Examining the evolution of access to Alaska's halibut IFQ fishery

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Steinkruger, A., & Szymkowiak, M. (2023). Examining the evolution of access to Alaska's halibut IFQ fishery. *Ocean & Coastal Management*, 242, 106706.

Keywords: Alaska, Pacific halibut, rights-based management, individual fishing quota, catch share

Abstract

In fishing communities, livelihoods and well-being depend on sustaining access to key fisheries through changes in natural resource management. In Alaska, the rationalization of the commercial fishery for Pacific halibut (*Hippoglossus stenolepis*) in 1995 led to the consolidation of the halibut fleet. The high cost of halibut catch shares have since become a crucial barrier to prospective entrants, especially small-scale operations with few options for portfolio diversification. However, quantitative approaches to understanding that barrier face an information gap: datasets on harvest and catch share ownership in fisheries lack common identifiers for individuals. We match individuals across harvest and catch share ownership data from 1991 through 2019, enabling a detailed examination of entrants and non-entrants – those who acquire or do not acquire halibut catch shares over the time series. We compare fisheries portfolios in terms of participation and earnings through duration, dissimilarity, and network analyses. Differences over time and between entrants and non-entrants emerge across analyses. For both groups, cohorts of participants shrink and real individual earnings increase over the time series. However, entrants' cohorts have decreased further relative to historical participation, while entrants' real earnings and fisheries portfolio compositions have diverged from those of non-entrants. Our results reveal broad differences in Alaska fisheries participants' access to a critical fishery, underscoring the role of catch shares in shaping fishing communities' opportunities and resilience in the face of social and environmental change.

1. Introduction

Fisheries are critical to the well-being of coastal communities throughout the world, providing benefits from livelihoods and food security to cultural heritage (Bennett et al., 2021; Cohen et al., 2019). Yet opportunities in fisheries are at risk in socio-ecological systems struggling to adapt in the face of climate change (Craig, 2008; Szuwalski and Hollowed, 2016). Programs introducing rights-based management through catch shares have constrained access opportunities for some fisheries participants

(Carothers, 2015; Ringer et al., 2018). While catch shares often provide for economic efficiency gains, their distributional consequences also include lost opportunities for small boats, decreased fisheries diversification, movement of access rights away from rural communities, and landings in fewer ports (Abbott et al., 2022; Carothers and Chambers, 2012; Szymkowiak et al., 2020). These impacts leave some fishing communities more vulnerable to conditions associated with climate change through increased specialization diminishing portfolio resilience and ecological knowledge exchange, decreased generational turnover in fisheries, and decreased local tax revenues (Brinson and Thunberg, 2016; Eythórsson, 2000; Holland et al., 2017; Yagi et al., 2012).

In Alaska, the fishery for Pacific halibut (*Hippoglossus stenolepis*) is managed by the North Pacific Fishery Management Council ("the Council"), which manages fisheries in federal waters (from 3 to 200 nautical miles offshore). The State of Alaska manages all fisheries in state waters (from the coastline to 3 nautical miles offshore). The implementation of a catch share program for the halibut fishery has altered access to a way of life that has historically provided economic opportunities for residents of isolated and small coastal communities throughout the state (Carothers, 2015; Ringer et al., 2018). The halibut fishery off Alaska can be accessed nearshore with relatively small vessels, enabling broad participation, especially in the season preceding salmon fisheries openings when there are few alternative fisheries (Szymkowiak et al., 2020). Yet this accessibility contributed to growing capacity in the fishery and associated issues with overharvesting, safety, and poor fish quality that led the Council to implement an Individual Fishing Quota (IFQ) Program in 1995 (Szymkowiak et al., 2020). Under the IFQ Program, participants in the halibut fishery from 1988-1990 received quota shares (QS) equivalent to a percentage of the total allowable catch in a geographic area (Szymkowiak et al., 2020). Although the IFQ Program includes both halibut and sablefish, we constrain our analysis to halibut to focus on the fishery's accessibility — sablefish is harvested further offshore with larger vessels (Szymkowiak and Himes-Cornell, 2015).

Since IFQ implementation, gains in economic efficiency, shifts from frozen to fresh products, and other improvements in product handling have led to increased earnings expectations reflected in QS price

increases on the order of 500% in some IFQ areas (North Pacific Fishery Management Council and National Marine Fisheries Service, 2016; Szymkowiak et al., 2020). Increasing prices are a critical barrier for aspirational entrants without collateral for loans to purchase QS, unlike initial recipients who use QS allocations to support the acquisition of additional shares (North Pacific Fishery Management Council and National Marine Fisheries Service, 2016; Szymkowiak et al., 2020). Instead, new entrants must offer substantial down payments and rely on other capital to enable QS acquisition (North Pacific Fishery Management Council and National Marine Fisheries Service, 2016; Szymkowiak et al., 2020). Although definitions of entry differ over individual and policymaking perspectives (Henry, 2021), we define entry with respect to the initial acquisition of halibut QS, including any first purchase of halibut QS by an individual.

Access to the halibut IFQ fishery is analogous to participation opportunities in other small-scale, local fisheries, where constraining entry risks adverse socioeconomic outcomes for fishing participants, fleets, and communities (Eythórsson, 2000; Hannesson, 2013). Young fisheries participants in Alaskan waters have increasingly shifted to rely on state fisheries, especially salmon, for earnings and for opportunities to accumulate capital for halibut QS acquisition (Ringer et al., 2018; Szymkowiak, 2020a). This specialization can present substantial problems to stabilizing revenues over time (Kasperski and Holland, 2013; Ringer et al., 2018; Szymkowiak, 2020a). The challenges faced by aspiring entrants tend to result in participants of increasing average age in fleets and fishing communities (Donkersloot and Carothers, 2016).

Factors influencing entry into catch share fisheries are an area of intense concern in Alaska (Donkersloot and Carothers, 2016; Szymkowiak et al., 2020) and elsewhere (Bertheussen et al., 2021; Cramer et al., 2018; Hoefnagel and de Vos, 2017; Hoshino et al., 2020; Johnson and Mazur, 2018; Pinkerton and Edwards, 2009). In the halibut IFQ fishery alone, researchers have examined entry through multiple approaches. Some analyses consider the demographic characteristics of individuals who buy and sell quota shares (Carothers, 2013; Carothers et al., 2010; Szymkowiak et al., 2019). Others analyze changing entry patterns and altered succession associated with leasing practices and capital needs

(Szymkowiak and Himes-Cornell, 2017, 2015). Researchers have also described the generational and community-level impacts of lost access to the fishery (Carothers et al., 2010; Ringer et al., 2018).

Recognition of tremendous changes in access opportunities into the halibut IFQ fisheries since 1995 has led the Council to implement diverse strategies in pursuit of multiple social objectives. In particular, the Council has sought to facilitate participation by small and remote communities (Carothers, 2011) and reduce leasing and related adverse outcomes for aspirational entrants (Szymkowiak and Himes-Cornell, 2017, 2015). However, these strategies have found limited success in terms of impacts on new entrants numbers (Szymkowiak et al., 2020). Yet recent discussions at the Council to pursue more drastic initiatives to facilitate entry into the halibut IFQ fishery (Henry, 2021), modeled on similar measures in catch share fisheries elsewhere in the world (Cullenberg et al., 2017), were tabled due in part to concerns over distributional impacts from such measures on new entrants who had already invested in QS. Owning QS indicates investment and engagement in the fishery, buffers against revenue declines in other fisheries, and provides collateral for other fisheries loans or for crewing opportunities dependent on fishery access (Ringer et al., 2018; Szymkowiak et al., 2020). Yet critical questions remain about who has successfully entered the halibut IFQ fishery, what drives entry decisions, and how opportunities and outcomes for fisheries participants have changed over time.

This study examines entry into the Pacific halibut fishery through analyses of multiple dimensions of fisheries participation. We use a unique dataset linking entrants to earnings to understand QS acquisition through changes in participation among entrants over time and differences in participation between entrants and non-entrants across all state and federal fisheries off Alaska. We analyze timing of QS acquisition and dissimilarity in fisheries permit portfolios for entrants and non-entrants. Through these analyses, we find that entrants to the halibut fishery have decreased in number while increasing their earnings and the diversity of their portfolios. We expand on the role of fisheries participation choices through network analysis, illustrating the structure of fisheries participation for entrants to the halibut fishery and detailing shifts in linkages within that structure. This research complements recent work examining entry into a different subset of Alaska fisheries managed with limited entry (Szymkowiak et

al., 2022). Together, these studies contribute to critical questions on individual entry, investment, and resilience in fisheries, building on work that has focused on decisions at the vessel level (Cordón Lagares et al., 2016; Tidd et al., 2011; Ward and Sutinen, 1994).

2. Material and Methods

2.1. Data

The data for these analyses consists of annual halibut QS holder data joined with annualized harvest and processing data. The QS data identifies individuals and their QS holdings each year and originates with the Alaska Fisheries Information Network (Pacific States Marine Fisheries Commission, 2023). The harvest data, provided by the Alaska Commercial Fisheries Entry Commission (Alaska Commercial Fisheries Entry Commission, 2023), identifies individual landings by permit holder, earnings, fisheries, species, the port of landing, and the processor of first sale (Beaudreau et al., 2019; Szymkowiak, 2020b). Permit holders are individuals making landings, most often with a limited access permit specific to a fishery defined by species, gear, and area. We restrict analyses to permit holders with complete records of commercial landings under active permits outside of harvesting cooperatives in the trawl sector, which operate largely in the Bering Sea and harvest halibut strictly as bycatch. Both the QS holder and the harvest data include unique identifiers allowing us to aggregate QS holdings and harvests by individual and year, although these identifiers are not comparable across datasets. We aggregate QS holder data to observations of each individual in each year, from 1995 to 2019. We summarize harvest data from 1985 to 2019, aggregating observations so that each represents the earnings of one individual in one fishery. We adjust participants' earnings to 2019 dollars using the Consumer Price Index (United States Bureau of Labor Statistics, 2021).

Because there are no consistent, unique identifiers across our datasets, we join QS and harvest data on first, last, middle names; and birth years. We iterate over all individuals in each dataset, both matching and non-matching, to check for false positive matches and false negative matches. We correct

false positive matches where individuals share first, last, middle names and birth years, but do not match on an additional field – for example, two individuals with common names and the same birth year who maintain different permanent addresses. We correct false negative matches where an individual fails to match on one field but does match on an additional field – for example, an individual whose first name differs across datasets due to a nickname, but whose permanent address matches across datasets. The resulting joined dataset eliminates all false positive and negative matches that are falsifiable on additional fields.

The dataset is constrained to permit holders making landings in the harvest data. While other fisheries participants (e.g. crewmembers) can also acquire QS, data describing their participation prohibit matching and analysis at the resolution enabled by harvest data. Of 2,378 individuals who acquire halibut QS in our time series between 1985 and 2019, 475 are entrants under our criteria for analysis. First, entrants must appear in harvest data in a year prior to the year of their QS acquisition to reveal portfolio strategies independent of QS ownership. Second, their first appearance in harvest data must occur in 1991 or later to eliminate the effect of participation choices in 1988-1990, the qualification period for initial allocation of QS (North Pacific Fishery Management Council and National Marine Fisheries Service, 2016). Third, entrants must not be initial recipients of QS – this is redundant with the previous criterion in principle. Fourth, and finally, entrants must not acquire QS in 1995, the first year of the IFQ program, in order to avoid misleading comparisons between the first year of markets for QS and later years. This subset of 475 entrants is also limited by the IFQ Program's requirement of at least 150 days-at-sea commercial fishery harvesting experience in any U.S. fishery.

To compare entrants to non-entrants, we also identify the subset of 19,278 non-entrant participants who forgo halibut QS acquisition after rationalization. These are participants who appear in harvest data in at least one year from 1991-2019, with their first appearance in 1991 or later to avoid comparing entrants and non-entrants with different opportunities under the IFQ Program. This subset also excludes participants who acquire QS but are otherwise not entrants under the previous definition.

To facilitate visual inference into fisheries participation, we aggregate over common species, gears, and management strategies following Szymkowiak and Kasperski (Szymkowiak and Kasperski, 2021). The resulting groups of fisheries, henceforth "fisheries," appear in Table 1 with their constituent species and gear. These fisheries include all commercial landings in state and federal fisheries off Alaska, excepting landings by trawl catcher-processors in fishery cooperatives – which are not comparable to individual entrants – and landings with incomplete data. Some fisheries in Table 1 require further explanation. Halibut sometimes appears in landings by permit holders without QS, including both entrants prior to their QS acquisition and non-entrants. There are two exceptions enabling this: landings by participants who harvested halibut prior to rationalization (1991-1994), and landings by lessee participants who harvest halibut through leasing agreements with quota holders. Beyond halibut, the fishery requiring further detail is "Other," which includes groundfish species exclusive of other groups, as well as anadromous and freshwater species and products exclusive of groups for Pacific salmon species. We conduct all analyses shown in the Results section on these groups, with analyses on alternative fisheries definitions available in Appendix A.

Table 1. Descriptions of fisheries.

Group	Fisheries
Halibut	*Hippoglossus stenolepis* harvested with hook-and-line gears.
Sablefish	*Anoplopoma fimbria* harvested with hook-and-line and pot gears.
Demersal Shelf Rockfish, Lingcod	*Sebastes* spp. and *Ophiodon elongatus* harvested with multiple gears.
Pacific Cod	*Gadus macrocephalus* harvested with multiple gears.
Herring	*Clupea pallasii* harvested with seine, gillnet, and pound gears.
Invertebrates	All crustaceans, mollusks, and echinoderms.
Chinook Salmon	*Oncorhynchus tshawytscha* harvested with multiple gear types.

Coho Salmon	*Oncorhynchus kisutch* harvested with multiple gear types.
Pink & Chum Salmon	*Oncorhynchus gorbuscha* and *keta* harvested with multiple gear types.
Sockeye Salmon	*Oncorhynchus nerka* harvested with multiple gear types.
Other	All landings unaccounted for in other groups.

2.2. Analysis

2.2.1. Descriptive Analysis

We conduct all analyses in R (R Core Team, 2021) and RStudio (RStudio Team, 2020) with tidyverse packages (Wickham et al., 2019) and additional statistical packages detailed in specific analyses.

We describe trends in entrants' experience of fisheries in relation to that of non-entrants using time series of participation and earnings. This approach draws out interpretable differences over time, over fisheries, and over entrants and non-entrants. We first visualize entrants and non-entrants' years of participation as permit holders in Alaska fisheries to capture long-term trends in entry, along with Kaplan-Meier estimates (Kassambara et al., 2017; Szymkowiak et al., 2022) of probabilities of QS acquisition in each year for entrants. These approximate the lag from entrants' first experience of permit holding to their actual entry to the halibut fishery. Together, time series of permit holding within *any* fishery and estimates of entry to the halibut fishery illustrate critical shifts in participation within groups over time and across groups.

We next examine distributions of individual earnings by entrant and non-entrant groups over the time series, showing differences within each group, across groups, and across years. We contextualize counts of participants in each fishery with the distribution of individual mean earnings over the time series in each fishery. We also expand on the implications of fisheries cross-participation for individual diversification through supporting figures (A7, A8) illustrating participants' aggregate and annual values for the normalized Herfindahl-Hirschman Index (HHI) applied to earnings by fishery following Kasperski and Holland (2013). Normalized HHI measures earnings concentration on a scale of 1 to 0, where an

individual with an HHI of 1 earns revenues in only one fishery and an individual with an HHI of 0 earns revenues in the greatest number of fisheries with the greatest dispersal of revenues across those fisheries of any individual in the dataset. These visualizations add important context to analyses of participation, in particular the distribution of revenues over individuals and their associated roles in fishing operations, fleets, and communities.

Finally, we review two metrics for the dissimilarity of entrants' and non-entrants' portfolios of fisheries permits. First, we calculate an index for dissimilarity (Duncan and Duncan, 1955) from counts and earnings of entrant and non-entrant participants across fisheries by year, following Szymkowiak (2020b) in interpreting differences in fisheries portfolios across groups through dissimilarity. This yields time series of normalized values from zero to one, which indicate differences in portfolio composition for all entrants and non-entrants in each year. Second, we aggregate counts and earnings of entrants and non-entrants across years by fishery to recalculate the dissimilarity index from participants' portfolios over the time series. These metrics characterize specific group differences, contextualize descriptive figures, and introduce metrics underlying network analysis.

2.2.1. Network Analysis

We represent the interconnectedness of fisheries through networks to understand entrants' fisheries participation. Researchers have applied network analysis in Alaska fisheries to understand potential spillover of vessel-level effort between fisheries in response to management shocks (Addicott et al., 2019). We follow Addicott et al. in examining connections between fisheries through network analysis. Networks of fisheries and participants feature nodes, which count individuals participating in a fishery prior to their QS acquisition, and edges, which count individuals participating in each combination of two nodes. Together, nodes and edges comprise a network graph. We visualize this graph to support inference about the relative importance of fisheries for halibut entrants. Furthermore, the connections between fisheries suggest differential resilience over fisheries and their participants. We implement network graph visualizations through R packages igraph (Csardi and Nepusz, 2006) and ggraph (Lin Pedersen, 2022).

We also measure weighted degree centrality of nodes to compare networks by group and over time. Weighted degree centrality quantifies the number of other fisheries with which any given fishery is connected via edges, normalized by the number of fisheries in the network and weighted by the proportion of participants of each group in each node. A fishery connected to a greater relative number of other fisheries in the network with greater relative proportions of participants has a greater weighted degree centrality. For entrants, these metrics provide information on the extent to which potential shocks in the network could affect participation in the halibut fishery. For example, impacts mediated through networks could affect participants' expected earnings from their portfolio and in turn affect participants' decisions to acquire or forgo halibut QS.

3. Results

3.1. Descriptive Analysis

Visualizing differences in participation across all fisheries by entrants and non-entrants reveals changes within and between groups over time. Panel A of Figure 1 illustrates counts of participants in each group by their first year appearing in harvest data. The groups' difference in relative magnitude is critical to note, with non-entrants to the halibut fishery outnumbering entrants by an order of magnitude throughout the time series. Each group exhibits a consistent decrease from 1991 through 2002 and subsequent divergence, with counts of entrants' first appearances continuing to decrease while non-entrants' counts vary around 500. The sharp drop in counts of entrants from 2015 is an important trend requiring interpretation: individuals who are non-entrants through the available time series could acquire QS in the future, so that the available time series misclassifies some participants who acquire QS after 2019. Estimating the impact of this bias in later, less complete years from data for earlier, more complete years is possible with tools for duration analysis, in particular a Kaplan-Meier curve.

The Kaplan-Meier estimates of probabilities of an entrant's QS acquisition in each year, shown in Panel B of Figure 1, indicate that most entrants acquire QS less than six years after first appearing as a permit holder. Of entrants who acquire QS after seven years, a small subset acquire QS only after 11 or

more years – this group is distinguished by the sharp decrease in the slope of estimated probabilities for participants with 11-25 years of permit holding. Altogether, these estimates suggest the time series captures almost all QS acquisition choices for entrants and non-entrants. Finally, the estimated curve for entrants' timing suggests the high relative costs of QS acquisition: despite the value of the halibut fishery in diversifying entrants' portfolios, even successful entrants tend to acquire QS only after several years of permit holding.

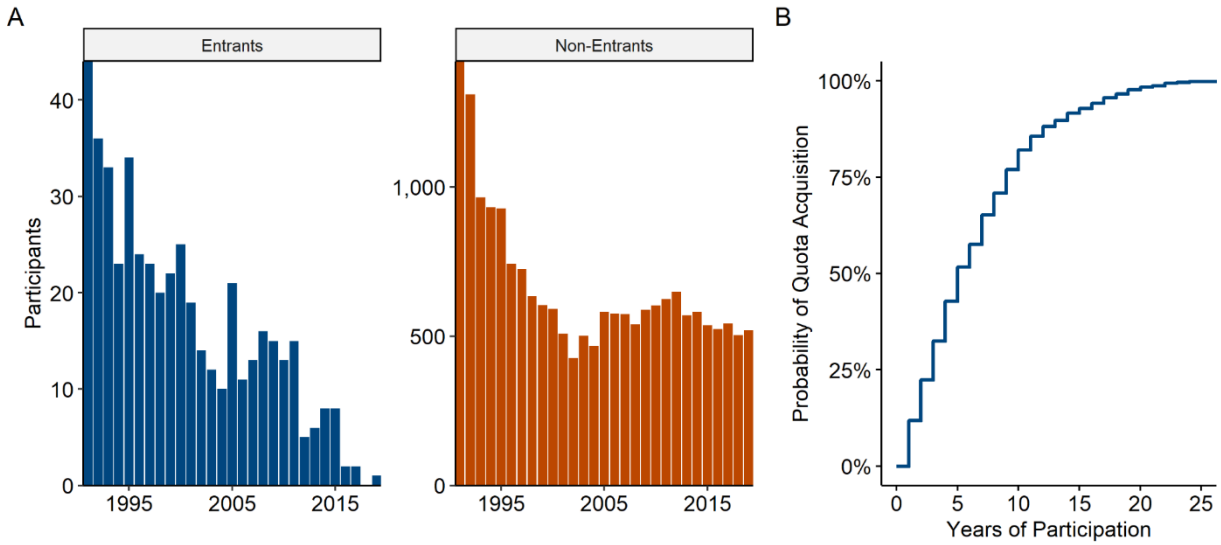

Figure 1. Counts of entrants' and non-entrants' first appearances in annual harvest data (A) and Kaplan-Meier estimates of annual probabilities of quota acquisition from an entrant's first appearance (B).

Participants' earnings over time and in each fishery captures differences between and within the groups of entrants and non-entrants. In Panel A of Figure 2, time series of distributions of individual earnings contextualize the decrease in new participants in both groups. The trend toward increasing real earnings for the median participant suggests shifts in access. Earnings also highlight group differences: entrants' earnings are greater than non-entrants' at the median in all years except 2019, but the median value for earnings shows greater variation for entrants. However, this difference in variation could be a result of the lower count of entrants in each year relative to non-entrants. While outliers are not shown in Figure 2, non-entrants include participants with outlying high earnings of US$1-3M, whose greater

relative earnings appear to be a function of fishery assets — permits, vessels, and gear — and not a random function of the greater count of non-entrants.

The distribution of individual mean earnings across all years for each group in Panel B of Figure 2 indicates complex caveats to the time series in Panel A. "Other" fisheries support the greatest total earnings in aggregate despite returning low relative earnings for all individuals below the 90th percentile, showing that a large proportion of earnings accrue to a small proportion of participants in specialized, capital-intensive fisheries, especially groundfish trawl fisheries. That holds less for entrants than for non-entrants: across fisheries, entrants at the median and upper quartile tend to earn more in the mean year. This suggests that the median entrant has greater financial resources than the median non-entrant to access opportunities for QS acquisition, supporting the obvious intuition that higher-earning participants are more likely to acquire QS. The trend toward higher earnings for the median entrant appears in salmon fisheries but stands out in halibut, sablefish, and herring fisheries.

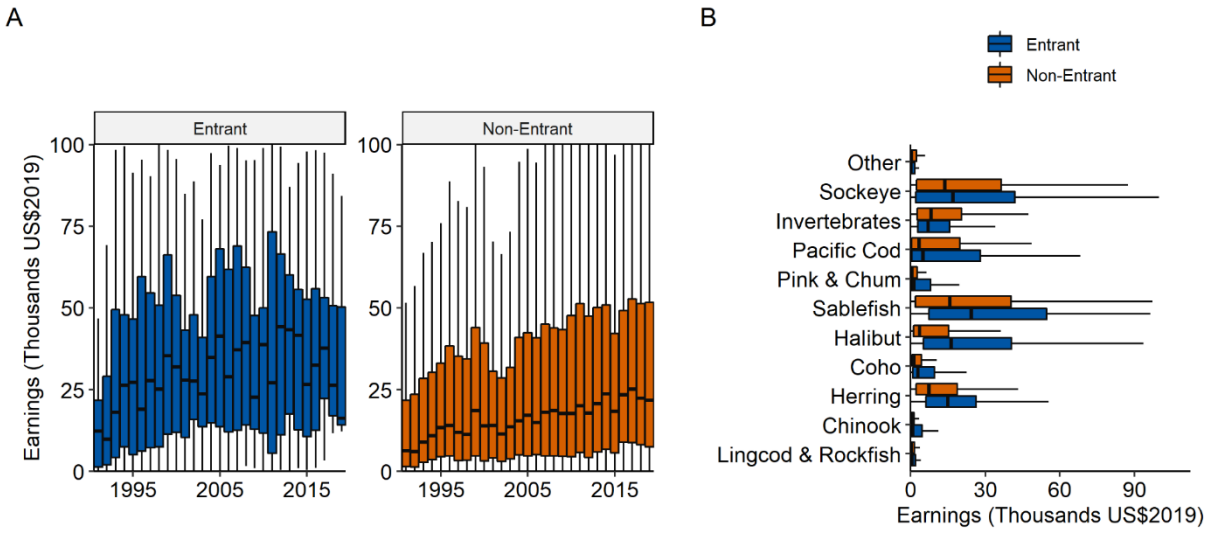

Figure 2. Distributions of earnings for entrants and non-entrants in each year for all fisheries (A) and distributions of mean earnings for entrants and non-entrants in each fishery (B). Distributions feature medians in horizontal bars, interquartile ranges in boxes, and remaining percentiles (0-25, 75-90) in whiskers. Earnings appear without the top decile to highlight the distribution of earners around the

median. With the top decile, outliers include participants earning one to three million US$2019. In (B), fisheries are ordered by decreasing total earnings across participants of both groups.

Examining dissimilarity in participation and earnings, along with proportional participation and earnings by fishery, introduces additional differences between entrants and non-entrants. In Panel A of Figure 3, the time series of dissimilarity of participation – whether individuals appear in a fishery at least once prior to quota acquisition – reflects little change between entrants and non-entrants over time, with low counts of entrants complicating interpretation of the rapid increase from 2015-2019. In the same panel, the time series of dissimilarity of earnings indicates a shift: although the dissimilarity between entrants' and non-entrants' earnings by fishery fell to the time series minimum from 1991 to 1996, in the following years the index has increased. While the relative volatility of the index on earnings complicates interpretation, two key observations emerge: dissimilarity of earnings imperfectly tracks dissimilarity of participation, and dissimilarity of earnings tends to increase over the time series.

The aggregate differences in participation and earnings that drive time series of dissimilarity are explicit in Panel B of Figure 3. In terms of participation, the relative importance of each fishery to entrants and non-entrants is comparable: salmon fisheries support the greatest proportions of participants, while other fisheries support lower proportions with greater differences in participation between groups. Fisheries for halibut, sablefish, Pacific cod, lingcod and rockfish, and "Other" species are especially stark in their difference, indicating the role of entrants' access to groundfish fisheries in their success. Earnings offer different information, with "Other" fisheries accounting for a larger proportion of non-entrants' earnings, while pink and chum salmon, halibut, sablefish, and Pacific cod account for notably larger proportions of entrants' earnings. This result is driven by the high earnings of a small number of groundfish harvesters, echoing their role in Figure 2.

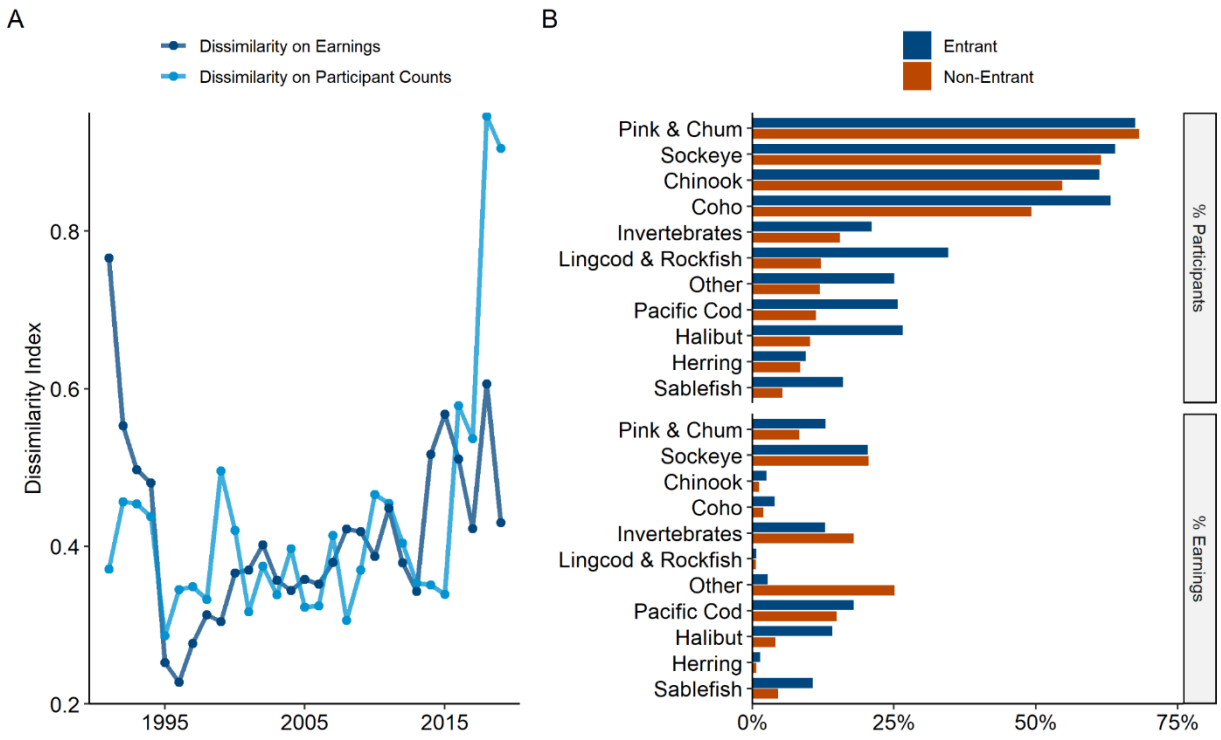

Figure 3. Dissimilarities of entrants and non-entrants in each year calculated from each group's earnings and count of participants by fishery (A) and each group's earnings and counts of participants by fishery (B). In (B), percentages of counts of participants sum to more than one due to cross-participation; percentages of earnings sum to one.

3.2. Network Analysis

Figure 4 illustrates networks of fisheries participation drawn from all years of each individual's permitholding, aggregated over the time series for fisheries described in Table 1. Nodes are percentages of participants in each fishery; percentages are the quotient of participants in each fishery and the total count of participants over the time series. Because participants can hold permits in multiple fisheries, the sum of percentages is greater than 100%. Edges are also percentages, but for each pair of fisheries with participants in common. Labels on nodes indicate counts and percentages of participants. The fisheries participation network's structure illustrates aggregate features of participants' permitholding for visual inference.

Salmon fisheries are a linchpin in both networks, with 61-67% of entrants fishing salmon of each grouping prior to QS acquisition and 49-67% of non-entrants fishing salmon of each grouping in at least one year of the time series. The upper bound on percentages of both groups participating in salmon fisheries suggests specialization into other species and the logistical barriers to fisheries diversification. The remaining prominent fisheries — lingcod and rockfish, halibut, Pacific cod, "Other," invertebrates, and sablefish, in decreasing order for entrants — account for a large proportion of participants who forgo access to salmon fisheries. Halibut stands out for entrants' rate of participation, representing access to halibut fisheries through QS leasing or participation between 1991 and 1995. The fisheries with lower proportional participation in both groups are sablefish and herring, both of which are specialized fisheries. While comparisons of distributions of individual mean earnings from Figure 2 to distributions of individual participation are meaningful for all fisheries, sablefish is prominent for two reasons. First, sablefish supports a high-value fishery with low relative participation. Second, a much greater proportion of IFQ entrants target sablefish than non-entrants because halibut and sablefish require similar gear and skills and are managed under the same IFQ Program.

Connections among fisheries in both networks indicate some specialized groups of participants among both entrants and non-entrants. Connections among all fisheries are stronger for entrants – more participants prosecute more fisheries – but some differences in edge weights appear for each group. Cross-participation in salmon fisheries is also more common for entrants than non-entrants, reinforcing the impression from Figure 3 that entrants participate in more diverse portfolios of salmon fisheries than non-entrants. Entrants prosecuting invertebrates are also better-connected than their non-entrant counterparts, adding information to a unique corner of the network. In the edges between nodes for lingcod and rockfish, halibut, Pacific cod, "Other," and sablefish, entrants also cross-participate more than non-entrants, suggesting paths to entry. Altogether, network edges show that despite some differential specialization, networks of entrants and non-entrants are of similar structure but differ in the strength of cross-participation: entrants participate in more fisheries, suggesting more resilience to shocks and more resources to access other fisheries.

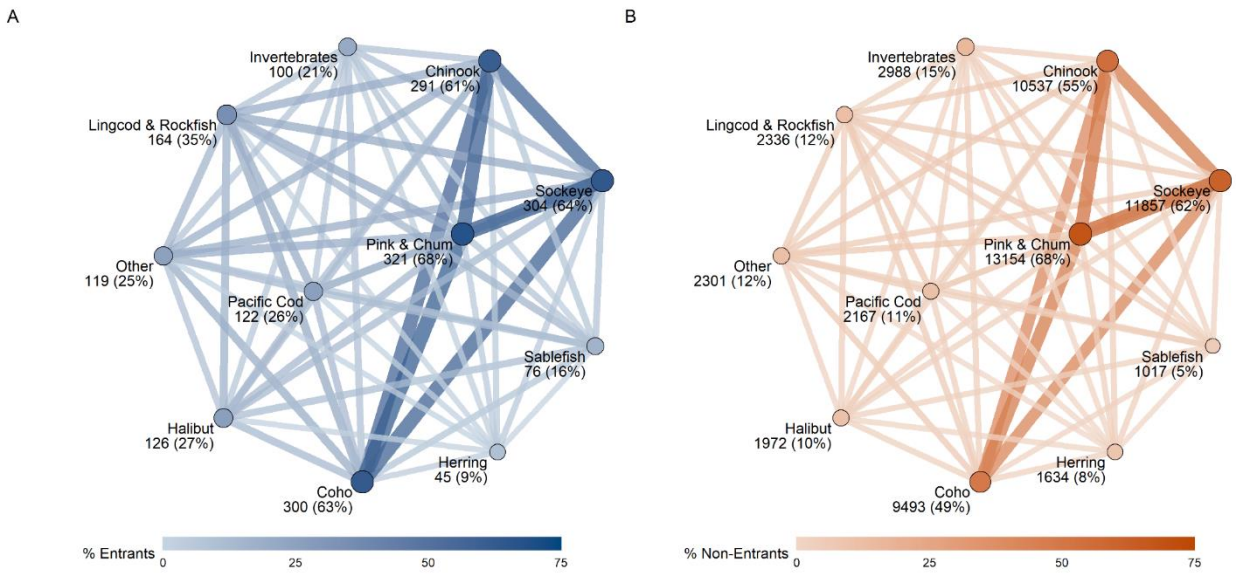

Figure 4. Networks of fisheries participation for entrants (A) and non-entrants (B). Each node counts cumulative participants over the time series, with each node's size and color illustrating the percentage of all participants appearing in that node's fishery in at least one year. Each edge counts individuals who participated in both groups of fisheries corresponding to that edge, with symbology matching nodes. Tables A1 and A2 detail values of all nodes and edges.

While Figure 4 captures critical features of the fisheries participation network with aggregation over the time series, some trends within the time series bear discussion. Figure 5 illustrates annual weighted degree centrality, where weights are percentages of participants, as in Figure 4, and capture the strength of each node's ties. For both groups, salmon fisheries feature greater weighted degree centrality throughout the time series reflecting the critical importance of this family of fisheries within the region. The importance of salmon nodes increased in both entrant and non-entrant portfolio networks after rationalization, with the weighted degree centrality of salmon nodes in the entrant network increasing faster and remaining at greater values throughout the time series than in the non-entrant network. This result underscores the greater relative strength of connections across the entrant network and the importance of salmon fisheries to entrants' success.

Although trends in nodes of lower weighted degree centrality are noisy, another difference across the time series is the greater degree centrality of non-salmon nodes for entrants. This pattern corresponds

to entrants' higher proportional participation and earnings in those fisheries shown in previous results. While the weighted degree centrality of salmon nodes has increased on average for both groups, values for non-salmon fisheries exhibit no clear trend for either group, suggesting alternative portfolio strategies across these fisheries have not emerged despite their potential to enable entry and diversification. The panel of Figure 4 for lingcod and rockfish suggests an exception, as degree centrality increased considerably for entrants from 2013-2019. Although the timing and magnitude of this shift do not establish an unequivocal pattern, the trend indicates entrants have found greater opportunities in these fisheries than non-entrants; this could be explained by commonalities in gear and area between lingcod and rockfish fisheries and the halibut fisheries. Altogether, these trends underline the importance of understanding participants' portfolio strategies through network analysis as well as standard descriptive statistics applied to time series.

Figure 5. Time series of weighted degree centralities for networks of fisheries participation. Each line represents a node and a fishery. Each y-axis coordinate indicates the node's degree centrality with weights for counts of participants in each year. Shading highlights differences between entrants and non-entrants.

4. Discussion

Barriers to fishing opportunities and access associated with catch share programs present formidable issues throughout the world in food security, livelihood, and sociocultural wellbeing derived from fisheries (Olson, 2011). However, quantitative analyses of fisheries entry thus far have often focused on entry-stay-exit decisions at least the vessel level (Pradhan and Leung, 2004; Tidd et al., 2011), constraining their relevance to policy on facilitating entry for individual fishermen (Szymkowiak et al., 2022). This work addresses this issue through quantitative analyses indicating trends in fisheries participation affecting opportunities for entry to a critical fishery off Alaska and exploring fisheries participants' exposure to social and environmental change. Findings of increasing portfolio diversification for a decreasing number of entrants over time can inform state and federal fisheries policy to enhance opportunities and resilience in the halibut fishery and in Alaska fishing communities more broadly.

The consistent decline in the count of participants acquiring quota shares follows broader narratives on consolidation and diminishing access into catch share fisheries (Carothers, 2015; Szymkowiak et al., 2020). However, the simultaneous decrease in entry to all other fisheries provides critical context about broader sociocultural shifts and perceptions of the viability of fisheries livelihoods (Ringer et al., 2018; Szymkowiak, 2020a). Information on earnings in specific fisheries narrows the scope of difference between entrants and non-entrants: the median entrant earns more than their non-entrant counterpart, especially in salmon and more capital-intensive groundfish fisheries. Entrants' apparent access to opportunities for higher earnings, whether through different fisheries, gears, vessels, or other fishing technologies or techniques, indicates the role of capital access in achieving entry. These issues fit into broader academic discourse on differential access to fisheries across generations of aspirational entrants in Alaska (Coleman et al., 2019; Ringer et al., 2018; Szymkowiak et al., 2022) and other regions (Drakopulos and Poe, 2023; Haugen et al., 2021; Johnson and Mazur, 2018). This critical literature interrogates the future of fishing communities where access to and ownership in fisheries have transformed with changes in fisheries management.

Trends in individual fisheries portfolio composition capture multiple dimensions of change between entrants and non-entrants. Shifts in portfolio dissimilarity illustrate that differences in the composition of each group's earnings have increased, although without a clear change in the set of fisheries each group accesses. Instead, the winnowing of the entrant group to smaller cohorts of fisheries participants has increased the apparent importance of certain fisheries to entrants' portfolios, including halibut, sablefish, and Pacific cod. Changes in earnings across salmon fisheries also appear to drive dissimilarity – while differences between groups are smaller for salmon fisheries than others, the outsize importance of salmon to both entrants' and non-entrants' portfolios means that a small proportional change to the group difference in salmon participation or earnings can return a large change in aggregate dissimilarity. The importance of salmon is also distorted across subgroups, especially seasonal participants and fishing families with greater commercial dependence on salmon runs (Szymkowiak, 2020a). However, the key finding across fisheries is that portfolios have become more capital-intensive over time for entrants.

The same pattern appears in network graphs, where entrants' greater relative connectedness measured in cross-participation indicates greater access and resilience prior to entry than non-entrants. The evidence for greater access is clear – entrants participate in more fisheries than do non-entrants – but one implication for entry is important: the mechanisms enabling some individuals to access more fisheries could also enable their QS acquisition. These could speculatively include greater individual earnings from permit holding, from crewing, or from employment outside of fisheries; greater access to capital through formal or informal loans; or differential expectations of earnings conditional on fisheries access, which could drive entrants to invest in more fisheries. Of these mechanisms, only earnings from permit holding are legible in available data. Entrants' greater access also suggests that their portfolios can weather shocks better than those of non-entrants, enabling entrants to sustain their investments in fisheries (and later acquire QS) instead of exiting. While the differential access captured in network graphs is clear, further exploring differences of access over time series of fishery degree centrality offers evidence in more detail.

The greater degree centrality of fisheries in entrants' network of portfolios also highlights the critical role of accessible fisheries, especially salmon, in opening pathways to robust participation (Beaudreau et al., 2019; Carothers, 2015; Ringer et al., 2018). The differential diversification of entrants and non-entrants further provides a nuance to the literature on spillovers of fishing effort between fisheries (Addicott et al., 2019; Cunningham et al., 2016) in that differences in portfolios at the time of QS allocation or subsequent changes in rights-based management could drive differential responses in terms of exit and QS consolidation. This result also adds to academic discourse on the implications of catch share programs for diversification (Abbott et al., 2023; Holland et al., 2017; Kasperski and Holland, 2013), as the increasing relative degree centrality of fisheries in entrant portfolios suggests that shifts in access can intensify long after the initial consolidation of QS.

For policy makers, the differences between entrants and non-entrants shown through degree centralities of fisheries could motivate multiple priorities. In state fishery management, expanding opportunities for portfolio diversification could help aspiring entrants to stabilize and increase revenues toward eventual entry to the halibut fishery. Beyond management, state and local policy makers can support local resources necessary to the development of fishing operations: waterfront infrastructure, processing capacity, and access to regional supply chains. In federal fishery management, opportunities for diversification to other groundfish fisheries could also aid aspirational entrants, as the uptick in lingcod and rockfish participation suggests. Changes to federal policies for fishery disaster aid could stabilize fishing incomes through extreme events, especially in terms of more timely, targeted, and equitable disbursements of aid (Bellquist et al., 2021). Further, the Council and partner agencies could advance policies to directly support entry – for example, creating a bank of rotating QS for entrants and improving the flexibility of existing loan programs, as discussed by the Council in the past (Henry, 2021).

While available data support detailed insights into permit holders' operations prior to entry, the fisheries participants whose choices are legible in data are a subset of individuals who might access QS. Those left out of this analysis include crew and participants in fisheries outside of Alaska, whose QS acquisition decisions affect the QS market and access for those included in our analysis. Participants

crewing in Alaska fisheries can benefit from acquiring QS to secure positions in fisheries besides halibut by contributing to a fishing operation's options, but barriers to QS acquisition are especially high for participants whose only asset in fisheries is their labor (Ringer et al., 2018). Conversely, fisheries participants in Alaska who also hold fisheries permits in other regions have benefited from differential capital access and opportunities in Alaska's rationalized fisheries (Szymkowiak and Himes-Cornell, 2015). The incentives and opportunities for both groups could intensify some effects of rationalization, as later generations of crew unable to buy in to the halibut fishery are no longer able to invest in permitholding, and later entrants from outside Alaska are better able to overcome financial hurdles to ownership and maintenance of a halibut operation. Further research into groups left out of detailed fisheries data could clarify the implications of their decisions for the future of the halibut fishery and fishing communities.

Policy to support entry to the halibut fishery for specific groups, especially crewmembers, could benefit from broader evidence for shifts in access. While the results at hand suggest aspiring entrants face increasing hurdles, crewmembers in particular could encounter unique challenges – for example, fewer crewing opportunities in consolidating fleets. Changes in crewmembers' incomes and skill development, e.g. time developing skills necessary to transition from crewing to permit holding, are not represented in available data on fisheries off Alaska. Capturing this information would support research and policy to expand opportunities for crewmembers to access permits and QS, for example training in business development available through extension programs. Similarly, reconciling participation data for Alaska and other regions would shed light on the differential access of fisheries participants with and without assets outside of Alaska. Together, data explicating crewing and cross-regional participation decisions would inform social dimensions of policy to expand entry opportunities.

Meanwhile, the accumulation of climate change impacts across the Gulf of Alaska (Suryan et al., 2021) threatens shocks to salmon abundance as well as halibut and sablefish, increasing the exposure of fisheries to risk through environmental change. The increasing dependence of both entrant and non-entrant participants on salmon fisheries of uncertain climate resilience (Beaudreau et al., 2019; Litzow et

al., 2018), threatens to exacerbate effects of climate change in fishing fleets and communities. The decreasing rate of entry to all fisheries as well as the halibut fishery raises a similar issue: fleets and communities must depend on fewer, more efficient fishing operations, despite the uncertain effects of consolidation on long-term resilience. While policy makers can address this fundamental challenge by expanding opportunities to enter fisheries and increasing the flexibility of management, detailed information on shifts in fishing portfolios under fast-changing conditions is key to designing sustainable solutions. This work underlines the importance of research to understand challenges to entry across fisheries and the complex effects of diminishing fisheries access in fishing operations, fleets, and communities across Alaska.

5. Conclusions

Fisheries often undergo profound and unpredictable changes, and fishing communities have historically sustained livelihoods through access to alternative fisheries. With the intensifying impacts of climate change and broader social change on fisheries, fishing communities face unprecedented challenges to their resilience. Key results of the IFQ Program are clear: access has consolidated and entrants depend on extensive portfolios prior to acquiring quota shares, while dependence on critical fisheries has increased for participants outside of the halibut fishery. These outcomes diminish fishing communities' adaptive capacity under rapid social and environmental change, indicating opportunities for changes in policy and management to support communities through fisheries access. In state management, maintaining participants' access to key fisheries, especially salmon fisheries, would aid aspirational entrants in sustaining their careers and building assets to enable QS acquisition. In federal management and policy, enhancing support for entrants through flexible loan programs, rotating QS pools, and additional measures tabled in past deliberations would decrease the capital requirements and risk of entry. Expanding opportunities for entry is critical under current conditions, as counts of entrants remain at a historic low. The role of proactive management in enabling entry underlines importance of continuing research into aggregate and distributional effects of shifts in access, especially on social

dimensions left out of available data. Crewing, cross-regional participation, and ties within families and communities are critical to fishing fleets and communities, and better understanding their roles in fisheries entry is key to advancing effective and equitable management.

Acknowledgements

We extend thanks to Steve Kasperski and to three anonymous reviewers for their invaluable comments on an earlier draft of the manuscript.

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