

Contract and sustain: evaluating the results of progressive implementation of limited entry and catch shares in West Coast and Alaska Fisheries over four decades

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Abstract

Access to West Coast and Alaskan fisheries has been progressively tightened for more than four decades with limited license programs, buybacks, and catch share programs. We document the implementation of a series of limited access and catch share programs in federally and state managed fisheries of the West Coast and Alaska, and evaluate trends in participation, diversification, vessel revenue, and variation of revenue between 1981 and 2022 for this large interconnected system of fisheries. Over time, progressive tightening through further input controls, buybacks, and catch shares led to substantial consolidation and greater specialization coinciding with increased temporal diversification, maintained or increased revenue per vessel, and reduced variation in inter-annual revenue. However, low levels of fishery diversification for many fishers, and high dependency on a few key fisheries, may have left fishers vulnerable to ecological and economic shocks that impacted key fisheries leading to increased income variation and further declines in participation in recent years.

Key words: diversification, catch shares, fisheries, limited access, limited entry, risk

1. Introduction

The need to limit access to fisheries to avoid depletion of both fish stocks and resource rents has been understood at least since 1911 (Warming 1911; Andersen 1983), and proposals to preserve resource rents by limiting access and capacity (Crutchfield 1961, 1979), or with individual quotas (Christy 1973), were suggested as a means to achieve both objectives. Despite these warnings, global catch rose rapidly after the Second World War (tripling between 1950 and 1970), leading to widespread overfishing across much of the world (FAO 1994; Action 2020). This in turn led to the expansion of national exclusive economic zones (EEZs) to 200 miles, exclusion of foreign fleets, and, eventually, attempts to reduce domestic capacity (Holland 2000). However, implementation of management systems to limit fishing capacity and catch generally lagged behind the development of fisheries and advances in harvesting technologies. When limited entry programs did succeed in increasing profitability, they often created incentives for fishers to increase capacity by increasing inputs not well controlled by the programs requiring further reductions in licenses (Rettig 1984; Wilen 1988; Townsend 1990; Homans and Wilen 1997). Attempts to limit total allowable catch directly often led to a race for fish that spurred further capacity increases, reduced product quality and value, and reduced fishing safety (Homans and Wilen 1997). Capac-

ity reduction programs implemented in many fisheries were often followed by rebuilding of fleets with more powerful vessels and continued overfishing and rent dissipation requiring additional measures to constrain or reduce fishing capacity (Holland et al. 1999). Constraining license or quota in particular fisheries has also caused spillovers into other fisheries that do not have strict capacity controls or have underutilized permits (Addicott et al. 2019; Kroetz et al. 2019).

Programs to limit or actively reduce participation and fishing capacity in fisheries on the US West Coast and Alaska began with salmon fisheries in the 1970s but only after participation was higher than stocks could support (Rettig 1984). Attempts to limit licenses in offshore fisheries off the West Coast and Alaska did not occur until the 1990s when capacity already far exceeded that needed to prosecute the fisheries (Holland 2000). In both coastal and ocean fisheries, successive rounds of tightening access and limits on inputs (e.g., traps, nets, vessel size), or on total or individual catch, were required to maintain or rebuild fish stocks and maintain economic viability (Holland and Kasperski 2016). Catch share programs that were successful at improving economic viability in specific fisheries may have also caused spillover into other fisheries, extending and prolonging the process of bring capacity down to efficient levels (Addicott et al. 2019; Kroetz et al. 2019).

As access to more and more West Coast and Alaskan fisheries was constrained in the 1990s and 2000s, the opportunities for vessels to build or maintain diversified fishing portfolios became fewer and more expensive, requiring purchases of permits or of quota that many fishers could not afford or find financing for (Szymkowiak et al. 2019a; Haugen et al. 2021; Steinkruger and Szymkowiak 2023). This is concerning because diversification of fishing activities is a key means for fishers to grow revenue when opportunities within their current fisheries are constrained. Fishers with higher diversification have been shown to have higher revenue on average (Abbott et al. 2023; White and Scheld 2024), though diversification may also require increased investments in permits and gear. As with crop diversification in agriculture (Heady 1952; Johnson 1967), diversification is an important risk management strategy for fishers who tend to face very high variability in catch and income creating substantial financial risk (Sethi et al. 2012; Kasperski and Holland 2013). Sethi (2010) proposed diversification as a means for fishers to reduce financial risk and demonstrated how diversification across multiple salmon fisheries could reduce variance in revenue. Kasperski and Holland (2013) showed that lower fishery diversification was correlated with higher inter-annual variation in revenue, suggesting that declines in diversification could be increasing financial risk for fishers. They also show (Kasperski and Holland 2013; Supplementary material) that the risk of having very low revenues relative to a vessel's own average revenues is decreased by diversification and note, "Small owner-operator vessels, may be less concerned with the overall variability of their income than with the possibility that their revenues fall below a minimum level where they may be forced to default on their loans or face other economic hardship". Diversification can also be important at the level of fishing communities. Cline et al. (2017) showed that communities with less diverse fishing portfolios were less able to maintain revenues in response to regime shifts.

Several studies have documented declines in fishery diversification of commercial fishing vessels in West Coast and Alaskan fleets in the last several decades and suggest declines in diversification were coincident with, if not due to, implementation of limited entry programs and catch share programs (Kasperski and Holland 2013; Holland and Kasperski 2016; Anderson et al. 2017; Ward et al. 2018; Beaudreau et al. 2019), and similar declines have been documented in other regions when limited entry systems were implemented (e.g., Stoll et al. 2016). Abbott et al. (2023) expanded the concept of fishery diversification to also incorporate temporal diversification, quantifying the spread of fishery revenue over the year, and found that, while fishery diversification had been declining for most West Coast vessels since the mid-1990s, temporal diversification had been increasing on average through 2014. Furthermore, temporal diversification was found to be a more important predictor of inter-annual revenue variation than fishery diversification—so much so that temporal diversification overwhelmed declines in fishery diversification, causing average inter-annual revenue variation for the fleet to decline from the 1990s through 2014. This was likely due in part to lengthening seasons under lim-

ited entry and later catch shares, which enabled the remaining fishers to fish more of the year. This is particularly likely when catch share programs were introduced to fisheries that experienced a race for fish. In a study of 39 US catch share fisheries, Birkenbach et al. (2017) find that catch shares extended fishing seasons in a substantial majority of cases.

Several of the limited access and catch share programs on the West Coast and Alaska have been evaluated in terms of economic and social impacts (PFMC 2010; Thunberg et al. 2015; Brinson and Thunberg 2016; NPFMC 2016; Errend et al. 2018; Pfeiffer 2018; Szymkowiak et al. 2019a, 2019b). However, a holistic and long-term review of the cumulative impact of these access restrictions across the full range of affected fisheries, fleets, and fishing communities has not been undertaken. This holistic analysis is called for given the interconnectedness of many West Coast and Alaskan fisheries due to movement of fishers between fisheries both within and between years and because the results of management actions in particular fisheries are often the cumulative impacts of multiple progressive attempts to reign in capacity over time. In this paper, we describe trends in participation, consolidation, and diversification over 40 years along with trends in the levels, variation, and distribution of revenue.

The primary focus of our study is on how vessel level fishery and temporal diversification have been impacted by cumulative tightening of access over time and how that has impacted vessel level revenue and inter-annual variation in revenue. We also show that higher fishery and temporal diversification are correlated with higher average vessel revenue, suggesting that increasing diversification does not necessarily represent a trade-off between higher revenue and lower revenue risk. We do not attempt to evaluate impacts of particular management actions or causes of trends due to the complexity of programs, cross participation of vessels, and the influence of other factors such as changes in global markets and supply chains, aquaculture, demographic change, and ecological shocks. We are unable to construct a counter-factual scenario to compare outcomes to what might have occurred with alternative management or lack thereof. Rather, we provide a summary of the cumulative changes in fleet-level economic indicators coincident with progressive tightening fishery access across this complex social-ecological system and evaluate how changes in diversification (whatever the cause) have impacted variation in revenue and the individual vessel and fleet level.

We make several contributions to the existing literature. We document the progressive tightening of access to Alaskan and West Coast fisheries over 42 years with limited access programs, license and vessel buybacks, and catch share programs. We expand on the analysis of Abbott et al. (2023) to include Alaskan vessels as well as the West Coast fleet. We also extend that analysis from 25 years to a 42-year period from 1981 to 2022, finding a reversal after 2015 of the upward trend in temporal diversification found by Abbott et al. (2023) as well as a reversal of the declining trend in revenue variation. In addition, we evaluate trends in fleet size, entry and exit, and vessel revenue over this 42-year period to

Table 1. Timeline of Limited Entry, Vessel Buybacks, and Catch Share programs in West Coast and Alaska Fisheries.

Year	Program Type	Region	Milestone
1973	Limited Entry	West Coast	Washington Herring Limited Entry
1974	Limited Entry	West Coast	Washington Salmon License Moratorium
1974	Limited Entry	West Coast	California Herring Limited Entry
1974	Limited Entry	Alaska	Alaska Salmon Limited Entry
1975	Limited Entry	West Coast	Series of Salmon License Buybacks in OR and WA (1975–1997)
1977	Limited Entry	Alaska	Southeast Alaska Herring Fisheries Limited Entry
1979	Limited Entry	West Coast	California and Oregon Salmon Licenses Moratoria
1984	Limited Entry	Alaska	Southeast Alaska Tanner and King Crab Limited Entry
1985	Limited Entry	Alaska	Southeast Alaska Sablefish Limited Entry
1988	Limited Entry	Both	Foreign Harvesting in US EEZ Eliminated
1989	Limited Entry	West Coast	California Sea Urchin Dive Limited Entry
1992	Limited Entry	Alaska	Groundfish Permit Moratorium in Alaska
1992	Catch Share	Alaska	Western Alaska Community Development Quota (CDQ) Program
1994	Limited Entry	West Coast	Washington Dungeness Crab Limited Entry
1994	Limited Entry	West Coast	West Coast Groundfish Limited Entry
1995	Limited Entry	West Coast	California and Oregon Dungeness Crab Limited Entry
1995	Catch Share	Alaska	Alaska Halibut & Sablefish ITQ
1996	Limited Entry	West Coast	California Spiny Lobster Limited Entry
1997	Limited Entry	West Coast	California Sea Cucumber (Dive or Trawl) Limited Entry
1999	Catch Share	Alaska	Alaska American Fisheries Act—Shore-based Cooperatives
2000	Limited Entry	Alaska	Alaska Groundfish and Crab Limited Entry
2000	Catch Share	Alaska	Alaska American Fisheries Act—At-sea based Cooperatives
2000	Limited Entry	West Coast	West Coast Coastal Pelagic Species Limited Entry
2000	Limited Entry	West Coast	California Pink Shrimp Trawl Restricted Access in Northern Area
2001	Catch Share	West Coast	West Coast Sablefish (Fixed Gear) Permit Stacking
2002	Limited Entry	West Coast	California Spot Prawn Trap Limited Entry
2003	Limited Entry	West Coast	California Nearshore Fishery Limited Entry
2004	Limited Entry	West Coast	California Market Squid Limited Entry
2004	Limited Entry	West Coast	West Coast Groundfish Trawl Vessel Buyback
2005	Catch Share	Alaska	Aleutian Islands Pollock Cooperatives
2005	Catch Share	Alaska	Bering Sea King & Tanner Crab IFQ
2005	Limited Entry	West Coast	California Spiny Lobster permits become transferable
2006	Limited Entry	West Coast	California Halibut Bottom Trawl
2008	Catch Share	Alaska	Alaska BSAI Amendment 80 Cooperatives
2011	Catch Share	West Coast	West Coast Groundfish Catch Shares (Cooperatives and ITQ)
2011	Catch Share	Alaska	Central Gulf of Alaska Rockfish Catch Shares
2024	Catch Share	Alaska	BSAI Pacific cod Trawl Cooperative (PCTC) Program

provide a more holistic understanding of results of four decades of progressive tightening of access to West Coast and Alaskan fisheries. Overall, our results suggest that this tightening of access has been successful at reducing capacity and increasing revenue, and likely profitability, for the remaining fleet. However, while this may have helped increase, and even stabilize, revenues for the fleet for most of the last few decades, it may have left some fishers vulnerable to shocks to those fisheries that may be difficult to weather for fishers without strong financial reserves or other income sources. The apparent win–wins from tightening access through 2015 found by [Abbot et al. \(2023\)](#) may be coming to an end revealing previously hidden trade-offs between specialization and fishery diversification.

2. The timeline of limited entry, capacity reduction, and catch share introductions in Alaskan and West coast fisheries

Alaska implemented limited entry programs for Salmon fisheries beginning in 1974, after a change in the state constitution to allow it ([Table 1](#)). In general, a maximum number of gear units was set equal to recent participation levels and allocated to individuals based on a point system ([Schelle and Muse 1986](#)). A planned second stage that would have progressively reduced the number of permits to an optimal level through buybacks funded by a tax on revenues of

remaining permit holders was deemed unconstitutional and never implemented. Limited entry programs for herring were implemented in 1977–1978, for tanner and king crab in 1984, and for sablefish in 1985. A groundfish permit moratorium was introduced in Alaska in 1992, and license limitations for Alaska groundfish and crab fisheries were passed in 1996 though not implemented until 2000.

On the US West Coast (Washington, Oregon, and California) limited entry also began with a focus on salmon, with Washington introducing limited entry in 1974, and Oregon and California following in 1979. Oregon and Washington implemented a series of salmon license buybacks between 1975 and 1997 to make capacity reductions needed in part due to a court order known as the Boldt decision (*United States v. Washington* 1975), which allocated 50% of Washington salmon harvest to Native American tribes. Limited entry was introduced to the federally managed West Coast groundfish fishery in 1994. Limited entry programs with pot limits were implemented in the Dungeness crab fisheries in Washington in 1994 and in Oregon and California in 1995. The West Coast Coastal Pelagic Species federal management plan implemented limited entry in 2000. California also implemented limited entry with transferable permits in a number of smaller state fisheries between 1989 and 2006 (herring 1974; sea urchin 1989; sea cucumber 1997; nearshore groundfish 2003; spot prawn 2002; market squid 2004; spiny lobster 2005; California halibut 2006).

In 1995, the focus on capacity limitation for federally managed Alaska and West Coast fisheries began to transition from limiting licenses to allocating exclusive catch rights either in the form of individual quotas or as shares of the total catch allocated to cooperatives. This was due largely to a recognition that license limitations had failed to limit capacity and stem the race for fish in many fisheries, leading to dissipation of resource rents both through reduced product value and increased costs associated with excess capacity. Alaska led off with implementation of the Alaska Halibut and Sablefish Individual Fishery Quota (IFQ) program in 1995. In 1999, the walleye pollock fishery moved to a catch share system based on cooperatives implemented through an act of Congress—the American Fisheries Act. An IFQ program was implemented in the Bering Sea King and Tanner Crab fisheries in 2005, and Amendment 80 to the Bering Sea–Aleutian Islands (BSAI) Groundfish FMP implemented a catch share system based on cooperatives to non-pollock groundfish catcher-processors in the BSAI in 2008, followed by a catch share system in the Central Gulf of Alaska Rockfish fishery in 2011, also based on cooperatives. The newest program, set to be implemented in 2024, is the BSAI Pacific cod Trawl Cooperative (PCTC) Program, which shares similar features of other cooperative programs in Alaska.

Implementation of catch share systems on the West Coast began in 2001 when the West Coast fixed gear sablefish fishery implemented a permit stacking program that effectively created an individual quota system. In 2004, a vessel buyback program in the West Coast groundfish trawl fishery bought out 91 vessels, which accounted for over 40% of the catch history of the primary target species at a cost of \$46 million (Holland et al. 2017b). The buyback was followed by im-

plementation of a catch share program, which was already envisioned at the time of the buyback, though there was a delay of 7 years between the buyback and catch share implementation due, in part, to constraints in the Magnuson Act on creating new individual transferable quota (ITQ) programs (Holland et al. 2017b). The buyback also retired 121 pink shrimp and Dungeness crab permits, and those fisheries along with groundfish were required to help repay the loan that funded the buyback with landing fees. In 2011, the West Coast groundfish trawl catch share program was implemented with an IFQ for the shore-based groundfish trawl fishery and a catch share system based on cooperatives for the catcher–processor and mothership sectors of the US Pacific whiting fishery.

By 2011, almost all significant fisheries off Alaska and the West Coast had implemented either limited entry regimes with resalable permits (and often capacity limits such as a trap limits) or catch share systems. Only a few fisheries such as the albacore fishery and some small nearshore fisheries remained open access, and purchase of permits or quota to access other fisheries had become costly.

3. Data and methods

3.1. Data sources

Our analysis is based primarily on landings (fish ticket) data and vessel registration data for commercial fishing vessels operating in Alaska and on the West Coast (Washington, Oregon, and California) from 1981 to 2022. These data are collated and provided by the Alaska Fisheries Information Network (AKFIN) and the Pacific Fisheries Information Network (PacFIN) of the Pacific States Marine Fisheries Commission. Fish ticket programs are administered by each state and are mandatory for vessels operating in both state and federal fisheries. Therefore, they provide comprehensive vessel-level data on landing and revenue except for catches by catcher processors and catches delivered to at-sea processors known as motherships. On the West Coast at-sea processing is almost entirely Pacific whiting, while in Alaska, it includes much of the pollock catch as well as other groundfish.

The complete landing data set covers the period 1981–2022 and includes data on over 74 000 vessels that fished in Alaska and Washington for at least 1 year over that period. Many of these vessels have very low levels of revenue or fish in only 1 year. We limit our analysis to vessels with commercial revenue for at least 2 years and with average revenue of at least \$5000 over the years they appear in the data. We also exclude catcher processors and motherships (floating processors) from this analysis. While these vessels are an important component of the fishing industry of the West Coast and Alaska, there are relatively few of them, so removing them does not have much impact on total fleet size or average diversification levels. However, because their revenues can be three orders of magnitude higher than the median for other vessels, including them has a very strong influence on average revenue and revenue variation measures, masking trends for the great majority of the fleet. These exclusions reduce the overall number of vessels in the data set to 28 359

though there are never more than 15 000 vessels included in any given year between 1981 and 2022. All revenue values are adjusted to 2005 US dollars using the US personal consumption expenditure index.

3.2. Metrics and methods

We calculate metrics such as annual revenue, the variation in inter-annual revenue, and diversification at the individual vessel level and for individual ports. We present average trends as well as decomposing those trends using fixed effects models to distinguish the effect of changes in behavior by continuing fishers vs. compositional impacts due to entry and exit. Because our analysis is done at the vessel rather than vessel owner level it does not account for diversification across multiple vessels owned by the same individual or firm. [Abbott et al. \(2023\)](#) found that about 10% of West Coast vessel owners operated more than one vessel in 1990 with the proportion of multi-vessel ownership rising to 15% by 2015. Multi-vessel owners tend to be more diversified overall than would be apparent from the individual vessels since the vessels often specialize in different fisheries, so we may tend to underestimate the level of diversification of multi-vessel owners. However, matching vessels numbers to owners over time is problematic for our large data set, particularly for earlier years, thus we follow previous analysis ([Kasperski and Holland 2013](#); [Holland and Kasperski 2016](#)) and calculate metrics only at the vessel level.

In determining the numbers of vessels entering and exiting each year, we utilized the first year a vessel number appears in the data as the entry year (noting that many if not most vessels in our first year of data, 1981, may have entered in earlier years) We used the last year a vessel appears in the data as the exit year. We do not report the number of exiting vessels in the final 2 years, since it is possible that a substantial number of those vessels could return to the fishery in subsequent years.

We follow the previous literature by measuring fishery diversification in terms of the allocation of ex-vessel revenues across species and species groups (e.g., [Kasperski and Holland 2013](#); [Holland and Kasperski 2016](#); [Anderson et al. 2017](#); [Holland et al. 2017a](#)), which we refer to as “fishery diversification”. We use the same species grouping used for several prior West Coast analysis ([Kasperski and Holland 2013](#); [Holland and Kasperski 2016](#); and the California Current Integrated Ecosystem Assessment, which has included diversification indices annually since 2014). These species groupings are listed in the supplemental materials (Table S1.1). We also measure “temporal diversification” as the spread of revenue across weeks of the year ([Abbott et al. 2023](#))

Following [Holland and Kasperski \(2016\)](#), as a measure of diversification, we utilize the effective Shannon index (ESI) defined as

$$(1) \quad ESI = \exp \left[\sum_{i=1}^{S_j} \sum_{j=1}^4 - (p_{ij} * \ln p_{ij}) \right]$$

where p_{ij} represents the proportion of a vessel's total gross revenues derived from species group i in region j , and S_j is

the total number of species groupings in region j . We define p_{ij} as the percent of an entity's total annual gross revenue from one of 40 different species groupings in one of four regions—the Bering Sea/Aleutian Islands, Gulf of Alaska, Alaskan in-state waters, and the West Coast. Not every species group is caught in each region, so there are a total of 84 total region-specific species groupings. The ESI increases both as revenues are spread across more fisheries and as revenues are spread more evenly across fisheries. However, it does not disproportionately weight higher or lower shares ([Jost 2006](#)), a desirable property as we have no rationale for such a weighting. ESI also has a useful intuitive meaning. When revenues are spread evenly across categories (e.g., fisheries), it equals the number of categories represented ([Jost 2006](#)). For example, ESI takes a value of 2 if a fisher's revenues are spread evenly across two fisheries, a value of 3 if spread evenly across three fisheries, and so on. ESI declines progressively below the number of fisheries as revenue is less evenly spread across them. Our temporal diversification metric measures the spread of revenue over the 52 weeks of the year using the same formula as [eq. 1](#) with p_i representing the share of a vessel's revenue in each week of the year. Analogous to the fishery metric, a value of 10 would be calculated for a vessel with revenue spread evenly over 10 weeks, and this would decrease as the spread became less even across weeks and would increase as the revenue is spread over a greater number of weeks.

We present trends in average diversification for both Alaska and West Coast fleets. These fleets are largely distinct though; 2%–5% of vessels fish in both Alaska and the West coast in a given year. Following [Abbott et al. \(2023\)](#), we also distinguish changes in average diversification and revenue due to changes in the “portfolio” and activity decisions of active vessels (individual-level changes) vs. those due to changes in the makeup of fleets through entry, exit, and inactivity decisions (compositional changes)

$$(2) \quad \text{Diversification}_{i,t} = \alpha + \alpha_i + \sum_{t=1982}^{2022} \beta_t d_t + \varepsilon_{i,t}$$

where d_t are annual indicator (dummy) variables and α_i are vessel-specific intercepts (i.e., a “fixed effect”), reflecting the presence of persistent cross-sectional differences in diversity across vessels. If we estimate [eq. 2](#) using ordinary least squares (OLS), but ignore the α_i and instead estimate a single common intercept α , the resulting “pooled OLS” estimates for β_t for each year are equal to the difference in the sample mean of diversification levels across active vessels in each year relative to the omitted base year of 1981 showing the mean trend in diversification including both individual and compositional effect. If we estimate [eq. 2](#) while including a separate dummy variable for every vessel in the data (i.e., a vessel-specific intercept), the resulting “least squares dummy variable” estimates absorb cross-sectional differences in mean diversification across vessels and uses only within-vessel variability in diversification over time to estimate each β_t , revealing the average vessel-level change in diversity relative to 1981—the “individual effect”. The difference between

the overall mean and this individual effect is the compositional effect, which is meant to represent changes in the average diversity of vessels within the changing sample each year, relative to the base year. We use the same statistical approach to distinguish individual and compositional effects in trends of vessel revenue.

Our metric of financial variability in each period is the coefficient of variation (CV) of revenue per vessel over successive 8-year periods. CV has been used as a metric of variability in several previous studies of fisheries (e.g., Kasperski and Holland 2013; Sethi et al. 2014; Holland et al. 2017a; Abbott et al. 2023) and has the merit of providing a normalized, unit-free measure of “relative risk”. We use 8-year blocks of time because we are interested in evaluating changes in CV after 2014 when temporal diversification began to decline. Abbott et al. (2023) tested statistical relationships of diversification and CV of revenue with 6, 8, and 12 years blocks and found the results robust to the number of years used to calculate CV.

We evaluate the relationship between CV of revenue and fishery and temporal diversification (eq. 3) as well as the relationship between average revenue and diversification (eq. 4). We regress logged vessel-level CV of revenue and average revenue over successive 8-year periods (p) against the vessels’ average fishery and temporal diversification over those periods:

$$(3) \quad \ln(CV_{i,p}) = \alpha + \alpha_i + \beta_1 \overline{temporal}_{i,p} + \beta_2 \overline{fishery}_{i,p} + \gamma X_{i,p} + \gamma_p + \varepsilon_{i,p}$$

$$(4) \quad \ln(AvgRev_{i,p}) = \alpha + \alpha_i + \beta_1 \overline{temporal}_{i,p} + \beta_2 \overline{fishery}_{i,p} + \gamma X_{i,p} + \gamma_p + \varepsilon_{i,p}$$

X_{ip} contains controls for the number of active years for vessel i in period p . The γ_p are a series of period dummy variables, included to control for shared temporal trends in CV of revenue in the fishery that could be otherwise confounded with the average trend in diversification. Similarly we control for trends in average revenue in eq. 4. The vessel fixed effect α_i represents unobserved, time-persistent factors at the vessel level that may cause a vessel to experience a greater or lesser degree of revenue variability (or higher or lower mean revenue) than average and may be correlated with the vessel’s diversification strategy. For this reason, we estimate eqs. 3 and 4 using the within (i.e., fixed effects) estimator (Wooldridge 2015) to ensure that the effects of diversification on CV and mean revenue are estimated solely on the basis of within-vessel changes in diversification across 8-year time periods. To ease interpretation of the effects of diversification on risk and facilitate comparisons across the different types of diversification, we standardize the diversification indices by subtracting the population mean and dividing by the standard deviation (converting to a z score), so that the coefficients can be interpreted roughly as the percentage effect on relative risk of a 1 standard deviation change in each form diversification¹. Note that our regressions are modeling si-

¹ $1 - \exp(\text{coefficient})$ yields the percentage change for a one-standard deviation change in the variable, which is close but slightly less in magnitude to the coefficient.

multaneous changes in diversification and revenue variation for vessels over time as opposed to evaluating the effect of a diversification strategy on revenue variation in future years. Unlike, financial diversification, fishery diversification is not an ex-ante (buy and hold) strategy but a dynamic one influenced by effort and participation decisions made in response to expected profits and other factors like time-area closures that may impact a vessel’s ability to participate. Nevertheless, these choices may be heavily constrained by prior decisions on permits purchased, vessel characteristics, and previous experience (Vasquez et al. 2023).

To evaluate the expected impact of changes in diversification across vessels and time on revenue variation, we use eq. 3 to predict CV for each vessel and period and compare mean predicted CV levels across periods. These comparisons include both compositional and within-vessel changes in average relative risk. To isolate the impacts of adaptive (within-individual) changes, we evaluate the change in vessel level predictions of CV for vessels that persist (have revenue) across at least two 8-year periods focusing on changes between the 2008–2014 and 2015–2022 period.

We suspect that the observed decline in the temporal diversification post 2014 was due to a series of environmental and economic shocks associated with marine heatwaves and COVID that may have particularly impacted vessels with lower fishery diversification if they were dependent on fisheries most impacted by these shocks. To better understand the causes of the decrease in temporal diversification and which types of vessel were more impacted, we evaluate trends in total effort (vessel weeks) across fisheries. We also model the trend in temporal diversification in the 8-year periods before and after 2015 to explore how changes in diversification at the vessel level relate to their pre-2015 levels of temporal and fishery diversification.

$$(5) \quad \left(\overline{temporal}_i^{2016-2022} - \overline{temporal}_i^{2008-2014} \right) = \alpha + \beta_1 \overline{temporal}_i^{2008-2014} + \beta_2 \overline{fishery}_i^{2008-2014} + \varepsilon_i$$

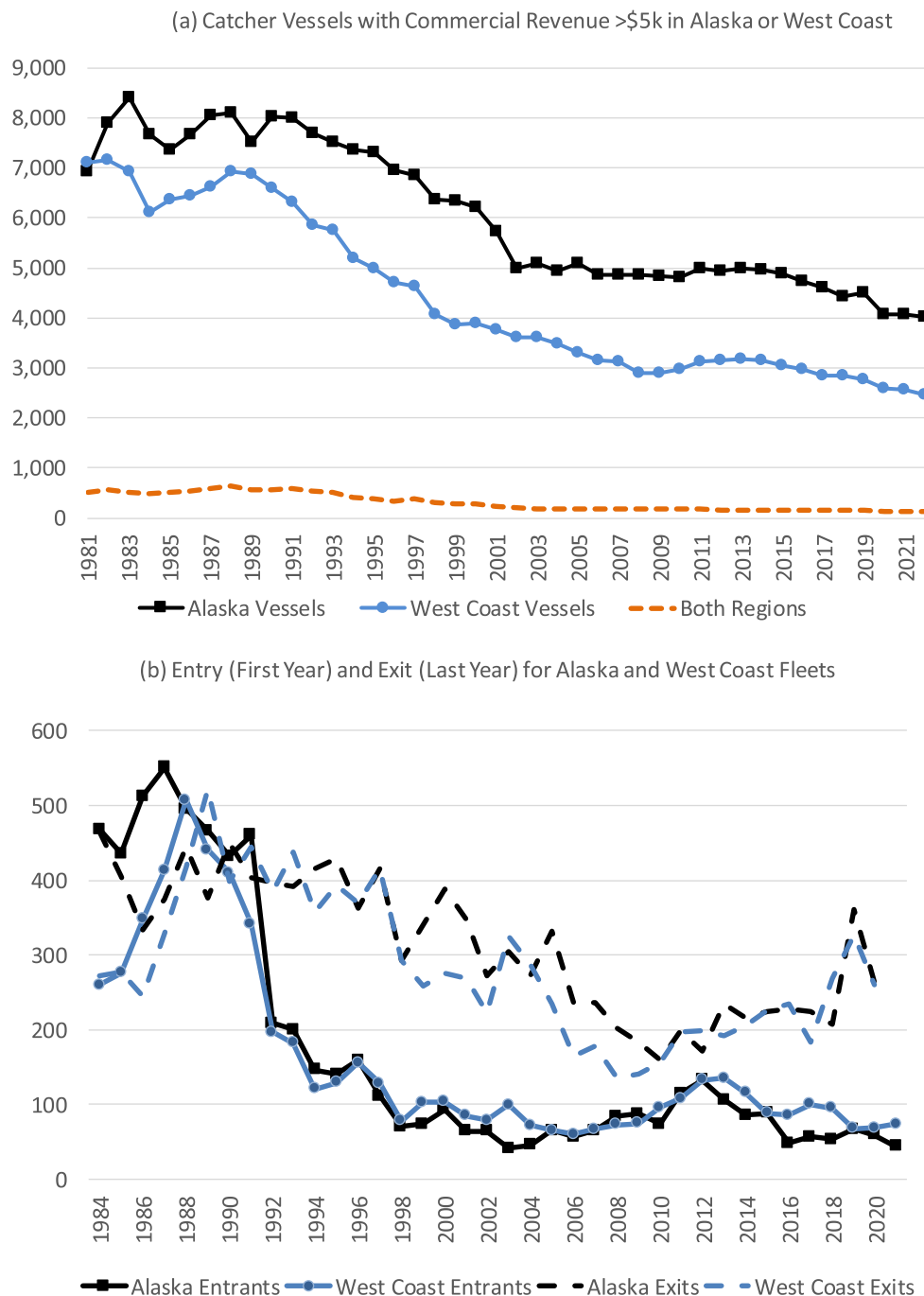
We standardize the diversification indices used as explanatory variable as z scores so that they are comparable and so that the coefficients, β_1 and β_2 , can be interpreted as the effect on the absolute change in temporal diversification from one standard deviation change in the level of temporal or fishery diversification during the 2008–2014 period.

4. Results

4.1. Trends in participation

Excluding catcher processors and vessels with less than \$5000 in average revenue, the number of vessels participating in the Alaska and West Coast fisheries between 1981 and 2022 ranged from a high of 14 810 in 1983 to a low of 6349 in 2022. There was a steep decline in number of vessels fishing in Alaska between 1990 and 2002 falling from over 8000 vessels to under 5000 vessels, followed by a period of fairly stable participation through 2015 and then nearly a 25% decline between 2015 and 2022 to about 4000 vessels (Fig. 1a). The West Coast fleets began to decline in 1989 falling from around 7000 vessels to under 3000 by 2008. The West Coast

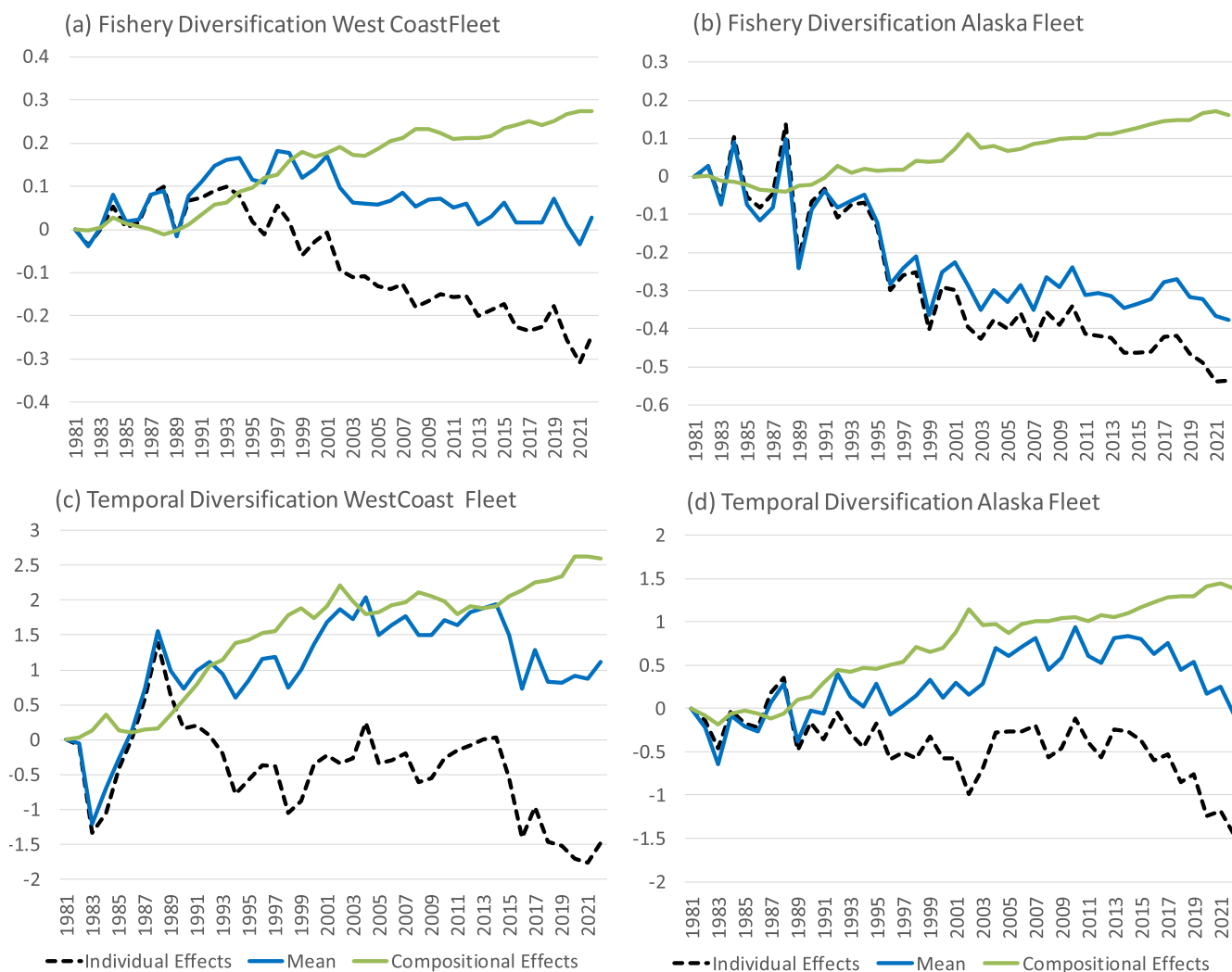
Fig. 1. Trends in (a) number of active vessels, and (b) entry and exit for Alaska (black lines) and West Coast (blue lines) and combined (orange dashed line) commercial fishing fleets (excluding catcher-processors and vessels with average revenue less than \$5000).



fleet size then rose slightly reaching 3169 in 2013 before beginning to decline again, falling to 2467 in 2022. A small minority of vessels participate in both Alaska and West Coast fisheries in a given year, and that fleet also has declined over time falling from a peak of 651 in 1988 to only 126 in 2022. Note that these fleet sizes don't include catcher processors or motherships. The steep declines in Alaska and West Coast fleets in the 1990s coincided with the implementation of permit moratoriums and limited entry programs in a number of

fisheries, including groundfish fisheries in both regions and Dungeness crab fisheries in West Coast states (Table 1). More recent declines since 2015 appear to be associated primarily with declines in salmon fisheries in both regions as well as some compression of Dungeness crab seasons on the West Coast and, more recently, impacts of COVID19 and disruptions in global fisheries supply chains amid ongoing trade disputes and the war in Ukraine. The decline in number of vessels likely is greater than the decline in fishing capacity

Fig. 2. Decomposed trends showing mean (blue line), individual (black dashed line) and compositional (green line) for (a and b) fishery diversification and (c and d) temporal diversification for Alaska and West Coast commercial fishing fleets (excluding catcher-processors and vessels with average revenue less than \$5000).



due both to technical change and higher attrition by smaller vessels. However, we did not attempt to evaluate changes in fishing capacity due to a lack of comprehensive data to do so and because physical measures (e.g., based on horsepower and length) may not be good indicators of relative fishing power across diverse fisheries.

Although the fleets have been generally declining in size since 1990s, there have been a considerable number of new entrants each year offsetting some of the exiting vessels (Fig. 1b). The number of vessels exiting each year rose in the late 1980s to a peak of 853 in 1989 for Alaska and West Coast fleets combined and then declined until 2010 with 270 vessels exiting that year. The number of exiting vessels then began to increase again after 2015 rising to 582 in 2019. The number of vessels entering each year peaked at 903 in 1988 and then declined steeply to below 200 new entrants by 1998. A larger number of vessels appear for the first time in our data in 1982 and 1983, but it is likely that many of those were already active prior to the start of our data series in 1981. New entrants

briefly rose above 200 in 2011–2013 but then declined again in the following years with only 115 new vessels appearing in 2021. The trends in exit and entry have been qualitatively similar in Alaska and the West Coast. Both saw a decline in both exit and entry in the 1990s and early 2000s and both have seen a surge in exiting in the last several years, though it is possible that some of the vessels that exited in the last few years could return to the fishery at some point.

4.2. Trends in diversification

Both Alaska and West Coast vessels have seen considerable year-to-year variation in the diversification of their annual revenue across species groups and there is a great deal of variation across individual vessels (see Figs. S2.1 and S2.2 in the Supplementary material). While the trend is somewhat erratic and does not decline in all years, average fishery diversification has generally trended down over the 40-year period (Figs. 2a and 2b). For the fleet fishing in 2022, average fishery diversification was at its lowest level in the time series.

Table 2. Regressions of change in vessel average temporal diversification from the 2008–2014 period to the 2016–2022 period (dependent variable) on standardized average temporal and fishery diversification in the 2008–2014 period (explanatory variables).

Model	Regression coefficients		Obs.
	Std. temporal diversification	Std. fishery diversification	
	2008–2014	2008–2014	
Alaska vessels			
OLS	– 1.9536***	0.1267**	5471
Quantile regression	– 1.8147***	0.0401	5471
OLS—drop extreme outliers based on $\text{abs}(\text{Dfbeta}) > 0.1$	– 1.8055***	0.0387	5446
OLS—drop extreme outliers based on $\text{abs}(\text{Dfbeta}) > 0.027$	– 2.0793***	0.0986*	5083
West Coast vessels			
OLS	– 2.4081***	0.4060***	4066
Quantile regression	– 2.0821***	0.3166***	4066
OLS—drop extreme outliers based on $\text{abs}(\text{Dfbeta}) > 0.1$	– 2.3602***	0.3304***	4055
OLS—drop extreme outliers based on $\text{abs}(\text{Dfbeta}) > 0.031$	– 2.3525***	0.2251**	3869

Note: Temporal and fishery diversification indices used as explanatory variables are standardized by subtracting the mean and dividing by the standard deviation to make ease comparison and interpretability. We run the model with various transformations of the dependent variable and removal of outliers to determine the robustness of the results and the degree to which they are driven by a small number of outliers. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

Overall trends differ for the Alaskan and West Coast fleets. For the Alaska fleet, fishery diversification was on a declining trend in the 1980s and 1990s and then fairly stable over the last two decades. For the West Coast fleet, average fishery diversification showed an increasing trend through around 2000 and then declined in the last two decades (Figs. 2a and 2b). The decline in fishery diversification is due to a decline in the level of diversification by individual vessels over time as opposed to a compositional change (Figs. 2a and 2b). The decline is actually mitigated by the compositional effect, which is due both to less diversified vessels being more likely to leave and because entering vessels tend to be more diversified than exiting vessels on average. This is the case for both the Alaskan and West Coast fleets.

For temporal diversification, we see quite different trends relative to average fishery diversification (Figs. 2c and 2d). Average temporal diversification was generally increasing for both Alaska and West Coast fleets until 2015 and then began to decline in both regions. The increase in temporal diversification likely reflects the fact that fewer vessels were competing for fish in limited access fisheries allowing for longer seasons, with greater overall flexibility in when to fish. When catch shares were introduced, individuals were able to spread their fishing over the year without fear of losing out on revenues from those fisheries, and those with permits in other fisheries could participate in those fisheries and then switch to the catch share fishery when the others were closed or less profitable.

As with fishery diversification, the mean trends in temporal diversification were impacted both by individual and compositional effects (Figs. 2c and 2d). Individuals tended to reduce temporal diversification on average beginning in the early 1990s, but compositional effects associated with exit and entry kept the mean trend in both Alaska and the West Coast rising until 2015. After 2015, a steep decline in individual temporal diversification more than offset increases associated with compositional effects, causing the mean level of temporal diversification to fall as well. There is a signifi-

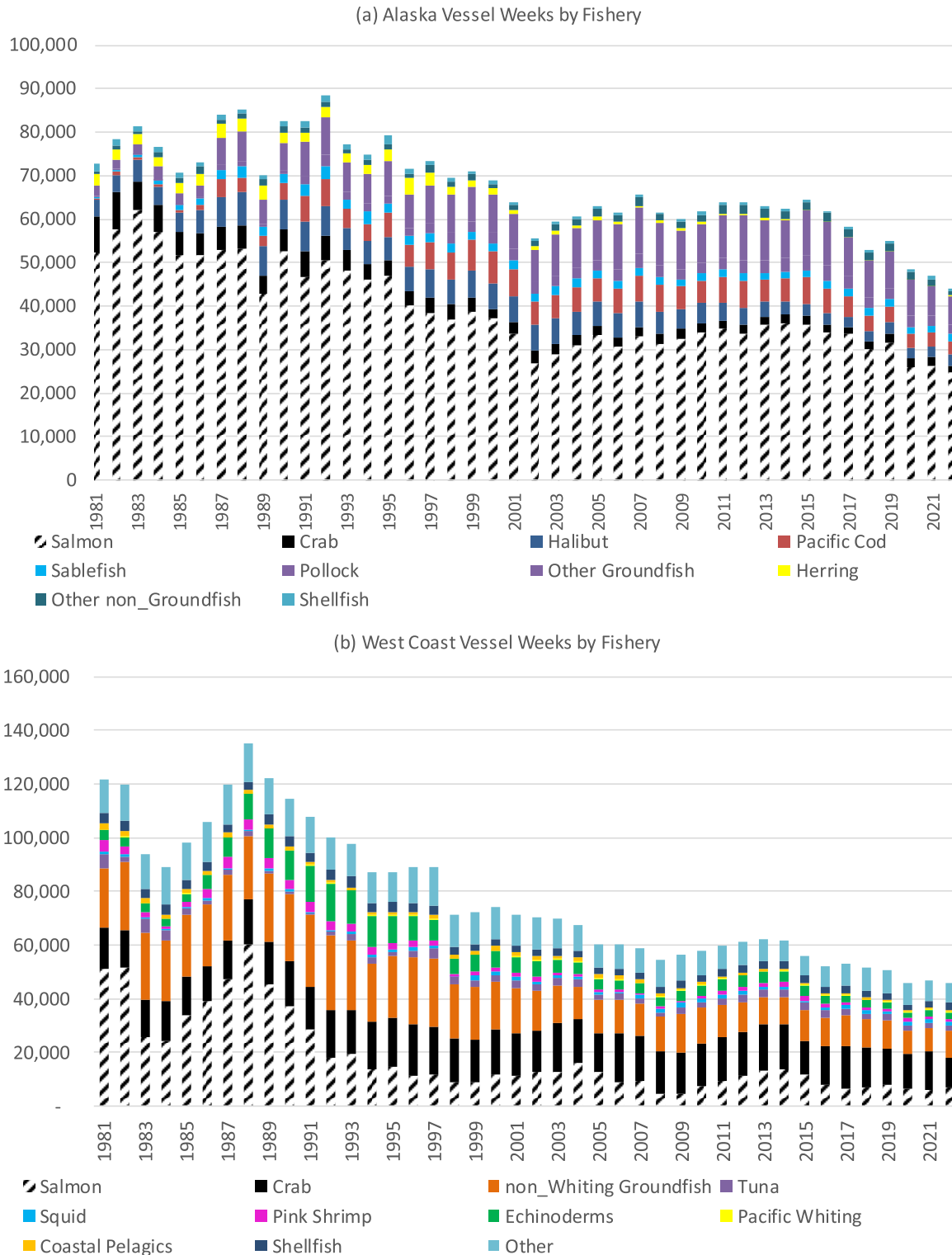
cant drop in average temporal diversification at the individual level between the 2007–2014 and 2015–2022 periods, and the trend in temporal diversification reversed and became negative after 2014 for both Alaska and West Coast fleets (see Supplementary material S2 for description and results of statistical tests).

The decline in average temporal diversification between the 2008–2014 period and the 2016–2022 period is due mainly to the decline in temporal diversification of fishers that had relatively high levels of diversification in the 2008–2014 period. Temporal diversification in the 2016–2022 is significantly negatively correlated with the vessels' temporal diversification in the 2008–2014 period (Table 2 and Supplementary material Figs. S2.1 and 2.2). While salmon and crab fisheries have seen the largest declines in effort (Fig. 3), those declines impacted diversified fishers' portfolios and thus temporal diversification. Fishers with revenue in many different fisheries prior to the 2015 (e.g., chinook salmon, groundfish, and Dungeness crab on the West Coast and chinook salmon, halibut, and Pacific cod in Alaska) did see declines in temporal diversification. However, on average, vessels with higher fishery diversification had relatively smaller declines in temporal diversification after 2014 as evidenced by the positive coefficient on 2008–2014 fishery diversification, though this effect is only weakly significant for the Alaska fleet (Table 2).

4.3. Trends in vessel revenue and inter-annual revenue variation

Mean trends in revenue per vessel (in 2005 dollars) for the combined Alaskan and West Coast fleets over the 1981 and 2022 were mostly increasing. However, the trend for the Alaska fleet was declining in the late 1980s and 1990s, and the trend for the West Coast fleet during that period was relatively flat. If we decompose the trends into individual and compositional effects, as was done for diversification, we see that the decreasing trend in the late 1980s and 1990s was due primarily to individual effects (reduced earnings for those

Fig. 3. Number of vessel weeks of fishing effort by fishery in (a) Alaska and (b) West Coast fisheries 1981–2022.

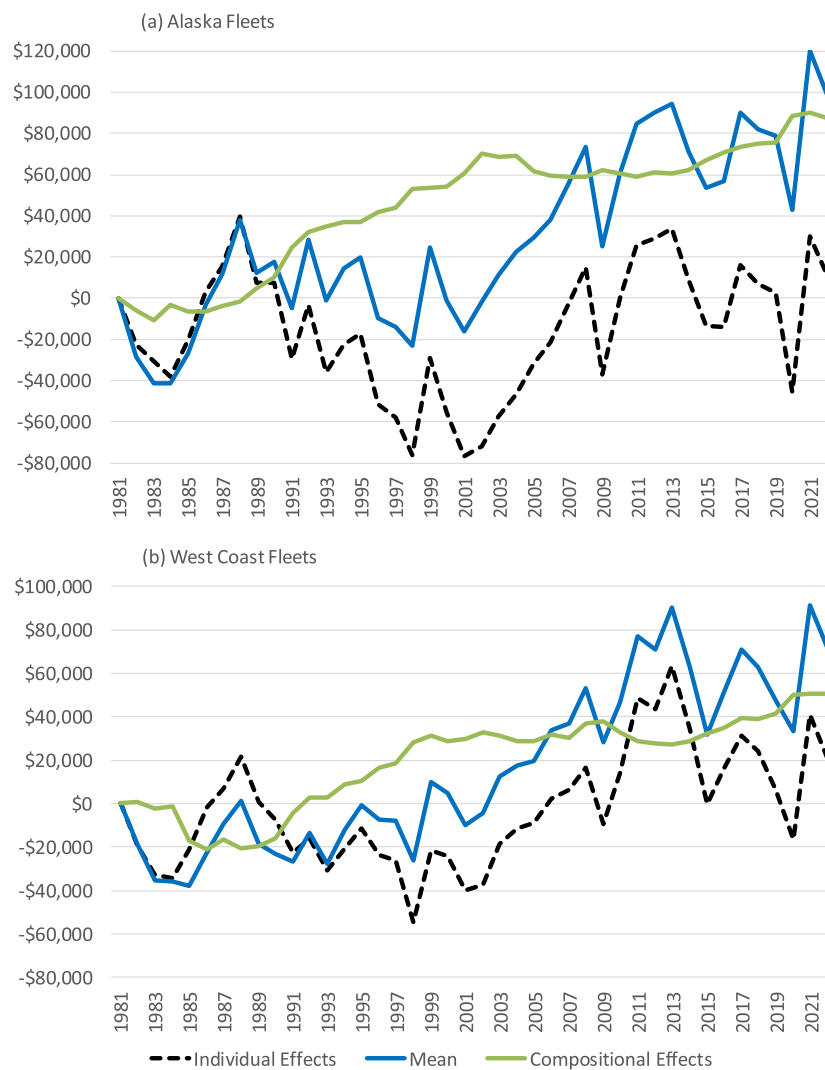


staying in) and was mitigated by the compositional effect, with those leaving tending to have lower revenues on average than vessels that remained and new entrants (Fig. 4). After 2000, the compositional effect was relatively flat, and gains in vessel revenue were associated with the individuals already in the fleets increasing earnings over time. The compositional

effect in average vessel revenue did begin to increase again around 2015 for the fleets in both regions.

Despite the decrease in fishery diversification, the CV of inter-annual revenue (measured over 8-year periods) declined fairly steadily between 1981 and 2014 and the distributions generally become more concentrated at lower levels of CV

Fig. 4. Decomposed trends in vessel revenue showing mean (blue line), individual (black dashed line), and compositional (green line) for (a) Alaska and (b) West Coast commercial fishing fleets (excluding catcher-processors and vessels with average revenue less than \$5000). Revenues are in 2005 dollars.

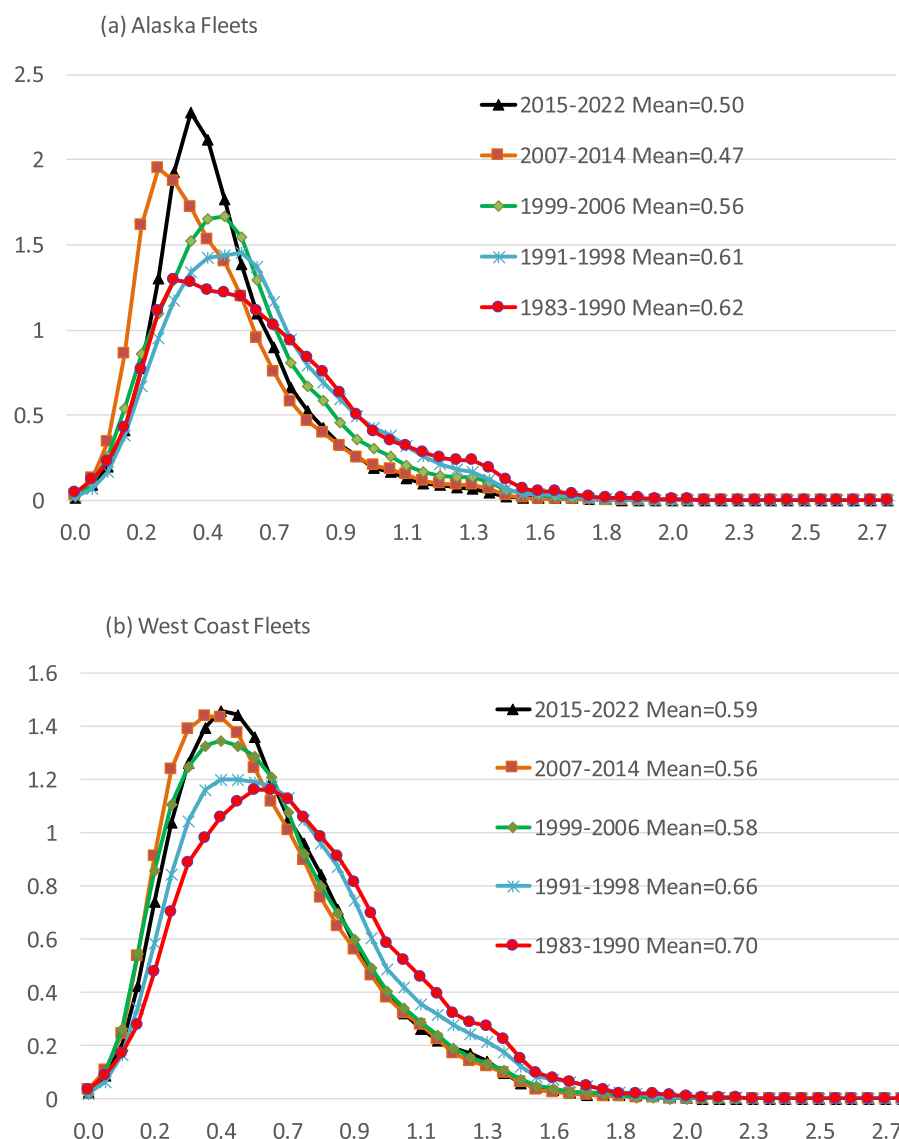


(Fig. 5). As Abbott et al. (2023) noted, CV of revenue is more strongly correlated with temporal diversification than fishery diversification, and temporal diversification was generally increasing through 2014. However, the CV of revenue increased in the 2015–2022 period (the distribution of CV across vessels broadened and shifted right). Notably, both fishery and temporal diversification declined significantly in that period for both Alaska and West Coast fleets (see Supplementary material for statistical test of changes).

Abbott et al. (2023) found that, for the West Coast fleet between 1990 and 2015, CV of revenue tended to decline with increases in fishery and temporal diversification, but that temporal diversification had a stronger effect. Our regressions over a longer period of time (1981–2022) for the Alaska fleet as well as the West Coast fleet confirm this relationship (Table 3). In both regions, CV for individual vessels was reduced with increases in both temporal and fishery diversification. For the Alaska fleet, the interaction be-

tween temporal and fishery diversification is also negative, suggesting that the two types of diversification complement each other to reduce revenue variation. The interaction term is not significant for the West Coast fleet, but both temporal and fishery diversification have a stronger impact in reducing revenue variation individually. A one standard deviation increase in temporal diversification reduces CV by 20.1% for Alaska vessels and by 26.7% for West Coast vessels. A one standard deviation increase in fishery diversification reduces CV by 4.4% and 9.5%, respectively for Alaskan and West Coast vessels. Using eq. 3 to predict CV for vessels in different time periods predicts a decline in average CV of 29% for the Alaska fleet between the 1983–1990 period and the 2007–2014 period but then an increase of 12% in the 2015–2022 period. The predicted average CV declines 20% for the West Coast fleet between the 1983–1990 period and the 2007–2014 period but increases 7.6% in the 2015–2022 period. Fishery diversification was declining over all these periods but

Fig. 5. Kernel density estimates of the distribution of coefficient of variation of vessel revenue over 8-year periods for (a) Alaska and (b) West Coast commercial fishing fleets (excluding catcher-processors and vessels with average revenue less than \$5000).



temporal diversification was increasing until the final period (2015–2020), more than compensating for the effect of fishery diversification on CV. If we look at the change in predicted CV only for vessels that are observed in both the 2007–2014 and 2015–2022 periods, eliminating the compositional effect of exit and entry, the predicted increase in CV is greater at 20.1% and 14.3% for the Alaska and West Coast fleets, respectively.

We also explored the relationship between average revenue and diversification to see whether there is a trade-off between mean revenue and variation in revenue. Our regressions indicate that, for both the Alaska and West Coast fleets, average revenue tends to increase with higher fishery diversification and higher temporal diversification (Table 4). As with CV or revenue, temporal diversification tends to have a stronger effect, but this is not surprising given that temporal diversification is highly correlated with the number of weeks

the vessels fish. Unlike the model of CV, the interaction term between the two types of diversification is negative.

5. Discussion

Limited access programs and direct catch limits introduced in the 1980s and 1990s often failed to sufficiently limit capacity, overfishing, and rent dissipation leading fishery management councils and state agencies in Alaska and the West Coast to restrict season length, implement input controls such as trap limits, reduce capacity with buybacks, and implement catch share programs either with IFQs or cooperatives. The cumulative effect of these policy measures over the last four decades has been to reduce the number of vessels participating in Alaskan and West Coast commercial fisheries by more than half.

Table 3. Regression of the coefficient of variation (CV) of vessel revenue (dependent variable) on fishery and temporal diversification levels (explanatory variables).

Variable	Alaska coefficients	West Coast coefficients
Temporal diversification	− 0.225***	− 0.311***
Fishery diversification	− 0.045***	− 0.099***
Temporal–fishery diversification interaction	− 0.046**	0.016
1983–1990 constant	0.027**	0.065***
1991–1998 constant	0.107***	0.058***
1999–2006 constant	0.036***	− 0.009
2007–2014 constant	− 0.131***	− 0.043***
Year count	0.026***	0.027***
Constant	− 0.915***	− 0.809***
R-square	0.09	0.13
Sigma u (fixed effect)	0.56	0.53
Sigma e	0.49	0.49
% decrease in CV from 1 Std. Dev. Increase in diversification		
-Temporal diversification	20.1%	26.7%
-Fishery diversification	4.4%	9.5%
Predicted CV 1983–1990	0.67	0.75
Predicted CV 1991–1998	0.64	0.66
Predicted CV 1999–2006	0.57	0.59
Predicted CV 2007–2014	0.47	0.57
Predicted CV 2015–2022	0.53	0.62
% change overall predicted average CV between 2007–2014 and 2015–2022	12.0%	7.6%
% change predicted CV matched vessels between 2007–2014 and 2015–2022	20.1%	14.3%

Note: Dependent variable natural log of CV of vessel revenue over 8-year periods. Diversification coefficients are standardized. Vessel level fixed effects. With logged dependent variable and standardized coefficients, one standard deviation increase in the dependent variable leads to a decrease in the CV equal to $1 - \exp(\text{coefficient})$.

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

Table 4. Regression of the average vessel revenue (dependent variable) on fishery and temporal diversification levels (explanatory variables).

Variable	Alaska coefficients	West Coast coefficients
Temporal diversification	0.565***	0.720***
Fishery diversification	0.228***	0.305***
Temporal–fishery diversification interaction	− 0.237***	− 0.301***
1983–1990 constant	0.367***	0.061***
1991–1998 constant	− 0.026**	− 0.200***
1999–2006 constant	− 0.289***	− 0.255***
2007–2014 constant	0.032***	− 0.025*
Year count	0.058***	0.053***
Constant	10.532***	10.384***
R-square	0.24	0.24
Sigma u (fixed effect)	1.09	0.53
Sigma e	0.45	0.49

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

The implementation of limited entry and catch share programs coincided with steady declines in fishery diversification over time. This might have been expected to result in lower vessel revenue and increased revenue variation, which had been shown to be correlated with reduced fishery diversification (Kasperski and Holland 2013). However, temporal diversification generally increased from the late 1980s through

2015. As Abbott et al. (2023) showed and was reconfirmed in our analysis over a broader spatial and temporal sample, temporal diversification has a stronger moderating impact on inter-annual variation of revenue than fishery diversification. The reduction in the CV of inter-annual revenue average from the late 1980s through 2015 that coincided with increases in temporal diversification suggests that the seasonal

flexibility and elongation of the fishing season associated with limited entry and catch share programs may have more than mitigated their dampening effects on fishery diversification at the industry level (though not necessarily for all fishers). As fleets contracted under limited license moratoriums, vessels, particularly new entrants, were able to spread fishing over more of the year. In catch share fisheries, seasons often lengthened dramatically as fisheries transitioned from derbies to year-round fisheries, a result that is widely observed after implementation of catch share programs (Birkenbach et al. 2017). Holland et al. (2017a) found that, when catch share program were implemented, inter-annual variation in vessel revenue did not generally increase despite a reduction in fishery diversification, suggesting that these programs may have had revenue-stabilizing effects that offset the effects of lower fishery diversification.

These trends have seen a significant reversal in recent years. Since 2015, we have seen reductions in both temporal and fishery diversification, increased inter-annual revenue variation, and further attrition from both Alaska and West Coast fleets. One narrative that is consistent with the trends we have uncovered is that high dependency on a few fisheries, may have left fishers vulnerable to ecological and economic shocks that impacted key fisheries, leading to increased income variation and further declines in participation in recent years. During this period, both regions have suffered a number of climate related shocks as well as a pandemic. Ocean heat waves off Alaska and the West coast and reductions in sea ice have had major negative impacts on productivity for some species, particularly for salmon along the West Coast and for salmon and Pacific cod in the Gulf of Alaska, and most recently king and tanner crab in the Bering Sea. The lack of fishery diversification of fishers, and inability to move into other fisheries, may have reduced the ability of the fleet to adjust to these climate shocks leading to lower revenues in some years and greater attrition. We cannot say whether a higher level of fishery diversification on average would have had enable the fleets to mitigate the impacts of these ecological and economic shocks and avoid reductions in revenue and higher revenue variation, but we do find some indirect evidence to support that proposition. We found that the decline in average diversification for the fleet was driven mainly by vessels with relatively high levels of temporal diversification (the most active vessels), but the impact was mitigated for vessels with higher fishery diversification (Table 2).

The climate and economic shocks of the last decade not only impacted vessels that remained in the fishery, it also led many fishers to exit, at least temporarily. Much of the overall decline in effort since 2015 is associated with declines in salmon fisheries (Fig. 3) in both Alaska and the West Coast. Salmon fisheries, though not the highest contributors to overall regional revenues, have large numbers of small-scale participants, so these impacts on salmon fisheries have very pronounced impacts on overall participation and on average levels of diversification and average inter-annual variation in revenue. Richerson and Holland (2017) found that salmon fishers with low fishery diversification were more likely to cease fishing (sometimes permanently) rather than move to

other fisheries in the event of closures of major salmon fisheries. Salmon fishers do tend to have relatively high shares of household income from non-fishery sources (Treakle et al. 2023). Accordingly, they may be more able to leave the fishery when conditions are poor and support themselves and their households in other ways, so that recent increases in fishery revenue variability may overstate overall livelihood variability. The Dungeness crab fishery on the West Coast, which also has large numbers of participants, has been impacted by toxic harmful algal blooms that led to closures and delays. This reduced the primary source of fishing income for many fishers and led many to cease all fishing, at least temporarily (Holland and Leonard 2020). Owners of smaller vessels that are less mobile were particularly impacted by harmful algal bloom closures (Jardine et al. 2020). In addition, increased whale entanglements, which coincided with a shoreward shift of migrations following the ocean heatwaves, have further squeezed the Dungeness crab seasons, causing both delays in opening and earlier closures in California that have further reduced revenues (Seary et al. 2022). Altogether, the nature of the recent shocks to key fisheries—with their management-driven effects on season length and timing—may have limited fishers' capacity to mitigate their effects through temporal diversification within their limited fishery portfolios. Instead, the shocks have reduced opportunities for temporal diversification, fishers' previously most efficacious diversification strategy, after decades of growing fishery specialization.

While it is possible that recent trends of lower temporal diversification, higher revenue variation, and increased attrition will reverse in the future, the variation in climate and associated ecological shocks are likely to persist if not increase, underscoring the importance of finding new approaches to stabilize incomes for fishers and fishing communities. Liu et al. (2023) find that distributions and productivity of West Coast species are expected to change substantially with climate change requiring fishers to shift what and where they fish to remain profitable. Opportunities for fishers to diversify income by entering additional fisheries are limited or costly, requiring investments in permits, quota, and gear. There are a few fisheries such as Albacore tuna on the West Coast and small trip-limited groundfish fisheries in state waters that still have open access, but entry into other fisheries requires purchase of permits or quota from existing fishers, and these may be too costly for smaller vessel owners with limited access to capital. We lack the data on costs of diversification (particularly permit and quota values) to evaluate whether the gains from diversification in terms of higher revenue or lower revenue variation are sufficient to offset the costs. Haugen et al. (2021) found that younger fishers in Oregon feel that larger vessels and diverse permit portfolios are necessary to be successful in West Coast fisheries that are facing increased variability and shifting stocks under climate change, but they are reluctant to make these risky investments and find it difficult to access financing. Expanding access to financing for purchases of permits or quota for smaller operators through loan guarantee programs or direct financing mechanisms such as NOAA's fishery finance program could help fishers to increase both

fishery and temporal diversification as well as revenue, though there is a risk that subsidized financing could also put upward pressure on permit and quota prices. It is notable that, while our regressions of average revenue against diversification indicate both fishery and temporal diversification were associated with higher average revenue, temporal diversification has a stronger effect, with a negative interaction term between the two types of diversification. This may suggest that increasing the amount of fishing within a fishery may be better strategy in terms of increasing economic returns than doing so by spreading fishing across more fisheries. However, diversification across fisheries may be the only means to increasing temporal diversification if seasons are constrained.

Many of the participants in West Coast fisheries diversify household income with other non-fishing employment, including income from other household members as well as their own employment (Holland et al. 2019; Treacle et al. 2023). This diversification may be as, or more, effective than diversification within fisheries at reducing income variation, particularly if shocks from climate and ecological shocks increase in frequency, severity, and geographic scale to the point that they constitute a systemic (to the entire fishery complex) risk that is not effectively addressed through fishery and temporal diversification. However, there are trade-offs between diversification of income within and outside of fisheries. Fishers with higher temporal diversification in the fishery tend to have lower levels of non-fishery income (as a proportion of the income they contribute to their households) (Treacle et al. 2023). More research on livelihood diversification by fishers and its financial and social impacts on individuals and communities is needed.

Acknowledgements

We thank Chris Anderson for his comments on an earlier version of this paper.

Article information

History dates

Received: 4 September 2024

Accepted: 11 December 2024

Accepted manuscript online: 6 January 2025

Version of record online: 29 January 2025

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Data availability

The landings data and vessel registration data utilized for this study are confidential fisheries data and cannot be shared by the authors. They can be obtained through PacFIN (<https://pacfin.smfc.org/home/>) and AKFIN (<https://www.psmfc.org/program/alaska-fisheries-information-network-akfin>) upon completion of a data non-disclosure.

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Competing interests

We have no known conflicts of interest.

Funding information

Funding for this research was provided by the U.S. National Oceanic and Atmospheric Administration.

Supplementary material

Supplementary data are available with the article at <https://doi.org/10.1139/cjfas-2024-0271>.

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