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Port level fishing dynamics: Assessing changes in the distribution of fishing activity over time

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ABSTRACT

This article assesses changes in the relative distribution of commercial fishing activity within a system of ports. Like other coastal fisheries in the United States, fishing activity declined significantly at California's central and north coast region ports between 1981 and 2007. The central questions addressed in this paper are: how have the changes in overall fishing activity (as measured by total regional fishing trips, revenues, and landings) affected fishing activity in each of the central and northern California coastal region's 30 fishing ports? How have individual ports fared relative to other ports and the region as a whole during this decline? The analysis assesses the degree to which the relative distribution of fishing activity across ports-as measured by port rankings-is stable over time. The formal rank correlation analysis shows that ports' rankings have changed slowly and have changed more over longer intervals. In addition, the rankings change less (more) when the comparison is made over a larger (smaller) set of ports. Tests for the statistical significance of differences in percentage changes in fishing activity between region-wide totals and individual ports are performed. The results indicate that ports differ in terms of their dynamic fishing activity patterns over time, which constitutes a rejection of the null hypothesis that the *cumulative* percent changes at individual ports are the same as changes at the region-wide level.

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1. Introduction

Similar to some other regions of the U.S., fishing activity at California's central and north coast region ports has declined significantly since the early 1980s. The number of participating fishing vessels declined by 78% between 1981 and 2007 while the number of fishing trips, after increasing through the mid-1980s, declined by 73% between 1988 and 2007. Ex-vessel revenues (in constant dollar terms) and landings declined by 58% and 70%, respectively, between 1981 and 2007. Much of the decline in fishery participation and activity coincides with the introduction of more restrictive management in some major fisheries, although a range of social, economic, and environmental factors also have shaped these trends [1]. This article compares relative changes in fishing activity across multiple ports in the face of this long term reduction in total fishing activity.

Previous studies have explored the impacts of declining fishing activity and other change on port communities. For example, Knapp [2] and Knapp and Lowe [3] documented changes in and consolidation of processing capacity and associated infrastructure in Alaska following crab fishery rationalization. Portman et al. ([4,5]) assessed the impact of changing marine resource and fishing conditions on coastal land uses and essential fishery infrastructure over a two-decade period, and found that changes in species abundance influence the location of associated land-based marine-related activities. They conclude, "the cumulative effect of marine resource conditions can substantially alter marine industry's location decisions and may have long-term and multi-sector impacts at the community level," and highlight the importance of considering this information in decision-making about coastal land use planning and fisheries management [4].

However, to date, limited work has been done to quantitatively assess *relative* changes in fishery activity across systems of related ports in the context of broad-scale change, though some related work has examined relative changes in economic activity in coastal communities. Mulkey et al. [6] performed a shift-share analysis of Florida's coastal counties and found a net shift of economic activity (1) toward the study area relative to the nation, and (2) toward coastal counties relative to noncoastal counties within the state. Marti ([7,8]) applied shift-share analysis to waterborne energy imports via New England ports to test hypotheses related to (1) the level at which ports

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function relative to one another; (2) the consistency of foreign inbound energy cargoes over time; (3) factors driving port competition; and (4) inter-port competition over time. Working on a larger scale, Jin and Kite-Powell [9] used shift-share analysis to evaluate the competitive performance of shipyards within the U.S. shipbuilding industry, and found that those large U.S. yards that survived the recent industry contraction have done so by achieving a good product mix and remaining competitive in the quest for military contracts whereas those that have not have reduced operations or shut down entirely. Notteboom [10] examined the concentration of load center development within the European container port system for the period 1980–1994.

The central questions addressed in this paper are: how have the changes in overall fishing activity affected fishing activity at each of the central and northern California coastal region's 30 fishing ports? How have individual ports fared relative to other ports and the region as a whole during this decline? Has fishing activity become more or less concentrated in fewer ports and fewer fisheries? To explore answers to these questions, patterns in three indicators of fishing activity (measured in terms of trips, revenue, and landings) examined: (1) ports' shares of activity, (2) the concentration of fishing activity among ports and among fisheries, (3) rankings of ports in terms of their activity, and (4) ports' percentage changes in activity relative to overall, region-wide percentage changes in activity.

The article proposes a null hypothesis that overall changes in fishing activity have been distributed evenly across fishing ports in the study region. A series of tests are used to determine:

1. Whether individual ports' *shares* of fishing activity are constant over time.
2. Whether the *rank order* of ports' fishing activity changed significantly over time.
3. Whether the concentration of fishing activity among ports and fisheries has changed over time; and
4. whether the *percent change* of individual ports' fishing activity is the same as the region-wide changes.

2. Data and study area

2.1. Data

The analyses presented here use data on commercial fishing activity from the Pacific Fisheries Information Network (PacFIN)

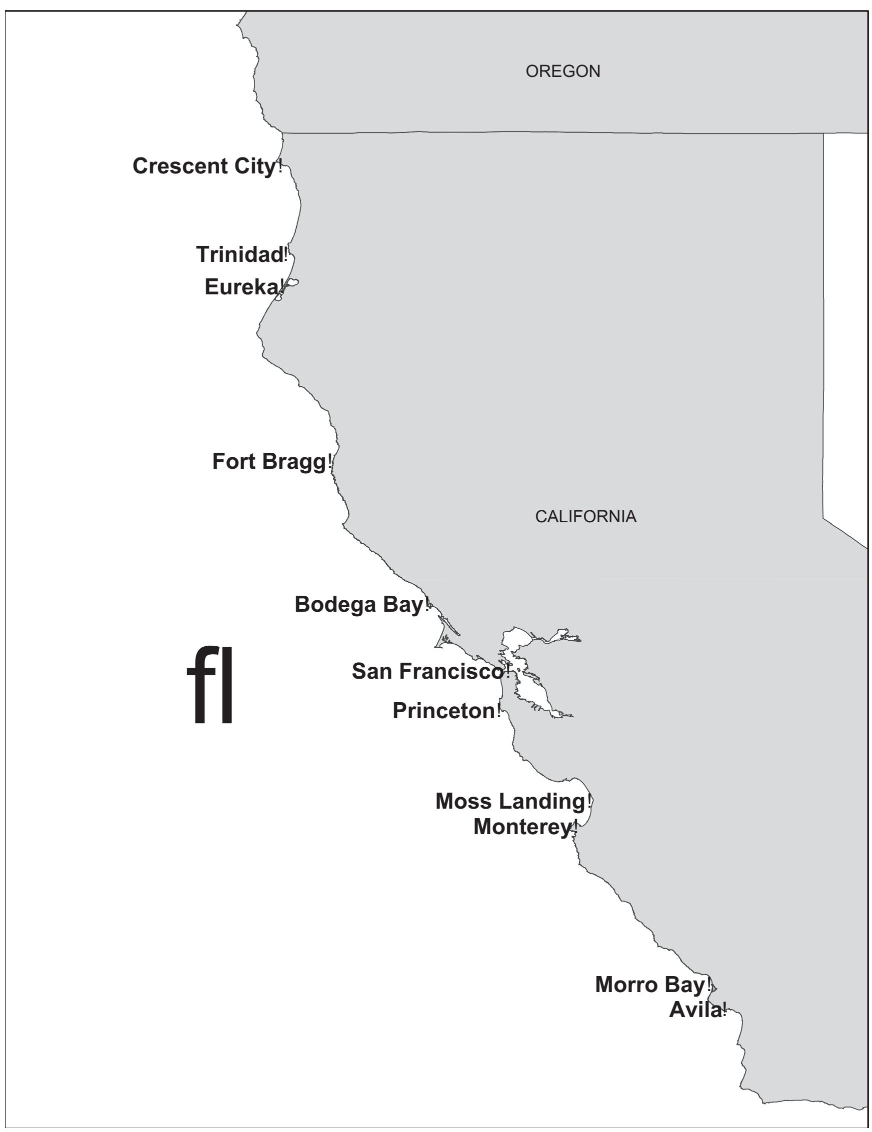

Fig. 1. Map of the study area: northern and central coast California ports. Selected major ports from Crescent city to Avila are indicated.

program, which manages West Coast commercial fishery landings data collected by California, Oregon and Washington. The data for California are extracted from landings receipts submitted to the California Department of Fish and Game by the first receiver of the catch. Data on gear type, species, port of landing, volume and value of landings, and the number of fishing trips and vessels for the period 1981–2007 are used in this analysis.

We use three metrics to test the hypotheses of interest: trips, ex-vessel revenue, and landings (pounds). Each trip represents a single departure and return of a fishing vessel. However, the length of that trip may range from several hours to several weeks. For example, a salmon troll trip typically lasts from one to five days, whereas an albacore troll trip lasts from a few days to several weeks. The ex-vessel value of (or revenue from) landings, which represents the total amount paid by first receivers of the catch to fishermen, is a product of the volume of the catch (which varies by fishery) and price (which may vary across and within fisheries). Landings are a measure of the catch by weight, and vary by fishery due to differences in vessel size, trip numbers and duration, and the nature of the market. Some fisheries such as salmon troll and nearshore rockfish are characterized as 'high value, low volume' whereas others, such as coastal pelagic species (CPS) seine and groundfish trawl, are known as 'low value, high volume' fisheries. These measures of fishing activity-trips, revenues and landings – are influenced by diverse sets of environmental, technological, regulatory and economic factors. Each measure has different implications for the larger fishery system. For example, the number of trips most directly affects demand for inputs such as fuel and ice, while landings directly affect the numbers and types of receivers and processors and offloading infrastructure. Thus, examining all three measures at once provides a more complete view of the fishing industry.

For this analysis, each fishing trip was assigned to one of 34 fisheries, each defined as a particular combination of species and gear type. A fishing trip may involve participation in more than one fishery. Each trip was assigned to the fishery accounting for the plurality of revenue derived from the trip. For 86% of the trips made during the study period, 100% of trip revenue was from a single fishery. For an additional 8% of trips, the fishery to which they were assigned accounted for 90–99% of trip revenue. In a very few cases (approximately 1% of all trips in the data set), a trip consisted of landings at multiple ports. For this study, each trip was assigned to the one port that accounted for the plurality of revenue for that trip.

2.2. Northern and Central California commercial fishery

Our analysis focuses on California's central and north coast region, which includes 30 distinct ports and several small landing sites located in 14 counties from San Luis Obispo County in the south to Del Norte County in the north (Fig. 1). The diverse ports in the region have many commercial fisheries-and associated management regimes – in common. In 2007, fishermen landed over 137 million pounds of fish at the region's ports with a dockside value of more than $58.5 million.

The top ports in the study area in terms of trips and revenue include Crescent City, Eureka, Fort Bragg, and Bodega Bay. In spatial terms, the magnitude of fishing activity generally declines from north to south, with Crescent City (the northernmost port) consistently being among the top ports on all three measures of fishing activity. This analysis focuses on 11 selected, high activity ports and combines the remaining 19 landing locations into the category of "Other ports."

From 1981 through 2007, three fisheries-crab pot, salmon troll, and groundfish trawl-dominated the region's fisheries, together accounting for almost three-quarters of ex-vessel revenue (Fig. 2). Other fisheries, including CPS seine, sablefish, and rockfish pot and hook-and-line, and albacore troll and jig, also accounted for a

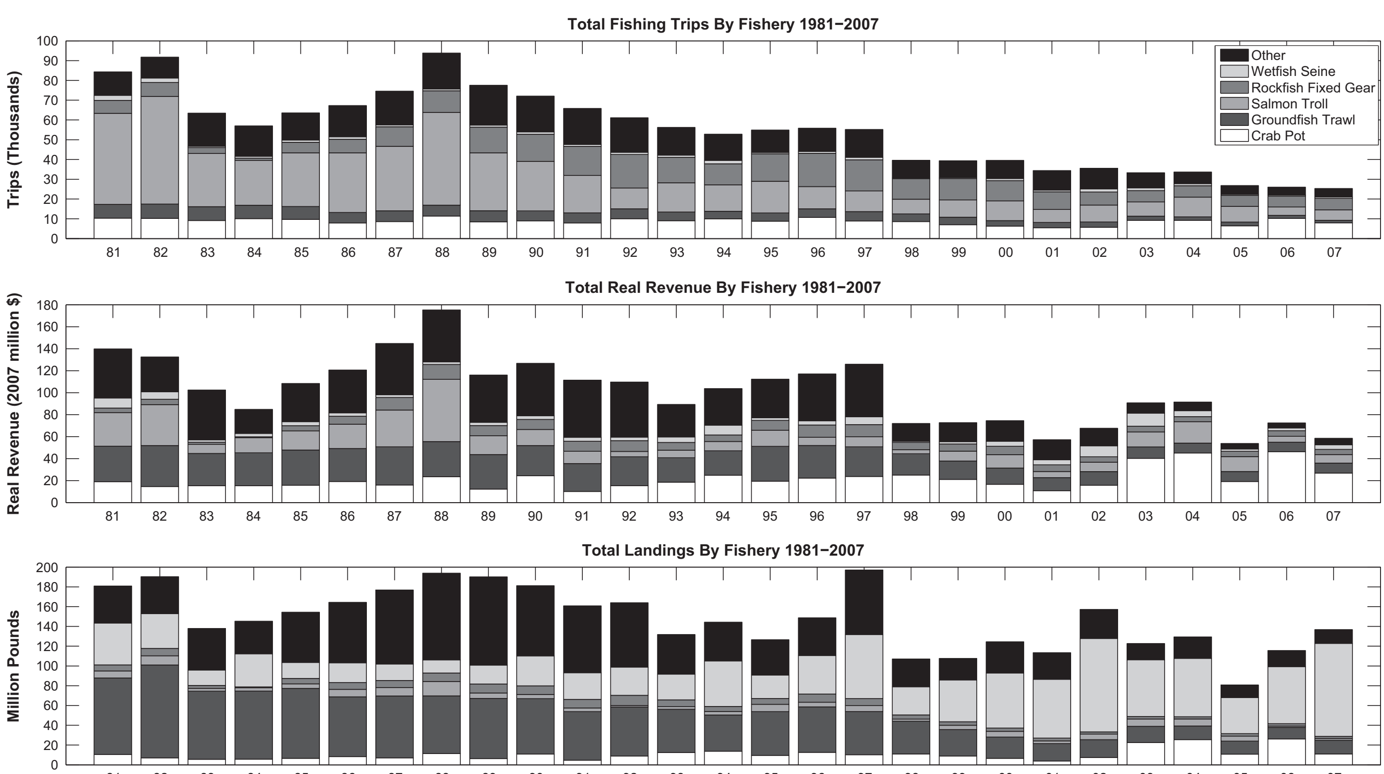

Fig. 2. Region-wide commercial fishing activity over time. The top panel is number of trips per year, the middle panel is real revenue (2007 dollars), and the bottom panel is landings. The height of each bar is total region-wide activity while individual sections are activity levels for the fishery indicated.

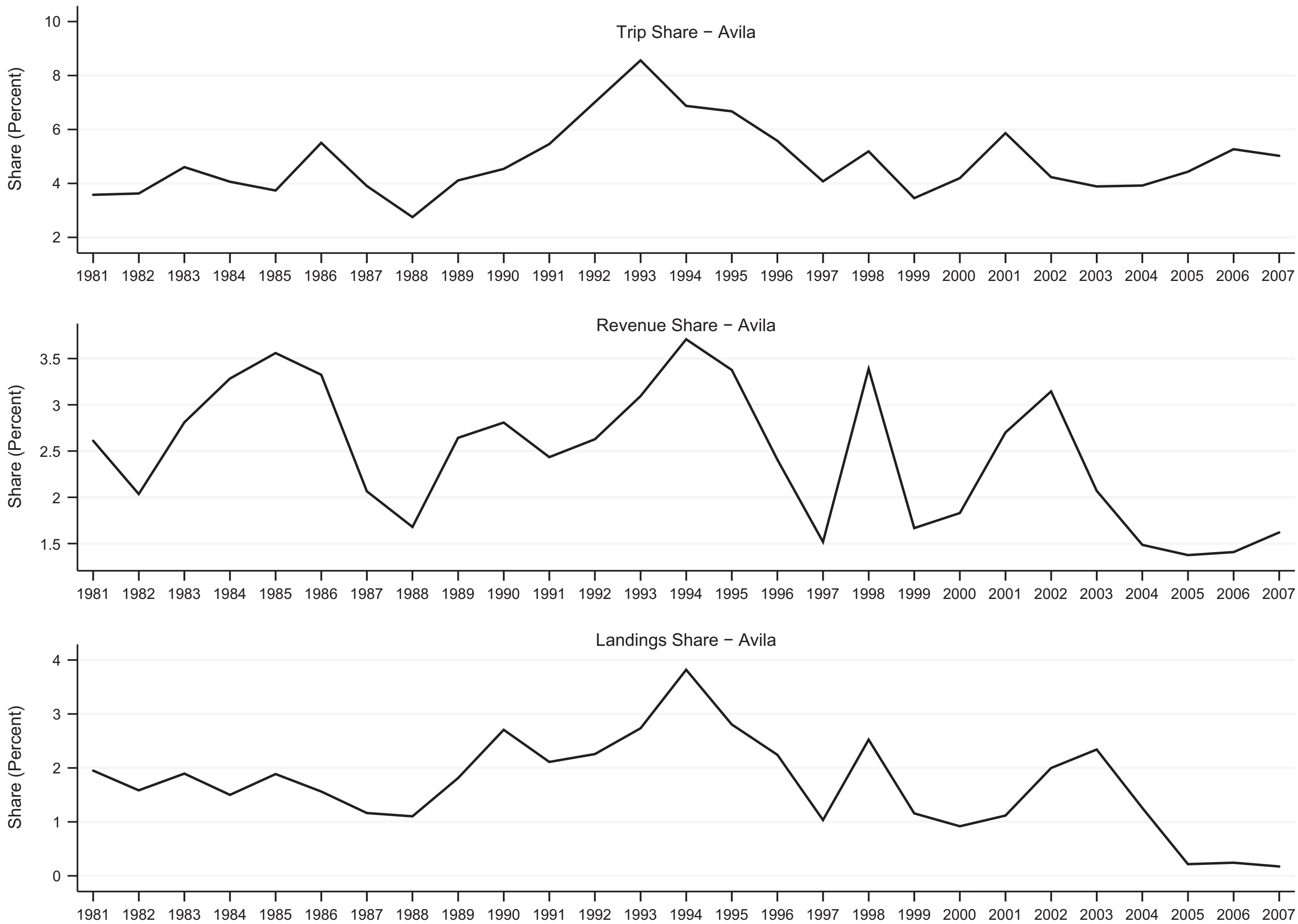

Fig. 3. Share of fishing activity-Avila.

significant, though lesser and more variable, proportion of fishing activity.

Over the study period, significant reductions in fishing activity occurred following the implementation of various measures aimed at capping or reducing fishing effort and/or capacity, and changes in resource availability and distribution, markets and other economic conditions. Limited entry capped the number of vessels in several fisheries including salmon troll (1983), groundfish (1994), and Dungeness crab (1995).[1] The federal West Coast groundfish trawl vessel buyback program (2003) reduced the groundfish trawl fleet by about one-third (within California and region-wide). Over the study period, concerns regarding salmon stocks listed under the Endangered Species Act also led to much more restrictive area and season closures in that fishery. The number of boats in the study region steadily declined by 78% from a high of 5257 in 1981 to 1178 in 2007. The number of fishing trips also exhibited a substantial decline over the course of the study period from 91,762 in 1982 to a low of 25,354 in 2007. Trends in fishery revenues are similar to those for fishing trips with real ex-vessel value declining from $140 million in 1981 to $85 million in 1984, then rising quickly to $175 million in 1988, and falling thereafter to a low of $58 million in 2007. The volume of landings rose and fell over the period, but generally trended downward from 180 million pounds in 1981 to 136 million pounds in 2007. Early in the study period, the mid- to low-price groundfish trawl fishery produced about half of the landed weight; the lower price-per-pound CPS purse seine fishery produced most of the landed weight in recent years.

3. Port shares of trips, revenue and landings

The question addressed in this section is whether, how and why individual ports' shares of fishing activity-as measured by number of fishing trips, revenue, and landings-have changed over time. It is apparent that the shares of fishing activity for the selected ports are not strictly constant over time (Figs. 3–14), but it is not clear whether these changes have been distributed proportionally across ports or what has driven the changes. Many of the changes in ports' shares of fishing activity may have been driven, in part, by regulatory actions (including those noted in the previous section and others) to limit or reduce fishing capacity, effort and catch during the study period.

3.1. Port share variability

To measure the degree to which the share of activity in each port fluctuates throughout the time series, the coefficient of variation for the shares of trips, revenue, and landings in 11 selected ports (plus an ‘other’ category representing the other 19 ports in the study area) is used (Table 1). The coefficient of variation is a measure of variability that is defined as the standard deviation of a port's annual share values divided by its mean share

[1] See [11] for a summary of limited entry and “restricted access” programs instituted through 2001.

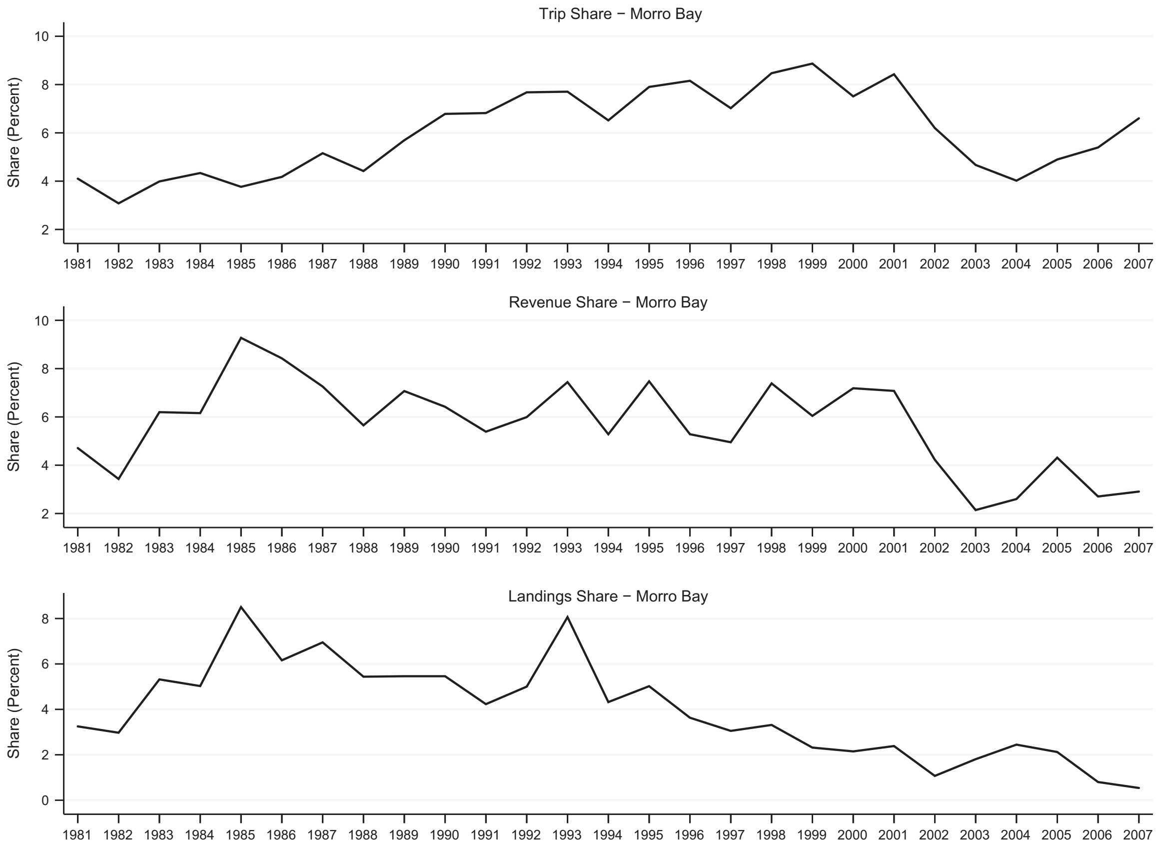

Fig. 4. Share of fishing activity-Morro Bay.

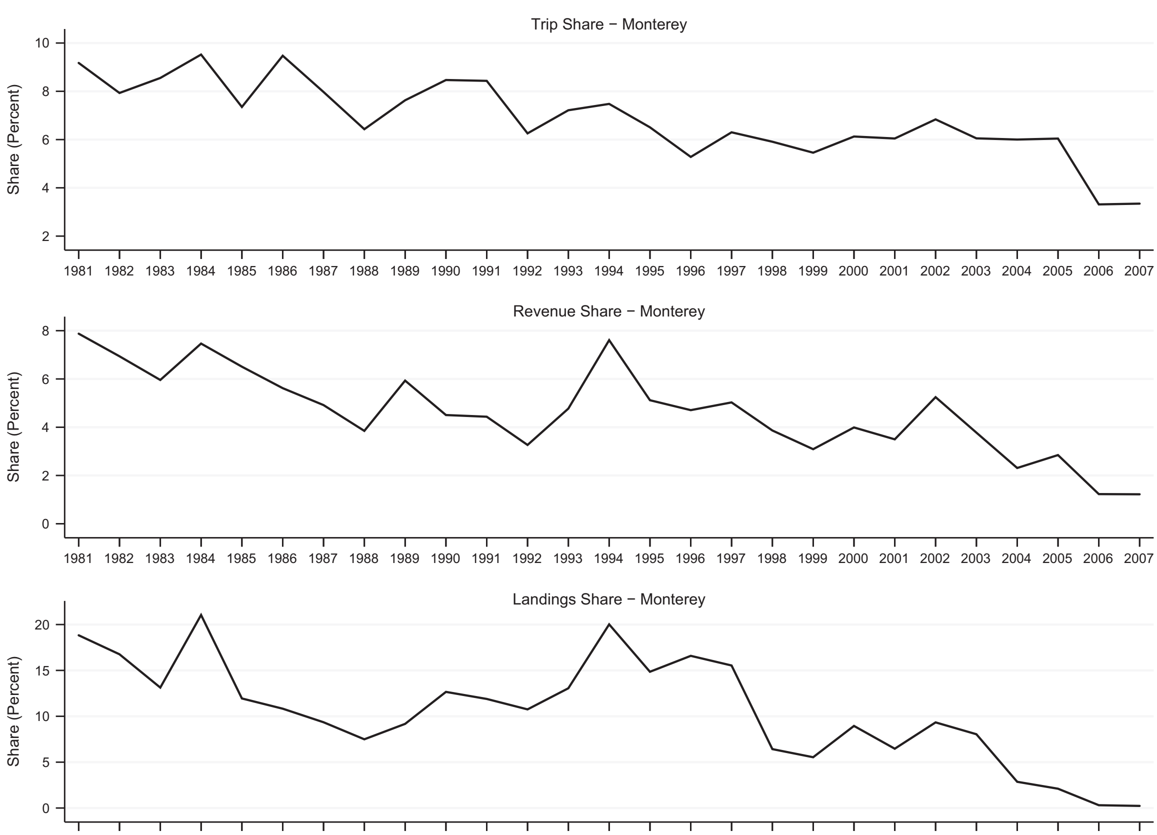

Fig. 5. Share of fishing activity-Monterey.

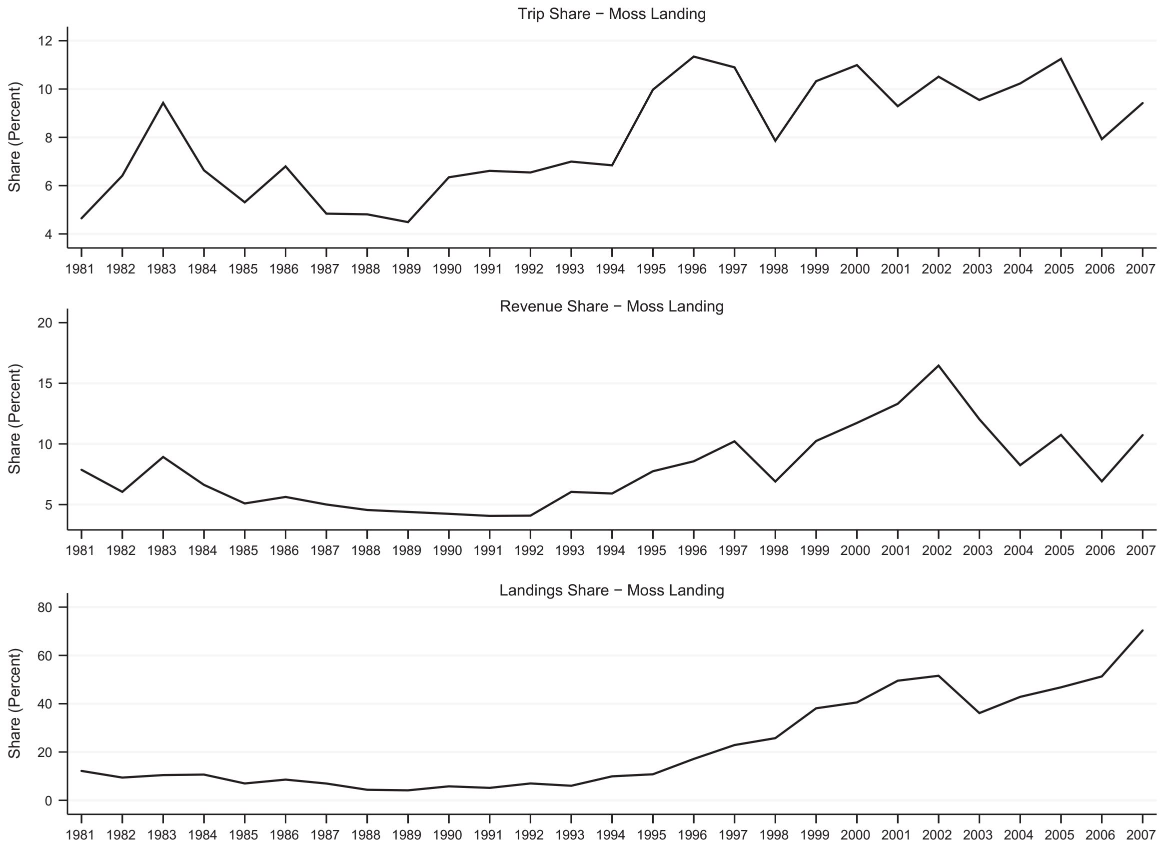

Fig. 6. Share of fishing activity-Moss Landing.

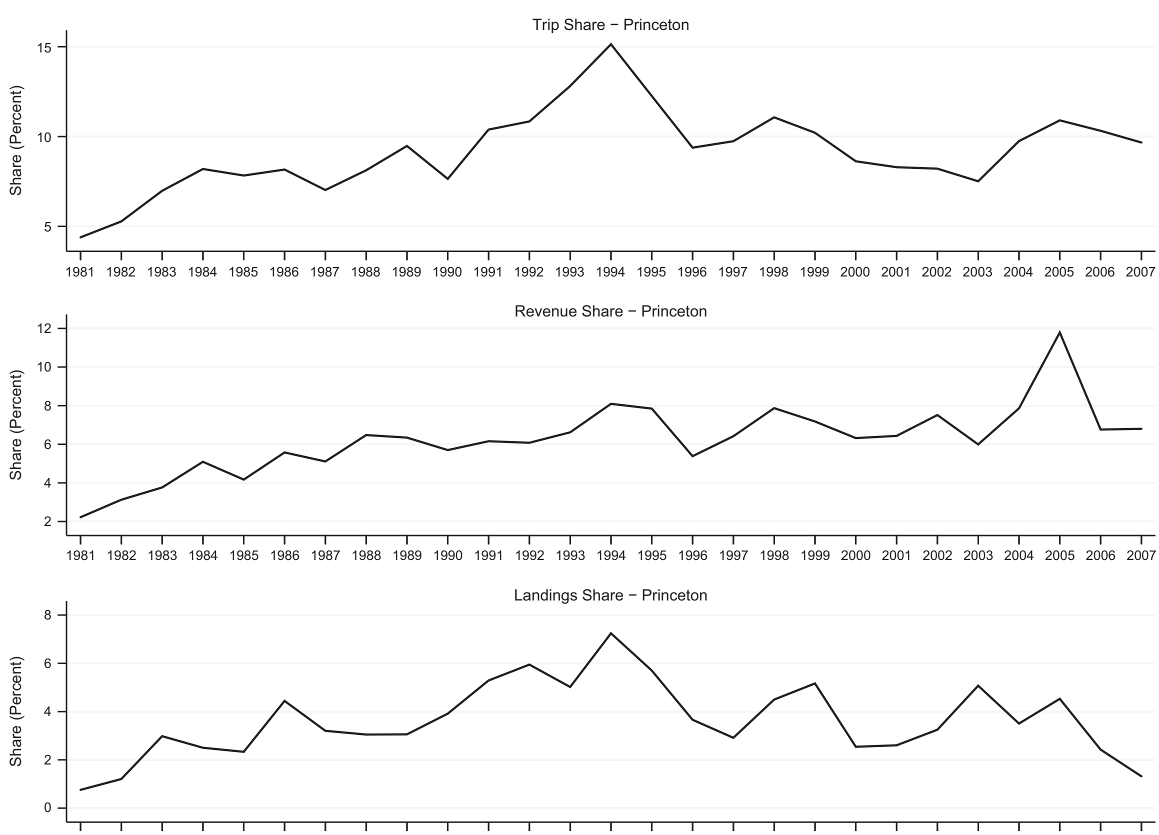

Fig. 7. Share of fishing activity-Princeton.

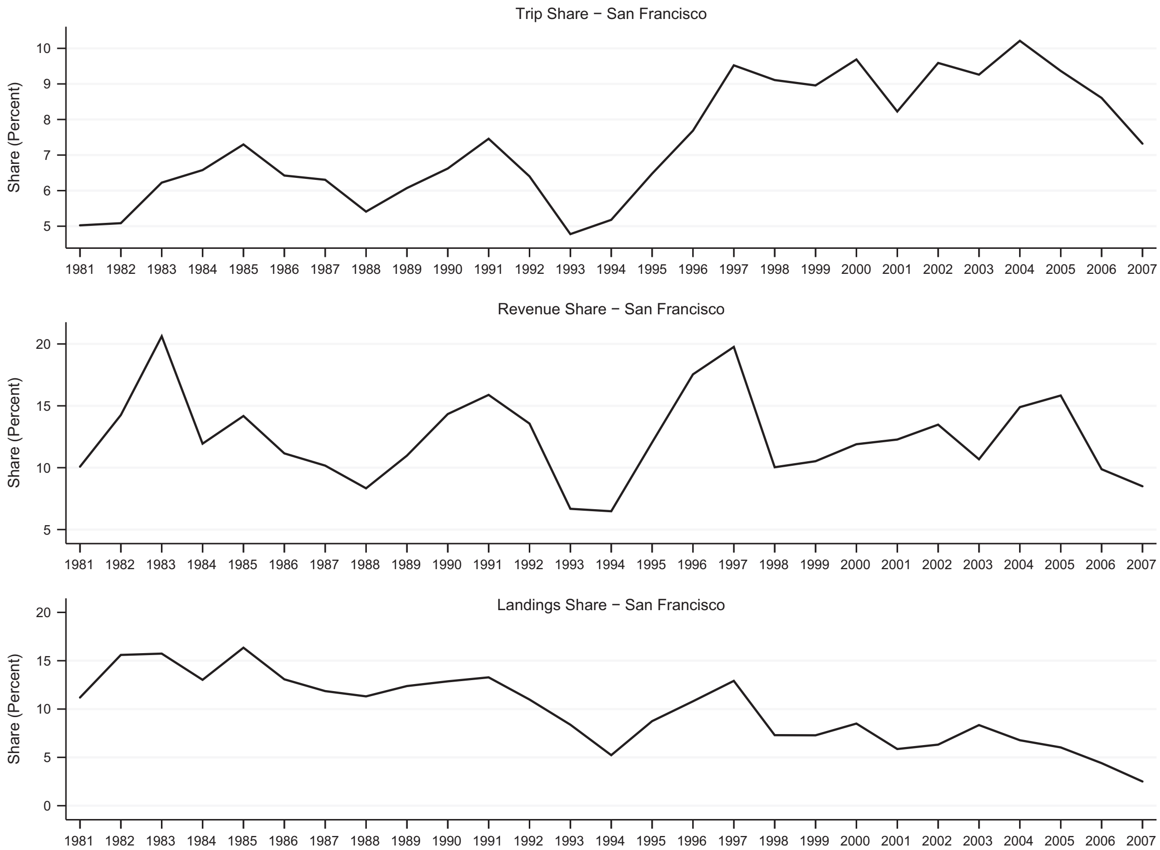

Fig. 8. Share of fishing activity-San Francisco.

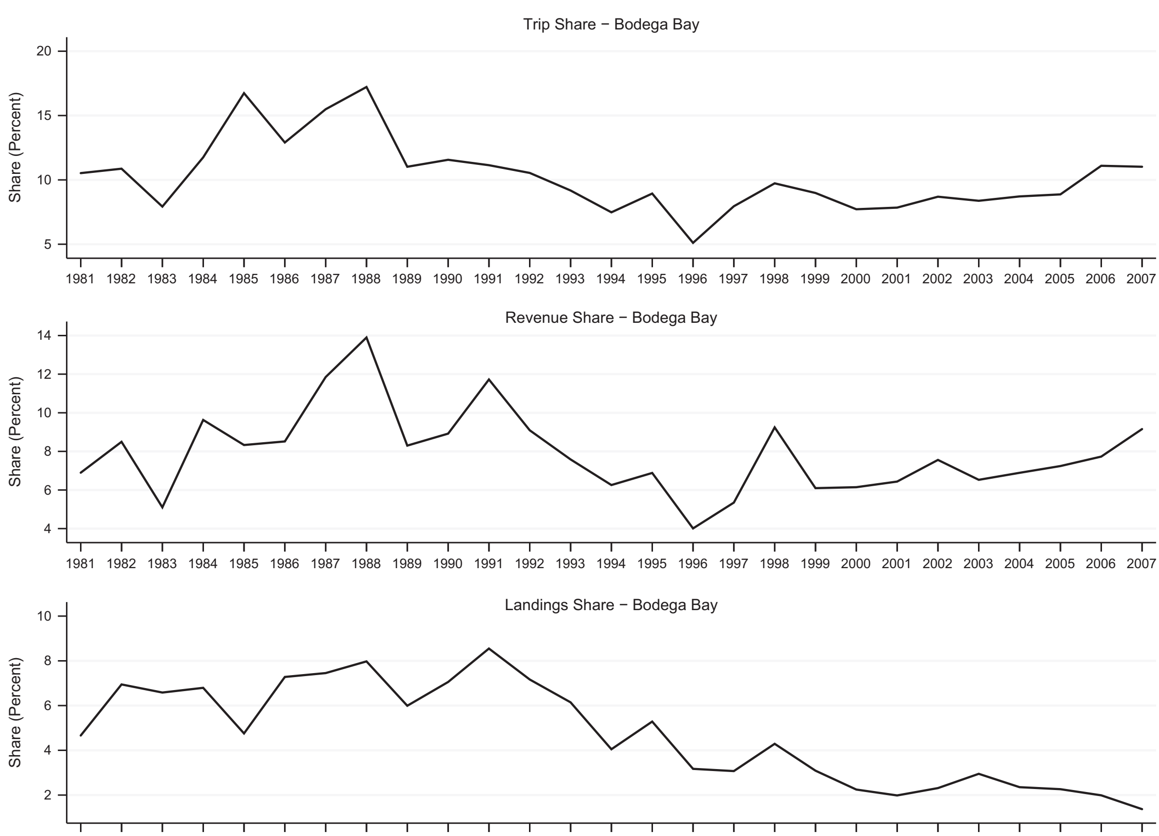

Fig. 9. Share of fishing activity-Bodega Bay.

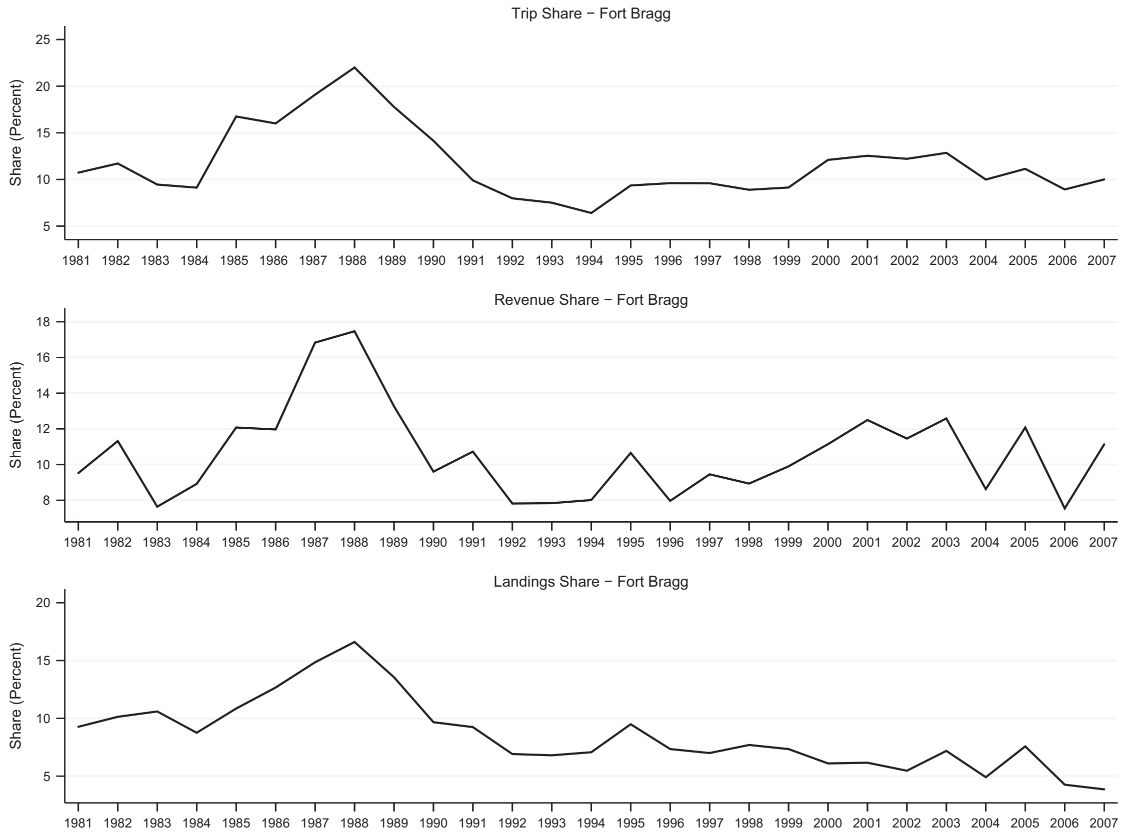

Fig. 10. Share of fishing activity-Fort Bragg.

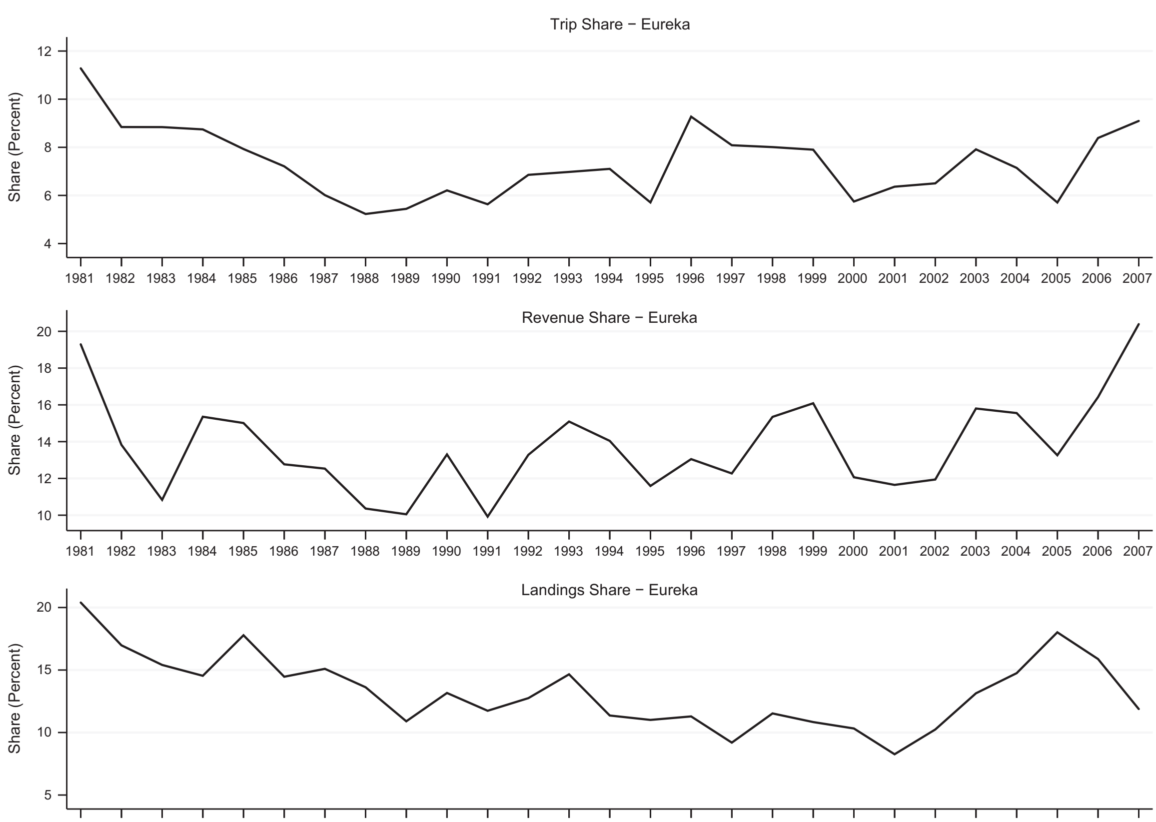

Fig. 11. Share of fishing activity-Eureka.

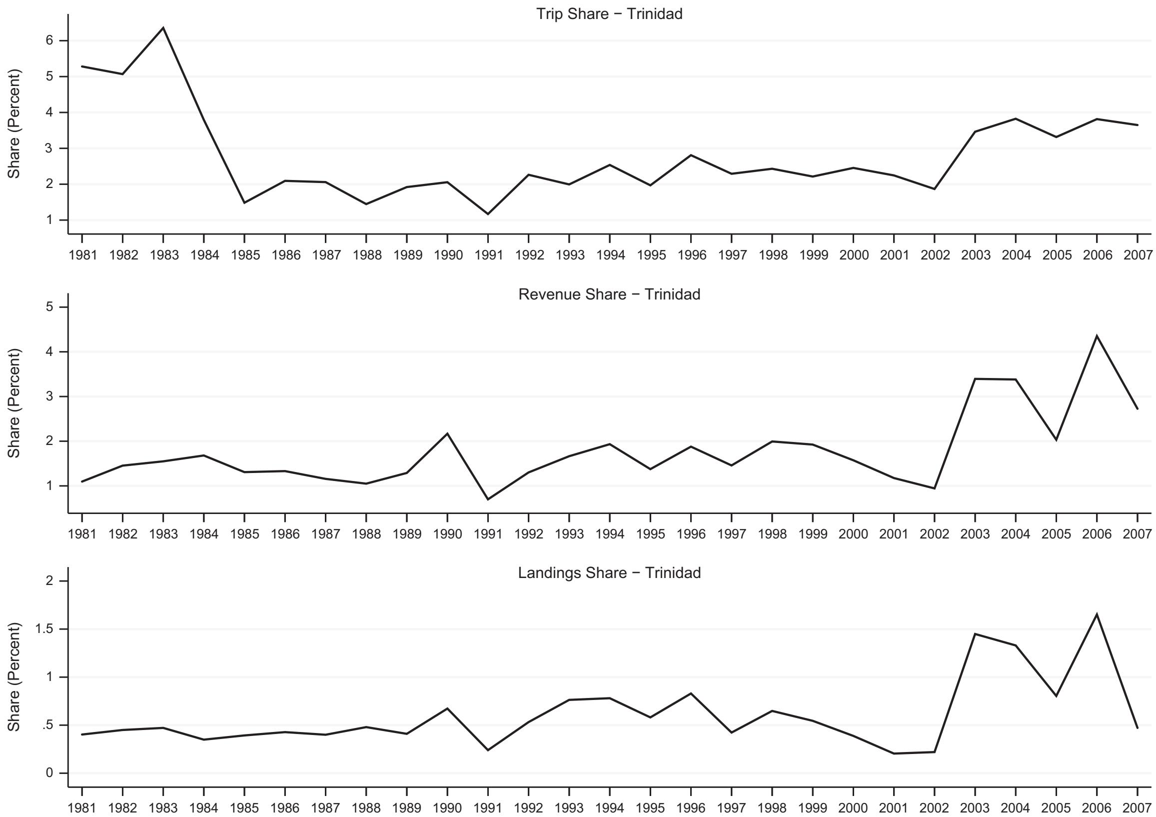

Fig. 12. Share of fishing activity-Trinidad.

Fig. 13. Share of fishing activity-Crescent City.

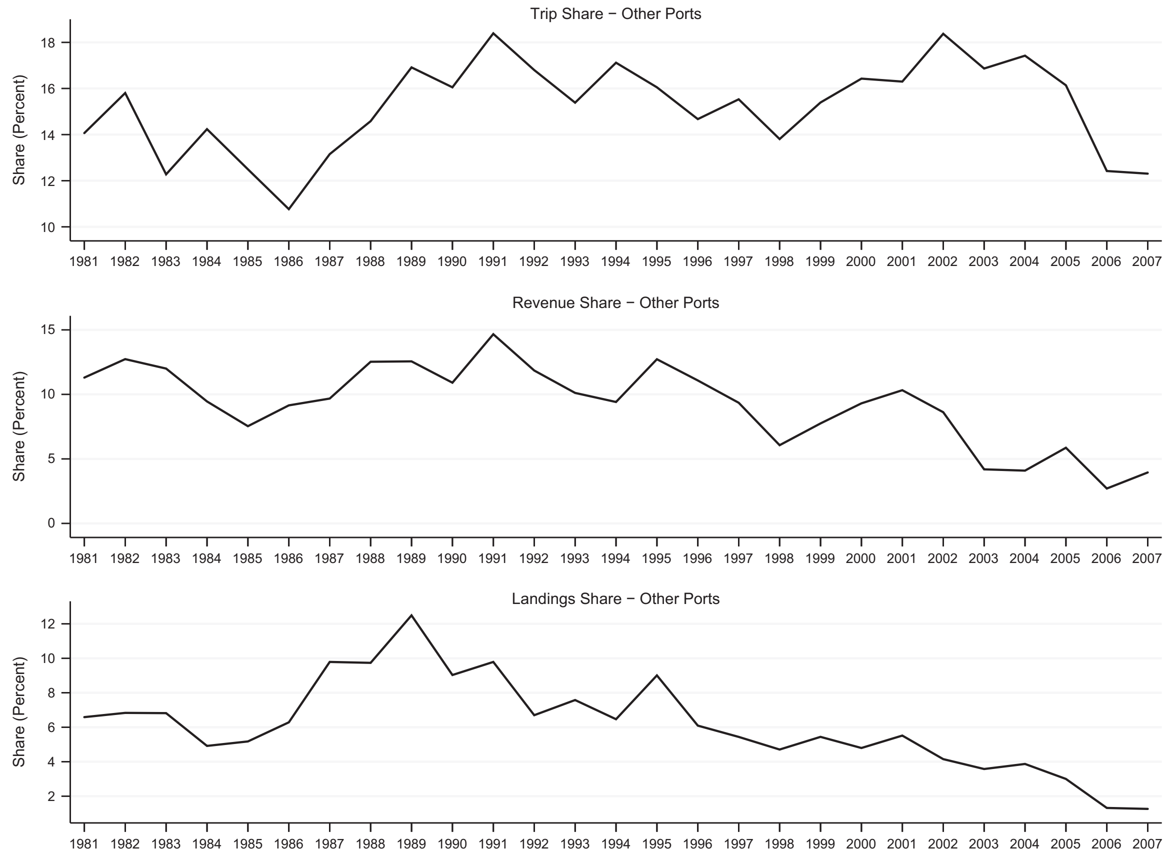

Fig. 14. Share of fishing activity-other ports.

Table 1
Coefficients of variation for shares of fishing activity, 1981 – 2007.

Port	Trip	Revenue	Landings
Other	0.13	0.34	0.43
Avila	0.27	0.30	0.50
Morro Bay	0.29	0.33	0.53
Monterey	0.23	0.38	0.54
Moss Landing	0.28	0.41	0.86
San Francisco	0.25	0.29	0.43
Princeton	0.23	0.28	0.37
Bodega Bay	0.27	0.27	0.47
Fort Bragg	0.32	0.24	0.36
Eureka	0.20	0.19	0.22
Trinidad	0.45	0.47	0.59
Crescent City	0.26	0.28	0.35
Average Coefficient of Variation	*0.26*	*0.31*	*0.47*

Table 2
Distances between adjacent ports. Mileage is approximate coastal driving distance.

Adjacent ports	Miles
Avila-Morro Bay	25
Morro Bay-Monterey	125
Monterey-Moss Landing	20
Moss Landing-Princeton	75
Princeton-San Francisco	30
San Francisco-Bodega Bay	70
Bodega Bay-Fort Bragg	110
Fort Bragg-Eureka	135
Eureka-Trinidad	25
Trinidad-Crescent City	65

value during the study period. The ports' shares of trips, revenue, and landings exhibit varying degrees of fluctuation over the study period. Coefficients of variation (CVs) indicate that shares of landings fluctuate the most (an average CV of 47%, almost half of mean landings shares), followed by port shares of revenue and trips (average CVs of 31% and 26%, respectively). Moss Landing's shares of trips, revenue, and landings appear to vary substantially over the time period of analysis. Moss Landing's high CV values are explained by the strong increasing trend in activity (refer to Fig. 6), particularly landings (associated with the dominance of the high-volume, low price-per-pound CPS fisheries there). The shares of activity at Eureka, where multiple fisheries are active, appears to fluctuate very little, while Trinidad, which is highly dependent on the crab fishery, exhibits high variability in all three activity measures (Figs. 11 and 12).

This evidence suggests that some ports' shares of fishing activity are relatively stable over time, which supports the null hypothesis. However, other ports' shares of fishing activity exhibit modest or high fluctuation and/or trends, which conflicts with the null hypothesis. These mixed results indicate that more systematic analysis is required.

3.2. Port share correlations

Related to the issue of differential fluctuations in fishing activity across individual ports is the question of whether shares of fishing activity move together among some ports in systematic ways. There are at least four possible types of systematic relationship between ports. First, ports may have a complementary relationship where the level of activity at one port positively affects activity at the related port. Such a relationship may exist if, for example, fishing activity at the related ports helps support

Table 3
Pairwise correlation in ports' trip shares*

TRIPS	Avila	Morro Bay	Monterey	Moss Landing	Princeton	San Francisco	Bodega Bay	Fort Bragg	Eureka	Trinidad
Morro Bay	0.52									
Monterey		−0.42								
Moss Landing		0.39	−0.53							
Princeton			−0.52	0.73						
San Francisco	0.69	0.56								
Bodega Bay		−0.48		−0.74						
Fort Bragg	−0.55	−0.40		−0.47		−0.49	0.72			
Eureka								−0.40		
Trinidad		−0.49				−0.42			0.69	
Crescent City		−0.40			−0.48				0.79	0.81

* Only significant results reported ($p \geq 0.05$). Shaded cells indicate pairs of adjacent ports.

shared services for the fishing fleet in both ports. Second, ports may be affected in the same way by a similar set of factors. This may be the case if, for example, the fleets from two ports tend to fish the same fish stock (subject to the same regulations and similar markets)-fishing activity would then fluctuate similarly at the two ports with the condition of the stock. Shares of activity that tend to consistently move in the *same direction* would be evidence of one or both of these types of relationship. Third, ports may have a competitive relationship where the level of activity at one port reduces the level of activity at the related port. This may be the case if, for example, nearby ports compete for a fixed number of boats in a fishery. Fourth, ports may be affected differently by a similar set of factors such as a shift in spatial distribution of a commonly targeted fish stock. Shares of activity that tend to consistently move in the *opposite direction* would be evidence of one or both of these types of relationship. In some cases, two or more of these types of relationship may exist between a pair of ports.

The extent to which two ports experience similar conditions may depend on the distance between the ports. Some of the 11 selected ports are farther from one another than other pairs of ports (Table 2). Adjacent ports that are relatively close to one another (≤ 30 miles) include Avila and Morro Bay, Monterey and Moss Landing, Princeton and San Francisco, and Eureka and Trinidad. Others are farther apart. For instance, three pairs of 'adjacent' ports are more than 100 miles from one another: Morro Bay and Monterey, Bodega Bay and Fort Bragg, and Fort Bragg and Eureka. The simple bivariate correlation coefficient for each pair of ports is used to assess the degree to which these types of relationships occur.

3.2.1. Trip share correlations

Among pairs of the 11 selected ports, 23 out of a possible 55 pairs have significant ($p < 0.05$) positive or negative correlations for trip shares (excluding correlations with the 'Other' ports category); nine are positive and 14 are negative (Table 3). Four geographically adjacent pairs of ports have positive correlations (Avila and Morro Bay, Bodega Bay and Fort Bragg, Eureka and Trinidad, Trinidad and Crescent City), while three geographically adjacent pairs have negative correlations (Morro Bay and Monterey, Monterey and Moss Landing, and Fort Bragg and Eureka).[2] Most of the significant correlations (16 of 23) do not involve adjacent ports. Morro Bay has the most significant correlations with seven (two positive and five negative), followed by Fort Bragg with five (one positive and four negative).

[2] Note that the 'Other' ports include smaller ports and landing sites that lie between some of the 11 selected ports.

3.2.2. Revenue share correlations

In terms of revenue shares, there are 17 significant correlations between pairs of ports, with six positive and 11 negative correlations among the 11 ports (Table 4). Four pairs of adjacent ports have positive correlations (Avila and Morro Bay, Bodega Bay and Fort Bragg, Eureka and Trinidad, Trinidad and Crescent City); none has a negative correlation. As with trip shares, most of the significant correlations of revenue shares (13 of 17) do not involve adjacent pairs of ports. Eureka has the most significant correlations with other ports (five), and the most positive significant correlations (three). Crescent City and Trinidad have the most significant negative correlations (six and four, respectively). Revenue at San Francisco, Bodega Bay, and Fort Bragg is correlated with just one other port each (all negatively).

3.2.3. Landings share correlations

In terms of landings, 24 significant correlations between ports were observed, 16 positive and eight negative (Table 5). Four pairs of adjacent ports have positive correlations (Avila and Morro Bay, Morro Bay and Monterey, San Francisco and Bodega Bay, Bodega Bay and Fort Bragg); one pair of geographically adjacent ports is negatively correlated (Monterey and Moss Landing). In terms of landings shares, Morro Bay is significantly correlated with the greatest number of other ports (six), whereas Eureka is not correlated with any other port on this measure.

3.2.4. Discussion

The positive correlations in measures of fishing activity between adjacent ports may be evidence of complementary relationships between ports or evidence that these ports are affected similarly by factors that drive local (as opposed to regional) fishing activity, such as changes in the abundance of fish stocks that their fleets target in common, and changes in common regulations. The strong positive correlations between shares of fishing activity at Bodega Bay and Fort Bragg provide an example of this phenomenon, especially with regard to the salmon, crab, and sea urchin fisheries. The north coast ports of Eureka and Crescent City afford another example of positively correlated ports located in the same regulatory zone and targeting the same fisheries (groundfish and crab).

Negative correlations in shares of fishing activity may reflect competitive relationships between nearby ports and/or differences in how ports are affected by factors that drive fishing activity. For example, salmon closures in the Klamath Management Zone (KMZ; affecting Crescent City, Trinidad, and Eureka) reduced trips at those ports and may have encouraged more fishing trips out of Fort Bragg, the first port south of the KMZ [1].

In the case of Monterey and Moss Landing, a shift in fishing activity from the former port to the latter began in the mid-1990s

Table 4
Pairwise correlation in ports' revenue shares*

REVENUE	Avila	Morro Bay	Monterey	Moss Landing	Princeton	San Francisco	Bodega Bay	Fort Bragg	Eureka	Trinidad
Morro Bay	0.61									
Monterey	0.64									
Moss Landing										
Princeton										
San Francisco			−0.53							
Bodega Bay				−0.54						
Fort Bragg							0.58			
Eureka		−0.39			−0.39					
Trinidad	−0.42	−0.61	−0.57						0.54	
Crescent City		−0.40	−0.41		−0.39			−0.50	0.51	0.79

* Only significant results reported ($p < 0.05$). Shaded cells indicate pairs of adjacent ports.

Table 5
Pairwise correlation in ports' landings shares*

LANDINGS	Avila	Morro Bay	Monterey	Moss Landing	Princeton	San Francisco	Bodega Bay	Fort Bragg	Eureka	Trinidad
Morro Bay	0.44									
Monterey	0.63	0.45								
Moss Landing	−0.59	−0.84	−0.70							
Princeton		0.64	0.57	−0.78						
San Francisco	0.58									
Bodega Bay		0.73	0.47	−0.87	0.73					
Fort Bragg		0.66		−0.72	0.66		0.75			
Eureka										
Trinidad					−0.40					
Crescent City	0.50	0.49		−0.62		0.51	0.47			

* Only significant results reported ($p < 0.05$). Shaded cells indicate pairs of adjacent ports.

with increases in the CPS and squid purse seine fisheries and in receiving capacity following the re-development of some of Moss Landing's infrastructure, among other factors [12]. Several seiners and some other vessels homeported at Monterey increasingly delivered their catch at Moss Landing, in some cases relocating their operations for part of the season or entirely.

The significant correlations that occur between ports distant from one another may simply be coincidental. However, one possible explanation for some of those correlations may be related to fishing patterns in spatio-temporally managed fisheries such as the salmon fishery. Some salmon trollers tend to “follow the fish” as areas are opened from south to north (and toward areas where the fish are generally more abundant) over the course of the season. Similarly, some of these fishermen also participate in the albacore troll fishery, where the location of activity is driven largely by where the fish are (which varies widely with environmental variability) and the location of buyers (which evidence suggests has changed markedly over the study period). Such mobile fishermen based in the Morro Bay and Monterey Bay areas are active closer to their home port at other times of the year, as they engage in other fisheries that are part of their “annual round.”

4. Concentration of fishing activity – among ports and among fisheries

4.1. Concentration of fishing activity in fewer ports

One possible consequence of the decline in the overall level of fishing activity in the study area is an increasing concentration of activity at fewer ports. Less fishing activity may mean that fewer ports are able to provide the specialized infrastructure and sustain support businesses necessary for commercial fishing. Larger, better equipped ports may draw fishing activity away from smaller ports that are unable to sustain a sufficient level of services. This type of concentration could have consequences for local economies, enhancing or straining those where activity has increased, while straining those where activity has decreased.

Changes in the concentration of fishing activity among ports are assessed by calculating the Herfindahl-Hirschman Index (HHI) over time. The HHI is commonly used to analyze market and industrial structure, specifically to assess the extent to which a market or industry is concentrated among a few firms.[3] In fisheries, the Hirschman-Herfindahl Index (HHI) has been used to explore such issues as the concentration of quota ownership ([13,14]) and processing capacity ([15,16]). The HHI is used here to measure the extent to which the concentration of fishing activity among ports, measured as trips and revenues by port and fishery, has changed over time. Note that the HHI is applied and calculated to analyze a different issue later in this article.

The HHI is simply the sum of the port shares squared. In formal terms,

$$HHI = \Sigma_{p=1}^{P} S_p^2 \tag{1}$$

where P is the total number of ports, and S_p is the share of revenues or trips for the p-th port. Higher values of HHI indicate more concentration; lower values indicate less concentration, with fishing activity more broadly distributed among ports.[4] Note that

[3] There are other measures of concentration including the Concentration Ratio, Dominance Index and others. The HHI is adequate for purposes of this paper, and has the added benefit that it is easy to calculate. The Gini Coefficient is not appropriate here because it is used primarily to measure inequality, and furthermore is complicated to calculate.

[4] For example, if there are 30 identical ports with 1/30th shares, $HHI = 30 \times (1/30)^2 = 0.033$. If 5 of the 30 ports have 10% shares, and the other 25 ports have 2% shares, $HHI = 5 \times (0.10)^2 + 25 \times (0.02)^2 = 0.60$. This illustrates how the HHI increases in value to reflect greater concentration, with more revenue or trips in a few ports and less in most ports.

Fig. 15. Concentration among ports-all fisheries.

it is not possible to attribute any particular interpretation to absolute values of the HHI (as is commonly done in analyses of imperfect competition). Rather, HHI values over time and across ports and fisheries are compared and used as an indication of relative concentration levels. Note that higher HHI values indicate activity is concentrated at fewer ports.

Industry-wide concentration of trips among ports (Fig. 15, top panel) increased sharply during the mid- to late-1980s, dropped through 1991 (consistent with a boom in the trip-intensive sea urchin dive fishery at a few ports, especially Fort Bragg), remained fairly stable across through 2004, and saw an uptick during the last three years of the study period. Industry-wide concentration of revenue among ports (Fig. 15, middle panel) was stable until about 2002, after which it increased sharply. Industry-wide concentration of landings (Fig. 15, bottom panel) grew steadily from the mid-1990s through the end of the period.

For the salmon fishery (Fig. 16), the three measures of fishing activity show similar patterns of concentration among ports. Notable spikes occur coincident with severe restriction in the length of the salmon season in the northern part of the study area: 1985 (when the KMZ was closed), 1987 and 1988 (salmon season shortened to 42 and 11 days, respectively, in the KMZ), 1994 (when the KMZ was closed), and 2006 and 2007 (salmon season closed and shortened to 3 days, respectively, in the KMZ). Reducing the level of salmon activity in ports subject to reduced season length, in this case the large ports of Crescent City and Eureka, leads to a higher proportion of activity in other, less affected ports. An additional large spike in concentration occurs in 2006, the result of a sharply increased season length in the vicinity of Fort Bragg and resultant increase in activity there. For the groundfish fishery (Fig. 17), all measures of fishing activity became more concentrated at fewer ports from about 2000 to the end of the period, as a higher share of groundfish trips, revenues and landings occurred at Eureka. The concentration of the groundfish fishery at Eureka coincides with consolidation of receivers and processors in the northern portion of the study area. In addition, 16 of 17 resident trawlers at nearby Crescent City participated in the 2003 federal Groundfish Trawl Buyback. The concentration of fishing activity in the crab fishery (Fig. 18) exhibits considerable fluctuation and appears to have drifted downward since the beginning of the study period. In other words, the crab fishery has become less concentrated among ports over time.

4.2. *Concentration of fishing activity in fewer fisheries*

A related issue is whether and to what extent fishing activity has become more concentrated in fewer fisheries over the study period. The structure of the fishing industry may change as fishing activity becomes more (or less) concentrated in fewer (or more) fisheries as a result of social, economic, regulatory and biological factors. For example, a decline in abundance or regulations to protect species of concern (e.g., some groundfish species) may lead to a shift of fishing activity into alternative fisheries (such as crab). These types of structural changes may affect local economies by altering the types of employment or support services needed to support commercial fishing or by making ports less resilient to changes in fishing regulations or stock conditions.

The Herfindahl-Hirschman Index (HHI) is calculated again, this time to assess changes in the concentration of fishing activity among fisheries over time. The calculated HHI in this case is the

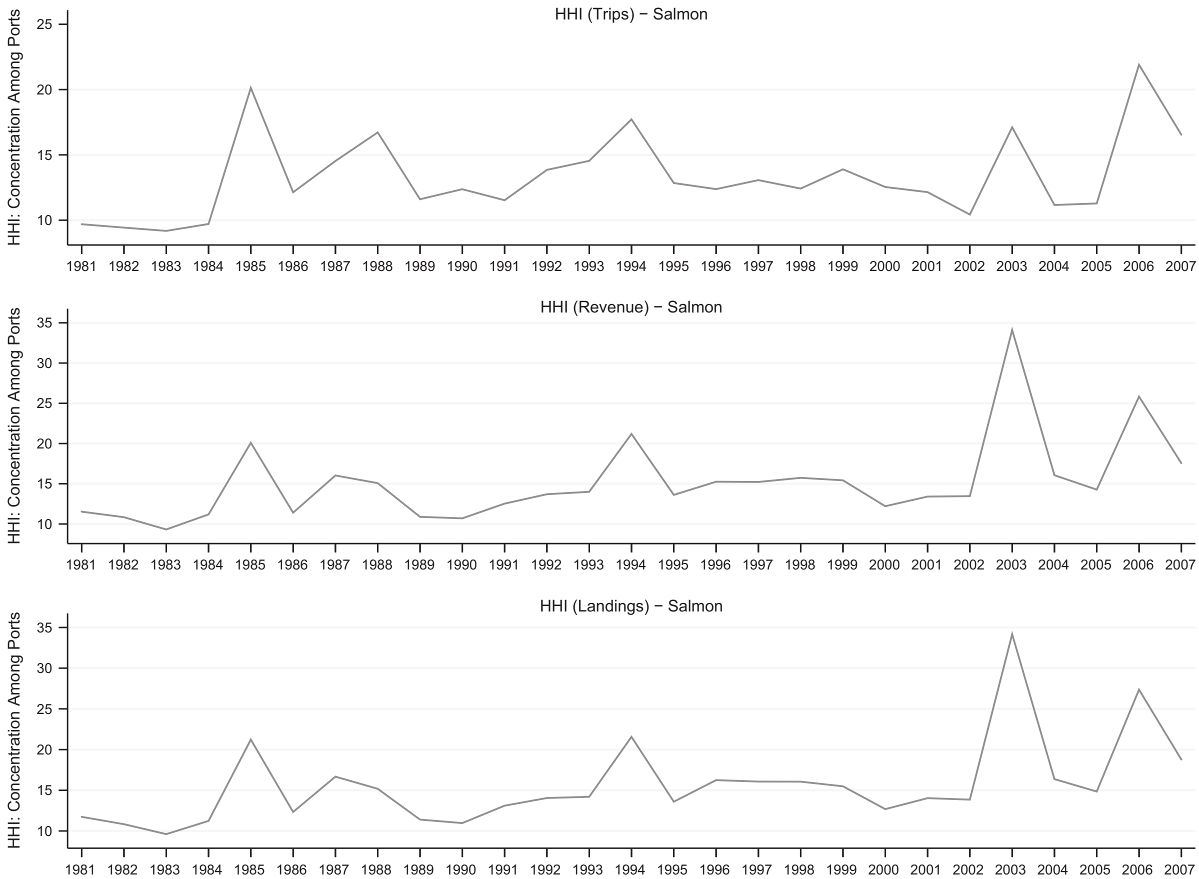

Fig. 16. Concentration among ports-salmon fishery.

Fig. 17. Concentration among ports-groundfish fishery.

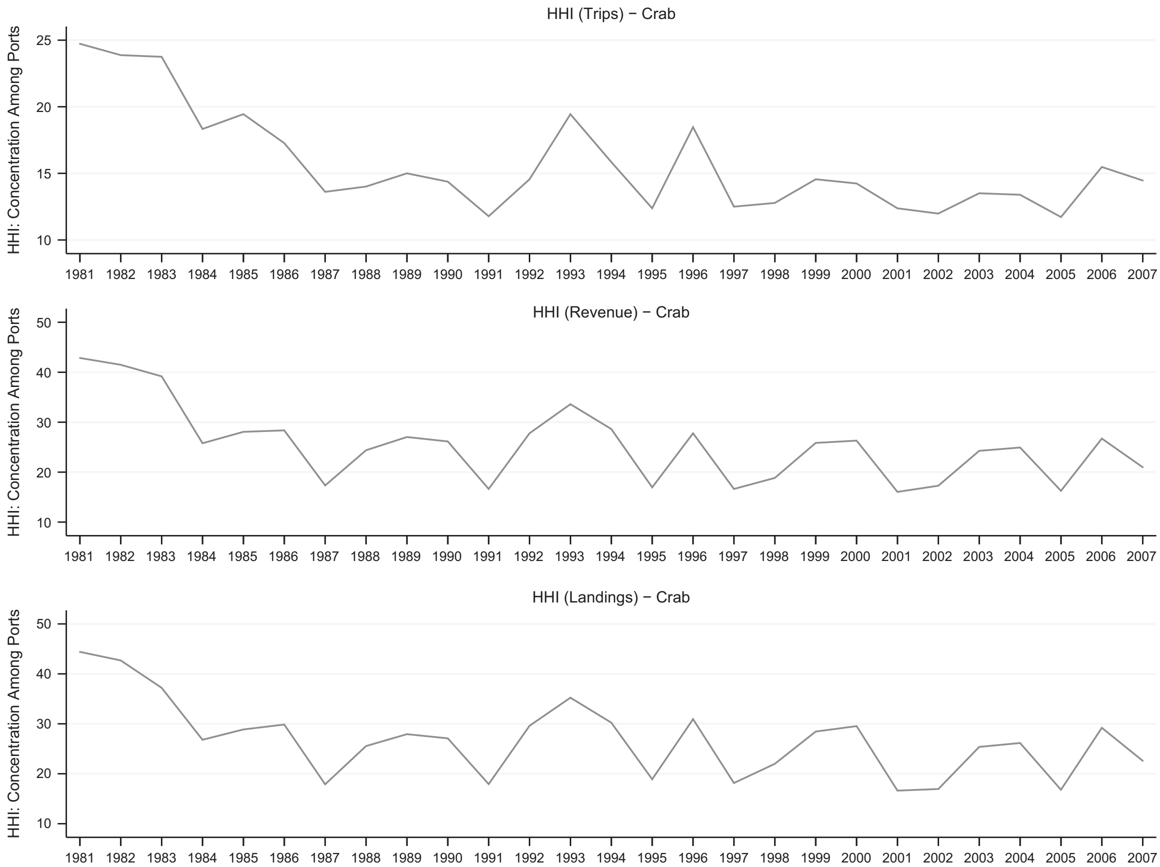

Fig. 18. Concentration among ports-crab fishery.

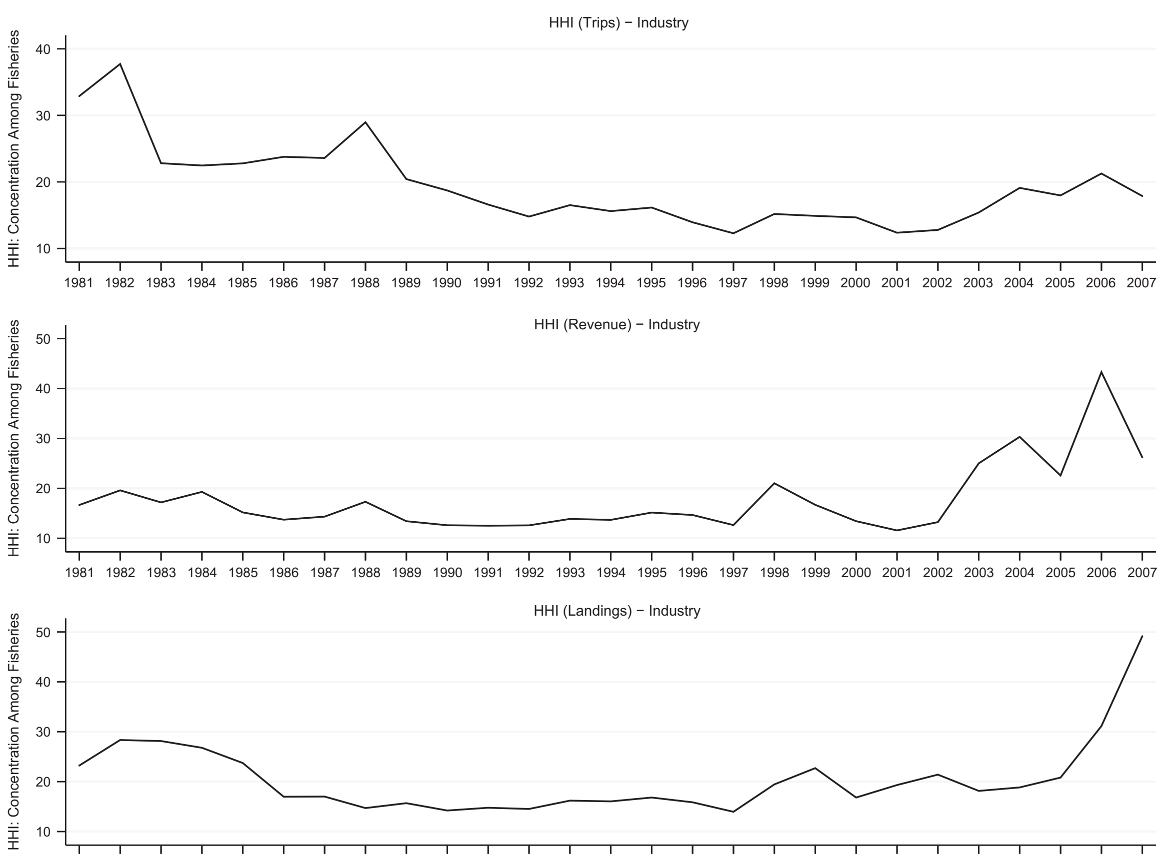

Fig. 19. Concentration among fisheries – HHI for region-wide industry.

sum of the fishery shares squared. In formal terms,

$$\mathrm{HHI} = \Sigma_{p=1}^{P} S_p^2 \tag{2}$$

where F is the total number of fisheries, and S_f is the share of revenues or trips for the f-th fishery. Higher HHI values in this context indicate that the fishing industry in the study area is more concentrated in a smaller number if fisheries.

Concentration of trips among fisheries (Fig. 19) declined from the early 1980s through the late 1990s. Trips then become more concentrated in fewer fisheries from the early 2000s through the end of the study period. Concentration of revenues and landings among fisheries remained relatively stable in the early portions of the study period and began becoming more concentrated in fewer fisheries beginning in the early 2000s through the end of the study period. The increased concentration that observed in the latter part of the study period occurs because of increased levels of activity in the Dungeness crab fishery and decreased levels of activity in the groundfish trawl fishery.

5. Rank stability analysis

The analysis in this section assesses the degree to which the relative distribution of fishing activity across ports-as measured by port rankings-is stable over time. Kendall's τ is a rank correlation statistic that measures the stability of rankings between two time periods and is calculated as

$$\tau = \frac{(N_c - N_d)}{[n(n-1)/2]} \tag{3}$$

where N_c is the number of ports whose rankings are the same in the two periods (concordant pairs), N_d is the number of ports whose rankings are different in the two periods (discordant pairs), and n is the total number of ports ranked. The resultant τ-value is a correlation coefficient ranging from -1 to 1. A τ-value of 1 indicates that rankings in two years are identical. A τ-value of -1 indicates that rankings in two years are exactly opposite (e.g., year 1={1,2,3}, year 2={3,2,1}). A τ-value of 0 indicates that rankings in two years are completely independent of each other. The τ-value can be tested for statistical significance, with the null hypothesis being that the two sets of rankings are unrelated (i.e., H_0: $\tau=0$). The sampling distribution of τ approximates the standard normal when $n > 10$, so hypothesis testing is performed by calculating

$$Z_\tau = \frac{\tau}{\sigma_\tau} \tag{4}$$

$$\sigma_\tau = sqrt\{2(2n+5)/9n(n-1)\} \tag{5}$$

such that $\sigma\tau$ is the standard deviation of τ. Greater (more positive) values of τ indicate that port ranks are more stable over the two periods.

We calculate τ-values for pairs of years that are 1, 5, and 10 years apart and plot these values (Figs. 20–25). Pairs that are 1 year apart include those beginning with 1981–1982 and ending with 2006–2007, while pairs that are 5 years apart include pairs beginning with 1981–1986 and ending with 2002–2007. Variation in τ-values across these pairs would indicate that some time periods exhibit more instability of port rankings than others. If the calculated τ-value for each year pair (solid line) is above the critical value of τ for $\alpha=0.05$ in a one-tailed test (dotted line), then the hypothesis that the two rankings are not independent (i.e., they are dependent, and the rankings are statistically the same and have not changed) is rejected.

Figs. 20–22 are plots of calculated τ-values (shown as solid lines) for rankings in trips, revenue, and landings, respectively, when all 30 ports are ranked for the three pairs of years (1-, 5-, and 10-year intervals). Figs. 23–25 are plots of calculated τ-values by measure of fishing activity when 11 selected ports are plotted at

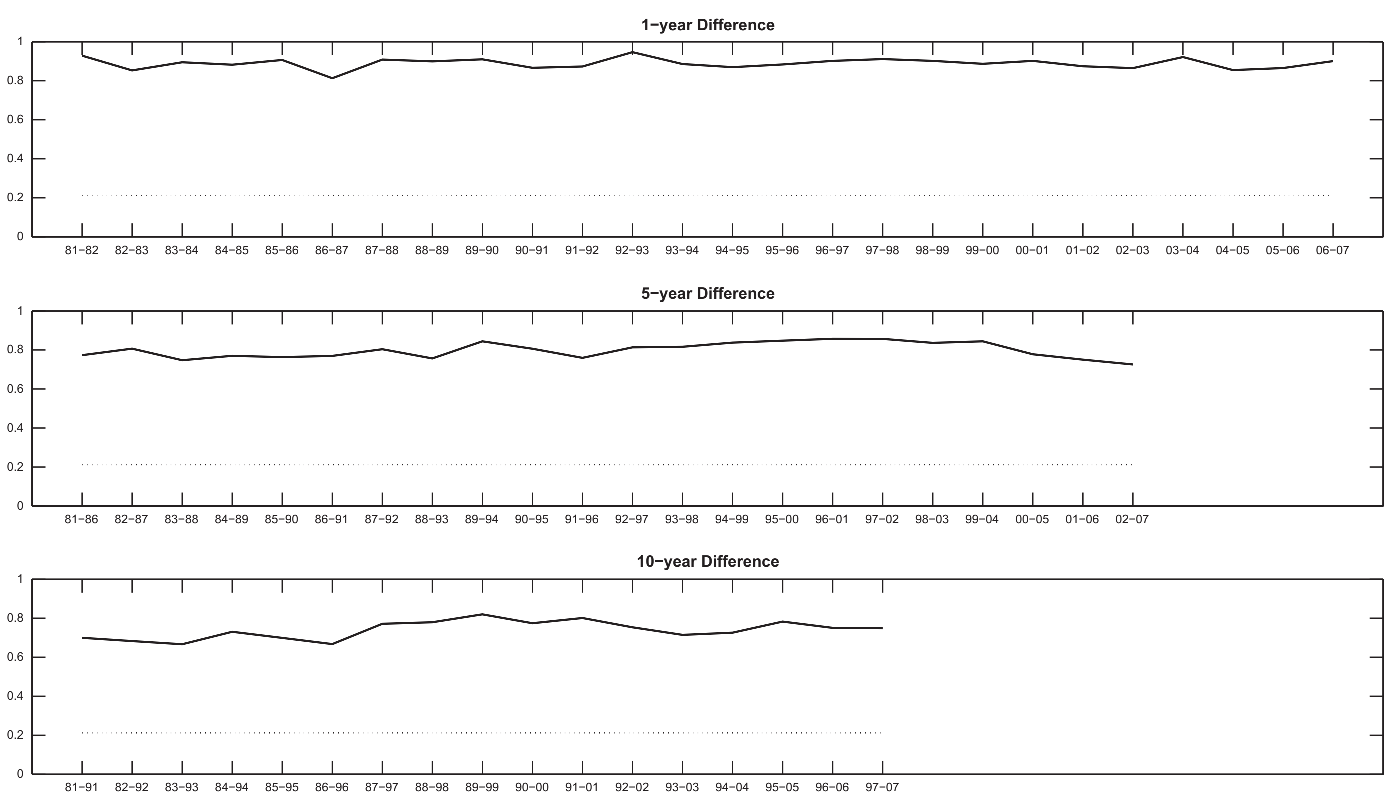

Fig. 20. τ (Kendall's Rank Correlation Coefficient) for pairs of years at 1-, 5-, and 10-year intervals. All 30 ports are ranked by number of *trips*. The x-axis indicates the year pair for which τ is calculated. The y-axis is τ. The calculated τ -value for each year pair is the solid line. The critical value of τ ($\alpha=0.05$ for a one-tailed test) is the dotted line.

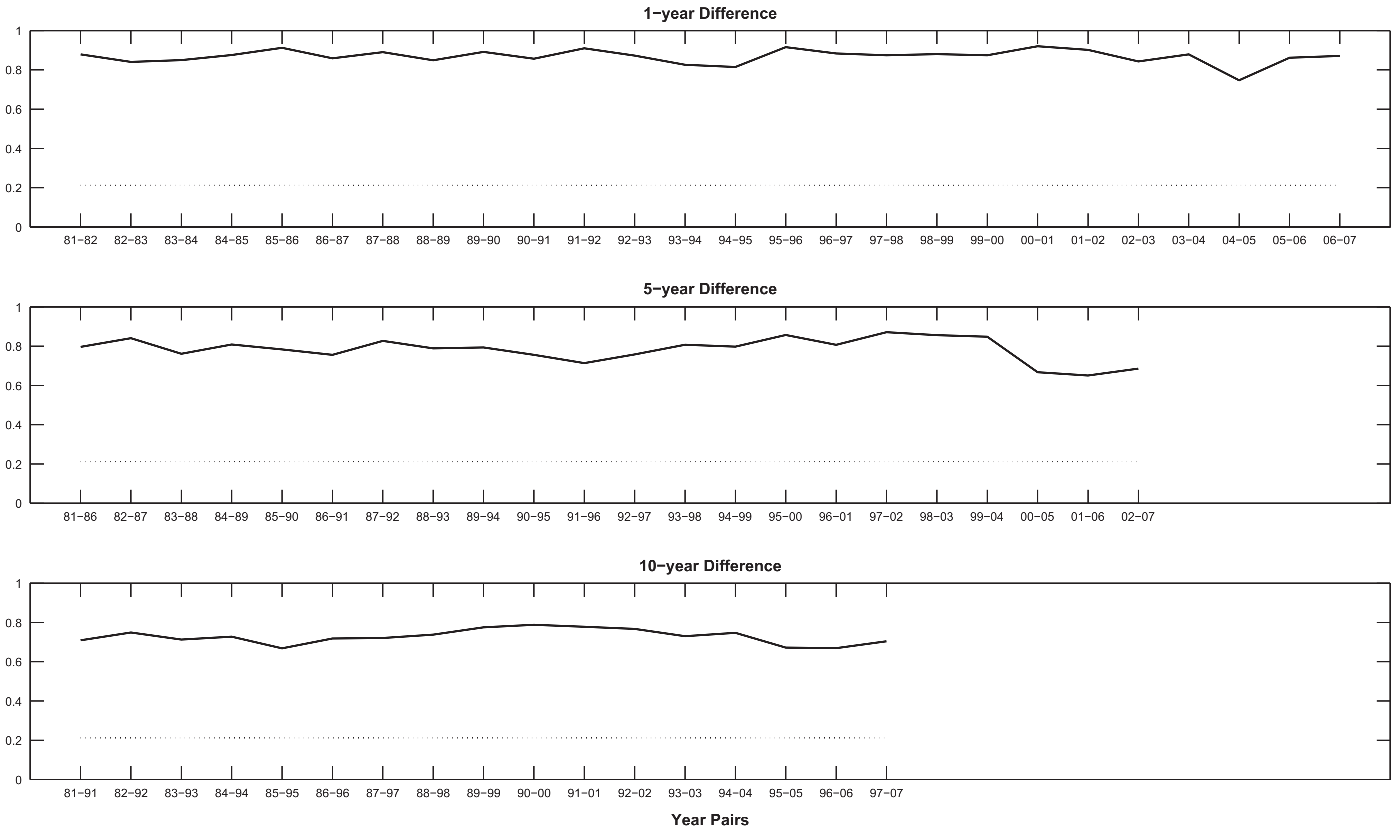

Fig. 21. τ (Kendall's Rank Correlation Coefficient) for pairs of years at 1-, 5-, and 10-year intervals. All 30 ports are ranked by ex-vessel *revenue*. The *x*-axis indicates the year pair for which τ is calculated. The *y*-axis is τ. The calculated τ -value for each year pair is the solid line. The critical value of τ (α=0.05 for a one-tailed test) is the dotted line.

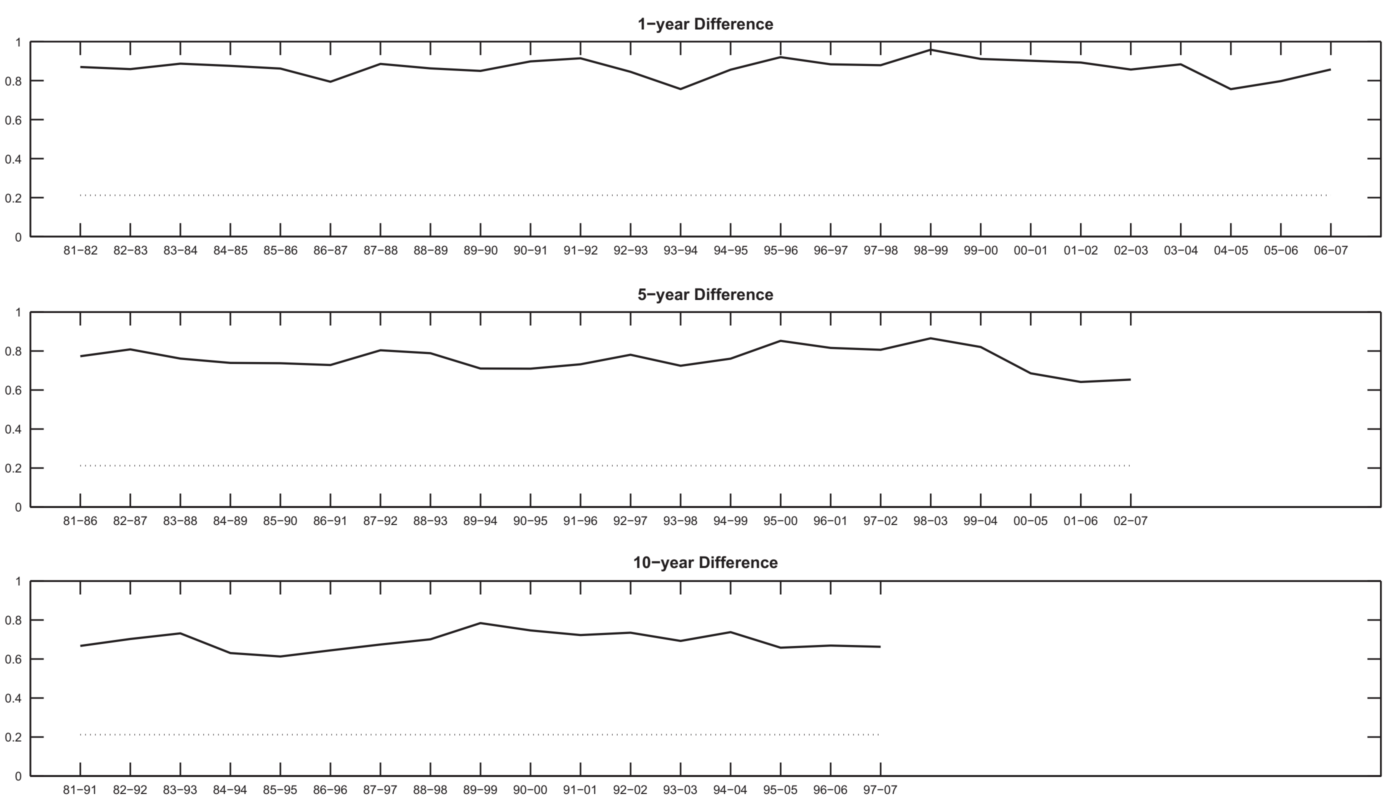

Fig. 22. τ (Kendall's Rank Correlation Coefficient) for pairs of years at 1-, 5-, and 10-year intervals. All 30 ports are ranked by *landings*. The *x*-axis indicates the year pair for which τ is calculated. The *y*-axis is τ. The calculated τ -value for each year pair is the solid line. The critical value of τ (α=0.05 for a one-tailed test) is the dotted line.

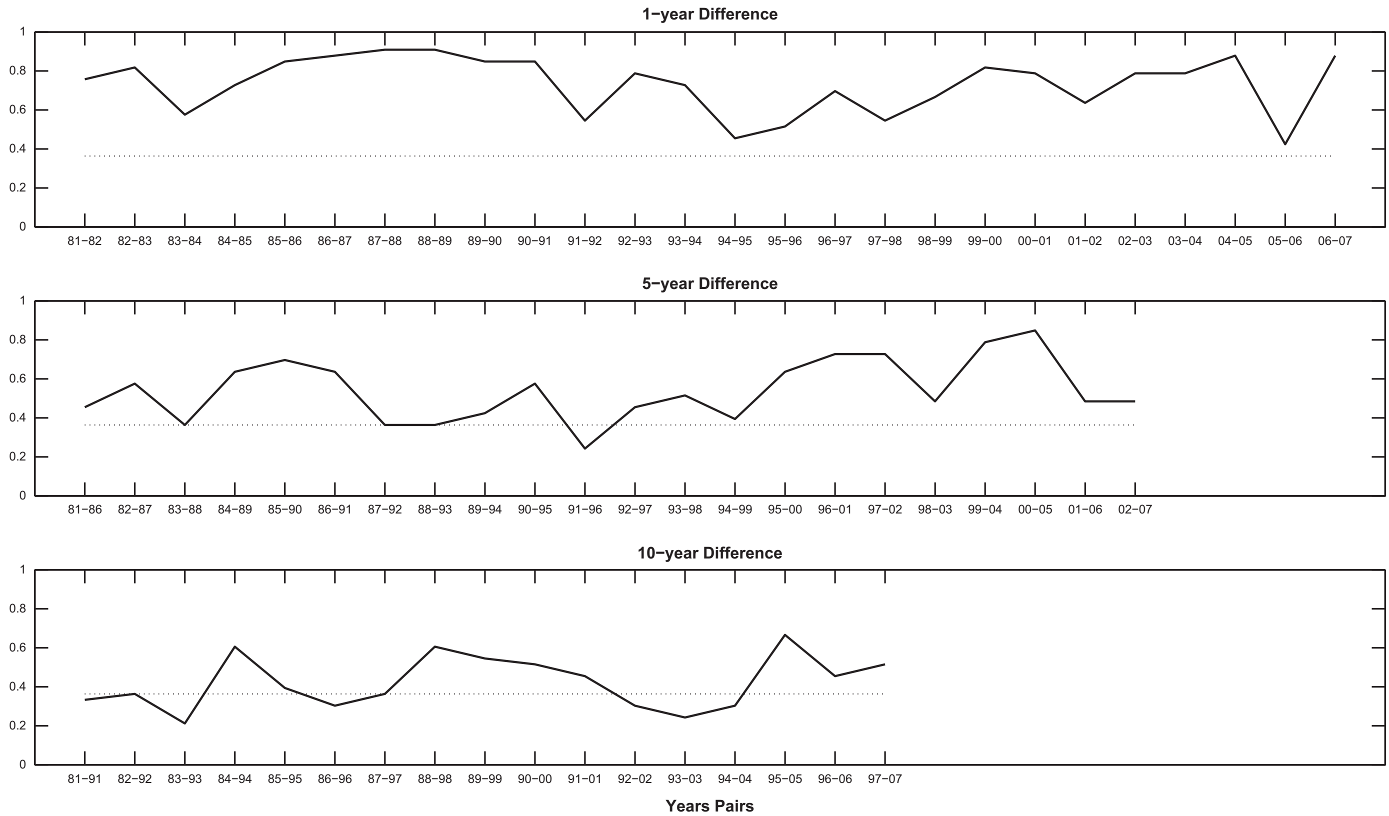

Fig. 23. τ (Kendall's Rank Correlation Coefficient) for pairs of years at 1-, 5-, and 10-year intervals. Ports are ranked by trips. Only 11 selected ports and an aggregate of other ports are used in the calculation. The *x*-axis indicates the year pair for which τ is calculated. The *y*-axis is τ. The calculated τ -value for each year pair is the solid line. The critical value of τ (α=0.05 for a one-tailed test) is the dotted line.

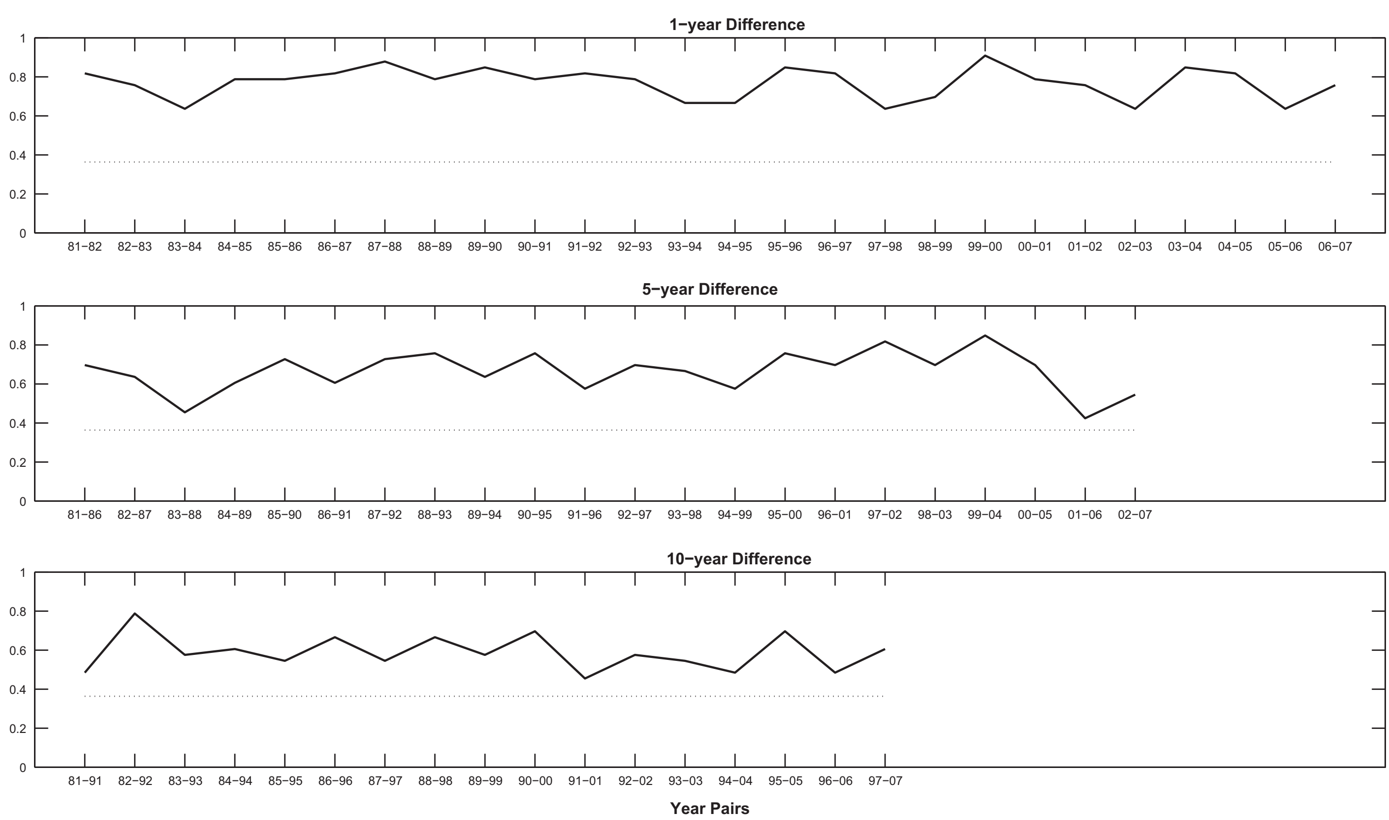

Fig. 24. τ (Kendall's Rank Correlation Coefficient) for pairs of years at 1-, 5-, and 10-year intervals. Ports are ranked by *revenue*. Only 11 selected ports and an aggregate of other ports are used in the calculation. The *x*-axis indicates the year pair for which τ is calculated. The *y*-axis is τ. The calculated τ -value for each year pair is the solid line. The critical value of τ (α=0.05 for a one-tailed test) is the dotted line.

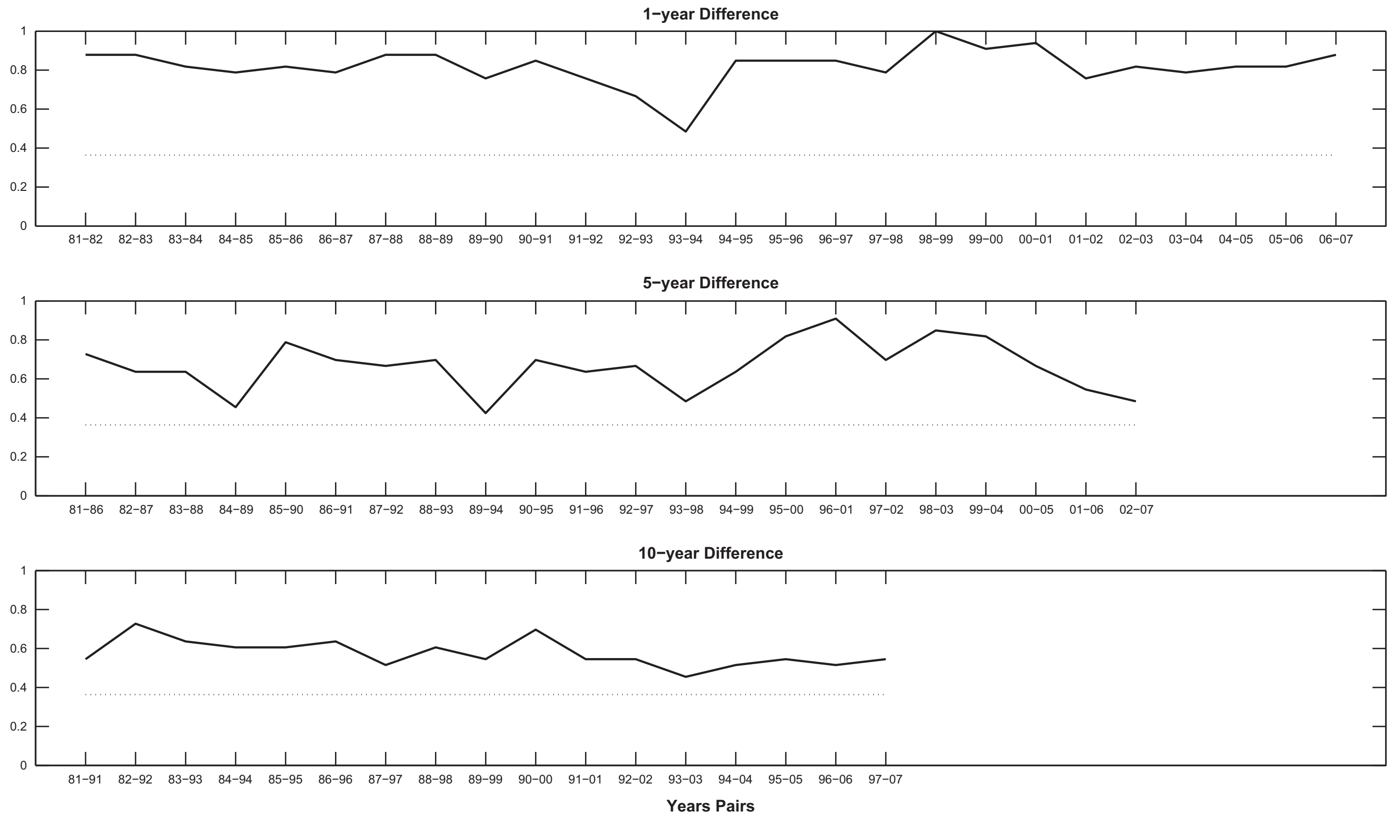

Fig. 25. τ (Kendall's Rank Correlation Coefficient) for pairs of years at 1-, 5-, and 10-year intervals. Ports are ranked by *landings*. Only 11 selected ports and an aggregate of other ports are used in the calculation. The x-axis indicates the year pair for which τ is calculated. The y-axis is τ. The calculated τ -value for each year pair is the solid line. The critical value of τ (α=0.05 for a one-tailed test) is the dotted line.

1-year intervals (top panel), 5-year intervals (second panel); and 10-year intervals (third panel).

The port rankings are very stable for all three activity metrics. This is particularly the case when all 30 ports are ranked. The significance levels associated with the calculated τ-values (Figs. 20–22) indicate that when all 30 ports are ranked, indicate that the rankings are *not* different from year to year. When only the 11 selected ports are ranked (plus the aggregated "Other ports") the rankings are somewhat less stable, particularly in terms of trips. For the 11 selected ports in terms of trips, three out of 22 5-year interval pairs and eight out of 17 10-year interval pairs indicate a statistically significant change in the rankings. None of the year pairs in the revenue and landings rankings is found to be different. These results indicate that ports' rankings have changed slowly over time, even over lengthy intervals (such as 10 years). These would seem to indicate that the rank order of ports has changed little over time.

6. Differences in percentage changes in fishing activity

One way to examine whether the distribution of activity among ports has been constant over the study period is to compare changes in fishing activity in individual ports to overall changes in the ports system as a whole. To do this, the statistical significance of differences between percentage change in the region-wide level of fishing activity and the percentage change in individual ports' levels of activity fishing activity are tested. In the first test, the null hypothesis is that the cumulative percent changes (in trips, revenue, or landings) at individual ports are the same as changes at the region-wide level, with changes measured relative to a fixed base year.

Examining changes relative to a base year will help determine if changes are persistent rather than due to variable short-term factors and adjust for the fact that total trips and revenue have declined over time. To determine if the results are robust to the base year chosen, two base years are examined: 1981 and 1991. The data set begins in 1981, so that base year utilizes the maximum amount of information. The data prior to 1991 suggest a period of greater fluctuation in revenue and landings relative to subsequent years (Fig. 2).

We calculate the percentage change values at port p in time t by subtracting the base year level of activity (trips, revenue, or landings) from the activity level at port p in year t and dividing by activity level in the base year. Percentage change values are similarly calculated at the region-wide level by subtracting base year region-wide activity from region-wide activity in time t and dividing by the base year level. These percentage change formulas are given in (6) and (7), where $x_{p,t}$ and $x_{R,t}$ are activity level (trips, revenue, or landings) in port p and region-wide (R) at time t.

$$\%\Delta_{p,t} = \frac{(x_{p,t} - x_{p,baseyear})}{x_{p,baseyear}} \tag{6}$$

$$\%\Delta_{R,t} = (x_{cw,t} - x_{R,baseyear})/x_{R,baseyear} \tag{7}$$

To determine whether all ports are changing at the same rate, the null hypothesis that the mean difference between the percentage change at port p and the percentage change at the region-wide level is equal to zero is tested. The t-statistic is calculated as in (8) and (9).

$$annual\ difference_p = \%\Delta_{p,t} - \%\Delta_{R,t} \tag{8}$$

Table 6
Differences between percent changes in region-wide fishing activity and fishing activity at individual ports, base year 1981.

Port	Trips		Revenue		Landings	
	Mean difference (percentage points)	*t*-statistic	Mean difference (percentage points)	*t*-statistic	Mean difference (percentage points)	*t*-statistic
Avila	21.7	4.40*	−7.3	−1.23	−9.3	−1.44
Morro Bay	27.7	5.52*	21.2	2.68*	22.6	2.17*
Monterey	−14.3	−9.33*	−44.6	−10.02*	−34.9	−8.87*
Moss L.	40.4	8.45*	−3.8	−0.47	56.7	2.49*
Princeton	68.8	10.62*	195.6	13.23*	311.8	10.40*
San Fran.	25.5	9.26*	25.8	3.29*	−6.3	−1.26
Bodega Bay	1.6	0.37	17.8	2.17*	6.0	0.77
Fort Bragg	9.9	1.60	14.2	2.07*	−3.1	−0.53
Eureka	−23.6	−9.50*	−32.2	−10.03*	−29.3	−12.78*
Trinidad	−31.7	−7.68*	66.5	4.13*	36.4	3.06*
Crescent City	−25.4	−10.17*	5.9	1.00	32.2	4.09*
Other Ports	5.0	2.73*	−17.9	−3.19*	−1.4	−0.21

* indicates significance at the 0.05 level.

Table 7
Differences between percent changes in region-wide fishing activity and fishing activity at individual ports, base year 1991.

Port	Trips		Revenue		Landings	
	Mean difference (percentage points)	*t*-statistic	Mean difference (percentage points)	*t*-statistic	Mean difference (percentage points)	*t*-statistic
Avila	0.4	0.11	−3.6	−0.60	−14.8	−1.91
Morro Bay	2.5	1.05	−4.4	−0.73	−22.5	−3.14*
Monterey	−17.9	−15.21*	−9.8	−1.53	−16.6	−2.13*
Moss L.	25.3	7.25*	112.2	9.31*	421.4	7.24*
Princeton	0.9	0.37	13.4	3.93*	−18.8	−3.73*
San Fran.	3.6	1.18	−19.5	−4.57*	−33.8	−10.90*
Bodega Bay	−14.4	−6.74*	−37.2	−11.24*	−49.0	−14.37*
Fort Bragg	−1.9	−0.78	−8.7	−2.90*	−23.8	−9.39*
Eureka	18.6	6.89*	38.5	10.30*	1.6	0.51
Trinidad	76.5	16.51*	179.3	7.07*	158.4	6.24*
Crescent City	9.0	3.67*	33.1	4.62*	−17.7	−3.47*
Other Ports	−8.9	−9.44*	−40.2	−10.51*	−39.7	−12.20*

* indicates significance at the 0.05 level.

$$t_p = mean(annual\ difference_p)/\{Std\ Dev(annual\ difference_p)/years\} \quad (9)$$

The number of years (26 when the base year is 1981, 16 when the base year is 1991) is n in the traditional t-statistic formula. Results of the differences for base year 1981 and base year 1991 are presented, respectively, in Tables 6 and 7.

The analysis of the cumulative percent changes in ports' fishing activity clearly shows significant differences from the region-wide level of cumulative changes. When the base year is 1981, all ports exhibit a significant difference on at least one of the three metrics; when the base year is 1991, all ports but one (Avila) exhibit similar significant differences.

These results are further evidence that shares of ports differ in terms of their dynamic fishing activity patterns over time, and also constitute a rejection of the null hypothesis that the *cumulative* percent changes at individual ports are the same as changes at the region-wide level.

7. Discussion

This paper investigates how the dramatic declines in overall region-wide fishing activity have been distributed among fishing ports in the central and northern California coastal region. Using a variety of methods, the null hypothesis that overall changes in fishing activity have been distributed evenly across all ports in the study region is tested. Using data on commercial fishing activity, fishing activity is measured in terms of the number of trips, revenue and landings at each port for the period 1981–2007.

Three questions are examined. First, have individual ports' *shares* of fishing activity been constant over time? Second, has the *rank order* of ports in terms of fishing activity changed significantly over time? Third, has the concentration of fishing activity changed significantly among ports and among fisheries overtime? Fourth, has the *rate of change* in fishing activity at individual ports been the same as the rate of change in the region-wide industry as a whole? Findings are summarized below.

Have individual ports' *shares* of fishing activity been constant over time? The evidence strongly indicates that the shares of fishing activity for the selected ports are not strictly constant over time. Ports' shares of trips, revenue and landings fluctuate to varying degrees over the study period. Shares of landings fluctuate the most (an average CV of 47%), followed by port shares of revenue and trips (average CVs of 31% and 26%, respectively). These results indicate that some individual ports' shares of fishing activity are *relatively* stable while other ports' shares show modest and high levels of fluctuation over the period. Also, fishing activity at some pairs of ports move together in systematic ways. Some pairs, such as Bodega Bay and Fort Bragg, exhibit statistically significant positive correlations in their shares of fishing activity, likely due to similar factors (such as changes in the abundance of fish stocks targeted in common by the ports' fleets and/or changes in common regulations) affecting fishing activity. Other pairs of ports showed significant negative correlations, such as the salmon closures that reduced trips at Crescent City, Trinidad and Eureka, and may have encouraged more fishing trips out of Fort Bragg.

Has the *rank order* of ports in terms of fishing activity changed significantly over time? To further measure the relative impact of changes in fishing activity on individual ports, the degree to which the relative distribution of fishing activity across ports-as measured by port rankings-is stable over time is assessed. The formal rank correlation analysis shows that ports' rankings have changed slowly, and have changed more over longer intervals. In addition, the rankings change less (more) when the comparison is made among a larger (smaller) set of ports.

Has the concentration of fishing activity changed significantly among ports? This question is addressed by assessing how the Herfindahl-Hirschman Index (HHI) for fishing activity among ports has changed over time. The results show that for the fishing industry overall, there is an apparent trend towards greater concentration of shares of fishing activity in fewer ports. Concentrations among ports in the salmon and groundfish fisheries show upward trends for some, but not all, of the three activity metrics. Concentration of fishing activity among ports in the crab fishery exhibited considerable fluctuation with a slight negative trend. In other words, the crab fishery has become less concentrated among ports over time.

Has the region-wide fishery become more concentrated in fewer fisheries over time? The HHI measure indicates that concentration among fisheries has increased from the early to middle portion of the study period to the end. The region's fishing industry as a whole has become concentrated in fewer fisheries from the early 2000s to the end of the study period in 2007 (Fig. 19).

Has the *rate of change* in fishing activity at individual ports been the same as the rate of change in the region-wide industry as a whole? To address this question, a test of the statistical significance of differences in percentage changes between the region-wide and individual ports' fishing activity for 11 selected ports was performed: *t*-tests of the null hypothesis that the cumulative percent change in trips or revenue at the port level is equal to the cumulative percent change region-wide. The results indicate that ports differ in the dynamics of their fishing activity patterns over time, thereby leading us to reject the null hypothesis that the *cumulative* percent changes at individual ports are the same as changes at the region-wide level.

The results clearly show that the overall changes in fishing activity have not been distributed evenly across ports in the region. However, the results also show that the rank order of ports by level of fishing activity is fairly stable and changes slowly over time. This indicates that while fishing activity has changed at different rates in different ports, the relative position of ports has not changed.

These results may help policy-makers, managers, and stakeholders to better understand the dramatic changes that have occurred in the region's fisheries as they consider investments in public goods that provide services to the fishing fleet, such as docks, hoists, or road access [17]. Specifically, the declines in fishing activity-along with increasing port operating costs and high uncertainty regarding the nature and extent of future fishery restrictions-have led some harbor managers and communities to question their ability to justify and finance maintenance of fishery infrastructure. Such analyses can be useful to those who provide goods and services such as fuel, ice, and vessel and equipment repair and maintenance. They also can be used to identify port communities that may be vulnerable to further change. The need for such information is particularly compelling for ecosystem-based regulatory actions that encompass multiple fisheries, as failure to consider such complexities may inadvertently undermine original policy objectives and lead to unintended and potentially irreversible socioeconomic consequences.

The techniques presented in this analysis also may be useful for developing methods for evaluating whether fishery management measure have similar effects on different fishing communities. This work does not attempt to perform this type of analysis, but does present a way to perform retrospective analysis of how fishing outcomes differ among ports.

Port level fishery dynamics and their impact on local communities is a rich area of future research. Future analyses could consider alternative measures of fishing activity, such as numbers and types of fishing vessels. Other potential research topics include the dynamics of entry and exit, and switching behavior among fisheries and ports in the region, and attempt to identify and measure the underlying drivers of these dynamic changes. These are important matters, especially given the substantial changes in fisheries in recent years, the apparent impact on and needs of fishing communities and working waterfronts, and the likelihood of further change amid dynamic environmental, economic and political conditions.

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