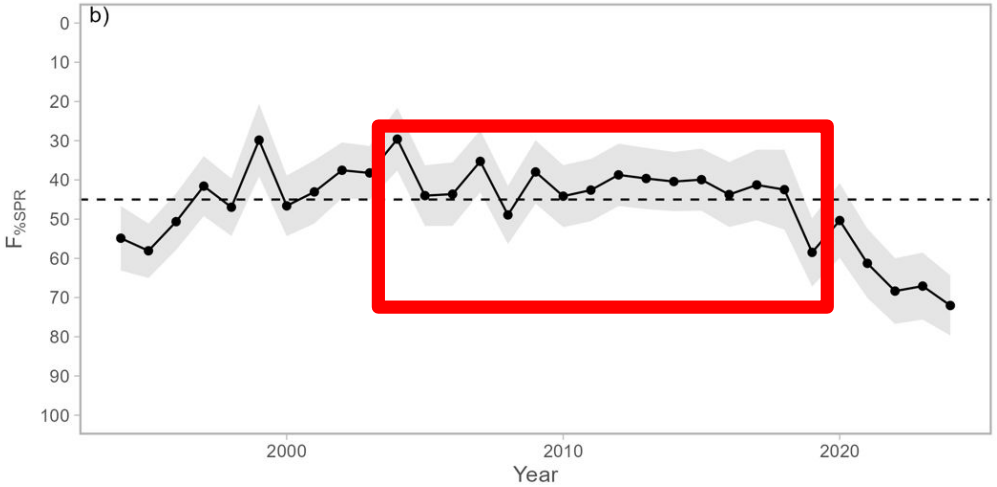
Preliminary future projections



- Under current fishing intensity (F2021-F2023)
  - Female SSB increase to around 83% of $SSB_{current, F=0}$ by 2034
  - 100% probability of female SSB above $14\%SSB_{current, F=0}$
  - 95.3% chance of fishing intensity remaining at or below $F45\%_{SPR}$

NOAA FISHERIES

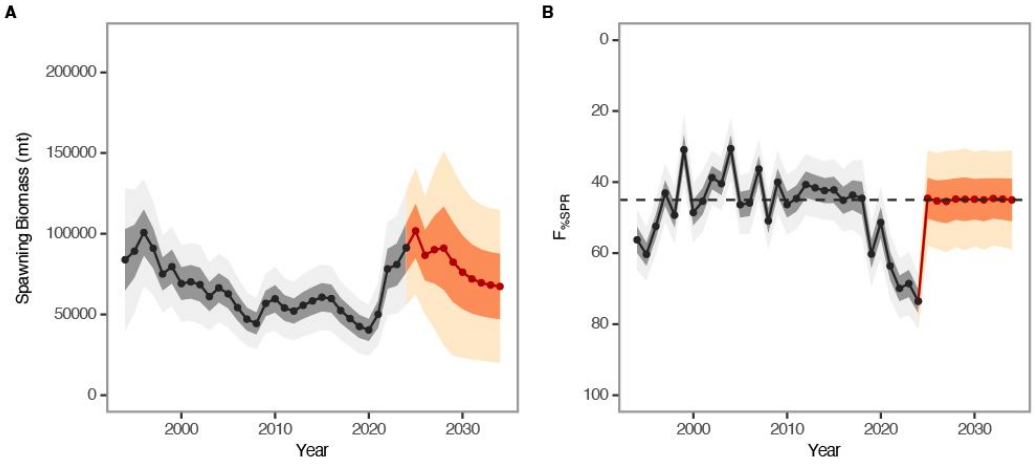
Preliminary future projections



- Randomly selected fishing intensity (F2005-F2019)

NOAA FISHERIES

Preliminary future projections



- Randomly selected fishing intensity (F2005-F2019)
  - Female SSB increase to around 52% of $SSB_{current, F=0}$ by 2034
  - 99.1% probability of female SSB above $14\%SSB_{current, F=0}$
  - 95.3% chance of fishing intensity remaining at or below $F45\%_{SPR}$

NOAA FISHERIES

ISC estimates of the historical impact of fleet groups

(Preliminary - Subject to Change)

WCPFC NC Request

- ISC ALBWG advised the WCPFC NC that fishing intensity (i.e., F%SPR) in the Harvest Strategy can be translated traditional management controls (Catch and/or Effort)
  - Strong relationships between catch and F%SPR
  - Moderate relationships between effort and F%SPR for some fleets (EPOSF, JPPL, & JPLLalbtgt)
- ALBWG noted that allocation rules needed to be provided by the WCPFC and IATTC to guide calculations
- In 2025,WCPFC NC requested ISC provide estimates of historical, fleet-specific, fishing intensity (F%SPR)
  - 2002-2004; 1999-2015
  - adjustments to fleet groups

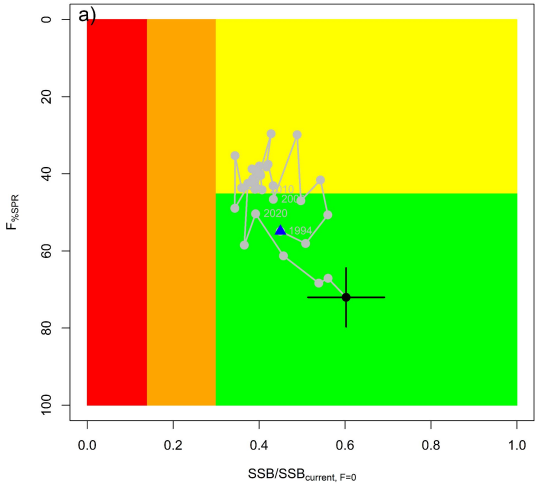
ISC ALBWG Response

- ISC ALBWG developed estimates of historical, fleet-specific fishing intensity (F%SPR)
  - preliminary science advice (to be reviewed by ISC Plenary)
  - available as IATTC SAC Info Doc (INF-U)
  - fleet-specific estimates are approximate
- ISC ALBWG developed North Pacific Albacore Harvest Strategy Tool (same info but more flexible)
  - https://connect.fisheries.noaa.gov/NPALB_harvest_strategy_tool/
  - Steve will do a walk through of tool

Implementing the Harvest Strategy for North Pacific Albacore fisheries

NPALB Harvest Strategy

- Preliminary 2026 assessment estimates $SSB_{2024}/SSB_{current, F=0}$ = 0.6



NP ALB Harvest Strategy

- Harvest Control Rules state:
- *If SSBcurrent/SSBcurrent, F=0 is above or equal to SSBthreshold with a probability of at least 50%, fishing intensity shall be maintained at or below the TRP on average over 10 years.*

Management Options

- Retain management status quo
  - Focus is on fisheries targeting NP ALB
  - Does not address harvest of catch for NP ALB from fisheries incidentally catching NP ALB
- Revise management measures
  - Address all sources of harvest
  - How to address catch of NP ALB from fisheries incidentally catching NP ALB
  - WCPFC management scope
- Address how NC should translate fishing intensity into management controls

Feedback on management options

Focus Question #1

What if any changes to the harvest strategy should be considered to help define fishing intensity?

- a) Should the harvest strategy explicitly reference the 2002-2004 baseline or continue to reference the baseline in the management measure?
- b) Are there clarifications that could be considered without materially changing the harvest strategy?

Focus Question #2

- Do you have suggestions on how to address incidental catch of NPALB from fisheries not targeting albacore (e.g., catch limit for 0-10N, de minimis clause for non-targeting vessels)?
  - a) Is there a need to define targeting? If so, how?

Focus Question #3

- What feedback do you have to offer about the impact of other harvest strategies (i.e., WCPO skipjack, WCPO BET, EPO BET, or SPALB) on the further development of harvest strategies and/or management measures for NPALB?

Focus Question #4

Expansion and contraction of fishing opportunities

- a) Do stakeholders understand how the U.S. fleet would and would not be affected if the harvest strategy were fully implemented?
- b) When might the U.S. troll fleet expand from its 02-04 baseline period?
- c) What guardrails should be in place if other countries expand from their 02-04 baseline?
  - i.e., requiring Electronic Monitoring onboard **longline** vessels

Focus Question #5

- What would stakeholders like to see in order to better address compliance and enforcement concerns?



Focus Question #6

What types of data would be useful to have more readily available? How frequently should those data be updated?

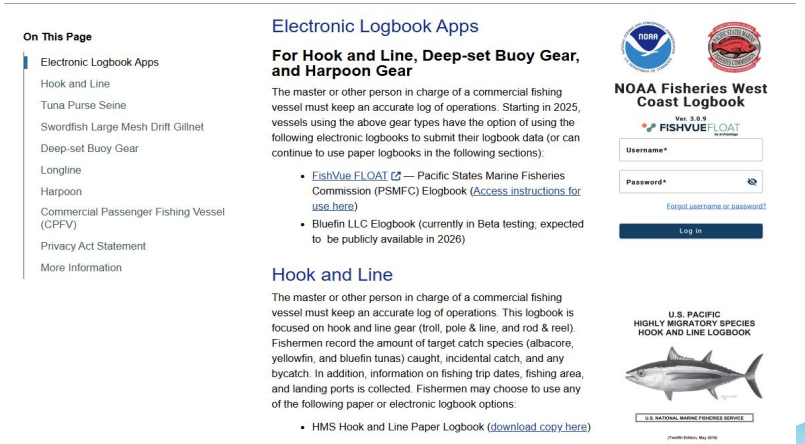
- Reporting of catch AND effort (in vessels and days) for all countries

Focus Question #7

- Are there any other management considerations stakeholders would like to raise?

Electronic Logbooks

- 1 electronic logbook app is publicly available
- Another should be available by the start of the season
- For updates: WCR HMS logbook webpage


On This Page

- Electronic Logbook Apps
- Hook and Line
- Tuna Purse Seine
- Swordfish Large Mesh Drift Gillnet
- Deep-set Buoy Gear
- Longline
- Harpoon
- Commercial Passenger Fishing Vessel (CPFV)
- Privacy Act Statement
- More Information

Electronic Logbook Apps

For Hook and Line, Deep-set Buoy Gear, and Harpoon Gear

The master or other person in charge of a commercial fishing vessel must keep an accurate log of operations. Starting in 2025, vessels using the above gear types have the option of using the following electronic logbooks to submit their logbook data (or can continue to use paper logbooks in the following sections):

- FishVue FLOAT — Pacific States Marine Fisheries Commission (PSMFC) Elogbook (Access instructions for use here)
- Bluefin LLC Elogbook (currently in Beta testing; expected to be publicly available in 2026)

Hook and Line

The master or other person in charge of a commercial fishing vessel must keep an accurate log of operations. This logbook is focused on hook and line gear (troll, pole & line, and rod & reel). Fishermen record the amount of target catch species (albacore, yellowfin, and bluefin tunas) caught, incidental catch, and any bycatch. In addition, information on fishing trip dates, fishing area, and landing ports is collected. Fishermen may choose to use any of the following paper or electronic logbook options:

- HMS Hook and Line Paper Logbook (download copy here)

NOAA Fisheries West Coast Logbook

Ver. 3.0.9 FISHVUEFLOAT

Username*

Password*

Forgot username or password?

Log in

U.S. PACIFIC HIGHLY MIGRATORY SPECIES HOOK AND LINE LOGBOOK

U.S. NATIONAL MARINE FISHERIES SERVICE

Focus Question #8

- As a way to encourage improved and more frequent data reporting from vessels that incidentally catch albacore, would stakeholders be in favor of requiring electronic logbook reporting in the EPO (*e.g.,* similar to CMM-2022-06)?

Important Dates

May 27th	Permanent Advisory Committee Meeting
Week of June 11th	Pacific Fishery Management Council Meeting
June 8th - 12th	IATTC Scientific Advisory Committee
June 22nd - 29th	ISC 29
June 29th	Northern Committee Proposals Due
July 13th-14th	22nd Northern Committee
July 20th-21st	General Advisory Committee (GAC) to the U.S. Section to the IATTC and Scientific Advisory Subcommittee to the GAC Meeting
August 31st - Sept 4th	IATTC Commission Meeting
Nov 30th - Dec 4th	WCPFC Commission Meeting

NOAA Changing Ecosystems and Fisheries Initiative (CEFI) Project:

Albacore Tuna CPUE Outlooks

Developing predictive models of albacore tuna Catch Per Unit Effort (CPUE) on the U.S. West Coast

Our goal is to provide stakeholders with actionable insights for improved operational efficiency

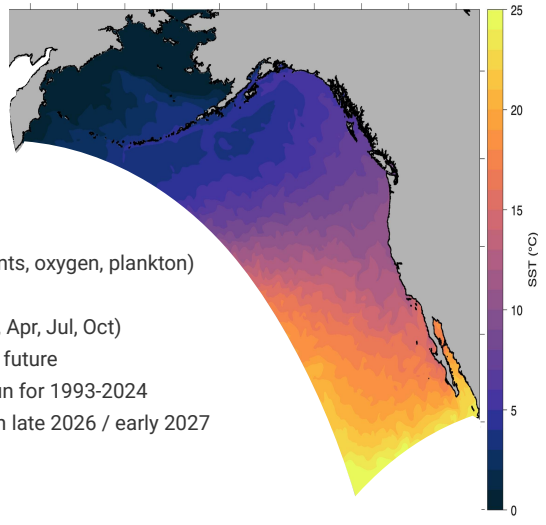
WHO: Caitlin Allen Akselrud, Peter Kuriyama, Steve Teo, Robert Wildermuth (SWFSC-FRD); Mike Jacox, Elliott Hazen (SWFSC-ESD), Barbara Muhling (UCSC), Allison Cluett, Nerea Lezama Ochoa, Desiree Tommasi (UCSC working in collaboration with SWFSC)

And ALL OF YOU

Model-based tools to help YOU

- Numerous communities along the U.S. West coast engaged in albacore fishery
- Local availability of albacore is highly variable
- **Our goal:** provide outlooks to help the planning and efficiency of the fishery
- Work is at early stages and PRELIMINARY
- Need your input to refine products

Leveraging NOAA's Next Generation Ocean Seasonal Forecasting Product - MOM6 model



Physics and biogeochemistry (nutrients, oxygen, plankton)
Approximately 10 km resolution
Forecasts produced 4x per year (Jan, Apr, Jul, Oct)
Forecasts extend 12 months into the future
Retrospective forecasts have been run for 1993-2024
Real-time forecasts will commence in late 2026 / early 2027

Step 1: Collate Relevant Covariates

Biological

- 2-yr lagged recruitment
- Mean age and length of EPO fleet catch in previous year

Socio-economic

- Albacore price in the previous month
- Fuel cost in the previous month
- Cumulative landings of dungeness crab, groundfish, salmon, & shrimp

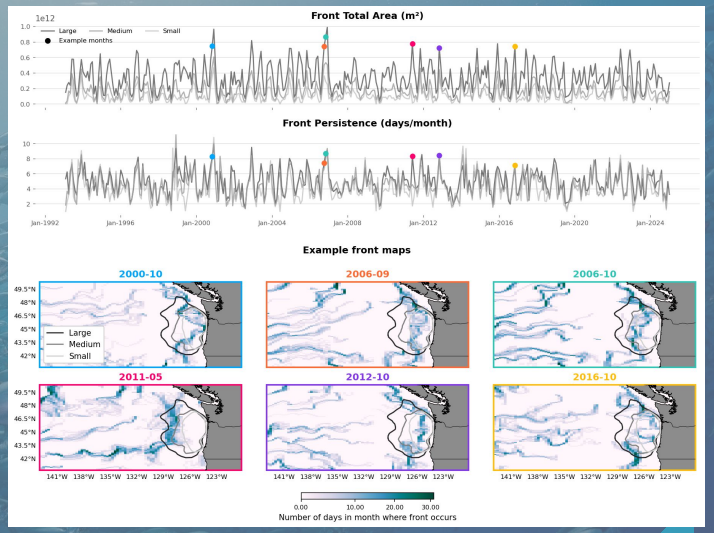
Environmental

- SST & Chlorophyll (mean and variability)
- Wind Speed
- Transition zone latitude (Jan-Mar)
- **NEW Frontal Metrics:** SST & Chl fronts

New Fronts Indicators Tailored to Albacore Fishing Grounds

New indices

Metrics to describe the average extent, strength, and persistence of fronts based on MOM6 SST and chlorophyll, for small, medium, and large fishing vessel footprints.



Step 2: Develop Preliminary Forecasting Model and Skill Metrics

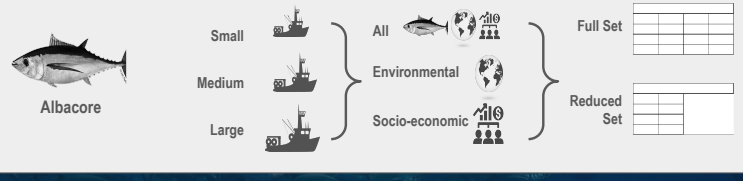
Monthly CPUE Forecasting

Utilizing **Random Forest** algorithms

Model evaluated first under known environmental conditions to establish what prediction skill exists

Prediction **skill evaluated on out of sample forecasts** for 2017-2024 (model trained from 2009 up to year being forecasted)

How do variable types and selection affect forecasting?

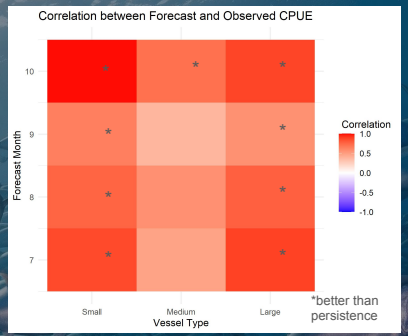


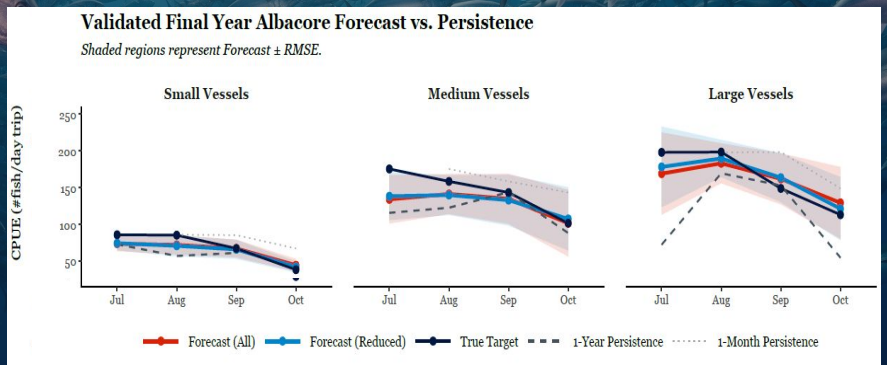
Step 2: Develop Preliminary Forecasting Model and Skill Metrics

Example Forecast

Split by vessel size as different fishing footprint and behaviour

Prediction **skill evaluated against persistence** (CPUE value observed in previous month or year)





Step 2: Develop Preliminary Forecasting Model and Skill Metrics

Example Categorical Forecast

Above Average

Average

Below Average

HEIDKE SKILL SCORE - Fractional improvement over random forecast
0 or less = no better than chance
1 = perfect score

	Small Vessels
Jul	1
Aug	0
Sep	0.6
Oct	1

Month		2017	2018	2019	2020	2021	2022	2023	2024
Oct	Forecast	✔	✔	✔	✔	✔	✔	NA	✔
	Observed							NA	
Sep	Forecast	✔		✔				✔	✔
	Observed								
Aug	Forecast				✔	✔			✔
	Observed								
Jul	Forecast	✔	✔	✔	✔	✔	✔	✔	
	Observed								

✔ Matches observation

Step 3: Refine Forecast Product with Stakeholder Input
What would be most useful?

Forecast Options

- Simple “Good” or “Bad” fishing season outlooks
- Stoplight: above, average, below
- Estimated CPUE + uncertainty
- Chance of extreme events (unusually low CPUE)
- Make-or-Break thresholds

Other Information

- Forecast maps of:
  - Ocean temperature
  - Front formation
- Summaries of previous year’s fishing
- Others?

Step 3: Refine Forecast Product with Stakeholder Input

Optimal Lead Time & Planning

Determining the optimal window for actionable insights.

- When does season planning typically begin?
- What is the ideal forecast lead time for operations?

Pre-Season vs. In-Season

Assessing the utility of full-season outlooks vs. in season updates.

- Is a pre-season overview of the entire season useful?
- Preference for month-by-month granularity?

Other

- For forecast of CPUE what amount of forecast error matters to you?
  - E.g. Forecast ± 10 vs 100 fish
- Interest in forecasting other specific metrics, e.g. albacore start-of-season?

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Thank You

NOAA FISHERIES

UC SANTA CRUZ

FISHERIES COLLABORATIVE PROGRAM
UC SANTA CRUZ – NOAA FISHERIES

CEFI
Changing Ecosystems
and
Fisheries Initiative

Thank you!

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NOAA FISHERIES

APPENDIX IV

Check for updates

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ORIGINAL ARTICLE

FISH and FISHERIES WILEY

Changes to the structure and function of an albacore fishery reveal shifting social-ecological realities for Pacific Northwest fishermen

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Abstract

Marine fisheries around the globe are increasingly exposed to external drivers of social and ecological change. Though diversification and flexibility have historically helped marine resource users negotiate risk and adversity, much of modern fisheries management treats fishermen as specialists using specific gear types to target specific species. Here, we describe the evolution of harvest portfolios amongst Pacific Northwest fishermen over 35+ years with explicit attention to changes in the structure and function of the albacore (*Thunnus alalunga*, Scombridae) troll and pole-and-line fishery. Our analysis indicates that recent social–ecological changes have had heterogenous impacts upon the livelihood strategies favoured by different segments of regional fishing fleets. As ecological change and regulatory reform have restricted access to a number of fisheries, many of the regional small (<45 ft) and medium (45–60 ft) boat fishermen who continue to pursue diverse livelihood strategies have increasingly relied upon the ability to opportunistically target albacore in coastal waters while retaining more of the value generated by such catch. In contrast, large vessels (>60 ft) targeting albacore are more specialized now than previously observed, even as participation in multiple fisheries has become increasingly common for this size class. In describing divergent trajectories associated with the albacore fishery, one of the US West Coast's last open-access fisheries, we highlight the diverse strategies and mechanisms utilized to sustain fisheries livelihoods in the modern era while arguing that alternative approaches to management and licensing may be required to maintain the viability of small-scale fishing operations worldwide moving forward.

KEYWORDS

albacore tuna, ecosystem-based fisheries management, fisheries diversification, harvest portfolios, small-scale fisheries, social-ecological systems

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1 | INTRODUCTION

Fisheries are increasingly recognized as complex and adaptive social–ecological systems (SES) (Perry et al., 2011; Pikitch et al., 2004) in which the exploitation of marine resources is driven by human interactions with dynamic environmental and socioeconomic conditions. Those dependent on fisheries resources must continuously adapt to external drivers of change that impact the structure and function of the SES in which they are embedded. Just as the ability of fishing communities to adapt to change is a fundamental part of the culture and ethos that has enabled their long-term persistence (Oestreich et al., 2019), the capacity of SES to reorganize while maintaining their essential attributes (often referred to as "resilience") is a core concept that underlies much of modern sustainability science (Folke et al., 2010). Though researchers and policy makers have recognized the need to move beyond single-species perspectives in pursuit of holistic and adaptive fisheries management strategies (Fogarty, 2014; Marshall et al., 2018), related discourse has focused predominantly on ecological food webs while ignoring the social–ecological linkages and feedbacks informing how fishers participate and shift effort amongst fisheries (Fuller et al., 2017; Kroetz et al., 2019).

Knowledge of how people operate in a fishery system can provide insight into how that system works (Salas & Gaertner, 2004). Yet most fisheries management plans, as mandated by legislation, continue to be based upon consideration of a narrow suite of technical parameters (Battista et al., 2018). Where acknowledgement of the human dimensions of marine resource systems does exist, fishers are often treated as uniform elements with little consideration of heterogeneity in goals, strategies and scales of operation (Fulton et al., 2011; Salas & Gaertner, 2004). Rather than existing as specialists, using specific gear types to target specific species, many fishers participate in multiple fisheries within and between years (Addicott et al., 2019). Decisions concerning how to allocate fishing effort are made in response to changes in species abundance and distribution (Cline et al., 2017; Finkbeiner, 2015), shifting regulations (Holland & Kasperski, 2016; Kroetz et al., 2019; Stoll et al., 2016) and market drivers (Kininmonth et al., 2017). A failure to acknowledge the complex SES interactions driving the dynamic, multi-species, multi-gear reality of most fisheries systems has resulted in a focus on discrete biological and economic objectives rather than sustainable development (Pascoe et al., 2014) and has limited the scope and effectiveness of many management approaches to-date (Cunningham et al., 2016; Fuller et al., 2017; Gaertner et al., 1999).

With marine social–ecological systems increasingly exposed to external threats and pressures (Kittinger et al., 2013), researchers have argued that diverse and flexible livelihood strategies are needed to sustain natural resource-dependent individuals and communities (Allison & Ellis, 2001; Cline et al., 2017). At sea, novel environmental conditions, driven by both long-term trends and extreme events, have disrupted historical patterns and processes (Pershing et al., 2019) while on land international institutions and seafood markets have exposed resource users to the pressures and priorities of distant actors and political systems (Crona et al., 2016; Frawley, Finkbeiner et al., 2019). Across North American fisheries, diverse harvesting portfolios are recognized as means of reducing exposure to such processes and for mitigating risk and uncertainty (Cline et al., 2017; Finkbeiner, 2015; Frawley, Crowder et al., 2019; Kasperski & Holland, 2013). However, many fishers are reliant on fewer species now than ever before (Holland & Kasperski, 2016; Stoll et al., 2016). As markets offer economic incentives to focus on particular local stocks (Anderson et al., 2017), modern management and licensing regimes have functioned to restrict resource access and limit fishing effort (Mansfield, 2004).

Here, we synthesize 35+ years of vessel-level landings data for Oregon and Washington in order to assess longitudinal changes impacting the fishery system with particular attention to the trajectory

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of the US North Pacific albacore troll and pole-and-line fishery. By grounding our findings in parallel analyses of diverse quantitative (fisheries logbooks, landings and vessel registration databases) and qualitative (fishermen interviews and focus group discussions) data sources, we (a) identify ecological and socioeconomic drivers of change relevant to the SES; (b) evaluate their impacts upon the livelihood strategies and harvest portfolios of diverse user groups; and (c) describe the processes and feedbacks mediating heterogeneous adaptive responses. This analysis is one of the most holistic and comprehensive investigations to date of fisheries connectivity across the Pacific Northwest and emphasizes that over the past several decades processes of social and ecological change impacting marine SES have been rapid, intense and intertwined.

2 | STUDY SYSTEM

The US West Coast fishery system is characterized by its high levels of diversity, productivity and variability. The coastal currents and wind-driven upwelling that fuel productivity in surface waters are mediated by seasonal cycles and are acutely impacted by interannual climate oscillations like the El Niño-Southern Oscillation and the Pacific Decadal Oscillation (Jacox et al., 2015). In order to adjust to the fluctuations of individual fisheries, many fishers across California, Oregon and Washington have historically targeted diverse species assemblages (Aguilera et al., 2015; Holland & Kasperski, 2016; Kasperski & Holland, 2013). However, in response to concerns surrounding declines in landings and revenue within the historically productive salmon and groundfish sectors, management authorities first began to restrict fisheries access in the 1970s and 80s by capping the absolute number of licenses and establishing gear restrictions (Holland & Kasperski, 2016; Richerson & Holland, 2017; Warlick et al., 2018). With the development of catch shares and other quota-based management systems (often referred to as "fisheries rationalization") across the United States in the mid- to late 90s (Mansfield, 2004; Olson, 2011) efforts to privatize fisheries continued to gain traction and many inactive or part-time fishermen were limited to small amounts of catch or gear of limited productivity (Kasperski & Holland, 2013).

As other fisheries have become increasingly restricted, the US albacore troll and pole-and-line fishery has remained open access. North Pacific albacore is a highly migratory species whose range spans the entire North Pacific Basin. Like many other tuna stocks that utilize the high seas and migrate between the jurisdictions of multiple states, North Pacific albacore are managed by Regional Fisheries Management Organizations (RFMOs) which share data, monitor effort and establish compliance criteria (Nikolic et al., 2017; Seto et al., 2020). After spawning and early development in the tropical and subtropical waters of the western and central Pacific (Chen et al., 2010), juvenile fish undertake transpacific migrations with many entering the productive coastal waters of the California Current to feed (Childers et al., 2011; Ichinokawa et al., 2008). Albacore distribution and migratory movements are strongly influenced by regional oceanographic processes (Laurs & Lynn, 1977; Muhling et al., 2019; Nieto et al., 2017; Xu et al., 2017), and the availability of albacore to US West Coast fishing fleets may vary substantially from year to year. On average, US vessels using surface gears account for ~17% of the total annual catch of albacore in the Northern Pacific, with the adjacent Canadian surface fleet reporting <10% and Japanese pole-and-line and longline vessels in the Western and Central Pacific landing the vast majority (ISC, 2017). Though RFMO members have agreed not to increase effort above levels observed in the early 2000s, there are currently no limits on the catch of albacore in the North Pacific (Nikolic et al., 2017).

Throughout the 100+ years of the US albacore fishery's existence, water temperature has influenced the latitude at which fish enter coastal waters and become accessible to West Coast fishermen (Clemens & Craig, 1965; Phillips et al., 2014). The location and extent of fishing grounds for albacore in this region, and other ocean basins in which it is found, are believed to be influenced by the climate regimes and interannual oceanic oscillations mediating local surface features and forage communities (Chavez et al., 2003; Phillips et al., 2014). During the fishery's initial development and expansion, albacore helped support one of the world's largest tuna canning industries in southern California as the most productive fishing grounds were located between Baja California and the Columbia River (Clemens & Craig, 1965). In recent decades, fishery operations have been concentrated off Oregon and Washington, with periodic expansions as far north as British Columbia and Alaska (Christian & Holmes, 2016). Though US landings have declined significantly following a post-World War II peak of 33,707 mt in 1950 (Clemens & Craig, 1965), the North Pacific albacore stock was considered healthy as of 2017 (ISC, 2017). Troll and pole-and-line fishers targeting the stock have been lauded for their use of sustainable and selective gear types and the US West Coast albacore fishery has been Marine Stewardship Council certified since 2007 (Blythe-Skyrme et al., 2012a).

3 | METHODS

We relied on methodological triangulation (Olsen, 2004) to achieve our research objectives, using mixed methods from the natural and social sciences in order to integrate quantitative analyses of diverse fisheries dependent data sources with qualitative data from fishermen interviews and focus group discussions. Triangulation approaches provide an opportunity to deepen, widen and contextualize scientific understanding of study systems (Angelstam et al., 2013; Bennett et al., 2017) and can help ensure the validity of results when studying marine fisheries and other complex systems with both social and ecological domains (Mason et al., 2019; Whitney et al., 2017).

3.1 | Semi-structured interviews and focus group discussions

Qualitative data obtained from semi-structured interviews and focus group discussions were used to identify research questions,

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generate hypotheses and validate research results. Semi-structured interviews (Bernard, 2017), carried out over the phone ($n = 15$) and in person ($n = 7$) between 2017 and 2019, were designed to explore social–ecological drivers of change impacting the US West Coast albacore fishery. Informants included 19 active or recently active albacore fishermen and 3 individuals representing industry organizations. Initial informants were identified through contact information listed in the 2017 US-Canada Albacore Treaty Agreement, and subsequent respondents were identified through referrals (i.e. snowball sampling; Goodman, 1961). With permission, all phone interviews were digitally recorded and transcribed verbatim. Data collected during in-person interviews were limited to field notes in order to establish rapport and facilitate the exploration of sensitive topics (Rubin & Rubin, 2011). Field notes and anonymized interview transcripts were imported into NVivo qualitative data analysis software and inductively coded using a grounded theory approach to identify emergent themes (Bernard, 2017; Glaser & Strauss, 1967) and generate hypotheses which could be tested using quantitative data. Focus group discussions were held during a stakeholder workshop at the project's outset (NOAA/National Marine Fisheries Service (NMFS) Future Seas Workshop, Focus Group 1, 06/2018) and following the presentation of preliminary research findings to management authorities (Oregon Department of Fish and Wildlife, Focus Group 2, 11/2019; Pacific Fisheries Management Council (PFMC) High Migratory Species Advisory Subpanel and Management Team, Focus Group 3, 11/2019) and industry organizations (Oregon Albacore Commission, Focus Group 4, 11/2019). These focus group discussions were used to guide the analysis and to identify and resolve contradictory research findings (Nyumba et al., 2018; Rubin & Rubin, 2011).

3.2 | Vessel landings, effort, and price data

Fishery dependent data were used to describe historical changes in albacore fishery landings and effort in addition to patterns and processes impacting the US West Coast fishery system at large. Fishery landings and effort data were obtained from 3 distinct sources: (a) Catch information reported at the level of individual vessels and fishing trips (1981–2018) via a landings receipt (i.e. "trip ticket") database maintained by the Pacific Fisheries Information Network (PacFIN). These confidential data included the weight (in pounds) and price (in dollars per pound) of all species landed during all fishing trips but, due to differences in protocols related to data sharing and access, were limited to landings made in Oregon and Washington; (b) US West Coast, non-confidential annual albacore landings (mt) and effort (# of boats) data (1981–2018) aggregated annually at the state level, including California, by PacFIN; (c) Confidential and spatially explicit albacore troll and pole-and-line logbook data recorded daily (1974–2016) for US West Coast and Hawaii fishing vessels provided by NMFS. Though the percentage of active fishing vessels participating in the logbook program has varied over time, we do not believe that there is any systematic reporting bias that would have impacted the relative patterns reported in our analyses (J. Childers, personal communication). To summarize changes in Catch Per Unit Effort (CPUE) across space and time, catch (# of fish kept) and effort (fishing hours) were aggregated annually by 1° × 1° grid cell using the "raster" v2.8 package in R (Hijmans & van Etten, 2016) and averaged across each decade. For each decade, we calculated the geographic centroid of CPUE and its dispersion (i.e. inertia) around the centroid, with dispersion calculated as the mean square distance between individual CPUEs and the centroid CPUE (Bez & Rivoirard, 2000; Carroll et al., 2019; Woillez et al., 2007).

3.3 | Fleet characterization

Descriptive vessel information (e.g. length, registration zip code) used to characterize different segments of the fishing fleet was assigned using multiple data sources. First, using the United States Coast Guard (USCG) vessel identification number, we generated a list of unique vessels from our database of landings receipts ($n = 14{,}601$ vessels). Then, we sequentially joined this list to descriptive vessel information obtained from a current registry of Merchant Vessels of the United States (USCG), the NMFS logbook database and the PacFIN landings receipt database. In instances where multiple lengths were reported, priority was given to (a) records maintained by the USCG and (b) the most frequent self-reported values in the NMFS and PacFIN databases. Vessel size classes were demarcated at 45 and 60 ft so that small vessels were those <45 ft, medium vessels were ≥45 ft and ≤60 ft, and large vessels were >60 ft. These cut-off values were informed by previous characterizations of the albacore troll fishery (Blythe-Skyrme et al., 2012a) and other US West Coast Fisheries (PSMFC, 2000) that described heterogeneity in operations by vessel size class, and were selected based upon approximately equal contributions to total fisheries revenue over the study period (small = 30.2%, medium = 31.7%, large = 37.9%). Owner residence (by US State) was assigned based on the "vessel owner address" zip code associated with each landings receipt. A residence state was assigned to each vessel in each year in order to account for cases where vessel ownership changed hands. In the case where multiple zip codes were associated with a given vessel in a given year, we choose the zip code most frequently reported. Using this method, 92.5% of all vessels reporting landings in OR or WA were associated with owners residing in one of those two states while 5.4% were associated with CA residences and 1.9% were associated with AK residences. To minimize the confounding effects of landings made by external vessels, only landings records associated with boats registered in Oregon or Washington were included in our analysis.

To characterize the distribution of vessel size classes for vessels participating in the albacore fishery across decades and hailing ports for the entire West Coast, we identified and characterized the unique list of vessels reporting albacore troll and/or pole-and-line landings in NMFS logbooks (our only vessel-level data source that was not geographically constrained) during each time period. Hailing ports during the most recent decade (2010–2016) were identified

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by joining our list of active vessels to current registries maintained by the USCG and Inter-American Tropical Tuna Commission (IATTC), enabling us to obtain descriptive information for 84.8% of the active vessels. It is important to note that vessels are frequently registered in ports distant from the town or state where the vessel owner resides. Differences in vessel lengths amongst states (WA,OR,CA) and hailing ports were assessed for significance using ANOVA and a Tukey Honest Significant Differences (HSD) post hoc test in the R "stats" package.

3.4 | Fisheries diversification, participation and connectivity

To evaluate changes in fisheries diversification, participation and connectivity, we first defined fisheries as harvest assemblages caught with specific gear types (Deporte et al., 2012). We assigned a single fishery (sometimes referred to as a "fishing métier") to each individual landings receipt in our database (n = 2,513,966) based on the dominant (as inferred by revenue) combination of landed species assemblage and fishing gear utilized. In order to minimize the number of unique combinations, species assemblages and gear types were aggregated at the "Management Group" and "Gear Group" level (as determined by PacFIN). Prior to final métier assignment, we modified our classification scheme and naming conventions to be consistent with those US West Coast fisheries previously identified and described using a multivariate clustering algorithm (Fuller et al., 2017). More information concerning the relative proportion of individual species and gears comprising each identified fishing métier can be found in Table S1. Given challenges associated with identifying owners with multiple vessels, vessels with multiple owners and/or changes in vessel ownership over time (Fuller et al., 2017; Kasperski & Holland, 2013) our efforts to assess the metrics described below primarily concerned vessels (rather than individuals) operating on annual (rather than interannual) timescales.

3.4.1 | Diversification indices

Annual diversification was assessed for different segments of regional fishing fleets using the Effective Shannon Index (ESI) as described by Holland and Kasperski (2016). To facilitate comparison of our results with previous studies (Holland & Kasperski, 2016; Kasperski & Holland, 2013), we limited diversification analyses to vessels that earned more that $5,000 (adjusted for inflation) during any given year. Albacore fishing fleet segments were comprised of vessels with one or more landings dominated by albacore troll/pole-and-line gear each year. To examine changes in diversification over time and to evaluate significance, ANOVA and Tukey HSD tests were conducted with diversity values grouped by fleet segment and time period and the Mann–Whitney U test was used to assess directionality between groups of interest.

3.4.2 | Fisheries participation networks

Changes in fisheries participation and connectivity over time were evaluated by generating annual "fisheries participation networks," (Fuller et al., 2017) in which individual nodes (i.e. fisheries) are connected by participating fishing vessels. In order to facilitate aggregation and comparison using descriptive statistics and network theoretic metrics, network size was standardized (Cinner & Bodin, 2010) with annual networks composed of the subset of fisheries records including the 15 most productive fisheries (i.e. nodes) by revenue across the Pacific Northwest (defined here as Oregon and Washington) each year. This cut-off point was selected to constrain the analysis to landings records representing >97% of total ex-vessel value for each subset and to maintain confidentiality for fisheries in which fewer than three vessels participated. A vessel was deemed to participate in a fishery if it earned more than 20% of its annual income from that fishery (see Section 4.3 for sensitivity). The edge weight of the linkages connecting fisheries nodes in each participation network was calculated as the number of vessels participating in both fisheries in a given year normalized by the total number of active fishing vessels reporting commercial landings during that year.

In order to assess the changes to participation network structure and the role of individual fisheries over time, we used several network metrics and node-level centrality measures. Node-level centrality measures identify fisheries of high importance, meaning those that most vessels participate in and obtain revenue from at some point during the year (Fuller et al., 2017). For each network, node strength was calculated as the sum of all edge weights connected to a given node while betweenness centrality was calculated as the number of shortest paths running through each node (Barthelemy, 2004). In fisheries participation networks, fisheries with larger node strength have more connections to other fisheries in the network and/or are part of groups of fisheries with strong shared participation; fisheries with larger betweenness centrality are most important in the overall ability of fishers to redistribute their effort (Fuller et al., 2017). At the network-level used to assess aggregate patterns of fisheries connectivity, network edge density measured the proportion of links in a network that are present in relation to the maximum number of possible links. While edge density is a useful metric for describing interconnectedness, it does not account for the number of vessels driving these connections (Addicott et al., 2019). To assess weighted network connectivity, we relied on average node strength (sometimes referred to as average weighted degree centrality, see Kroetz et al., 2019 and Yletyinen et al., 2018) and average edge weights calculations.

Network maps used to synthesize quantitative information concerning harvest portfolio diversity, composition and structure (Cinner & Bodin, 2010) were created by averaging annual networks across comparison periods (i.e. decades) of interest. To standardize the nodes included, annual networks used to construct network maps were composed of the 15 most productive fisheries across each time period rather than each year. To evaluate the significance

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and directionality of changes in network properties between decades of interest, we used the Mann–Whitney U test.

4 | RESULTS

4.1 | Decadal shifts in albacore distribution and fleet dynamics

The distribution of West Coast albacore fishery landings and effort has been highly variable across space and time (Figure 1). During the 1970s, the fishery was distributed in coastal waters from British Columbia to Baja California, with the majority of the fleet based out of Southern California (Focus Group 1). In the 1980s, the fishery began to shift offshore as its latitudinal range contracted. By the 1990s, the most productive fishing grounds were near 210° longitude (>1,500 km from shore) and substantial, additional fishing effort was reported as far West as the international dateline. With fishery operations concentrated on the high seas, several carrier and transport vessels were employed so that fishing vessels could maximize their time on productive fishing grounds, periodically offloading catch and taking on fuel (Interview 16). In the 2000s, as offshore catch declined, the longitudinal distribution of effort contracted and in most recent years (2010–2016) fishery effort has once again been concentrated in coastal waters, now in a localized area proximate to Oregon and Washington. The latitudinal range of CPUE during this time period (2010–2016) was significantly smaller than the long-term average (1974–2009; mean difference of 22°; $F_{(1,43)}$=13, $p < .0001$; Figure 1). Though increasing fuel prices have further incentivized range-restricted fishing operations in recent years, fishermen interviews (Interviews 3, 7, 13) support the notion that these trends were driven by a real though poorly understood shift in resource abundance: "For whatever reason, the fish in recent years seem to be not distributed over as big an area," (Interview 3).

Spatial shifts in CPUE have had asymmetric impacts on the different components of the albacore fishing fleet. In the late 1970s, the fleet was dominated by small- and medium-sized vessels, which collectively reported 85% of the total catch (Figure 2). Landings crested at ~23,000 mt in 1972 as over 2,000 fishing vessels were active (Focus Group 3). When the fishery moved offshore, the relative proportion of large boats participating in the fishery increased alongside their share of landings. The total number of active vessels dropped to a minimum of 179 in 1991 (landing a total of 1654 mt) before rebounding to 837 vessels in 1998 (12,628 mt) with the establishment of high seas operations (Figure 3). Between 1995 and 2015, West Coast albacore landings were remarkably consistent with the fleet averaging 12,083 mt/year (±*SD* 2,091 mt) despite the onshore shift of the early 2000s and progressive declines in fishing effort (Figure 3). In later years (2010–2016), the relative proportion of small- and medium-sized vessels comprising the albacore fleet (annual average = 644.71 ± 82.61 vessels), and their share of the catch, again increased as albacore in coastal waters could once again be opportunistically targeted (Interviews 2, 10). Though recent (2017–2019) logbook data are not yet available, landings data indicate that recent catches have fallen by ~40% as compared to the 1995–2015 average with 7,467 mt landed in 2017 (495 vessels), 6,950 mt landed in 2018 (434 vessels) and 7,200 mt in 2019 (471 vessels).

Albacore catches in Pacific Northwest coastal waters increased substantially between 2000 and 2016, yet the harvest reliant upon nearshore waters off Southern California failed to re-establish. Since

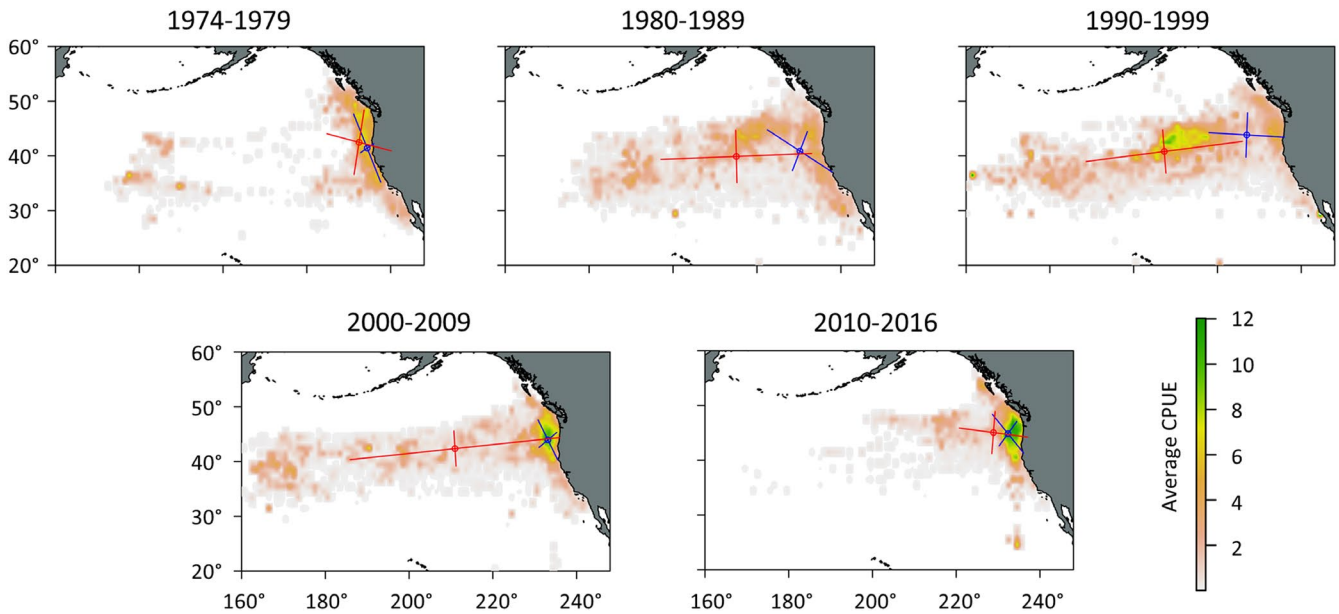


FIGURE 1 North Pacific albacore catch per unit effort (total fish/total hours aggregated by 1° × 1° degree grid cells) averaged across each decade, as reported in US troll and pole-and-line albacore fleet logbooks. Centre of gravity and inertia of small (blue; <45 ft) and large (red; >60 ft) vessel fishing effort are shown for each decade. Figure appears in colour in the online version only [Colour figure can be viewed at wileyonlinelibrary.com]

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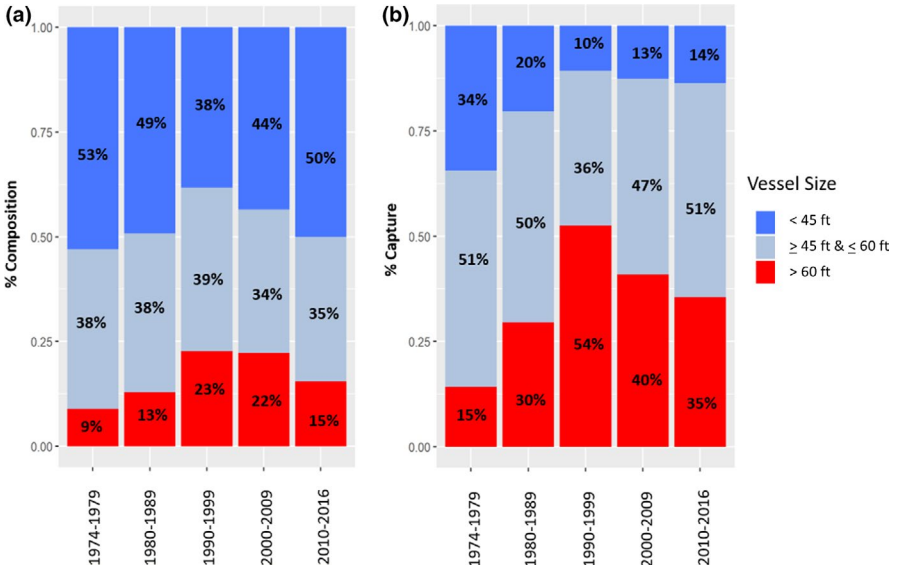


FIGURE 2 Contribution (by decade) of vessel size classes to (a) the composition of the US albacore troll and pole-and-line fleet across the entire US West Coast and (b) the capture of albacore (as inferred by # of fish landed) by this fleet. Due to a high attrition in effort across the study period, values have been normalized (reported by specified size class/reported by all size classes) prior to plotting. Data were sourced from NMFS logbooks. Figure appears in colour in the online version only [Colour figure can be viewed at wileyonlinelibrary.com]

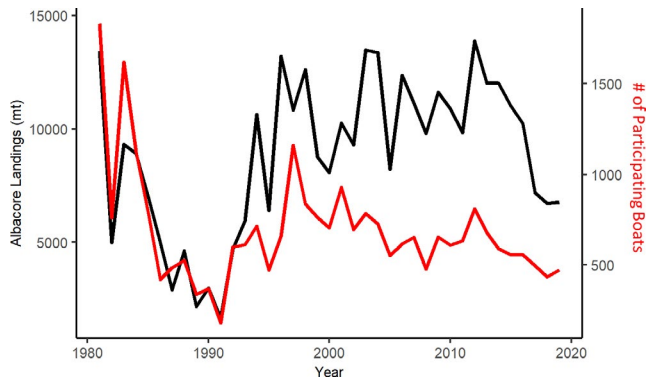


FIGURE 3 Time series of total US West Coast North Pacific albacore troll and pole-and-line fishery landings (black) and effort (red). Data were sourced from non-confidential PACFIN records. Figure appears in colour in the online version only [Colour figure can be viewed at wileyonlinelibrary.com]

the 1980s, both the annual landed weight of albacore (Figure S1A) and the number of vessels reporting albacore landings in California (Figure S1B) have declined precipitously while the opposite has been true in Oregon and Washington. Many albacore fishermen previously based in Southern California have retired from the fishery or established permanent residence in Oregon or Washington. Those continuing to target albacore and port their vessels in Southern California now relocate seasonally to the northern fishing grounds each summer and land their catch in Oregon and Washington ports (Interviews 3, 16). Active Southern California-ported vessels are significantly larger than those found in either Oregon or Washington ($p < .05$), primarily driven by large vessels ported in San Diego ($p < .01$; Figure 4; Table S2). While owner–operators remain ubiquitous across the PNW, a number of the large albacore fishing vessels ported in Southern California are managed via corporate ownership structures (Interviews 17, 20, 21).

4.2 | Changes in real value of landed albacore over time

Available evidence suggests that the real value (adjusted for inflation using 2005 as a base) of landed albacore has increased over the past decade as relative abundance has increased in waters offshore Oregon and Washington. Throughout the early history of the fishery, fishermen sold albacore almost exclusively to 3 major companies (Starkist, Chicken of the Sea, and Bumblebee) operating canneries in Southern California in what was frequently referred to as a monopolistic market (Interviews 4, 12, and 14). In the late 1990s, these companies began sourcing tuna from foreign fleets at lower price points and US fishermen were forced to identify and develop new markets (Morrissey, 2008). Non-profit organizations funded by the industry (e.g. the Western Fishboat Owners Association and the American Albacore Fishing Association) have leveraged sustainable seafood certifications and promotional campaigns to reduce the fleet's dependence on the market for canned tuna (Interview 16, Focus Group 2). Alternatives now include local fresh fish markets and a market for sashimi-grade products that must be bled and blast-frozen at sea. As one fisherman reports, "now the market's totally changed and we have like 25–30 separate buyers looking for different quantities and grades," (Interview 12). Analysis of changes in the dock price paid to fishermen in Oregon and Washington since the 1990s (Figure 5) reflect this recent product differentiation. We found a significant increase in the annual variability of price per pound paid to albacore fishing vessels over time (Mann–Kendall trend test, $p < .01$), while significant increases in the price per pound (Mann–Whitney U test, $p < .001$) were reported during the most recent decade (2010–2018) compared to previous decades. Such trends were most pronounced amongst large-sized vessels (Figure 5), who are more likely to be engaged in the lucrative, though volatile, blast-frozen markets (Interview 17, Focus Group 2).

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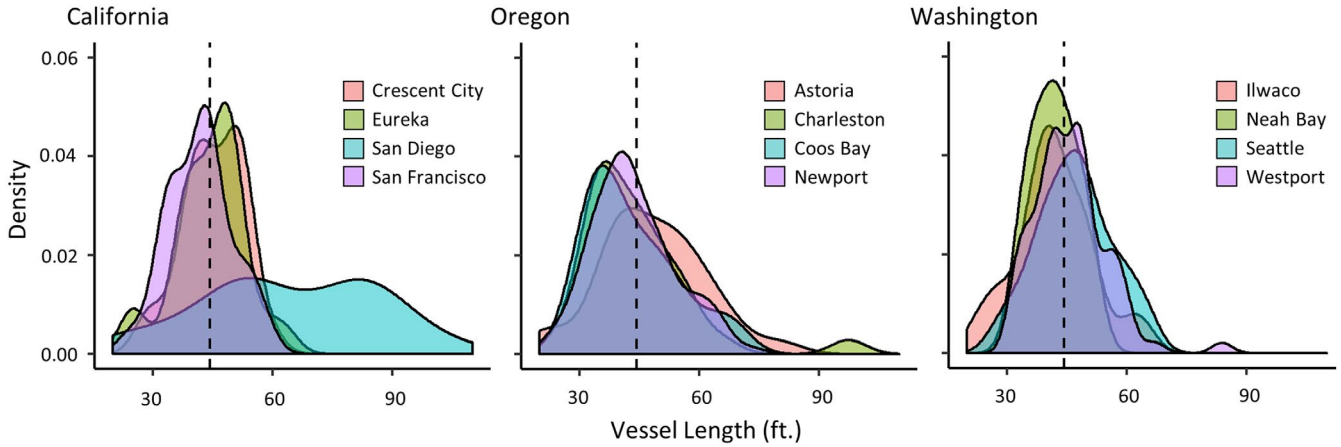
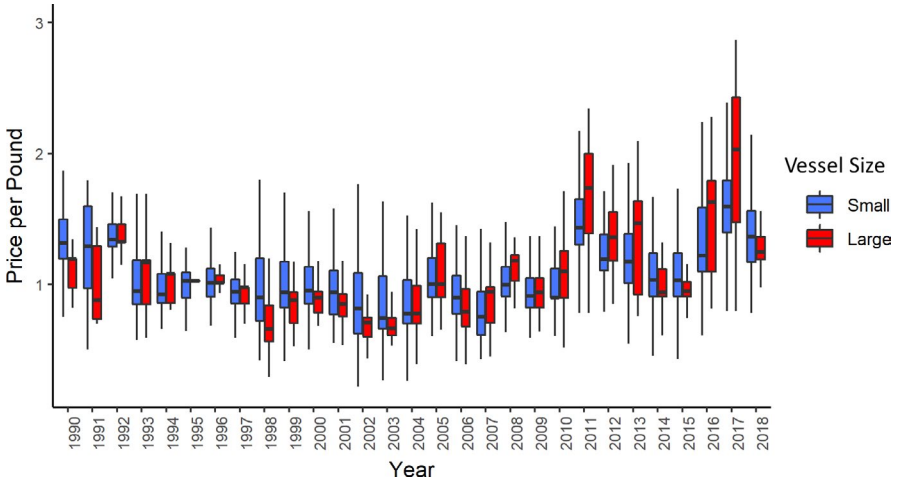


FIGURE 4 Density plots showing the distribution of vessels lengths of the troll and pole-and-line fishery (2010–2016, as inferred by NMFS logbook entries) by hailing port for the 4 ports with the most reported vessels in California ($n = 101$), Oregon ($n = 184$) and Washington ($n = 149$). The dashed line in each plot represents the mean vessel length (44.95 ± *SD* 13.69) across states and ports for vessels active in the North Pacific albacore fishery ($n = 839$). A two-way ANOVA indicates California has significantly larger vessels ($p < .05$), with post hoc analyses showing that vessel lengths in San Diego are significantly larger than all other ports shown ($p < .01$). Figure appears in colour in the online version only [Correction added on 2 December 2020, after first online publication: both Figure 4 and the caption have been updated] [Colour figure can be viewed at wileyonlinelibrary.com]

FIGURE 5 Box plot displaying the median values and distribution of data points for both small (<45 ft) and large (>60 ft vessels) of the price per pound (adjusted for inflation) for which albacore was sold to buyers in Oregon and Washington each year. Data were sourced from individual, confidential PACFIN landings receipts. Figure appears in colour in the online version only [Colour figure can be viewed at wileyonlinelibrary.com]



4.3 | Changes in regional fisheries participation and revenue diversification

The dominant signal in fisheries participation in Oregon and Washington during our study period was one of steady attrition. The number of total active fishing vessels (irrespective of gear type or target species) declined significantly ($p < .00001$) from 4,423 in 1981 to 1,427 in 2018, at a rate of −83.1 vessels/year (±*SE* 5.6). When considering vessel size classes separately, the largest decline was observed in the small vessel fleet (from 3,342 vessels in 1981 to 927 vessels in 2018; −68.8 vessels/year ± *SE* −13.4; $p < .00001$) as compared to medium (from 734 vessels in 1981 to 342 vessels in 2018; −9.4 vessels/year ± *SE* −0.6; $p < .00001$) and large (from 347 vessels in 1981 to 158 vessels in 2018; −4.8 vessels/year ± *SE* −0.4; $p < .00001$) vessels. During the same time period, the relative value of the albacore troll fishery increased substantially. Between 1981 and 1989, the albacore troll fishery was the 10th most important fishery by revenue accounting for an average of 2.6% (±*SD* 2.3%) of annual ex-vessel value in Oregon and Washington. By 2010–2018, it was the 3rd most important fishery, accounting for an average of 9.8% (±*SD* 2.1%) of ex-vessel value, trailing only the Dungeness crab (*Metacarcinus magister*, Cancridae) pot fishery (42.7% ± *SD* 8.9%) and the pink shrimp (*Pandalus jordani*, Pandalidae) trawl fishery (14.6% ± *SD* 7.5%). Increased accessibility of albacore in coastal waters (Figure 1) combined with an increase in the real value of landed albacore products (Figure 5) has resulted in an increase in the relative effort directed towards the fishery. Even as the total amount of active Pacific Northwest fishing vessels declined, the percentage of fishing vessels participating in the albacore fishery increased significantly ($p < .0001$; Figure 6).

Analysis of changes in revenue diversification over time reveals trajectories of change unique to PNW vessels participating in the albacore troll fishery (Figure 7). While revenue diversification has decreased in aggregate following a peak in the late 1990s and early 2000s (Figure 7a), there were no significant changes across decadal means amongst vessels participating in the albacore fishery (one-way ANOVA, $F_{(3,34)} = 0.63$, $p = .59$). These

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dynamics appear to be driven by the small vessels (Figure 7b) which comprise the vast majority of regional fishing fleets. During all decades, small albacore fishing vessels were significantly more diverse (Mann–Whitney *U* tests, $p < .00001$) than small vessels in aggregate and were able to maintain consistent levels of diversity over time (one-way ANOVA, $F_{(3,34)} = 0.31$, $p = .82$). In contrast, revenue diversity amongst the fleet segments composed of all medium (Figure 7c) and large-size (Figure 7d) vessels increased during the initial portion of the study period prior to stabilizing in more recent decades. Medium albacore fishing vessels were more diverse than their size class as a whole during the initial (1980–89; $p < .05$) and final (2010–2018; $p < .01$) decades. In contrast to small- and medium-sized albacore fishing vessels, large albacore fishing vessels became less diverse and more specialized than their size class overall as time progressed.

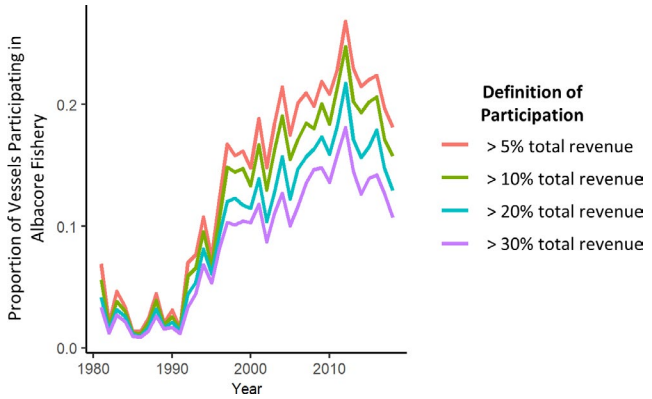


FIGURE 6 Time series depicting changes in the proportion of active PNW fishing vessels participating in the North Pacific albacore troll and pole-and-line fishery over time. Figure appears in colour in the online version only [Colour figure can be viewed at wileyonlinelibrary.com]

4.4 | Changes in social–ecological system structure and albacore fishery function

Network metrics reveal substantial changes to the function of the albacore fishery in the PNW and the structure of the broader social–ecological system that are not captured by revenue diversification statistics alone. Though average annual revenue diversification was not significantly different during 1990–1999 as compared to 2010–2018 (Tukey HSD test; $p = .74$), an examination of aggregated (i.e. all vessels) fisheries participation networks indicates that albacore has become an increasingly central component of regional harvest portfolios (Figure 8).

Network density metrics show that cross-fishery participation was higher but less uniform in 2010–2018 as compared to 1990–1999. Without incorporating edge weights (i.e. the number of vessels connecting two fisheries), annual networks were significantly less dense ($p < .05$) in 2010–2018 than they were in 1990–1999 (0.26 ± *SD* 0.19 vs. 0.38 ± *SD* 0.05). This describes a decrease in the number of potential connections between fisheries realized in the most recent decade. Yet average node strength, a metric that incorporates edge weights, suggests that cross-fishery participation increased significantly when comparing the same two time periods (0.025 ± *SD* 0.004 for 1990–1999 vs. 0.32 ± 0.002 for 2010–2018; $p < .05$). This increase was accompanied by a significantly larger variance in edge weights (Fligner–Killeen test, $p < .05$), as the links connecting certain pairs of fisheries grew stronger. Qualitatively, edge weights appear less uniform in recent years with the links between the albacore troll, chinook troll and Dungeness crab pot fisheries becoming more dominant (Figure 8). The strength of the connections between these 3 fisheries was referenced repeatedly by our informants (Interviews 14, 13, 10, 5). Though participation in more than one fishery may be increasingly common amongst Pacific Northwest fishermen, our analysis suggests that the suite of different fisheries which support diversification has been reduced.

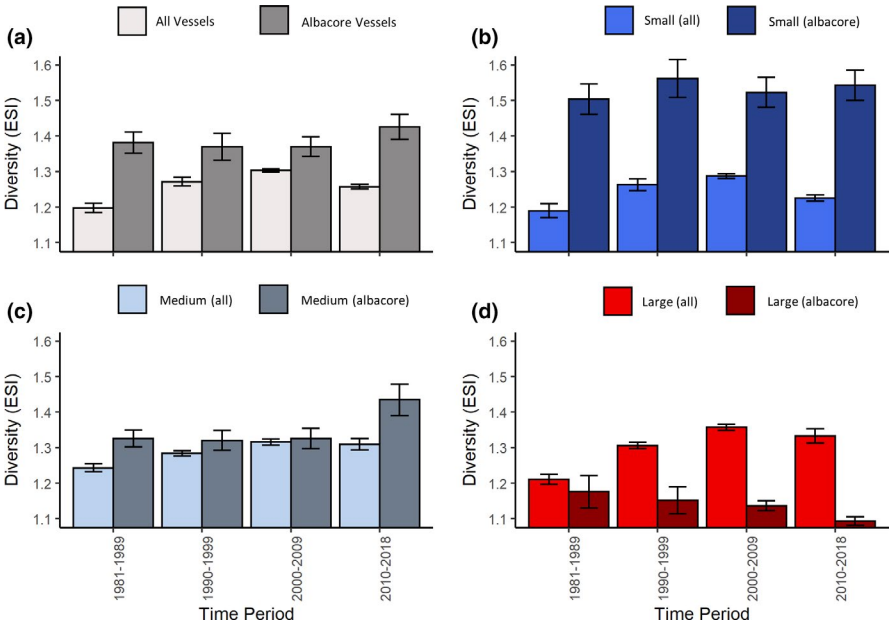


FIGURE 7 Changes in annual revenue diversification over time (as grouped by decade) for different vessel size classes. In each panel, revenue diversification is assessed for the all vessels in the specified size class and only vessels of the specified size class reporting landings dominated by troll or pole-and-line caught albacore tuna. Figure appears in colour in the online version only [Colour figure can be viewed at wileyonlinelibrary.com]

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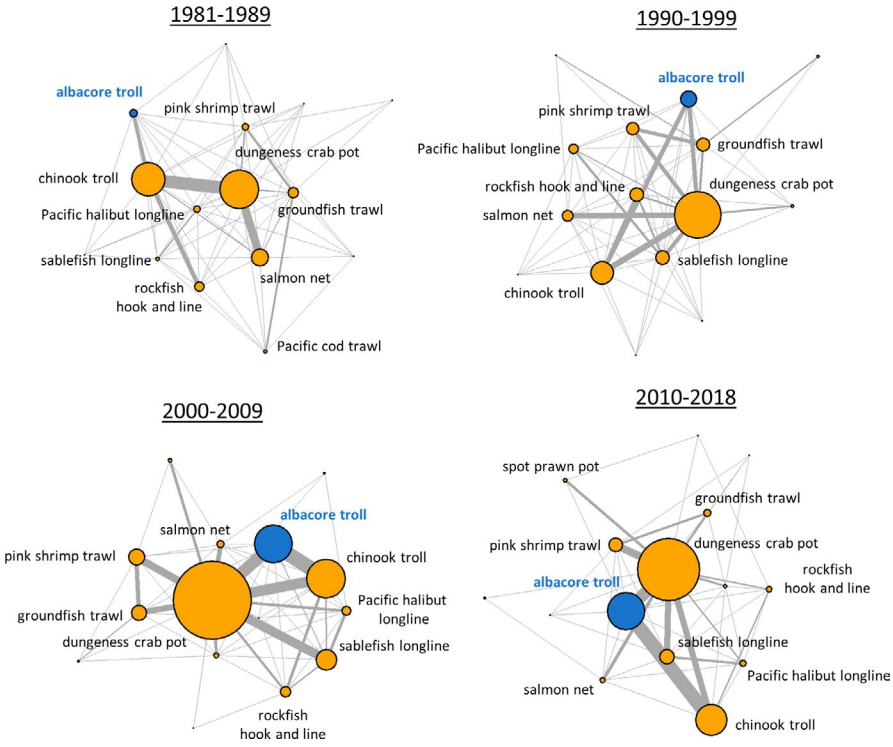


FIGURE 8 Summary networks for comparison decades of interest. Node size and edge weight thickness in each summary network represent averages across all annual networks in the time spans specified. For each annual network, edge weight thickness was determined as the number of active vessels participating (earning >20% of total fisheries revenue) in each pair of fisheries normalized by the total number of active vessels across all fisheries while node size was determined by node strength. Figure appears in colour in the online version only [Colour figure can be viewed at wileyonlinelibrary.com]

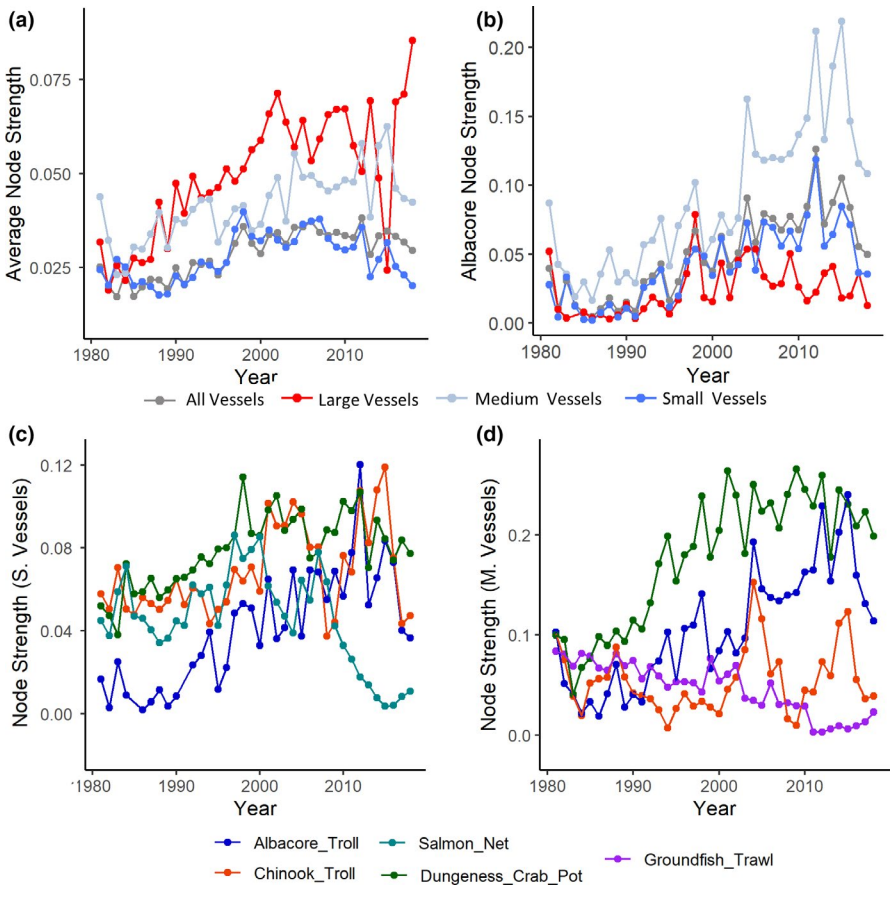


FIGURE 9 Time series depicting changes in fisheries participation network structure and the strength of component nodes as related to vessel size class. (a) Changes in average annual node strength ($n = 15$) for networks composed exclusively of all, small-, medium- and large-sized vessels. (b) Changes in the node strength of the albacore troll fishery over time for networks composed exclusively of all, small-, medium- and large-sized vessels. (c) Changes in node strength for the 4 most variable fisheries (throughout the entire time series) across networks composed exclusively of small vessels. (d) Changes in node strength for the 4 most variable fisheries across networks composed exclusively of medium vessels. The corresponding time series for large vessels can be found in Figure S2. Figure appears in colour in the online version only [Colour figure can be viewed at wileyonlinelibrary.com]

At the node level, average annual albacore node strength increased significantly ($p < .001$) between 1990–1999 (0.038 ± *SD* 0.021) and 2010–2018 (0.091 ± *SD* 0.024); during the latter decade, only the node strength of the Dungeness crab pot fishery was higher (0.146 ± *SD* 0.013). This increase suggests that amongst vessels participating in multiple fisheries, the albacore troll fishery has become

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one of most common sources of revenue and that those participating in the albacore troll fishery participate in a diverse suite of additional fisheries. We also observed substantial though non-significant increases ($p = .057$) in albacore troll betweenness centrality over the same time period (0.131 ± *SD* 0.103 for 1990–1999 vs. 0.263 ± *SD* 0.197 for 2010–2018), suggesting an increase in the importance of the albacore troll fishery in facilitating the distribution of effort across fisheries. Assessing node strength and centrality by decade rather than by year to explore interannual shifts in fisheries participation produced comparable results. These node-level comparisons support the aggregated network analysis described above in highlighting the emergence of albacore and a core group of linked fisheries that have enabled the persistence of diverse livelihoods strategies in the region.

4.5 | Heterogenous changes in fisheries connectivity

Recent changes in the fishery system have impacted different vessel size classes asymmetrically (Figure 9). Participation networks derived from different fleet segments confirm that participation in multiple fisheries increased for large and medium fishing vessels throughout the study period while declines have been observed amongst small vessels since the late 1990s (per average node strength, Figure 9a). Trends amongst large vessels appear to be driven by vessels increasingly using trawl gear to target groundfish and/or pink shrimp during the summer months (the same season during which the albacore fleet is active) before re-rigging to participate in the Dungeness crab pot fishery in the winter (Figure S2). The albacore troll fishery plays a comparatively minor role in fisheries connectivity for this segment of the fleet with its circumscribed node strength declining following a peak in the late 90s (Figure 9b). In contrast, albacore node strength increased progressively for small and medium vessels until 2012–2015 before declining substantially in 2016–2018. Amongst small vessels, this long-term trend was accompanied by an increase in the relative node strength of the salmon troll fishery, as the small vessel fishing fleet increasingly adopted troll gear to target both albacore and salmon when faced with substantial declines and restrictions impacting salmon net fisheries (Figure 9c). As one informant stated, "Salmon used to be the gravy run, but not so much anymore. I've had to move on," (Interview 12). For medium vessels, node strength and participation have increased for both the albacore troll and Dungeness crab pot fisheries as groundfish trawl has declined and salmon troll has become increasingly variable (Figure 9d). Taken together, these trends confirm that as the albacore troll fishery has become an increasingly important component of a diverse livelihood strategy for small- and medium-sized vessels even as large albacore fishing vessels have trended towards specialization.

5 | DISCUSSION

Over the past several decades, changes in the distribution and abundance of marine resources have operated in tandem with catch shares and limited entry licensing regimes to transform Pacific Northwest fisheries. Market-based reforms have been lauded for slowing the race to fish and increasing economic efficiencies (Birkenbach et al., 2017; Costello et al., 2008), but scholars have warned that they may incentivize capitalization, consolidation and specialization (Beaudreau et al., 2019; Hentati-Sundberg et al., 2015; Mansfield, 2004; Stoll et al., 2016) and raised concerns regarding their deleterious impacts on small-scale fishers and the coastal communities they inhabit (Olson, 2011; Pinkerton & Edwards, 2009). Reductions in portfolio diversity are of particular concern to those segments of regional fishing fleets that have historically relied upon flexibility to negotiate system change (Cline et al., 2017) as novel environmental conditions are increasingly observed across the northeast Pacific (Jacox et al., 2017). In highlighting changes to the structure and function of albacore troll and pole-and-line fishery, we demonstrate utility of maintaining open access for resources that are resilient to harvesting pressure. Indeed, our analysis suggests that the ability to shift effort between fisheries and opportunistically target certain species may be critical to the continued viability of range-restricted small-scale fishing operations that were not favoured by the initial allocation of fishing rights. As access to many Pacific Northwest fisheries has been progressively restricted, the albacore troll and pole-and-line fishery have functioned as a lifeline to keep many small-scale operations afloat.

5.1 | Regulatory reforms impacting West Coast fisheries

Previous research asserts that the average level of diversification of fishing vessels across the US West Coast and Alaska has declined since the mid-1980s (Holland & Kasperski, 2016; Holland et al., 2017; Kasperski & Holland, 2013) following the establishment of catch shares and limited entry licensing. However, such findings are likely sensitive to the subset of vessels analysed and the metrics through which diversity is defined and assessed. More specifically, decisions concerning whether to aggregate using species groupings or fishing métiers (of particular importance when considering the collapse and rationalization of the multi-species groundfish sector) or whether to integrate Alaska-based vessels and landings (where specialization associated with the rise of lucrative salmon fisheries is the dominant signal; see Anderson et al., 2017) are likely to alter results. While our analysis corroborates the notion that diversification has decreased in aggregate across the OR and WA fleet following a peak around the year 2000 (Holland & Kasperski, 2016), analysis of changes in diversification by vessel size class indicates that this trend is largely driven by significant decreases within the small vessel fleet. Indeed, our results suggest that in recent years diversification across medium and large-sized vessels has stabilized or may even be increasing. These differential responses, assessed using both network-derived metrics and traditional diversification indices, highlight the limitations of fleet-aggregated analyses. We hypothesize that such trends can be related to increasing capitalization amongst

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those large and medium-sized vessels that remained active following fisheries privatization and consolidation, many of which must now participate in multiple fisheries and operate year-round in order to remain profitable. Indeed, we likely underestimated diversification for this segment of the fleet as larger vessels are more likely to land catch and/or participate in fisheries outside of the Pacific Northwest (Kasperski & Holland, 2013). Observed declines in diversification amongst smaller fishing vessels may help explain the pronounced attrition observed in this segment of the fishing fleet. Without access to the capital required to participate in multiple fisheries and leverage economies of scale, many small-scale fishing operations are no longer viable.

5.2 | Shifting albacore fishery participation and socioeconomics

Acting in concert with regulatory reforms impacting the fishery system at-large, changes in the distribution of albacore over the past several decades have contributed to increasing heterogeneity across the different geographic segments of the troll and pole-and-line fleet. When accessible in coastal waters, albacore represents an important component of diverse harvesting portfolios amongst the smaller vessels in West Coast fishing fleets. While such trends are recent across the Pacific Northwest, there is historical precedent in Southern California (Clemens & Craig, 1965). In contrast to large vessels participating in other regional fisheries, large vessels participating in the albacore fishery may be comparatively specialized. But there is evidence to suggest they are less geographically constrained and may be less susceptible to episodic shifts in resource abundance. Large vessels based in Southern California have remained active despite significant longitudinal and latitudinal shifts in fishery production over the past 35 years. Indeed, many larger vessels target albacore year-round, travelling to distant fishing grounds in the South Pacific each winter–spring before returning to the US West Coast during the summer months (Blythe-Skyrme et al., 2012b; Childers & Miller, 2000).

Amongst tuna fisheries worldwide, the US albacore fishery now ranks amongst the highest economic performers due to its ability to access high-value markets and its development of infrastructure capable of preserving product quality (McCluney et al., 2019). When faced with stricter regulations, rising operational costs and competition from foreign imports, many fishers began to pursue new methods for engaging with consumers, restaurants and wholesale buyers (Brinson et al., 2011; Stoll et al., 2015). Over time the albacore fishing fleet benefited from reducing its reliance on canneries and commodity markets and by shifting its focus from volume to value-added products (Morrissey, 2008). Research demonstrating the high nutritional value, elevated fat content and low mercury levels of juvenile albacore (Wheeler & Morrissey, 2003) has stimulated the development of new domestic and international markets. As US industry organizations have leveraged sustainable seafood certifications to secure new markets in Spain and Japan, small-scale producers increasingly rely upon local gourmet markets and micro-canning operations across the Pacific Northwest (Morrissey, 2008). By engaging with place-based initiatives that emphasize product quality and sustainability, many regional fishers have been able to increase their profitability by capturing more of the value generated by their catch (Brinson et al., 2011). In addition to economic incentives offered by alternative seafood marketing programs, many have praised the social benefits derived from increased consumer awareness and support of the commercial fishing industry (Witter & Stoll, 2017).

5.3 | Environmental and ecological drivers impacting the SES

West Coast fisheries are known for their intrinsic fluctuations, yet there are signs that this variability may be increasing across the California Current (Black et al., 2014; Sydeman et al., 2013). Alongside anomalous oceanographic conditions observed in 2004–2006 (Peterson et al., 2006) and 2014–2016 (Bond et al., 2015; Jacox et al., 2016), numerous changes to ecosystem structure and function have been reported (Cavole et al., 2016; Lindley et al., 2009; Sanford et al., 2019; Walker et al., 2020). Despite landings trending positively in the early 2000s, West Coast salmon fisheries were severely restricted during the 2008–2009 and 2016–2017 fishing seasons amidst poor run strength and increasingly variable escapement associated with drought, warm ocean temperatures and limited food availability (Richerson & Holland, 2017; Satterthwaite et al., 2019). While salmon runs have been inconsistent, groundfish stocks have recently begun to recover following several decades of depressed landings attributed to overcapacity and overfishing (PFMC, 2018). The benefits of this recovery have largely been accrued by large vessels following the substantial consolidation and attrition of fishing effort which accompanied the rationalization of the sector (Russell et al., 2016, 2018). In contrast, the Dungeness crab biomass appears stable (Richerson et al., 2020), and in recent years, the fishery has occupied a central position in regional fisheries participation networks (Fuller et al., 2017), drawing diverse participants from US West Coast ports and generating the largest total ex-vessel revenue (Rasmuson, 2013). However, there are mounting concerns regarding the anticipated impacts of ocean acidification (Bednaršek et al., 2020) and hypoxia (Froehlich et al., 2014) on crab stocks, and in recent years, fishing opportunities have been constrained by harmful algal blooms (Moore et al., 2019; Ritzman et al., 2018) and whale entanglement issues (Santora et al., 2020) associated with climate variability and change.

With juvenile albacore distribution strongly influenced by temperature (Muhling et al., 2019; Phillips et al., 2014), the northern limit of their distribution in the California Current can extend in warm years (Christian & Holmes, 2016). Indeed, fishermen reported albacore "pushing north" during recent warm-water oceanographic anomalies (Interviews 5, 20), with schools of fish observed off Southeast Alaska (Cavole et al., 2016). A northward shift in fishing opportunities could coincide with future projections of favourable

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thermal habitat (Christian & Holmes, 2016), but studies conducted in other ocean basins have shown that albacore distributions are highly variable and do not always correspond with shifts in oceanographic habitat (Chust et al., 2019). Though more research is required to determine how interactions between climate, feeding, migration and spawning throughout the range of the species in the North Pacific are likely to mediate fishable biomass, we would suggest asymmetric impacts are likely across the different segments of North American fishing fleets.

5.4 | Value of diverse harvesting portfolios

Researchers have argued that a reliance on a narrow suite of species is likely to undermine the resilience of fishery SES following perturbation (Fuller et al., 2017; Steneck et al., 2011). Acknowledging the importance of diversification in sustaining fisheries livelihoods, fishermen repeatedly referenced the ability of the open-access albacore fishery to absorb displaced fishing effort and mitigate risk during interviews and focus groups discussions. As other fisheries have become more volatile and/or less accessible over time, the importance of albacore as an "insurance" fishery in the harvest portfolio of Pacific Northwest fishers has increased. This trend appears particularly evident for small- and medium-boat fishers who have been disproportionately impacted by the transition to limited entry licensing and catch shares in many fisheries (Olson, 2011), and who may lack the capacity for geographic redistribution in response to large-scale climatic drivers (Young et al., 2019). Management intervention designed to address declines in albacore landings observed since 2015 should be cognizant of such context as it functions to mediate the resulting impacts on different segments of the fishing fleet. Any change in stock status is likely to be met with calls for increasing regulation, yet we would suggest that open access and sustainable management need not be mutually exclusive when harvesting costs are high (Anderson et al., 2019) and fishing technology is limited to selective and/or time-intensive extraction methods (i.e. troll and/or pole-and-line gear which target one fish at a time). Indeed, maintaining the viability of this and other small-scale fisheries moving forward is likely to require new approaches that value equity and community stewardship rather than the exclusive mandate to maximize economic efficiency (Frawley, Crowder et al., 2019; Hanich et al., 2018; Pinkerton & Davis, 2015).

5.5 | Implications for transboundary marine resource allocation

The RFMO system used to govern tunas and other transboundary marine resources has helped to curb overfishing, yet more work remains to be done in order to ensure the equitable distribution of related social and economic benefits (McCluney et al., 2019). Despite stated desires to consider issues of equity alongside sustainability, in practice most RFMOs that have implemented resource allocation schemes to manage stocks have relied heavily on historical catch and effort levels, tending to favour nations with large-scale, industrial and/or distant water fishing fleets (Seto et al., 2020). While advocates of rights-based fishery management approaches have argued that the industrial tuna sector may be more technically efficient (Allen, 2010), our work supports the assertion that small-scale, local boats may be better positioned to harvest local resources (Pinkerton & Davis, 2015) and capture the quality-dependent premiums offered by certain high-end markets (McCluney et al., 2019). Furthermore, there are serious environmental justice concerns surrounding resource rights allocations that fail to deliver opportunities for small-scale producers and developing nations already disproportionately impacted by climate change (Hanich et al., 2018). Given that maintaining fisheries livelihoods and food security for these vulnerable user groups is likely to require transferring fishing effort from reef fish to tuna and other highly migratory species (Bell et al., 2018), equitable management strategies may need to expand access to pelagic fisheries resources rather than restrict it.

6 | CONCLUSION

Diversity is a key property that confers resilience by providing options through which a system can respond to disturbance (Holling, 1973). In recent years, this fundamental ecological theorem has increasingly been applied to the study of marine fisheries (Cline et al., 2017; Finkbeiner, 2015) and other coupled human-natural systems (Barnes et al., 2019; Biggs et al., 2012; Folke et al., 2010). Across the Pacific Northwest, the open-access albacore fishery has helped many fishers maintain diverse harvest portfolios even as access to other fisheries has been restricted. With vessel ownership and permits increasingly consolidated amongst a limited number of individuals, communities and corporations (Russell et al., 2016), the ability to opportunistically target albacore in coastal waters has been critical for the maintenance of regional small-scale fishing operations and traditional livelihood approaches.

The impacts of climate change on the distribution, abundance and diversity of marine species are predicted to be profound (Cheung et al., 2010), as are the implications for coastal fishing communities (Rogers et al., 2019). It has been argued that modern management and licensing regimes may be unable to respond to anticipated, large-scale ecological shifts (Reedy, 2019), and that high specialization with respect to target species is likely to result in higher vulnerability to extreme events (Kluger et al., 2019). Likewise, recent trade disputes (Gephart et al., 2019) and emergent public health crises (Bennett et al., 2020) have emphasized the connection between the flexibility required to navigate political and economic instability and the resilience of fisheries livelihoods. Alongside a desire to promote diverse and flexible harvesting strategies, the need to move beyond traditional, single-species management approaches has grown increasingly urgent. Portfolio approaches to managing fisheries can reduce barriers to diversification that may help maintain opportunity and choice for fishers faced with mounting risk and uncertainty

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(Beaudreau et al., 2019). Applied research dedicated to such aims must continue to work to transcend disciplinary boundaries, embrace complex systems thinking, and address the social–ecological linkages that inform how fishers participate and shift effort amongst fisheries (Barnes et al., 2019; Marshall et al., 2018). Climate variability and change represent significant challenges for many marine SES worldwide, but they also present opportunities to reform and recast existing management structures with explicit attention to restoring the connections between people, places and ecosystems while supporting sustainable and equitable development.

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CONFLICT OF INTEREST

The authors have no conflicts of interest to report.

DATA AVAILABILITY STATEMENT

Vessel-level landings and logbook data, collected by the Pacific Fisheries Information Network (PACFIN) and the NOAA National Marine Fisheries Service, are confidential U.S. government data. The raw data cannot be made public, under the Magnuson–Stevens Fishery Conservation and Management Reauthorization Act of 2006, section 402 (b), 16 U.S.C. 1881a. To request access to US West Coast vessel-level landings data please contact Jenny Suter (JSuter@psmfc.com). To request access to US Highly Migratory Species albacore logbook data please contact John Childers (John.Childers@noaa.gov). Descriptive vessel information was obtained through the two data sources referenced above and publicly available vessel registries (accessed online) maintained by the Inter-American Tropical Tuna Commission (www.iattc.org) and the US Coast Guard (https://www.dco.uscg.mil/).

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