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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

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 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, 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 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 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

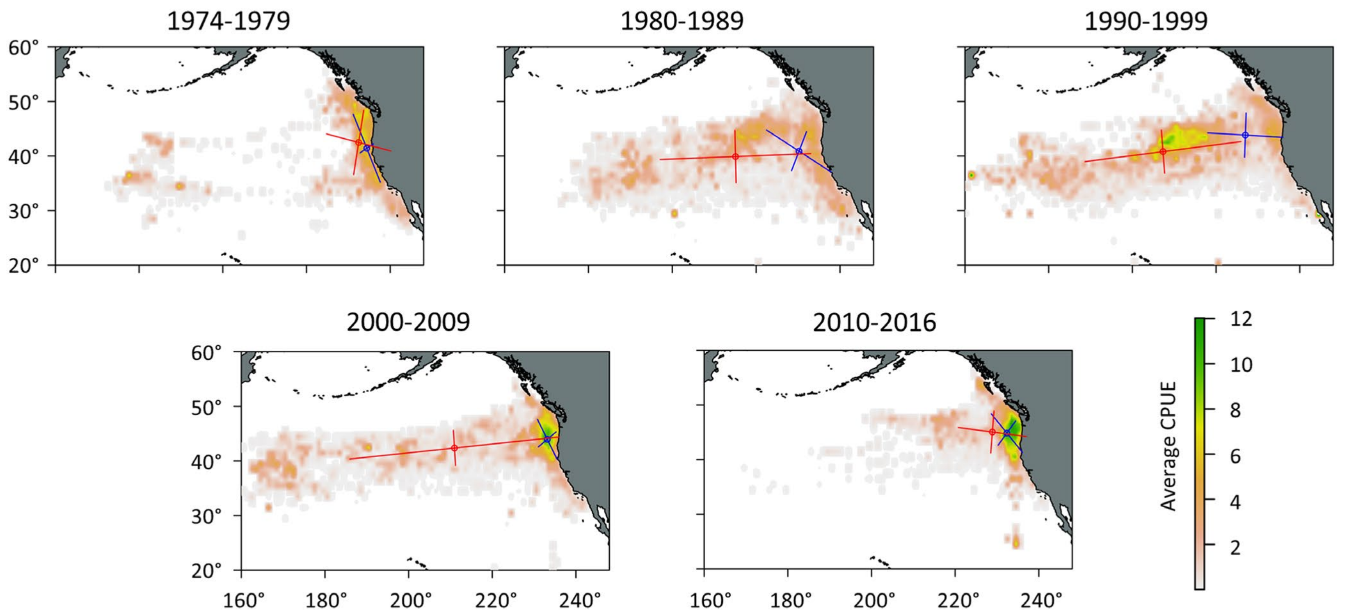


FIGURE 1 North Pacific albacore catch per unit effort (total fish/total hours aggregated by 1° × 1° degree grid cells) averaged across each decade, as reported in US troll and pole-and-line albacore fleet logbooks. Centre of gravity and inertia of small (blue; <45 ft) and large (red; >60 ft) vessel fishing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

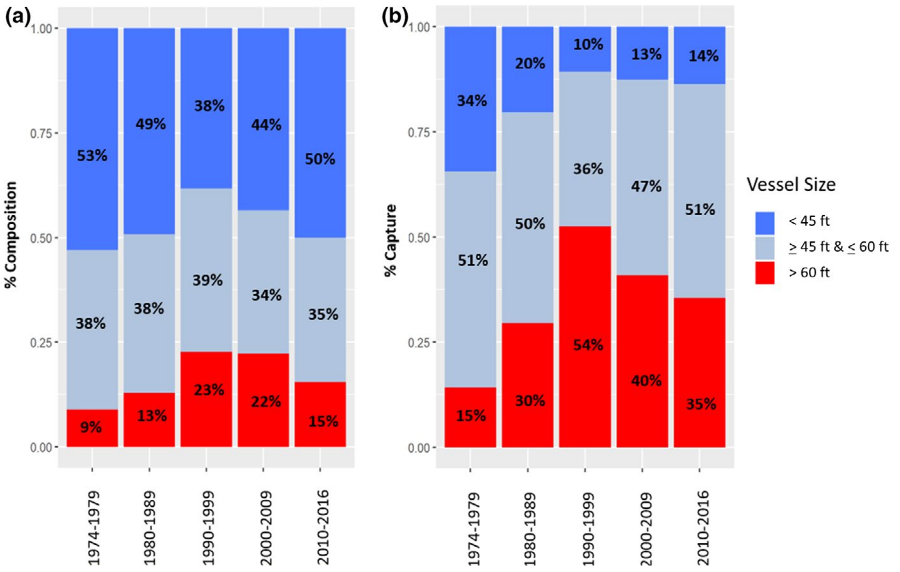


FIGURE 2 Contribution (by decade) of vessel size classes to (a) the composition of the US albacore troll and pole-and-line fleet across the entire US West Coast and (b) the capture of albacore (as inferred by # of fish landed) by this fleet. Due to a high attrition in effort across the study period, 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]

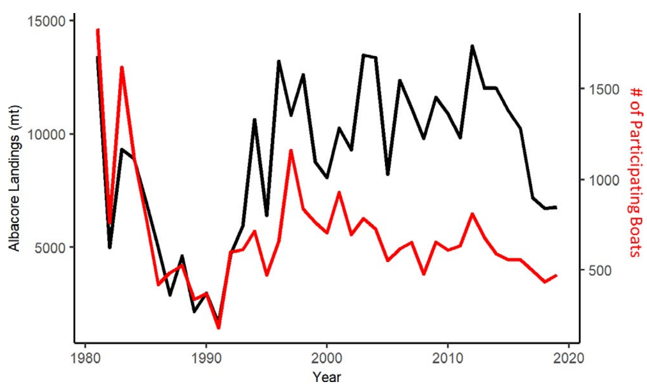


FIGURE 3 Time series of total US West Coast North Pacific albacore troll and pole-and-line fishery landings (black) and effort (red). Data were sourced from non-confidential PACFIN records. Figure appears in colour in the online version only [Colour figure can be viewed at wileyonlinelibrary.com]

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).

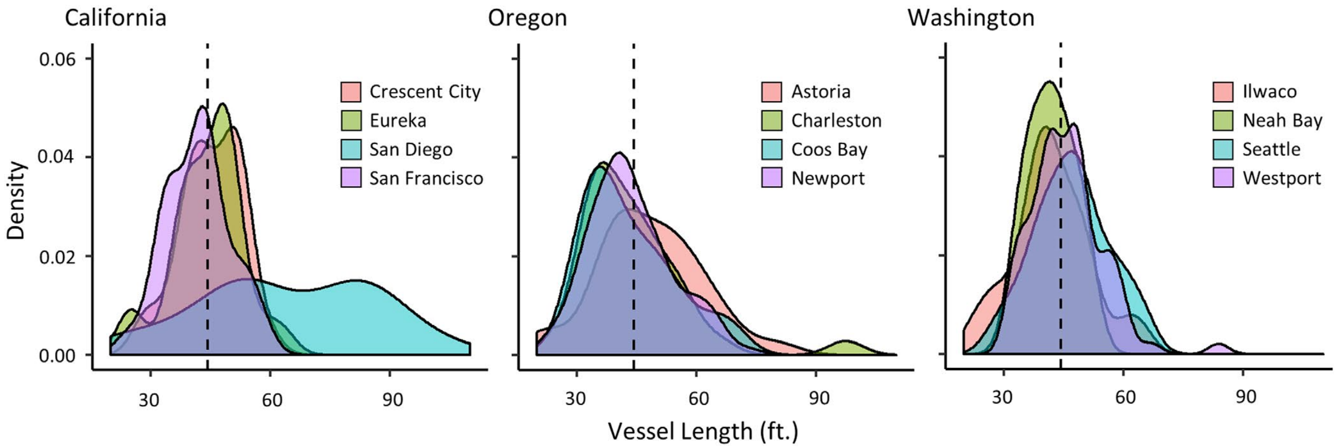
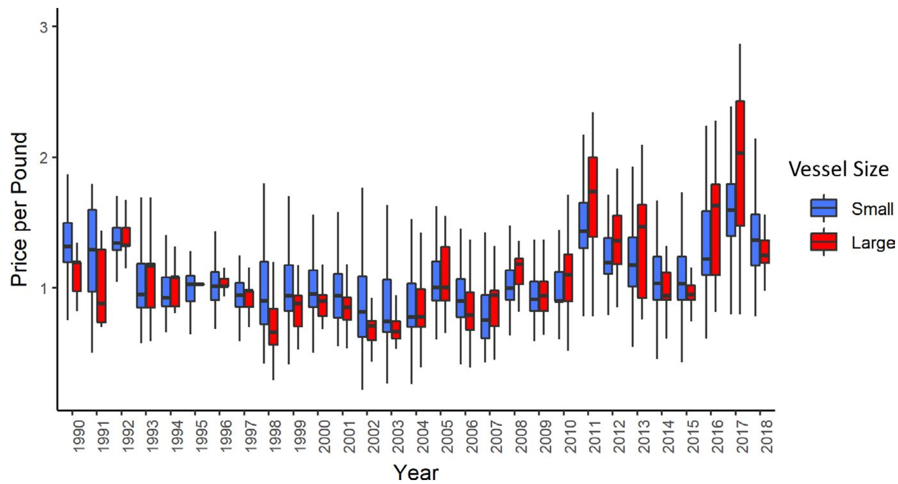


FIGURE 4 Density plots showing the distribution of vessels lengths of the troll and pole-and-line fishery (2010–2016, as inferred by NMFS logbook entries) by hailing port for the 4 ports with the most reported vessels in California (n = 101), Oregon (n = 184) and Washington (n = 149). The dashed line 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 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.

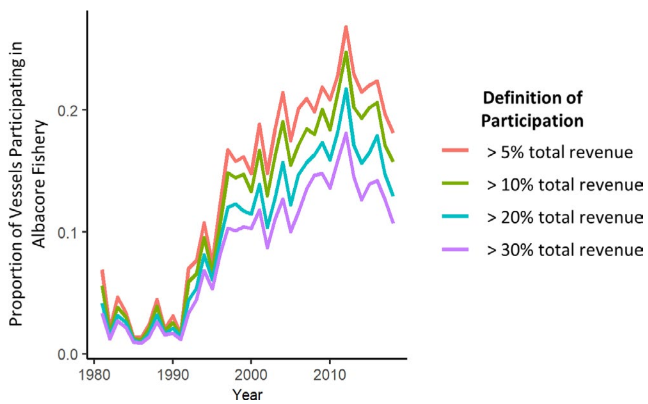


FIGURE 6 Time series depicting changes in the proportion of active PNW fishing vessels participating in the North Pacific albacore troll and pole-and-line fishery over time. Figure appears in colour in the online version only [Colour figure can be viewed at wileyonlinelibrary.com]

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.

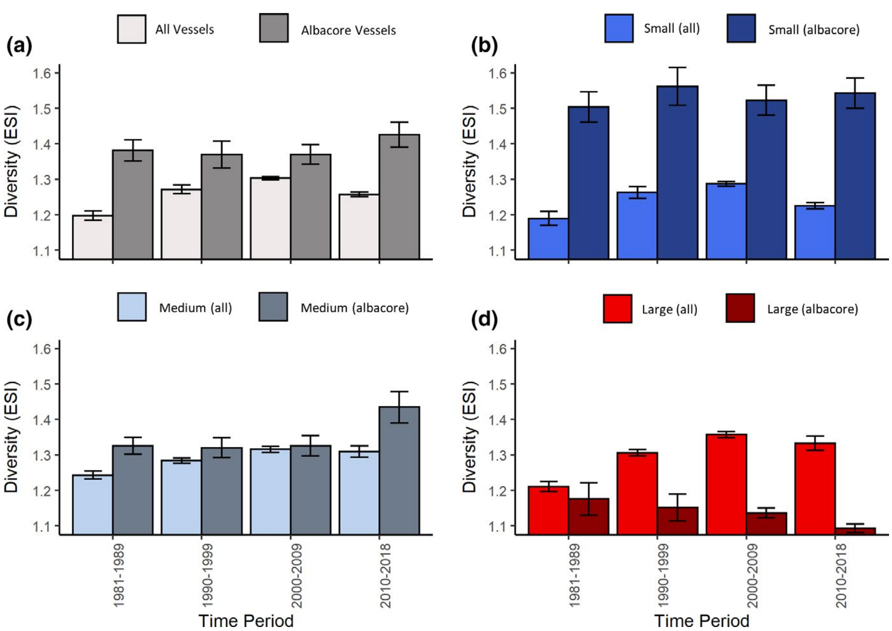


FIGURE 7 Changes in annual revenue diversification over time (as grouped by decade) for different vessel size classes. In each panel, revenue diversification is assessed for the all vessels in the specified size class and only vessels of the specified size class reporting landings dominated by troll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

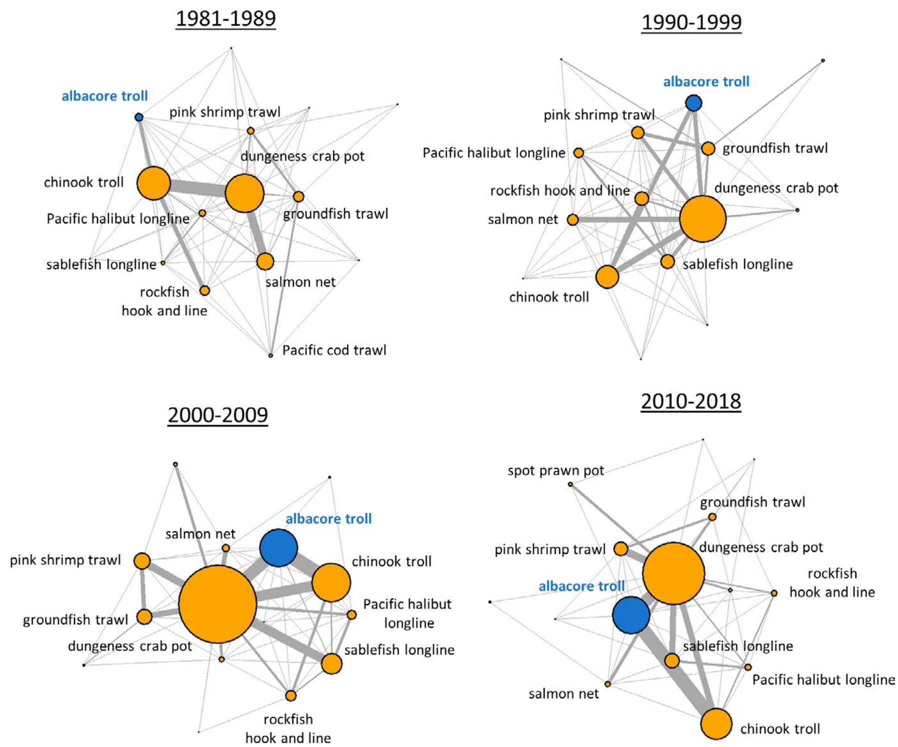


FIGURE 8 Summary networks for comparison decades of interest. Node size and edge weight thickness in each summary network represent averages across all annual networks in the time spans specified. For each annual network, edge weight thickness was determined as the number of active vessels participating (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]

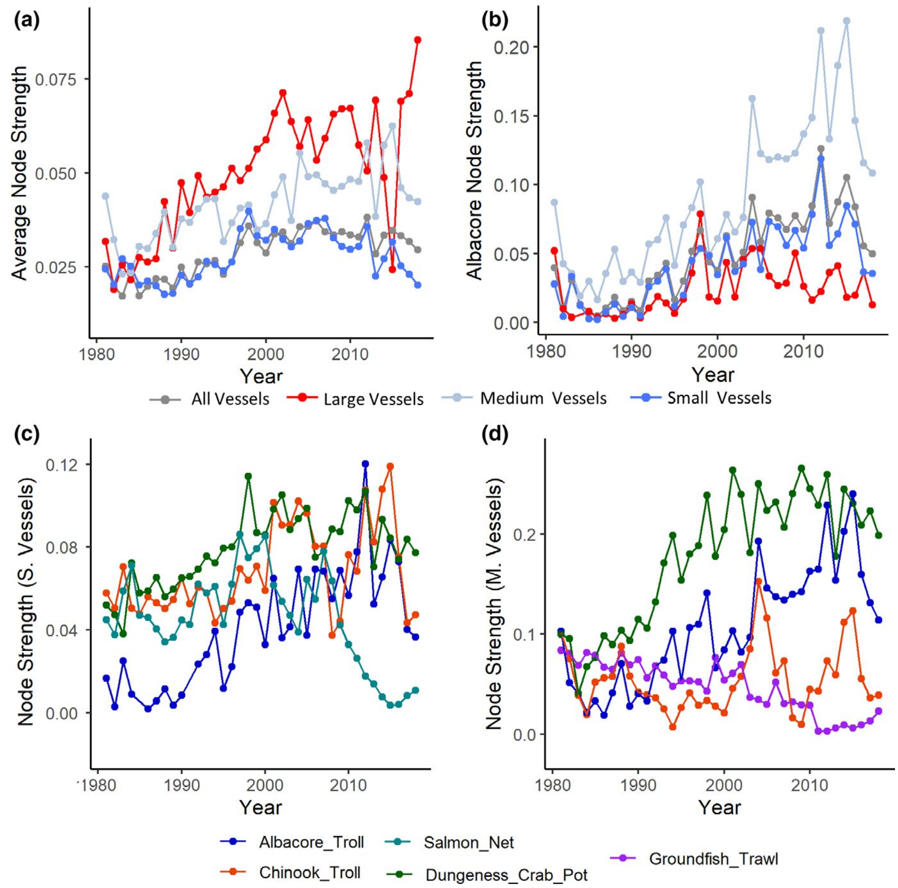


FIGURE 9 Time series depicting changes in fisheries participation network structure and the strength of component nodes as related to vessel size class. (a) Changes in average annual node strength ($n = 15$) for networks composed exclusively of all, small-, medium- and large-sized vessels. (b) Changes 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 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 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 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

(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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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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