

# Smoothing the Time Path of Landings

*A Statistical Analysis  
of U.S. Catch Share Programs*

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## ABSTRACT

Catch share programs implemented in U.S. fisheries provide an alternative to traditional fishing practices and a means to deter overfishing and overcapitalization in fisheries markets. Research suggests that catch share programs are responsible tools for sustainable fishing, but there are still open questions concerning their impact on fishing behavior. Catch share programs, more specifically Individual Fishing Quotas, give fishermen a greater window of opportunity in the season, as well as their own quota share of the total annual catch; this defeats the race to fish in the beginning of seasons that ultimately leads to overcapitalization. Fishermen may be less likely to oversaturate the market and less likely to freeze fish to sell at a later time. With more fresh fish in the market as a result of a catch share program implementation, it may be the case that market prices of fish increase as the pattern of landings become smoother and more consistent. This paper examines these hypotheses using data of landings and landings value from 10 U.S. catch share programs. This data is then analyzed as a time series using local polynomial smoothing and testing for structural breaks in the variance and the mean. The results of this study were not conclusive, as most species did not show a smoother time trend as a result of a catch share program introduction. The results do leave room for further analysis to better examine all the variables and underlying trends.

## 1. INTRODUCTION

Catch share programs integrated into United States commercial fisheries are an intricate policy offering ample opportunity for analysis of the structural changes in fisheries management. Once implemented, catch share programs may result in a smoothing of the time path of landings, causing a potential increase in prices of fish. The goal is to examine the impact of catch share programs on landings and price trends and compare these findings with theoretical predictions.

Originating in the 1970's, catch share programs were developed to target fish or shellfish species in specific regions that necessitated an improvement in management tools. Worldwide productivity of fisheries was in decline as fish stocks were increasingly depleted due to intense harvesting (OECP, 2006). These programs provide an alternative to open access fishing that has resulted in conflict within the commercial fishing industry, as fishing is completed in a narrow time frame, yet still fulfilling a year's worth of catch. This encourages overfishing and oversaturation of the market, causing more fish to be sold in large quantities and then frozen to be sold later on in the year. There is also a more appropriate inclusion of fishermen and the communities within the region that adopts a catch share program, as the policy allows them to better communicate of their needs. This policy also seeks to address economic disparities among fishermen in such a competitive market. Implemented programs also help minimize the broader impacts that commercial fishing can have on oceans, including ecosystem degradation and bycatch.

Catch share programs were adopted by federal fisheries within the United States in the 1990's, as many fisheries were underperforming both economically and biologically (NOAA Fisheries Service, 2017). These programs appropriately allocate a Total Annual Catch (TAC) of what is available and permitted to be caught (U.S. Department of Commerce, 2014). The distribution of the total allowable catch is divided through levels that are enabled specific privileges; this incorporates larger entities, communities, cooperatives, and individuals (U.S. Department of Commerce, 2014). The division of the TAC is based on what is feasible economically while maintaining conservation and sustainability goals based on what each fishing region needs. Fishermen are required to stop fishing when the quota is reached in their designated fishing region, however, the allocated quotas may be leased, traded, or sold at the quota holder's

discretion. This transferability allows greater flexibility while maintaining the TAC. In the United States, 9 regions are categorized by NOAA: North Pacific, Pacific, Western Pacific, New England, Mid-Atlantic, South Atlantic, Caribbean, Gulf of Mexico and Atlantic Highly Migratory Species. There are 15 catch share programs maintained in these 9 regions, governed by 6 Fishery Management Councils (FMC) (U.S. Department of Commerce, 2014). All of these regions include catch share programs, with the exception of the Caribbean, Western Pacific, and Atlantic Highly Migratory Species.

Research has explored the impact of catch share programs on fleet efficiency, but there is limited analysis of their impacts on fishing behavior and the resulting market outcomes. Implementing a catch share program can have an effect on seasonality and quality of product; changes in those variables could lead to an increase in the market value of fish. The smoothing of the time path of landings could be the link between commercial fisheries that have adopted catch share programs and the changes within the market.

To further understand the usefulness of this policy, catch share programs' effects on fishing behavior and market outcomes are important components to investigate. This research can serve as empirical evidence for the effectiveness of catch share programs in the broader goal to improve fisheries management. Investigating catch share programs, primarily Individual Transferable Quotas (IFQs), and their implementation in U.S. fisheries is a step into the direction of understanding their ability to smooth the time path of landings that may result in an increase in the prices of fish. IFQs are a type of catch share program that includes the privilege of transferability among fishermen.

To accomplish this research, data for landings and landings value for selected fish species was collected from the National Oceanic and Atmospheric Administration for use in statistical analyses. Utilizing this data as a time series, local polynomial smoothing is applied to each fish species to examine any patterns or trends, specifically at the time the catch share program was implemented. This was a first step in determining any patterns that warrant further analysis of the time trends becoming smoother because of the implementation of a catch share program, or if there are other variables creating the trend or pattern. Structural break testing in the variance and the mean was then applied to

determine if there were breaks in the structure of the time trend that could be captured at the point the catch share program was introduced.

The research did find that some species displayed a smoother time trend and structural breaks, however, most species did not. The red snapper provided the most substantial results, with a smoother time trend as well as structural breaks at the exact point of the catch share program introduction. The results from this research did yield results that allow a continuation of analysis to further understand what these analyses yielded, and no definitive conclusion could be made.

## 2. PREVIOUS LITERATURE

Prior research provides a baseline for speculation that catch share programs may be a catalyst for an increase in market prices of fish; however, research is surprisingly thin. This study attempts to bridge the gap between catch share programs in U.S. commercial fisheries and associated market prices by analyzing patterns in the time path of landings.

Catch share programs may increase prices by lessening the seasonality of landings. Although lengthened fishing seasons were not an intended goal in the implementation of catch share programs, they do sometimes have this effect (Brinson and Thunberg, 2016). With longer seasons to fish, the fluctuation between an abundance of fresh fish in season and the freezing of fish to sell outside of season will most likely level out – this research hopes to capture these phenomena. According to Brinson and Thunberg, an increase in price is one of the expected improvements synchronous with better product quality; better quality is a product of having more fresh fish available on a consistent basis (2016).

Catch share programs aim to eliminate the competition among fishermen using quota shares, and Buck describes these programs as introducing a new platform of flexibility that contributes to a change in seasonality. This flexibility is seen in fishermen's ability to choose their own means of operation, the location, and the ability to fish at different times. The fishermen that hold quotas are given property rights in the TAC so there is no longer a need for the competitive nature of open fishing. The ability to fish at varying times offers the opportunity for more consistent landings with better

quality product that is less likely to be frozen (1995). The author states that with more consistent landings and markets that are not flooded with fish stock, there is more opportunity to process the raw fish stock. This allows the processing to favor a fresh market with higher-value product (Buck, 1995). It can then be predicted that with more consistent landings, more fresh fish will be available, and the price of fish will increase in conjunction with product quality.

Catch share programs have had influences on fishing markets and their prices, seen through ex-vessel prices, which Brinson and Thunberg describe as one of the expected economic effects (2013). The authors suggest that as a result of U.S. federally managed catch share programs, ex-vessel prices, the prices fishermen receive at the point of landing, were expected to be higher. The research in this paper uses selected catch share programs that Brinson and Thunberg have included in their work. The authors explain that this is because of a dual effect seen in a reduction of market gluts, an improvement of timing in harvesting, and higher standards of product (2013). Changes in the market are still one of the confounding factors of catch share programs (Brinson and Thunberg, 2016). The authors note that these are expected outcomes, and there is no concrete evidence that solidifies their theory as true because of how many confounding variables exist, and that they need to be disentangled before any conclusions can be made (Brinson and Thunberg, 2016). However, as an outcome of less seasonality with more consistent landings, an increase in ex-vessel prices and higher standards of product could be a precursor to higher market prices of fish.

Market gluts have plagued fishermen and their market as the ‘derby fishing’ mentality calls for a race to fishing that is not only unsustainable, but also inefficient (Levy, 2010). Market gluts are an externality of the fishing industry and their methods of catching the most amount of fish in the least amount of time as the seasons are open and available, causing a surplus of fish stock relative to consumer demand. The authors’ findings indicate that on average there was a 19% increase in ex-vessel prices for all of the catch share programs that were investigated in comparison to the established baseline periods (Brinson and Thunberg, 2016). The authors state that because the scope of their research is too narrow, supply changes cannot be directly aligned with reduced market gluts, and demand changes with improved product quality (Brinson and Thunberg, 2016).

The shortages of evidence in Brinson and Thunberg's research allows speculation that the smoothing of time path of landings, another possible effect of catch share programs, could be reason for higher ex-vessel prices and an overall increased market value of fish.

In an analysis of the Red Snapper IFQ program and its economic performance within the first five years, the authors infer that there was an increase in dockside prices as a result of the program (Agar et al, 2014). This was a calculated outcome, and follows that fishermen with a quota privilege choose when they harvest their fish rather than rely on short fishing seasons. In selecting when they harvest, fishermen will use their quotas during times when market conditions are in their favor (Agar et al, 2014). In doing so, it maintains the prior idea that more consistent landings are established allowing more fresh fish to enter the market because fishermen will retail their landings when profits will be highest. Fresh fish within the market eliminates the need for fishermen to freeze landings and sell later on, and with the elimination of frozen fish it can be theorized that market prices of fish increases as well.

Previous research of regions that have implemented catch share programs offer evidence that seasonality and the resulting market gluts are structures within the fishing industry being dismantled. This enables fishermen to have a smoother time path in their landings, possibly leading to an increase in market prices.

### 3. DATA

This section maps out the variables of interest for this research and where these variables originated in the broader spectrum of U.S. fisheries data. It also gives additional background to the catch share programs and how they differ from one another.

The data consists of quantitative materials gathered by NOAA. The Fisheries Statistics Division of NOAA has available data for U.S. commercial fisheries landings that can be categorized by year, month and fish species. This data contains monthly landings (in pounds) and the dollar value of these landings, and this research will refer to landings data in the same units. NOAA collects this data from wholesalers by using a combination of surveys, paper logbooks, and independent observation; more recently using digital technologies (2016).

U.S. catch share program regions within this research includes 7 of the 9 regions categorized by NOAA, and 9 of the 15 catch share programs. Individual Transferable Quotas are the target catch share program, therefore most data will be collected from the Mid-Atlantic, Gulf of Mexico and North Pacific. The remaining regions will be used for comparison of patterns as they contain other types of catch share programs with variations of IFQs. Data will focus on species within the regions that include catch share programs designated for fish and will not include shellfish species (Table 1). Species designated to IFQs consist of golden tilefish, groupers, tilefish, red snappers, Pacific halibut and sablefish. To represent tilefish, blueline tilefish data will be used, and for the other portion of the grouper-tilefish IFQ, red groupers will be assigned for groupers. Species within these regions, but within other types of catch share programs incorporates pollock and rockfish.

This study focuses on IFQs and their outcomes within commercial fisheries. However, IFQs are a strategy within catch share programs that are used in the construction of other types of programs. The design of a catch share program differs based on what that specific region and included species needs and is decided on by the region's fishery council. The goals remain similar in reducing overfishing and increasing the length of fishing seasons, but differ in their structure and implementation. These differences in structure may have an impact on the outcomes of this research. The inclusion of other catch share programs is important for comparison of outcomes, as they are unique, but share the same goals of hindering overfishing and providing alternatives to fishing practices that are no longer sustainable. Analyzing multiple catch share programs with different fish populations and structural differences allows for a broader analysis. It is important to analyze catch share programs of multiple types because they may share similarities or have major differences; pinpointing these may help in understanding what makes a catch share program successful.

**Individual Fishing Quotas (IFQ).** This study is interested predominantly in individual transferable quotes (ITQs) also known as individual fishing quotas (IFQs), which are allowances of the total annual fish catch (TAC) that are given out as quota shares. These quotas regulate harvest pertaining to specific species of shellfish or fish through

appropriate limitations that can vary by region; limitations usually in percentages of TAC or until quotas are met. IFQs are transferable quotas that can be bought, sold, or leased at the quota holder's discretion.

The purpose behind IFQs is to extend the length of the season to hinder derby fishing (Buck, 1995). Open access fishing poses conflict in the potential to overfish and exploit resources; IFQs serve as a piece of policy that can help mitigate the conflicts surrounding open access fishing that still adhere to fishing interests (Kaplan et al, 2010). IFQs ultimately exist to help commercial fishing become a more efficient and sustainable market (Buck, 1995). They have the potential to serve as an alternative to current fishing practices that could replace traditional regulations that have failed thus far (Buck, 1995).

Allocating IFQs is a viable alternative to open access fishing with restrictions that allow conservation goals to partner with the incentives of the fishermen (Parkes et al., 2015). In doing so, the IFQs that are implemented can have positive outcomes in mitigating the severe declines in fish populations, as well as smooth the time path of landings; reduce the drastic seasonal variation where most fish are collected all at once because of season opens and closes (Parkes et al., 2015). Documenting this potential behavior within fisheries will help in understanding a possible impact of IFQs and their associated variables.

**Sablefish Permit Stacking.** The Pacific Sablefish Permit Stacking is a catch share program unique to Sablefish and to the Pacific region, and is a developed version of an IFQ (a starting point for the overall program) with the addition of permit stacking (NOAA Fisheries Service, 2009). The goal of this program includes reducing overfishing, lessening bycatch and improving the economy for fishermen (NOAA Fisheries Service, 2009). The initial program was implemented for prevention of overcapitalization of fishing vessels, as each approved fleet was assigned a quota based on a tier system that allocated catch limits (NOAA Fisheries Service, 2009). To enhance the program to be more economical for fishermen as well as account for the short window of a fishing season, a “stacking” of permits was introduced to the program. Stacking permits enables registration of no more than 3 permits to one vessel, giving more advantage to fishermen while maintaining overall quotas for sablefish (NOAA Fisheries Service, 2009). This

program also promotes more efficiency within the sablefish fishery; it lessens the number of vessels that participate in the program with the ability to have multiple permits for a single vessel (NOAA Fisheries Service, 2009).

**Groundfish Trawl Rationalization.** The West Coast Ground Trawl Rationalization is a complex program of a shore-based IFQ combined with at-sea fishing cooperatives (NOAA Fisheries Service 2010). The IFQ portion of this program is applied to shore-based trawl fleets, and the fishing cooperative segment incorporates Mothership and Catcher/Processor divisions (NOAA Fisheries Service, 2010). The development of this program is to also improve the economics for fishermen and provide accountability for bycatch and overfishing (Northwest Fisheries Science Center, 2015). Fishermen are offered more control in their participation as landings are to be caught at their discretion; they control the total allowable catch that is allocated into shares (Northwest Fisheries Science Center, 2015).

**Rockfish Cooperatives.** The Central Gulf of Alaska Rockfish Program, originated as a 5-year pilot from 2007-2011 that was adopted upon expiration in 2011 and fully implemented in 2012. The pilot program permitted an establishment of voluntary cooperative associations that allowed involved harvesters special privilege to groundfish (NOAA Fisheries Service, 2009). The rationale for the pilot program was to address the quality of groundfish as well as provide accountability for bycatch (NOAA Fisheries Service, 2009). The Rockfish Program was approved for an additional 10 years with the same regulations and measures as the pilot program.

**Western Alaska CDQ.** The primary goal of this community development program is to sustain community inclusion as it provides economic opportunity and lessens poverty for the region's villages (NOAA Fisheries Service, 2017). The program takes a percentage of the fish species within the region and redistributes them to village communities participating in the program, to remove barriers to accessibility to fisheries impoverished communities are faced with (NOAA Fisheries Service, 2017).

## 4. METHODOLOGY

The section will discuss the various statistical methods used in this research and their rationale. Section 3.1 will begin with a description of the unit of and how these variables will be operationalized through time series data. Section 3.2 will introduce local polynomial smoothing as a method for measuring the time trends of average landings and prices for each species. Section 3.3 presents multiple ways to further analyze structural changes in the time trends and relate them to catch share program implementation dates. It will also discuss another method for structural break testing in the variance using methods to determine change-points in the mean.

**3.1 Unit of observation.** The objective of this research is to determine how catch share implementation has affected patterns of landings and price trends across fisheries. Data on landings and value per pound are utilized for each species. Using each of the selected species with consideration of its region and catch share program (Table 1), this research seeks to identify raises in prices simultaneous with the implementation date of the catch share program. Establishing structural changes within the trends for each species should help in determining if the implementation date of a catch share program does have an influence in increasing the price of the fish.

The data is initially translated into time series as a preliminary step to the analysis of trends within the data and for further understanding of structural breaks and seasonality; this is done for all units previously mentioned. The data used for this research begins with January 2000 and ends in December 2014 for species with catch share programs starting after the year 2000 (Table 1). For catch share programs that begin prior to 2000, data collection is pushed back to January 1990. There are no catch share programs within the U.S. that were introduced prior to 1990. An implementation date is then added to the time trends as a marker indicating where a change would appear, seen in Figures 1 and 2, demonstrating landings and landings value. The analysis continues with local polynomial smoothing and structural break testing in the variance.

**3.2 Local polynomial smoothing.** This method of statistical analysis is used to examine the evolution of average landings and prices over time. If catch share programs affect

prices or total landings, this should manifest as a change in trends following implementation. Seifert and Gasser describe local polynomial smoothing as a method for nonparametric function estimation that offers a means to further investigate and visualize the data (2006). The authors suggest that smoothing functions are best estimated by polynomials, and this method is only applied locally to the data points. This method is used because local polynomials create a time trend able to display long-term trends disentangled from seasonality. The goal is to estimate the smooth function of  $r$  for each species:

$$Y = r(X) + \varepsilon,$$

where  $X$  represents time and  $Y$  is either monthly landings or monthly price per pound. The estimation of  $r$  is done at a sequence of points to obtain and plot an estimate which is then used to create a smoother trend of the data (Seifert and Gasser, 2006). At the point of  $X_0$ , the local polynomial estimator is based on a polynomial relative to  $r(x)$  within the bounds of  $X_0$  by condensing done within the equation:

$$\sum_{i=1}^n \left( Y_i - \sum_{j=0}^p \beta_j (X_i - x_0)^j \right)^2 K \left( \frac{X_i - x_0}{h} \right)$$

$K$  represents the *kernel* within this equation, which Seifert and Gasser explain as a nonnegative symmetric weight function for the minimizing equation aforementioned (2006). The *bandwidth* is denoted by  $h$  and is the smoothing parameter that may be dependent on  $X_0$ . The bandwidth is used for a type of “tuning” parameter that enhances the estimate based on the inputted value (Seifert and Gasser, 2006). The approximation of  $r(x_0)$  is executed by the local polynomial:

$$\sum_{j=0}^p \hat{\beta}_j (x - x_0)^j$$

where  $x = x_0$ :

$$\hat{r}(x_0) = \hat{\beta}_0;$$

When using local polynomial smoothing, the values  $K$  and  $h$  must be adjusted within the model. For the local polynomial smoothing performed within this research, the

bandwidth  $h$  for the estimate was inputted as 0.25, as this was a best fit for most of the species, with the exception of Pacific halibut. This species was more challenging because of larger irregularities from seasonality. This resulted in many instances of flux from zero values to very high amounts of landings within the time series data making visualization of the trends in the data utilizing local polynomials much more difficult. The bandwidth for this species was set to 1 instead of 0.25 for this reason. The kernel  $K$  for the local polynomial smoothing is set to “normal” designated as a Gaussian density function (Wand and Jones, 1995).

**3.3 Structural break testing in variance.** Structural break or parameter instability testing in the variance is administered using two methods: single breakpoints by application of F statistics and multiple breakpoints using a classical linear model. If catch share implementation effectively reduces derby fishing, this should be reflected in a lower variance of landings (and possibly prices). The structural break methodology is used to examine whether or not implementation dates correspond to sharp changes in variance.

Single breakpoints are calculated with the assumption that the breakpoint is unknown, as Andrews states is a “pure” change point in contrast to a partial change point derived by restricting the interval (1993). F statistics are incorporated into this research (also referenced as a Chow test statistic) as a function to measure where changes are happening beyond visualization of the time trend or local polynomials. For every change point within the time series data, a single F statistic is calculated given the parameter that is set within the function (Andrews, 1993). An OLS model is established for the observations of the data, one fit for before the suspected breakpoint and another fit for after (Andrews, 1993). After this OLS model is generated, another model is fitted to all of the observations, but with a restricted residual sum of squares and with a requirement of approximated  $k$  parameters (Andrews, 1993). The equation for this method is:

$$\left( F = \frac{(RSS - ESS)}{ESS} \right) \times (n - 2(k))$$

With the value  $n$  as the amount of observations within the time series data and  $k$  as the amount of regressors (degrees of freedom). For each species, a single breakpoint is calculated using the largest  $F$  statistic for landings and landings value to establish a structural change; these values are in Table 2.

Multiple breakpoints are discovered using the classical linear regression model:

$$y_i = x_i' b + u_i$$

through testing for changes in its stability (Bai, 1998). The classical model is reworked to account for changes from one stable regression relationship to the next within the coefficients, denoted as  $m$  breakpoints, and as  $m+1$  within the equation where the coefficients remain constant (Bai, 2003):

$$y_i = x_i' b_j + u_i \quad (i = i_{\{j-1\}} + 1, \dots, i_j, j = 1, \dots, m+1)$$

The equation determines these breakpoints by shrinking the residual sum of squares. This equation is used for each species for landings and landings value. The output of this equation gives as many as 5 breakpoints within the time series data.

Using similar methodology as testing for structural break testing in the variance, the analysis was continued using landings and landings value to produce an estimation at the point in which the probability distribution changes (Hinkley, 1970). These change-points are detected within the mean to further analyze the time trends and when underlying relationships deviate from one another.

#### 4. RESULTS

The results of this research are organized by species, describing the results yielded by the statistical analyses in the order in which they were introduced: time trends, local polynomial smoothing, and structural break testing in the variance and mean. Time trends are provided in Figure 1 and 2, Figure 1 displaying the time trend of landings, and Figure 2 the time trend of landings value. A red marker is added to each graph as a representation of the catch share program implementation. Local polynomial graphs are given in Figure 3, also including a red marker denoting the implementation date. Table 1 provides the time series values for each species and the implementation date of their

catch share program, used for comparison against the results of the structural break testing. Structural break testing in the variance for single breakpoints are within Table 2, and Table 3 supplies the data for structural break testing in the variance for multiple breakpoints. Table 4 is comprised of the data for change-points within the mean, accompanied by Figure 4 for landings and Figure 5 for landings value, that provide visualizations for the change-points detected in Table 4. The horizontal red markers within these figures represent the trends and where those trends diverge from one another.

**3.1 Golden tilefish.** For this species, the initial time trend in Figure 1 (A) showed patterns that would most likely continue with or without the implementation date, with the only potential for a structural break apparent within the beginning of the time trend. In Figure 2 (A) the irregularities within the data seem to increase at the implementation date, the opposite of what was predicted. Local polynomial smoothing for golden tilefish produced a trend increasing over time regardless of the implementation date, with no apparent structural breaks (Figure 3).

Structural break testing in the variance did not offer any detections in the single breakpoints in in Table 2, but did yield results in Table 3, testing for multiple breakpoints. The implementation date for golden tilefish is 109 within the time series data, and a breakpoint was detected at 108, indicating that a change exists in the trend at the implementation date. There were no change-points detected within the mean for this species.

**3.2 Red snapper results.** Of all the species used to analysis in this research, red snapper yielded the most valuable results. The time trend for red snapper shows an obvious structural change at exactly the time of the implementation date, shown in both Figure 1 (B) and Figure 2 (B). The irregularities within the data are significantly different before and after the red marker indicating the implementation date. Local polynomial smoothing, however, still produced an increasing trend that was consistent over time with no real evidence of a structural break.

Structural break testing in the variance also offered significant results for this research. Testing for single breakpoints revealed a structural change in landings as the implementation date within the time series is represented by 85 and a structural change was detected at 84 (Table 2). However, this was not the case for the landings value. In testing for multiple breakpoints, 84 was also detected, but for both landings and landings value (Table 3). Change-points within Table 4 also uncovered a change in the mean at 84, the same value that the structural breaks detected, for both landings and landings value. This is compelling evidence that there is a definite change in structure upon implementation of the program.

**3.3 Red grouper.** The time trend for the red grouper shows a small change in irregularities that do begin to minimize around the same time as the implementation date in both landings and landing value, generated by both graphs in Figure 1 (C) and Figure 2 (C). The local polynomials displayed in Figure 3 show a consistent increase in pattern, but no apparent deviations from that pattern.

Structural break testing for red grouper yielded no significant changes in the structure of the time series data. The closest structural break to the implementation date is seen in Table 3 within landings, with the break at 126 and the implementation date marked at 121. No change-points were calculated at or near the implementation date for the red grouper.

**3.4 Blueline tilefish.** In evaluating the time trend, Figure 2 (D) and Figure 3 (D), the blueline tilefish show similar results to golden tilefish where the occurrence of irregularities seems to increase at the marker of the implementation date, which is counter-intuitive to this research. Local polynomial smoothing shows potential structural breaks, but earlier in the time series and not at the marker of the implementation date.

Single and multiple breakpoints in structural testing in the variance offer little evidence of structural breaks around the time of the implementation date, also denoted as 121 in the time series. The closest breakpoints to the implementation date are 125 within the landings and 126 in the landings value, derived from testing for multiple breakpoints

(Table 3). Change-points also proved null of any structural changes within the mean, as there were no detections close to the implementation date for blueline tilefish.

**3.5 Pacific halibut.** This time trend was challenging to graph as the seasonality is much more turbulent than any of the other species. This species also includes two implementation dates, 25 and 61, as it is maintained by two different catch share programs. Using the time trends shown in Figure 1 (E) and Figure 2 (E), neither offer preliminary evidence that there may be a structural break at the implementation date for either landings or landings value. Local polynomial smoothing for this species is also inconclusive, with no trends deviating from the consistent trend of the data at the implementation marker.

For Pacific halibut, there were no detections of structural changes in testing for single and multiple breakpoints, and not even any detections of structural changes within the proximity of the implementation date. Change-point computations revealed the same results as did testing for single and multiple breakpoints; no detections of changes within the mean for this species.

**3.6 Sablefish.** Examining the time trends presented in Figure 1 (F) and Figure 2 (F), there is room for speculation that the time trend becomes smoother upon the implementation date, and this is the case for both implementation dates marked at 61 and 145. This species, similar to Pacific halibut, is also governed by two different catch share programs and therefore has the implementation date markers of both 61 and 145. The first implementation marker, 61, displays a change in the time trend that is less irregular, more so for landings than for landings value. The second implementation marker shows a smoother trend that is challenging to attribute to the implementation date, as it may be a previously established pattern that would continue with or without any influence from the catch share program implementation. Local polynomial smoothing in Figure 3 (F) also resulted in what seems to be a structural change around the second implementation date, as the smoother trend line deviates from the pattern at the red marker.

There were no detections of structural change seen in the single breakpoints for this species from structural break testing in the variance. The closest detection of a

breakpoint was discovered within the multiple breakpoints (Table 3), but is still six months removed from the implementation date marked at 151. No change-points were discovered for sablefish at the implementation marker or within a short distance from it.

**3.7 Rockfish.** Rockfish is another species that is overseen by two separate catch share programs and also includes two implementation dates. Inspecting the time trends of rockfish, within Figure 1 (G) and Figure 2 (G), there is evidence of structural breaks, but not for either implementation date at 85 or 133. The structural changes seem to occur well before the implementation dates. Local polynomial smoothing in Figure 3 (G) do, however, show a possible structural deviation from the pattern at the first implementation date, but not for the second. This species also displays a downward trend for both landings and landings value.

Despite the potential of structural change within the visualizations of rockfish, no breakpoints, either single or multiple, were detected for this species. There were no breakpoints even within the vicinity of the implementation dates. This is also the case for change-points within the mean; no detections of changes within the mean at the time of the implementation date.

**3.8 Pollock.** The time trends for pollock within Figure 1 (H) and Figure 2 (H) did provide evidence of a potential structural changes at the implementation dates marked at 109. However, it can be theorized that the changes in these figures aren't structural changes as a result of a smoothing of the time path, but instead in a change of direction from upward to downward. Local polynomial smoothing in Figure 3 (H) also reveals a probable structural change at the same point as the implementation date, providing further evidence of a possible structural change.

In testing for structural breaks in the variance for pollock, no significant results were obtained as neither single or multiple breakpoints were detected at the implementation date. However, a change-point in landings value was detected at 111, within two months of the implementation marker at 109. This was the closest value detected for this species within the change-points.

## 6. DISCUSSION

The findings subsequent to the statistical analyses within this research do not offer significant evidence that the time paths of species with catch share programs are removed of irregularities upon the implementation of a catch share program. Red snapper was the only species that provided evidence that confirms a smoothing of the time path of landings in concurrence with the implementation date of a catch share program. This was evident in both the time trends, structural break testing for single and multiple breakpoints in the variance, change-points within the mean, but not in the local polynomial smoothing. Golden tilefish offers little indication that an increase in price is because of a smoothing of the time path of landings, as the landings detected a structural change, yet the landings value did not. This species' value increase seen in Figure 3 (A) is most likely a trend that would have continued regardless of the inclusion of the catch share program.

Many species did exhibit structural changes within the time trends, but without reinforcement from testing for structural breaks and change-points, these structural changes have no grounds to determine if there is a smoothing of the time path of landings because a catch share program is adopted. This is also the case for local polynomial smoothing, which provided the means to understand underlying trends, but without verification from further analysis it remains inconclusive as to whether trends were changing because of a catch share program.

There were no other species that had detections in either single or multiple breaks, or in change-points aside from the red snapper, however, there were a few species that exhibited structural changes within a timeframe closely following the inclusion of a catch share program. All of these structural changes within a proximity to the implementation date were found as a multiple breakpoint and not for a single breakpoint. At five months from the implementation date, structural break testing for multiple breakpoints detected a structural change for red grouper landings. Blueline tilefish also had detections of multiple breakpoints detected at four months from the implementation date for landings, and at five months for landings value. Sablefish was the only other species with a breakpoint nearby the implementation date, found at six months.

Pollock was the only species that resulted in a change-point within the neighborhood of the implementation date, detected at two months after.

## 7. CONCLUSION & FUTURE RESEARCH

The statistical analyses conducted here did not find consistent evidence that the implementation of a catch share program smoothed the time path of landings or increased the market prices of fish. However, the analysis of red snapper did find substantial evidence linking the catch share program to lower landings volatility. The striking differential between the impact of the red snapper IFQ and that of the red grouper/golden tilefish IFQ in the Gulf fishery suggests a path for future research.

The time trends, local polynomial smoothing, structural breaks in the variance and change-points within the mean may not have yielded results convincing enough to make conclusions because many confounding variables were not accounted for. Other factors merit consideration as well. The data used here only extended as far as species within catch share programs and did not include species within the same region and not regulated by a catch share program. A comparison of species based on inclusion of a catch share program may prove useful in understanding the trends for species within a catch share program that could not be explained. Collecting data on seasons and/or permits within regions authorized for fishermen could also contribute to further research, as rationale for trends and irregularities may be uncovered. Overlap of programs may also be examined to determine if a catch share program for one species has an effect on another, an example being the red snapper and red grouper as they are both within the Gulf of Mexico region. A comparison of these species could offer insight into whether one species is a cause for changes in the structure of the other.

Expanding even further on collection of data for outside fish species, other potentially confounding factors are extreme events, other ocean commodities, and fluctuations in retail prices of USDA commodities that could influence the number of landings or landings value for any of the fish species included in this research. Extreme weather events, depending on the magnitude, could be a potential factor in its ability to hinder fishing for a given period of time. Extreme events could also include oil spills historic for the Gulf of Mexico region, damaging ocean resources short-term or even

permanently. This may also include issues of demand, as product tainted by an oil spill could become less desirable within the market. Other ocean commodities, namely shellfish, would be a variable to consider as shellfish is also incorporated into its own catch share program in specific regions. This may have effects for other species in the same region, depending on when the shellfish catch share program was implemented. Lastly, fluctuation in USDA market prices of comparable products such as beef, pork and chicken could be included as another means to understand irregularities in the time trends. Involving all of these factors may assist in the reduction of statistical noise to make solid conclusions regarding the trends and structural changes of the data.

A more sophisticated approach to volatility could be incorporated into future research. ARCH/GARCH models approach heteroscedasticity not as a problem, but as a variance that can be modeled (Engle, 2001).

Although inconclusive, this research sets into place a foundation for continued research to provide reasoning for the underlying trends and structural changes within the data. This, in turn, will lead to more conclusive evidence regarding the smoothing of the time path of landings because of the adoption of a catch share program, leading to an increase in price.

8. TABLES & FIGURES

TABLE 1. Catch share programs used within this research.

<b>Catch Share Program</b>	<b>Implementation Date</b>	<b>Time Series Date</b>	<b>Region</b>	<b>Species</b>
Golden Tilefish IFQ	2009	109	Mid-Atlantic	Golden Tilefish
Red Snapper IFQ	2007	85	Gulf of Mexico	Red Snapper
Grouper-Tilefish IFQ	2010	121	Gulf of Mexico	Red Grouper, Blue-line Tilefish
Halibut & Sablefish IFQ	1995	61	North Pacific	Pacific Halibut, Sablefish
Sablefish Permit Stacking	2002	145	Pacific	Sablefish
Groundfish Trawl Rationalization	2011	133	Pacific	Rockfish
Rockfish Cooperatives (pilot)	2007	85	North Pacific	Rockfish
AFA Pollock Cooperatives	1999	109	North Pacific	Pollock
Western Alaska CDQ	1992	25	North Pacific	Pacific Halibut

This table shows the species used within this research and their associated implementation date, the implementation date within the time series, the catch share program as well as the region in which the program was adopted.

TABLE 2. Single breakpoint in the variance for each species' landings and landings value.

<b>Species</b>	<b>Implementation Date</b>	<b>Observation Number for Landings</b>	<b>Observation Number for Landings Value</b>
Golden Tilefish	109	27	120
Red Snapper	85	84	153
Red Grouper	121	68	140
Blueline Tilefish	121	96	100
Pacific Halibut	25, 61	107	107
Sablefish	61, 145	106	106
Rockfish	85, 133	46	45
Pollock	109	48	216

Observation numbers for a single breakpoint in all species shown in landings and landings value in comparison to the implementation date denoted by the time series value using an F statistic (Chow test statistic).

TABLE 3. Multiple breakpoints in the variance for each species' landings and landings value.

<b>Species</b>	<b>Implementation Date</b>	<b>Observation Number for Landings</b>	<b>Observation Number for Landings Value</b>
Golden Tilefish	109	27, 54, 81, 108, 137	27, 66, 93, 120, 151
Red Snapper	85	30, 57, 84, 120, 153	30, 57, 84, 122, 153
Red Grouper	121	41, 68, 99, 126, 153	27, 54, 81, 108, 140
Blueline Tilefish	121	28, 55, 96, 125, 152	27, 72, 99, 126, 153
Pacific Halibut	25, 61	45, 107, 153, 198, 243	53, 106, 153, 198, 243
Sablefish	61, 145	53, 106, 151, 196, 250	52, 106, 159, 208, 253
Rockfish	85, 133	45, 72, 99, 126, 153	45, 72, 99, 126, 153
Pollock	109	48, 93, 154, 199, 244	49, 96, 147, 206, 252

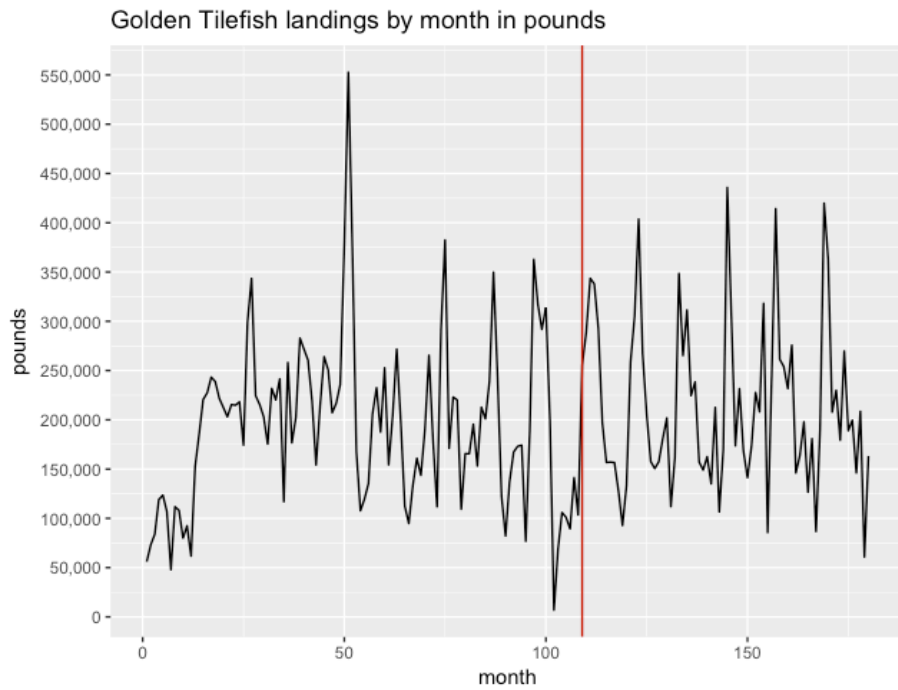
Observation numbers for multiple breakpoints in all species shown in landings and in landings value in comparison to the implementation date denoted by the time series value using a classical linear model.

TABLE 4. Change-points within the mean for each species' landings and landings value.

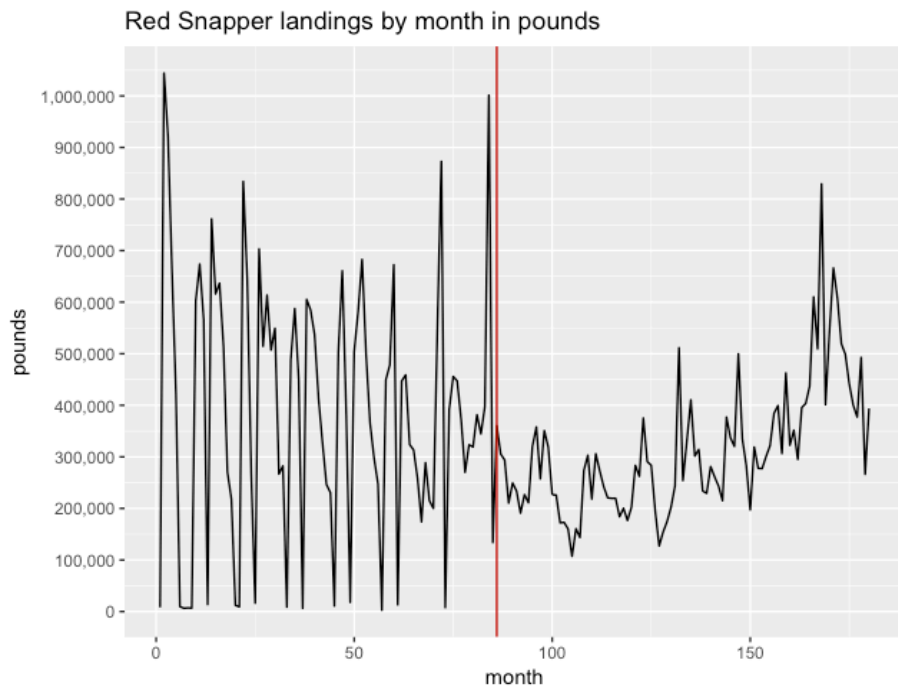
<b>Species</b>	<b>Implementation Date</b>	<b>Change-point for Landings</b>	<b>Change-point for Landings Value</b>
Golden Tilefish	109	49, 93, 123	50, 96, 144
Red Snapper	85	84	33, 84, 115, 149
Red Grouper	121	53, 103, 143	50, 81, 112, 146
Blueline Tilefish	121	30, 68, 102, 132	31, 68, 102, 133
Pacific Halibut	25, 61	57, 106, 137, 170, 201	57, 105, 147, 182, 225
Sablefish	61, 145	53, 105, 136, 170, 262	40, 71, 102, 135, 170
Rockfish	85, 133	42, 75, 117, 148	36, 75, 125
Pollock	109	31, 89, 178, 209, 240	31, 73, 111, 215, 262

Change-points calculated within the mean for each species and their associated landings and landings value in comparison to the implementation date represented by the time series value.

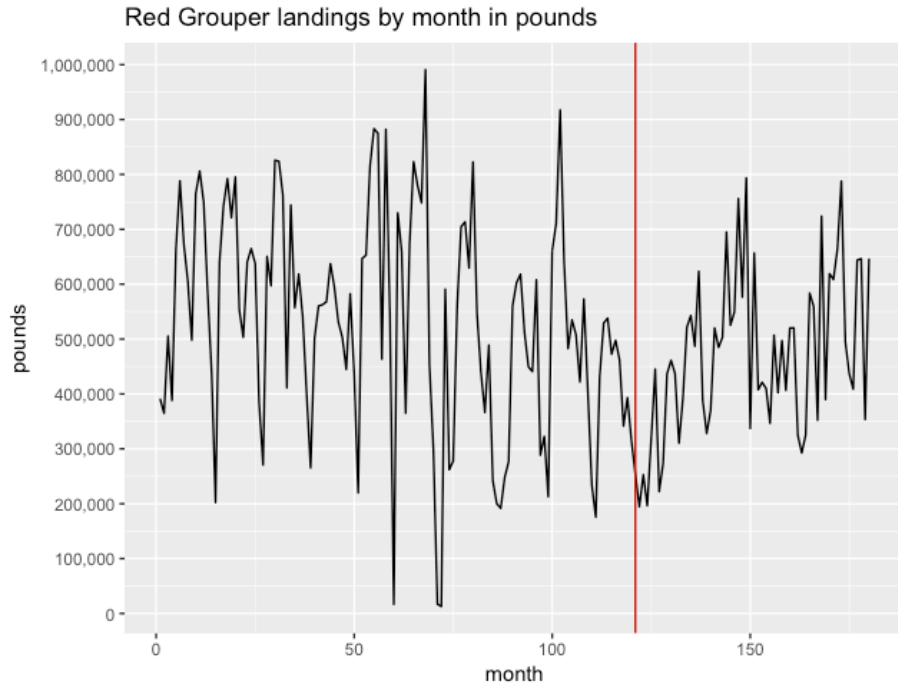
FIGURE 1. Time trends for each species' landings derived from time series data.



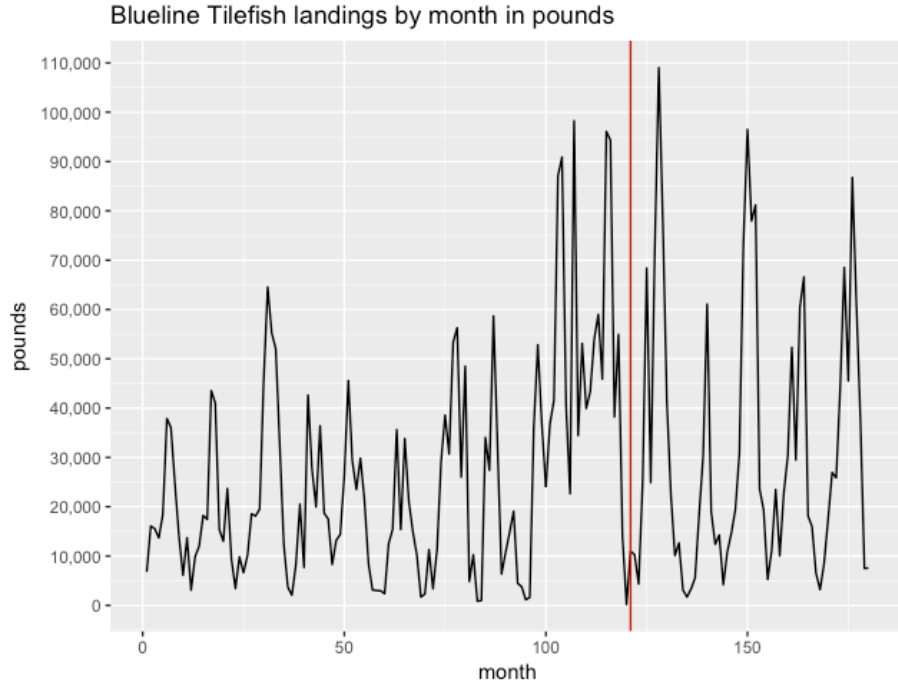
(A) Golden tilefish time trend shown in landings with a red marker to indicate the implementation date of 2009, denoted by 109 in the time series.



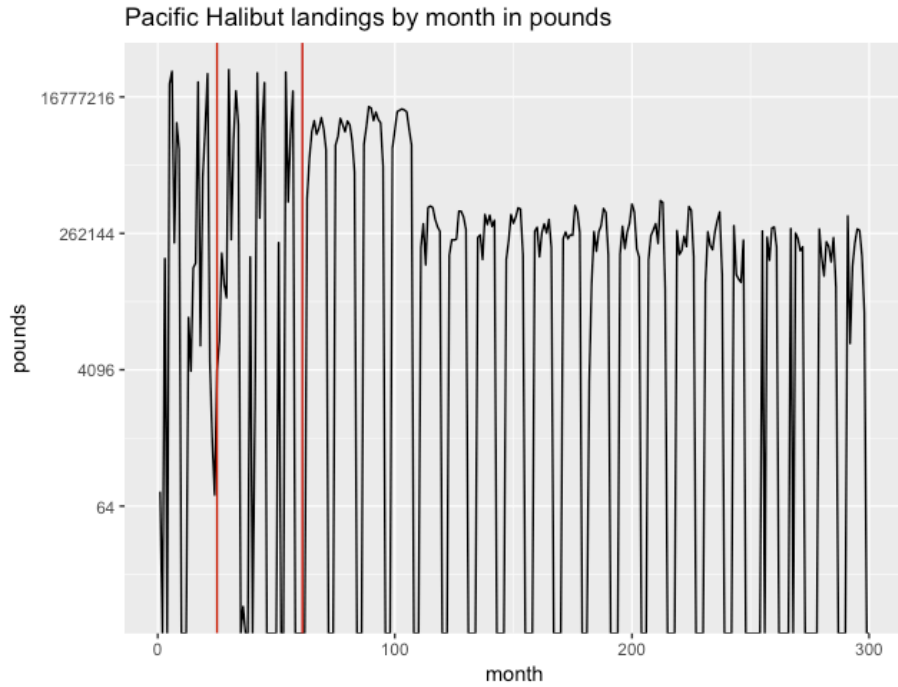
(B) Red snapper time trend shown in landings with a red marker to indicate the implementation date of 2007, denoted by 85 in the time series.



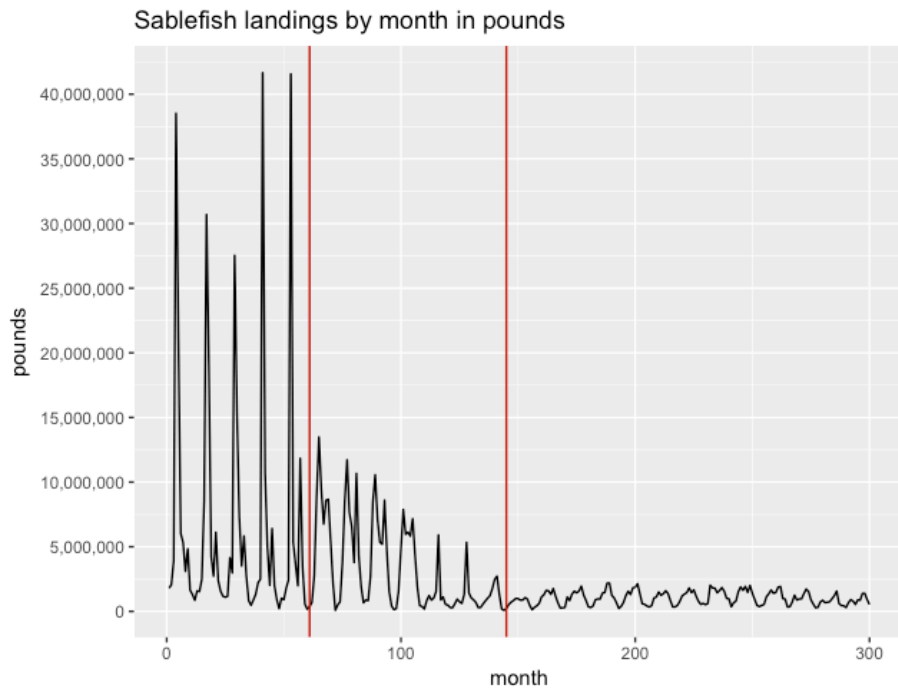
(C) Red grouper time trend shown in landings with a red marker to indicate the implementation date of 2010, denoted by 121 in the time series.



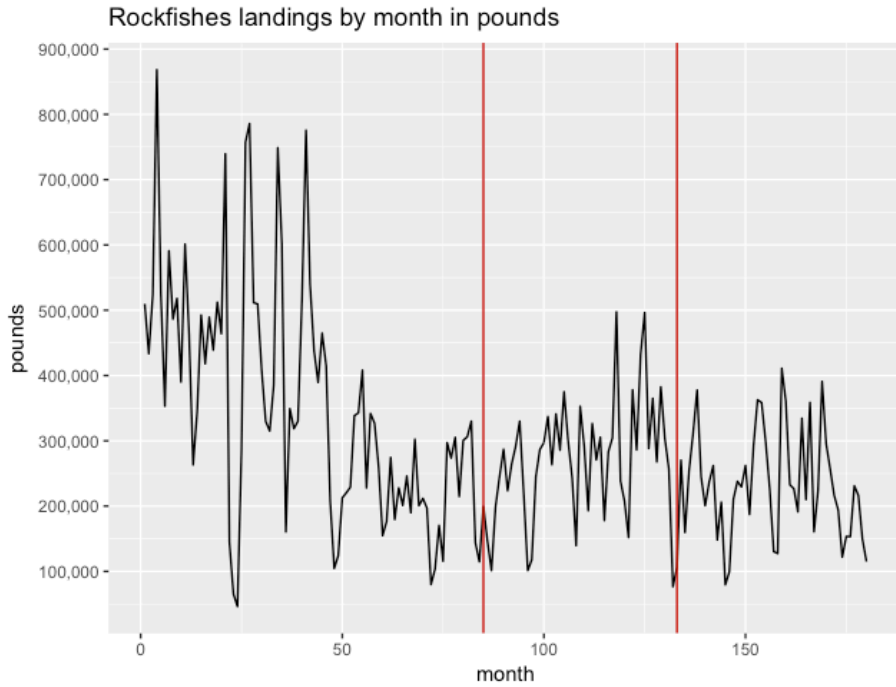
(D) Blueline tilefish time trend shown in landings with a red marker to indicate the implementation date of 2010, denoted by 121 in the time series.



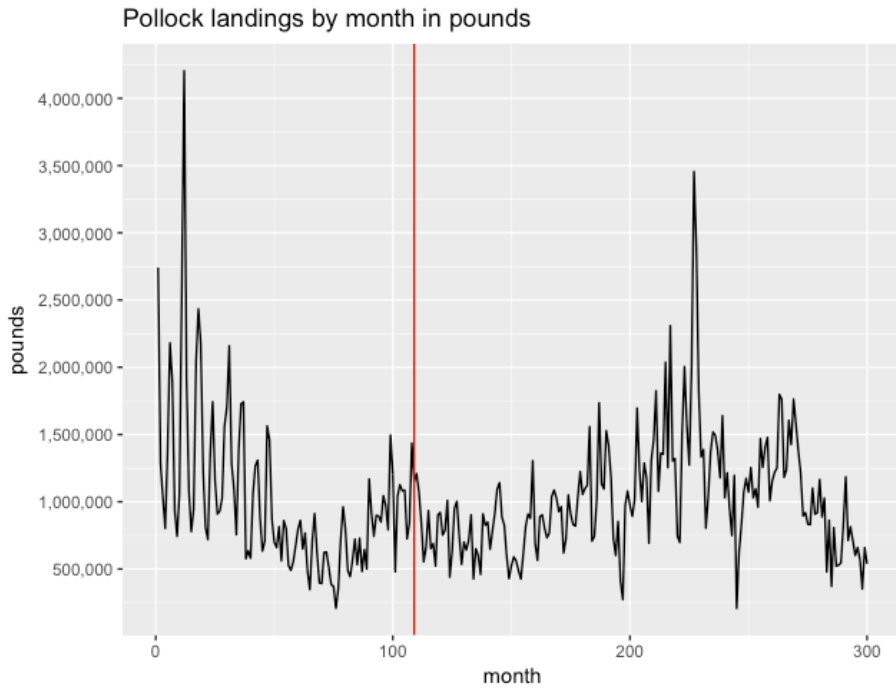
(E) Pacific Halibut time trend shown in landings with a red marker to indicate the implementation dates of 1992 and 1995, denoted by 25 and 61 in the time series.



(F) Sablefish time trend shown in landings with a red marker to indicate the implementation dates of 1995 and 2002, denoted by 61 and 145 in the time series.

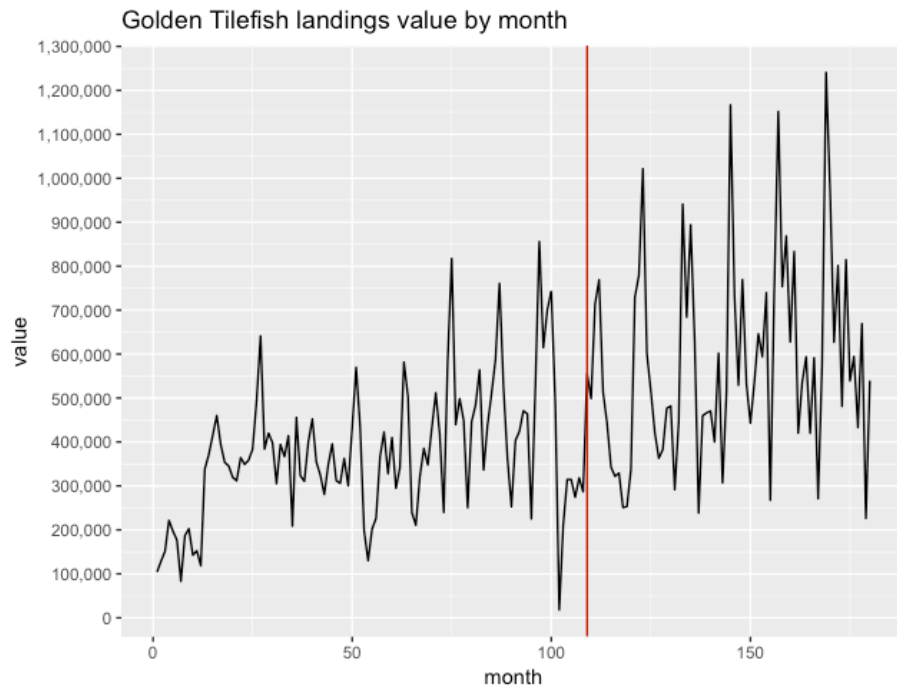


(G) Rockfishes time trend shown in landings with a red marker to indicate the implementation dates of 2007 and 2011, denoted by 85 and 133 in the time series.

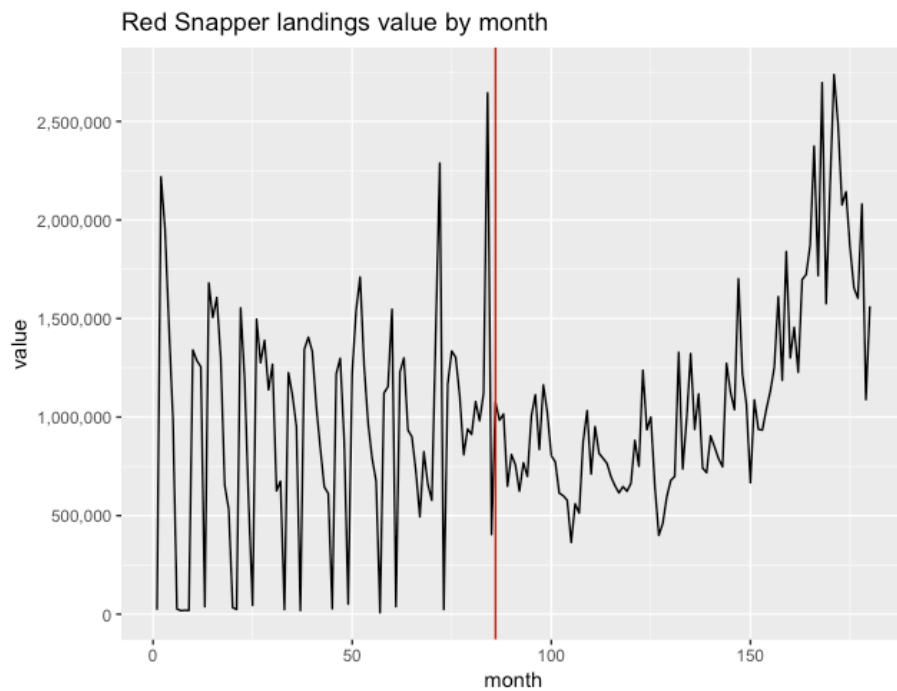


(H) Pollock time trend shown in landings with a red marker to indicate the implementation date of 1999, denoted by 109 in the time series.

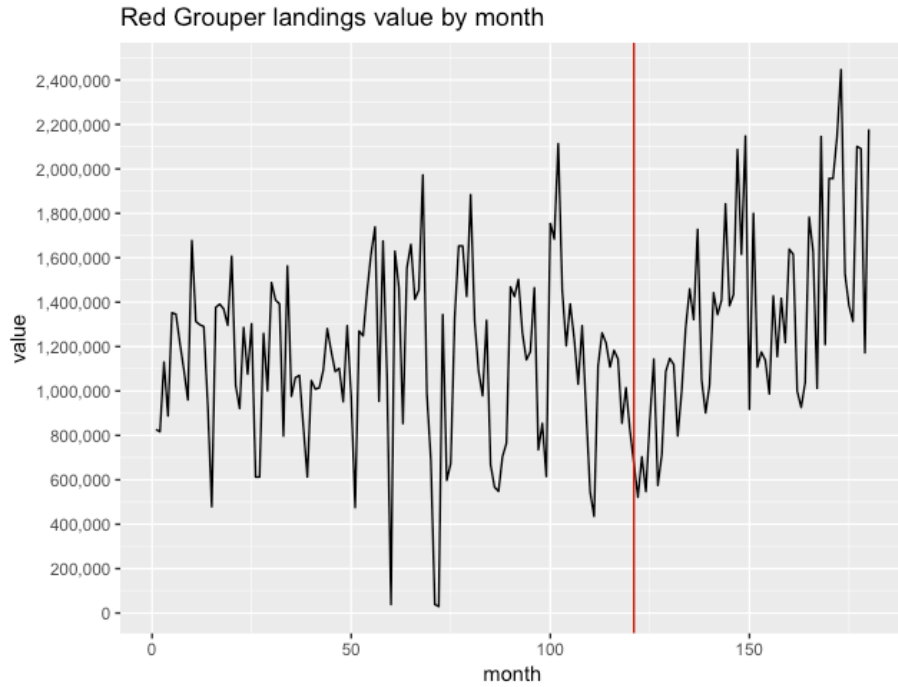
FIGURE 2. Time trends for each species' landings value derived from time series data.



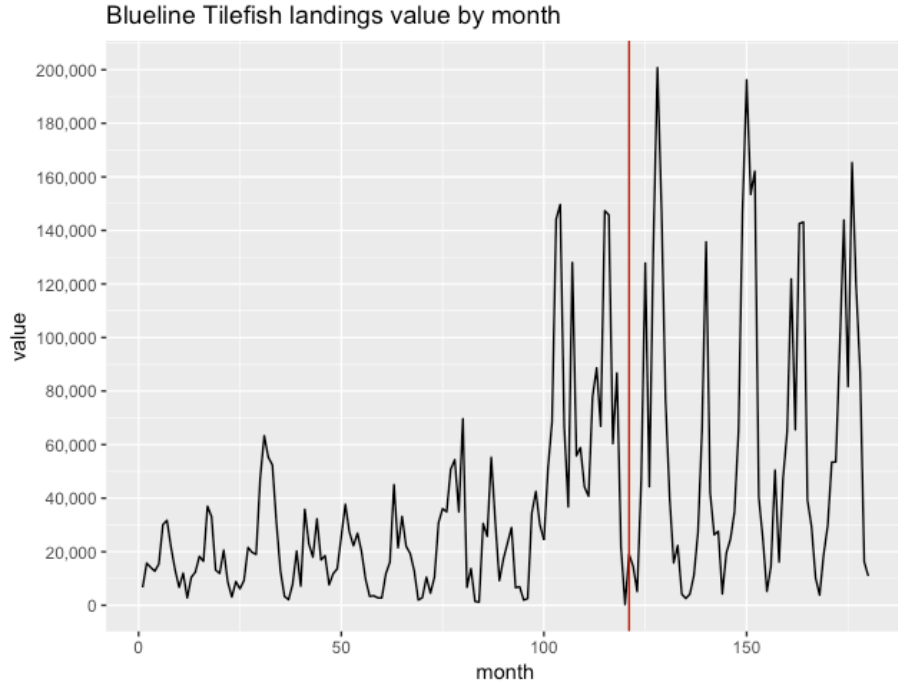
(A) Golden tilefish time trend shown in landings value with a red marker to indicate the implementation date of 2009, denoted by 109 in the time series.



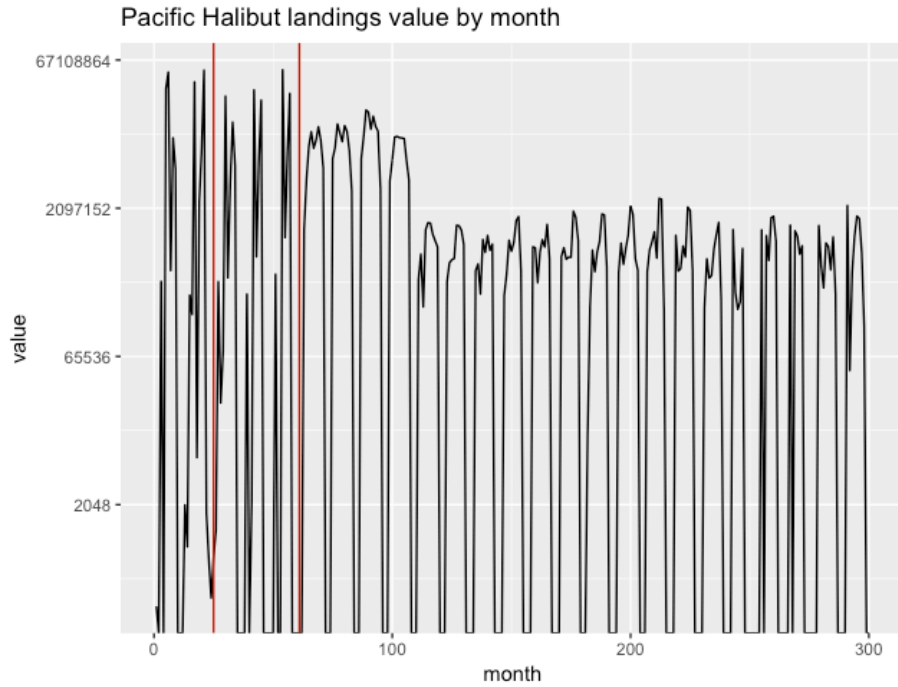
(B) Red snapper time trend shown in landings with a red marker to indicate the implementation date of 2007, denoted by 85 in the time series.



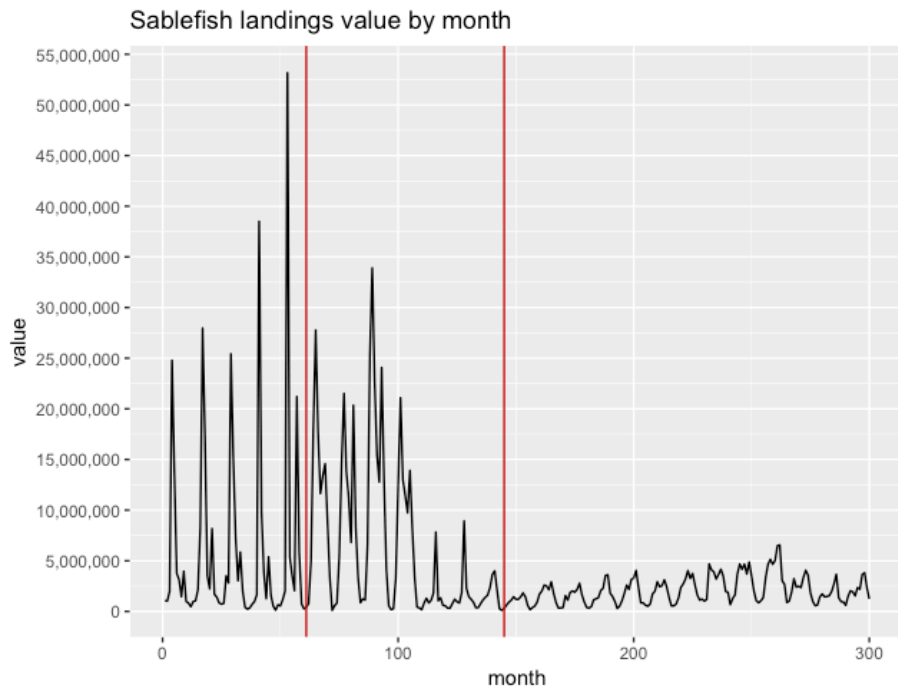
(C) Red grouper time trend shown in landings value with a red marker to indicate the implementation date of 2010, denoted by 121 in the time series.



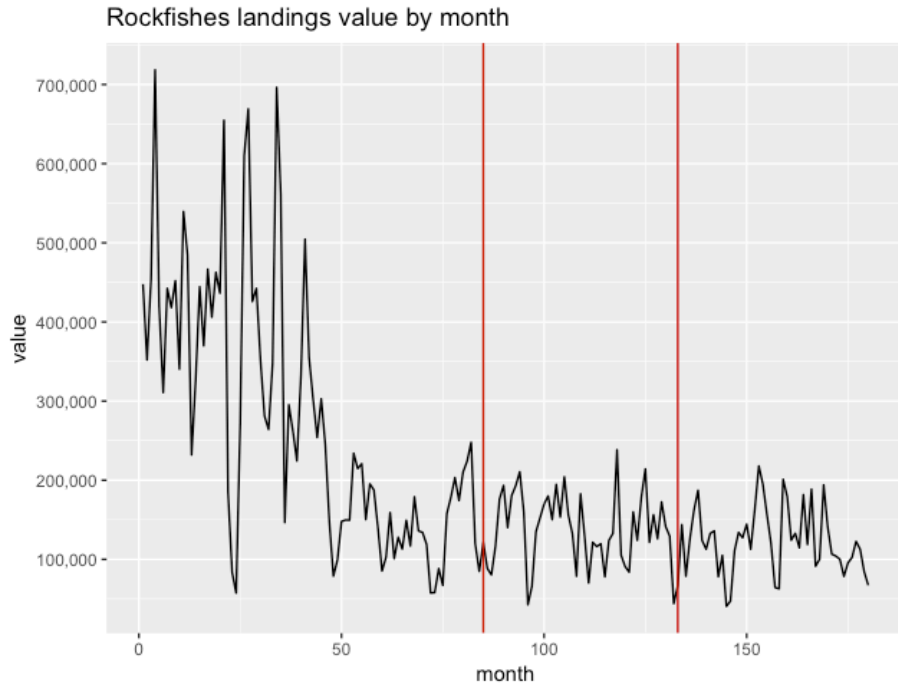
(D) Blueline tilefish time trend shown in landings value with a red marker to indicate the implementation date of 2010, denoted by 121 in the time series.



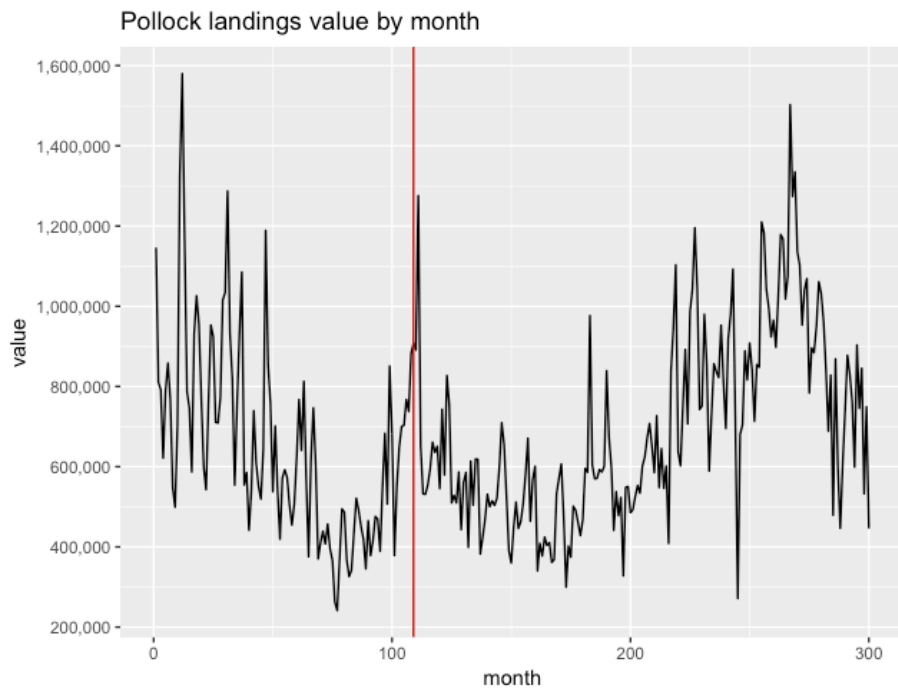
(E) Pacific Halibut time trend shown in landings value with a red marker to indicate the implementation dates of 1992 and 1995, denoted by 25 and 61 in the time series.



(F) Sablefish time trend shown in landings value with a red marker to indicate the implementation dates of 1995 and 2002, denoted by 61 and 145 in the time series.

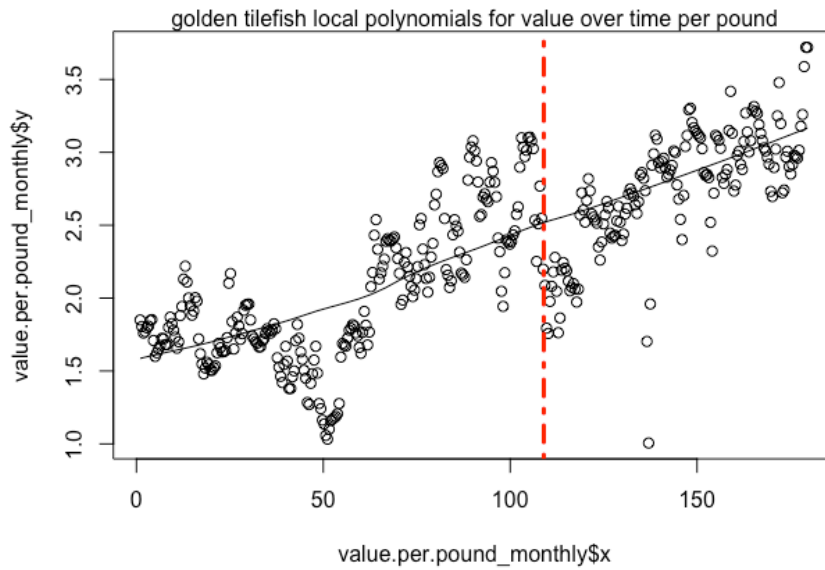


(G) Rockfishes time trend shown in landings value with a red marker to indicate the implementation dates of 2007 and 2011, denoted by 85 and 133 in the time series.

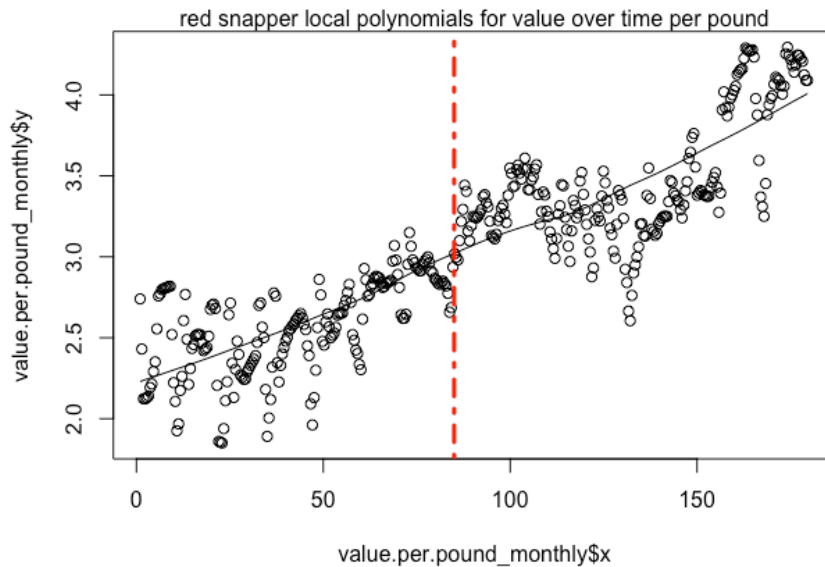


(H) Pollock time trend shown in landings value with a red marker to indicate the implementation date of 1999, denoted by 109 in the time series.

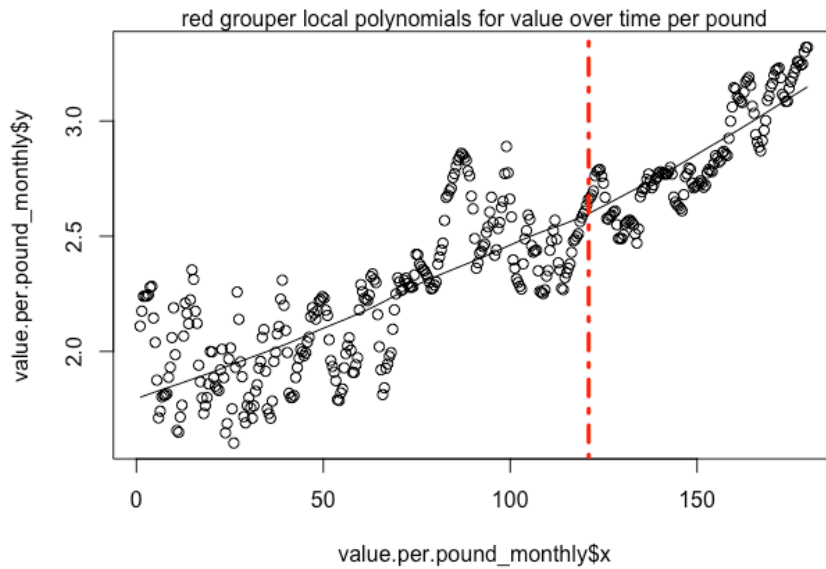
FIGURE 3. Local polynomial smoothing for each species' landings value per pound.



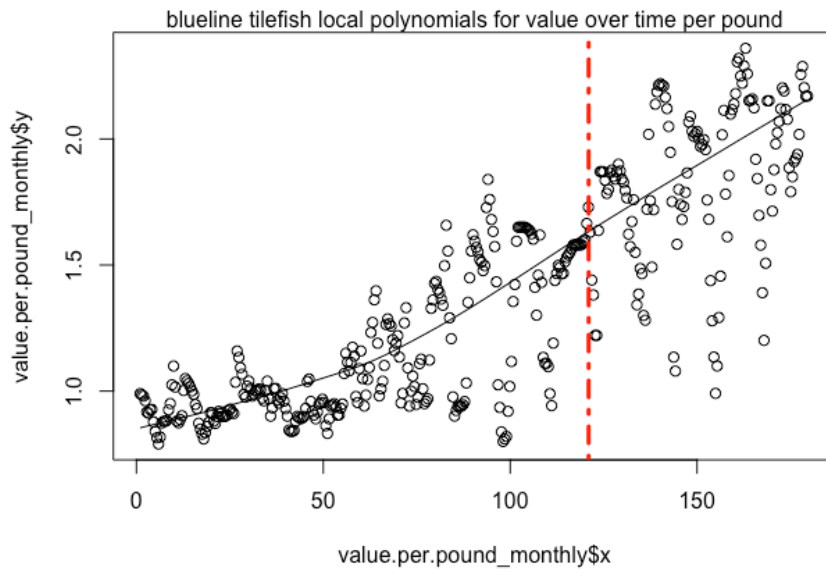
(A) Golden tilefish local polynomial smoothing shown in landings value per pound with a red marker to indicate the implementation date of 2009, denoted by 109 in the time series.



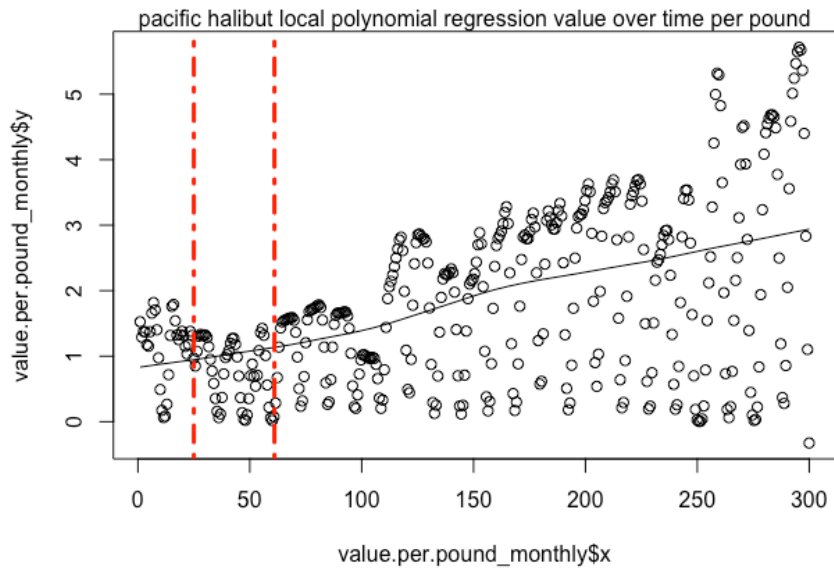
(B) Red snapper local polynomial smoothing shown in landings value per pound with a red marker to indicate the implementation date of 2007, denoted by 85 in the time series.



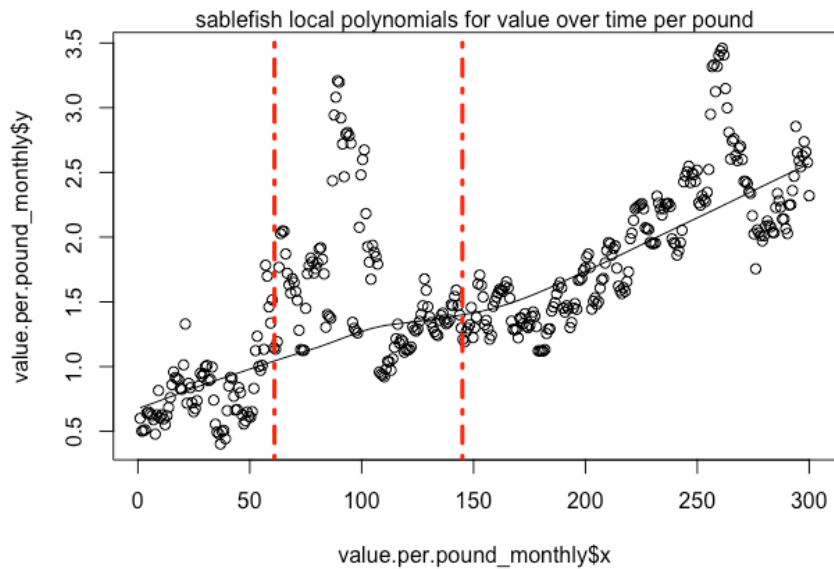
(C) Red grouper local polynomial smoothing shown in landings value per pound with a red marker to indicate the implementation date of 2010, denoted by 121 in the time series.



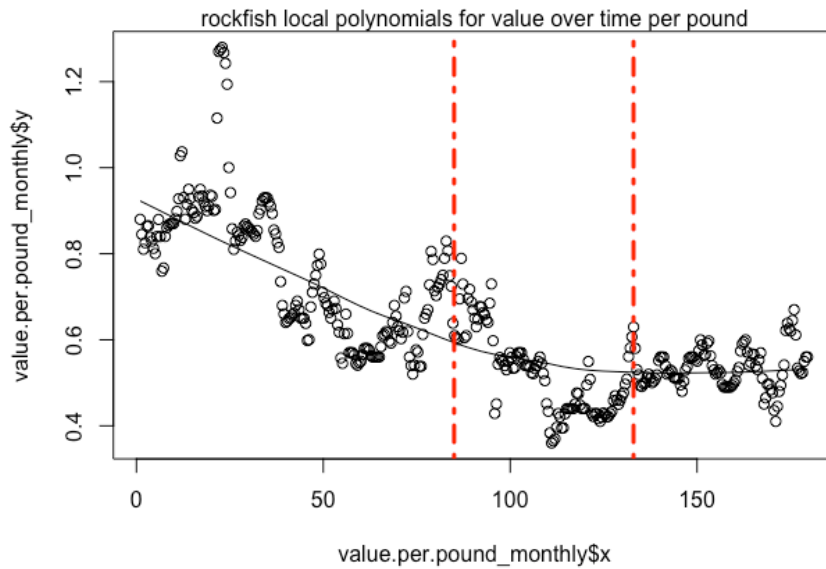
(D) Blueline tilefish local polynomial smoothing shown in landings value per pound with a red marker to indicate the implementation date of 2010, denoted by 121 in the time series.



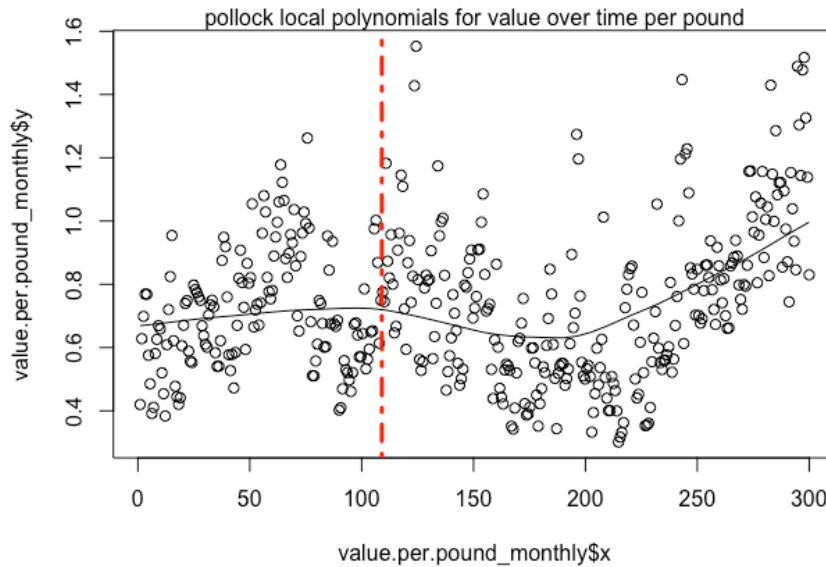
(E) Pacific Halibut local polynomial smoothing shown in landings value per pound with a red marker to indicate the implementation dates of 1992 and 1995, denoted by 25 and 61 in the time series.



(F) Sablefish local polynomial smoothing shown in landings value per pound with a red marker to indicate the implementation dates of 1995 and 2002, denoted by 61 and 145 in the time series.

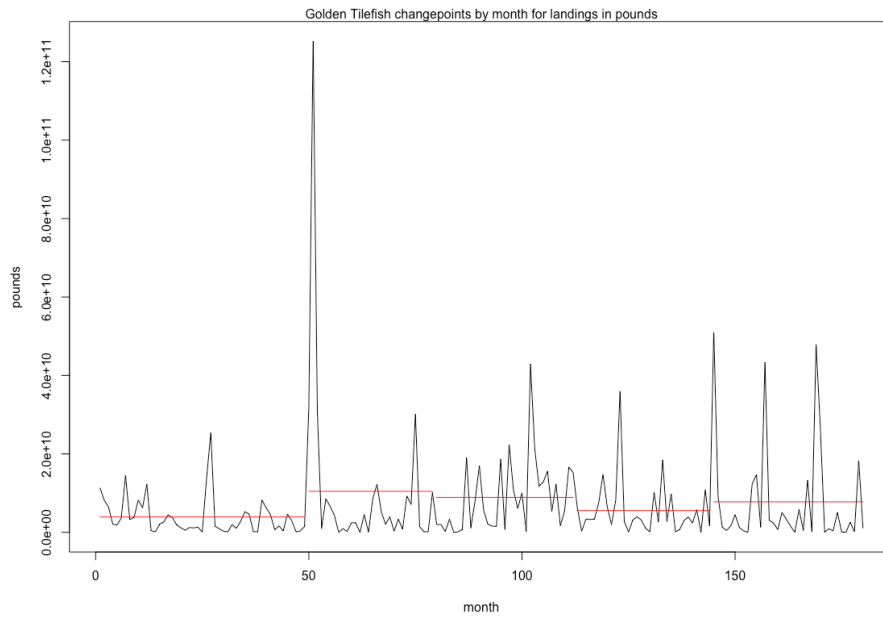


(G) Rockfishes local polynomial smoothing shown in landings value per pound with a red marker to indicate the implementation dates of 2007 and 2011, denoted by 85 and 133 in the time series.

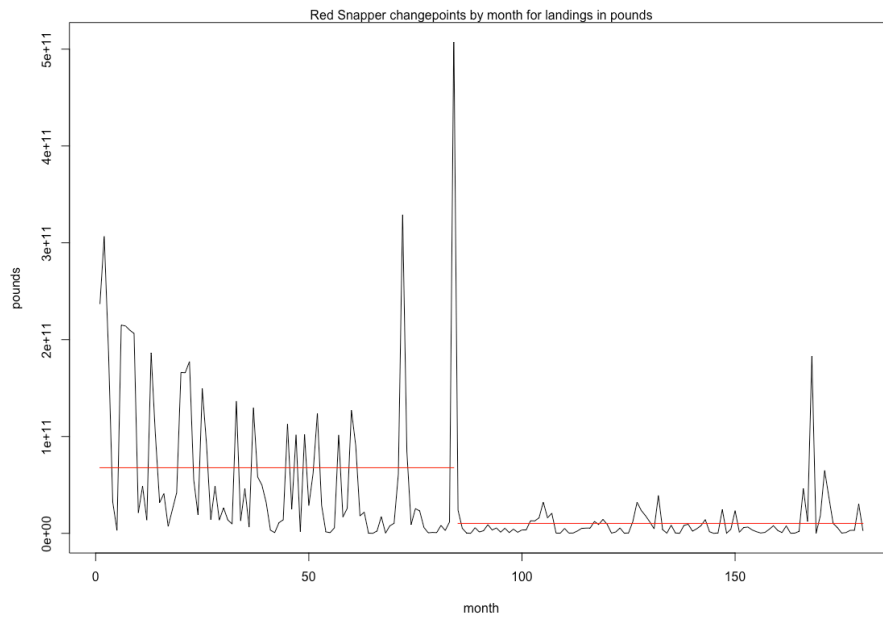


(H) Pollock local polynomial smoothing shown in landings value per pound with a red marker to indicate the implementation date of 1999, denoted by 109 in the time series.

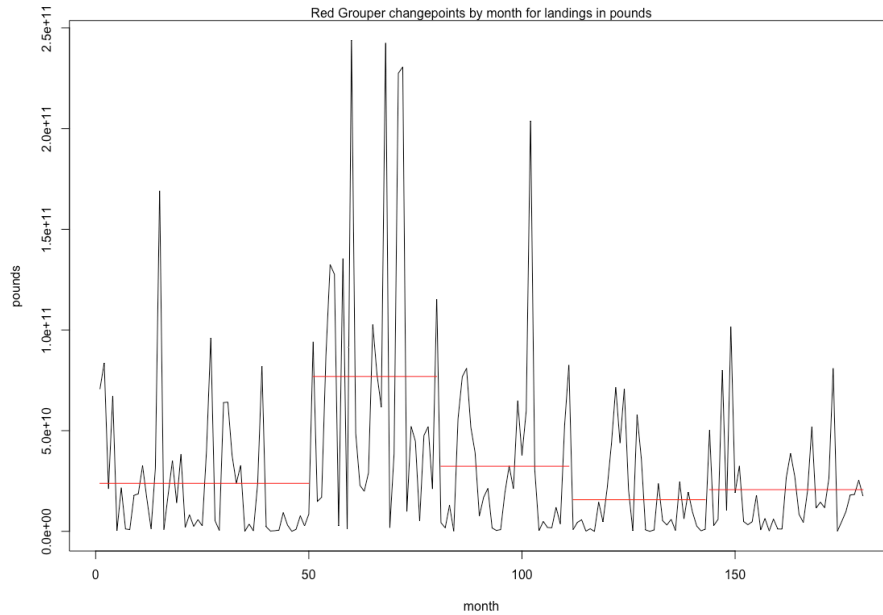
FIGURE 4. Mean change-points for each species' landings.



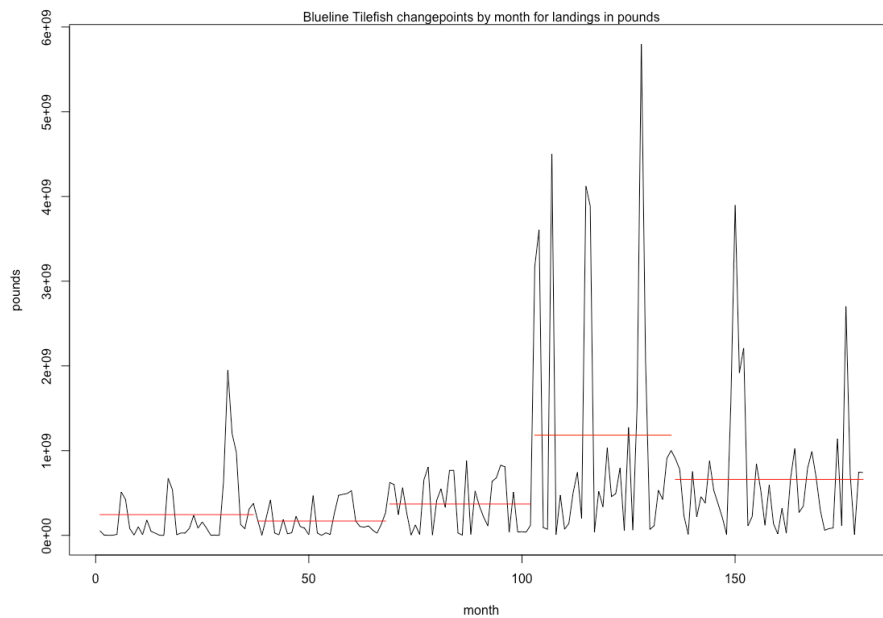
(A) Golden tilefish mean change-points shown in landings with horizontal red markers to indicate levels to which the change-point detected changes.



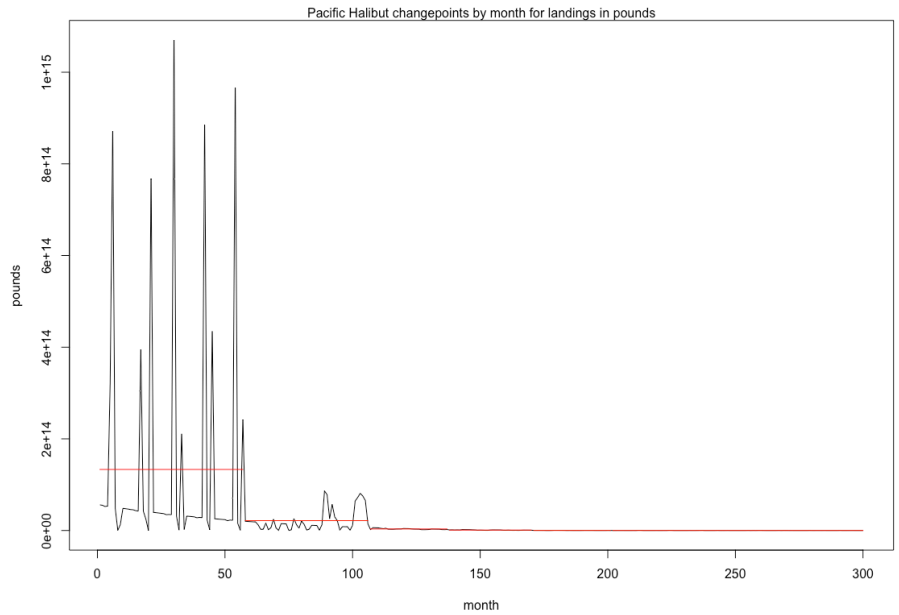
(B) Red snapper mean change-points shown in landings with horizontal red markers to indicate levels to which the change-point detected changes.



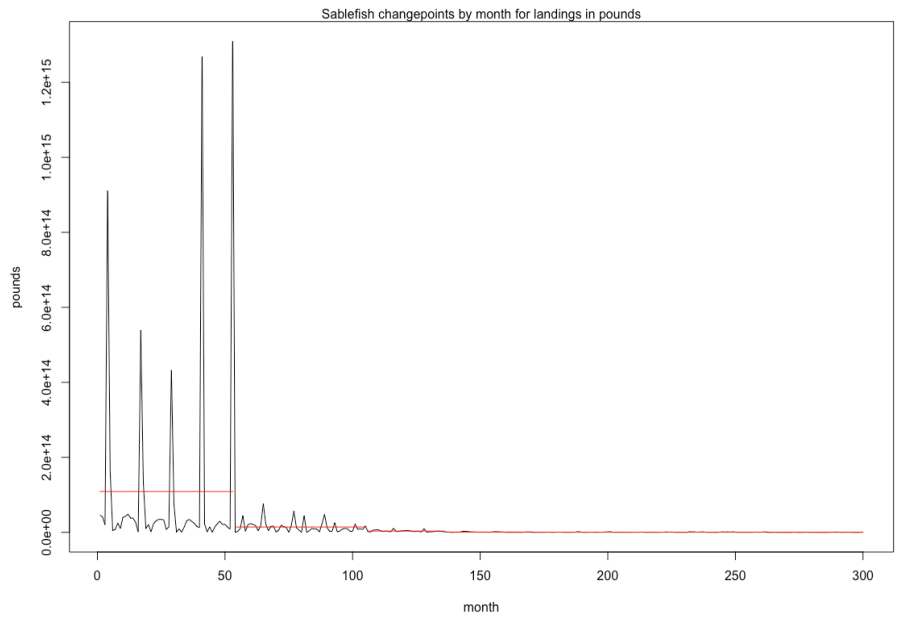
(C) Red grouper mean change-points shown in landings with horizontal red markers to indicate levels to which the change-point detected changes.



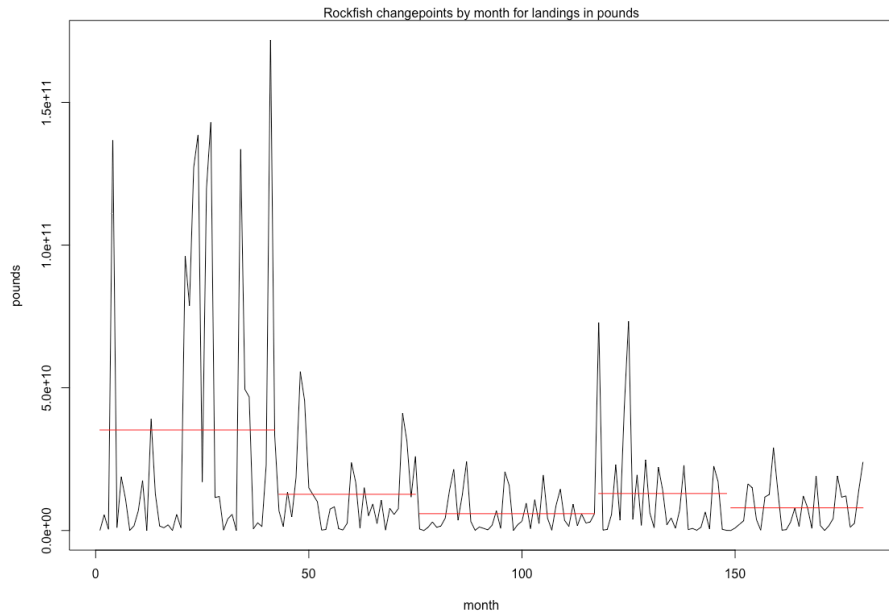
(D) Blueline tilefish mean change-points shown in landings with horizontal red markers to indicate levels to which the change-point detected changes.



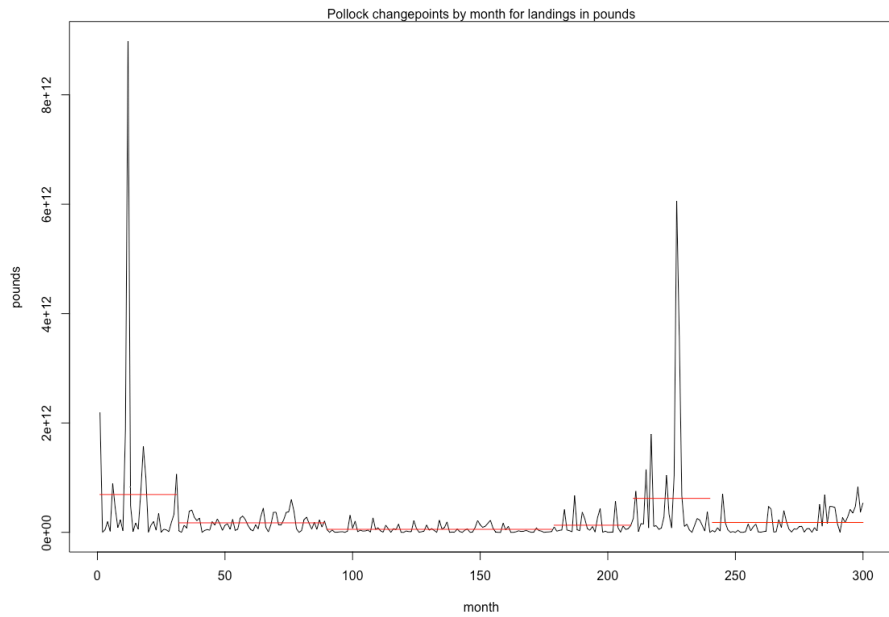
(E) Pacific halibut mean change-points shown in landings with horizontal red markers to indicate levels to which the change-point detected changes.



(F) Sablefish mean change-points shown in landings with horizontal red markers to indicate levels to which the change-point detected changes.

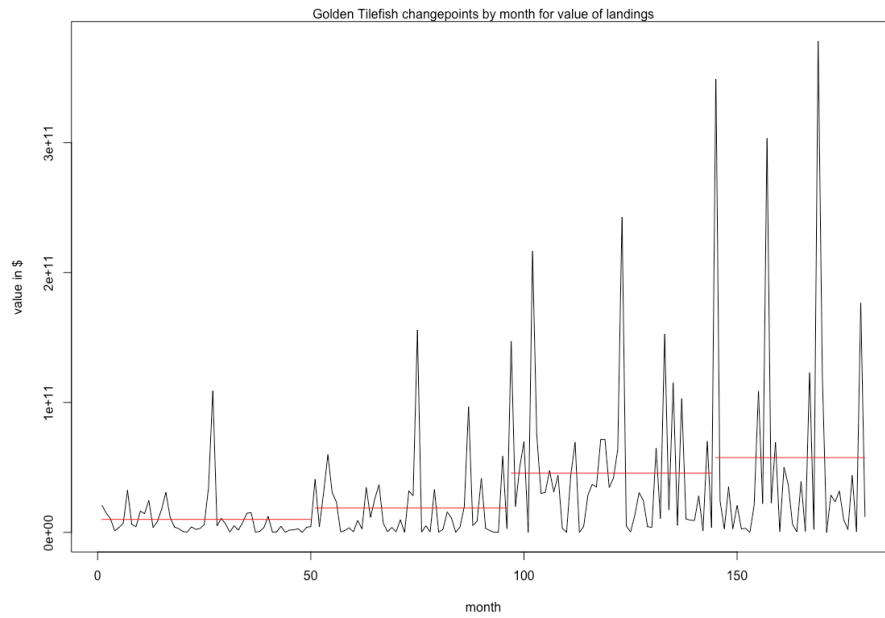


(G) Rockfish mean change-points shown in landings with horizontal red markers to indicate levels to which the change-point detected changes.

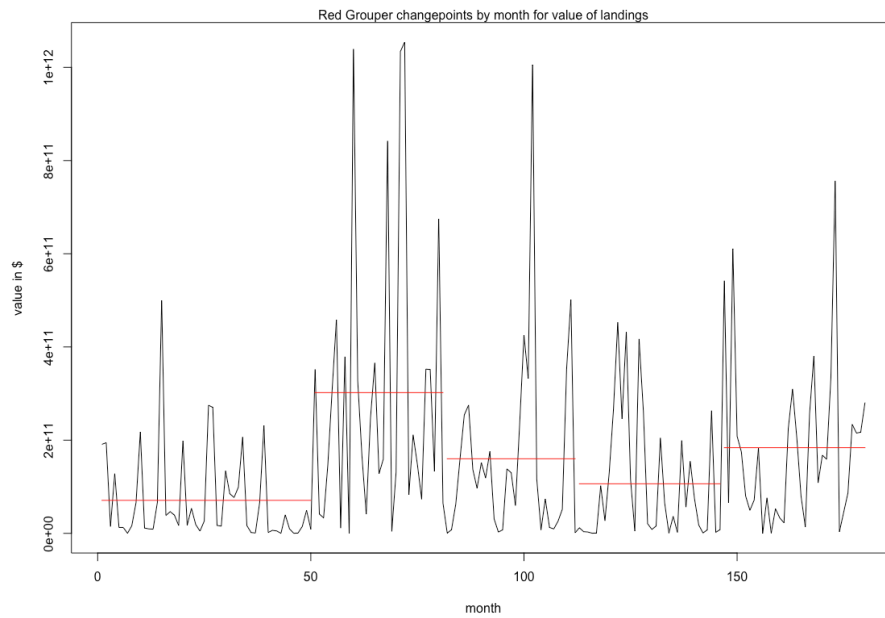


(H) Pollock mean change-points shown in landings with horizontal red markers to indicate levels to which the change-point detected changes.

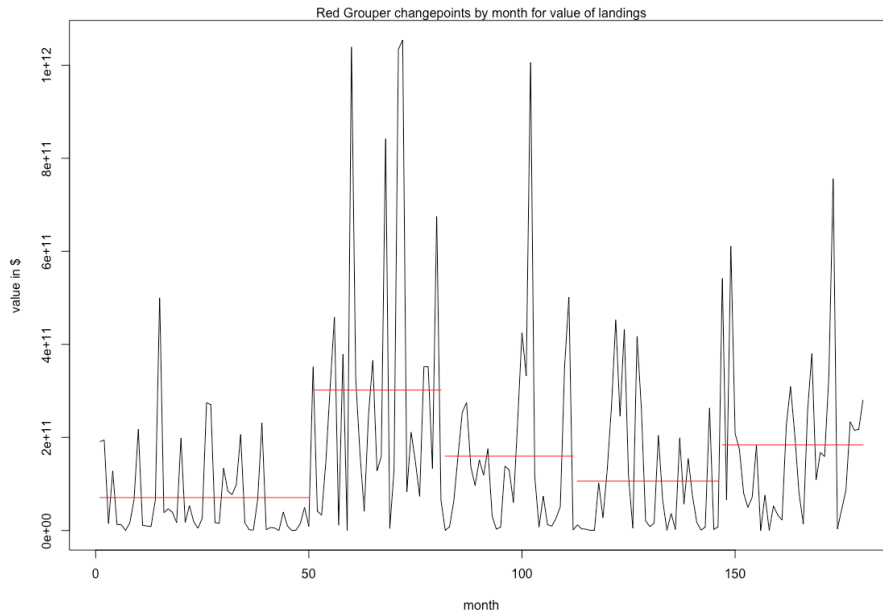
FIGURE 5. Mean change-points for each species' landings value.



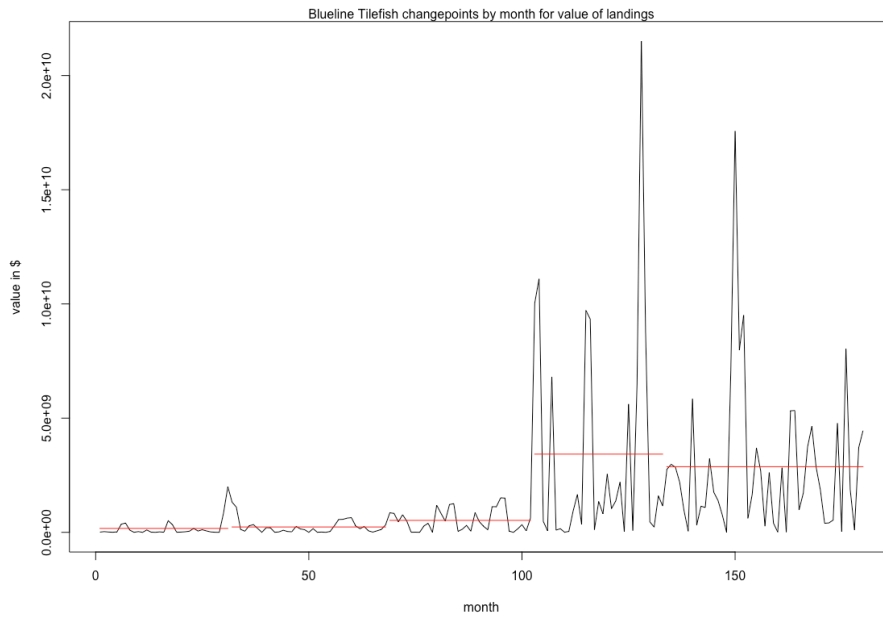
(A) Golden tilefish mean change-points shown in landings with horizontal red markers to indicate levels to which the change-point detected changes.



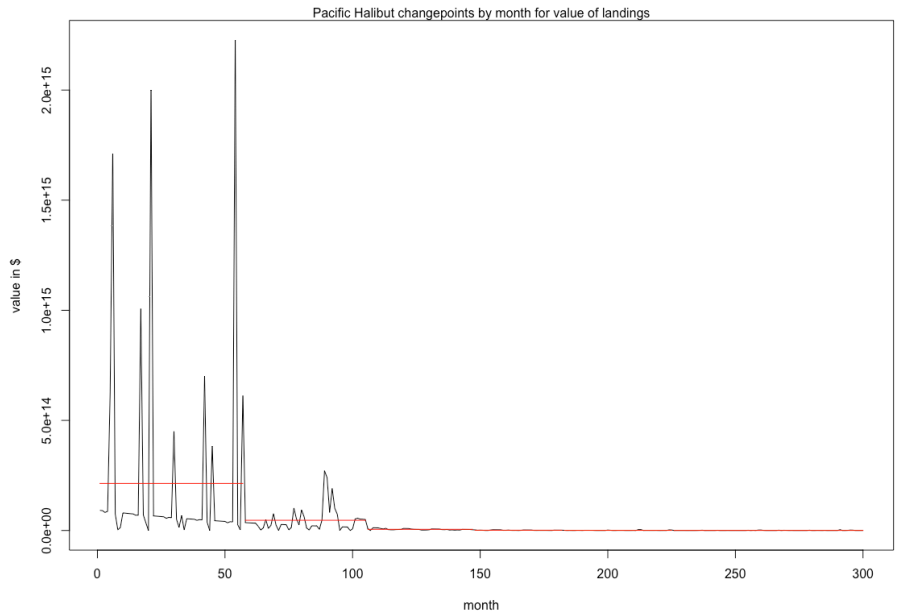
(B) Red snapper mean change-points shown in landings with horizontal red markers to indicate levels to which the change-point detected changes.



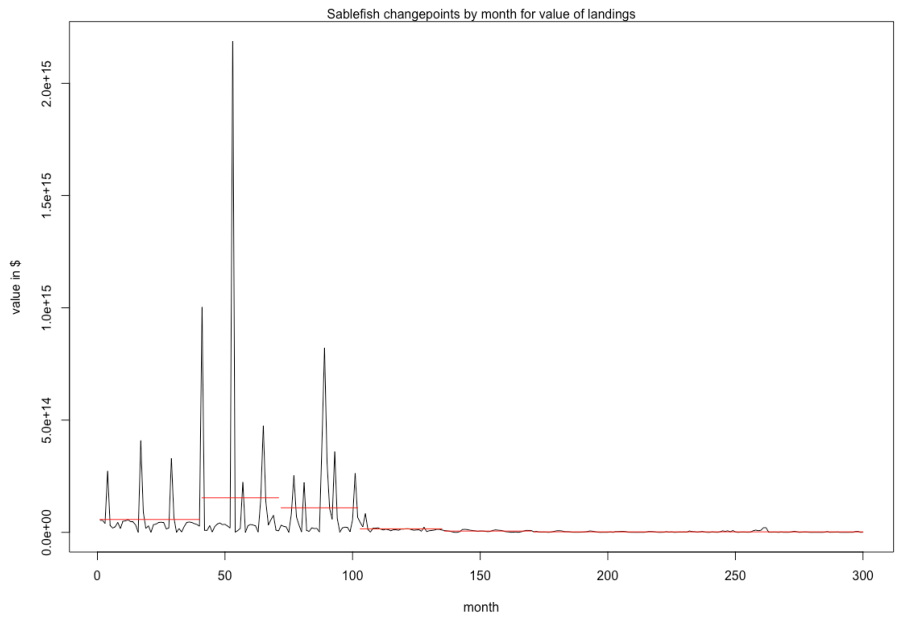
(C) Red grouper mean change-points shown in landings with horizontal red markers to indicate levels to which the change-point detected changes.



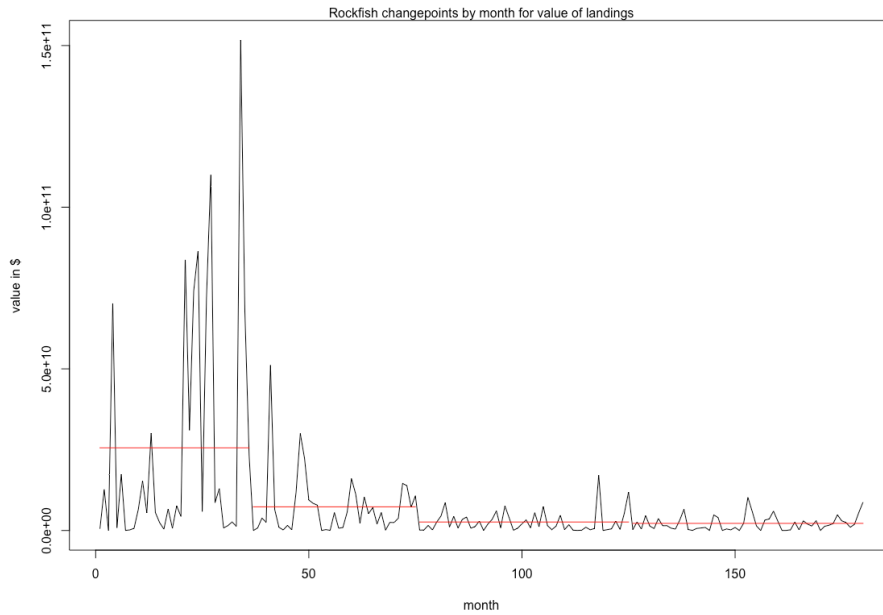
(D) Blueline tilefish mean change-points shown in landings with horizontal red markers to indicate levels to which the change-point detected changes.



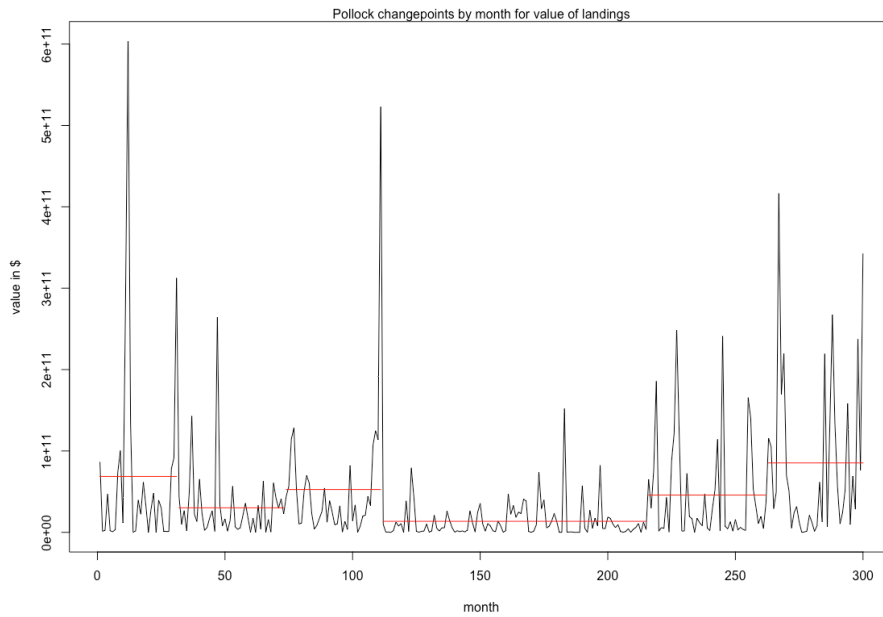
(E) Pacific halibut mean change-points shown in landings with horizontal red markers to indicate levels to which the change-point detect changes.



(F) Sablefish mean change-points shown in landings with horizontal red markers to indicate levels to which the change-point detect changes.



(G) Rockfish mean change-points shown in landings with horizontal red markers to indicate levels to which the change-point detect changes.



(H) Pollock mean change-points shown in landings with horizontal red markers to indicate levels to which the change-point detect changes.

## REFERENCES

- Agar, J., Stephen, J., Strelcheck, A., & Diagne, A. (2014). The Gulf of Mexico Red Snapper IFQ Program: The First Five Years. *Marine Resource Economics*, 29(2), 177-198.
- Andrews D.W.K. (1993), Tests for parameter instability and structural change with unknown change point, *Econometrica*, **61**, 821-856.
- Bai J. (1994), Least Squares Estimation of a Shift in Linear Processes, *Journal of Time Series Analysis*, **15**, 453-472.
- Bai J. (1997a), Estimating Multiple Breaks One at a Time, *Econometric Theory*, **13**, 315-352.
- Bai J. (1997b), Estimation of a Change Point in Multiple Regression Models, *Review of Economics and Statistics*, **79**, 551-563.
- Bai J., Perron P. (1998), Estimating and Testing Linear Models With Multiple Structural Changes, *Econometrica*, **66**, 47-78.
- Bai J., Perron P. (2003), Computation and Analysis of Multiple Structural Change Models, *Journal of Applied Econometrics*, **18**, 1-22.
- Buck, E.H. (1995). Individual Transferable Quotas in Fishery Management. *CRS Report For Congress*. 95-849. Retrieved from <http://dlc.dlib.indiana.edu/dlc/bitstream/handle/10535/4515/fishery.pdf?sequence=1>
- Brinson, A.A. and E. M. Thunberg. (2013). The Economic Performance of U.S. Catch Share Programs. *U.S. Dept. of Commerce.*, NOAA Technical Memorandum NMFS- F/SPO-133, 160 p.
- Brinson, & Thunberg. (2016). Performance of Federally Managed Catch Share Fisheries in the United States. *Fisheries Research*, 179, 213-223.
- Donald W. K. Andrews. (1993). Tests for Parameter Instability and Structural Change with Unknown Change Point. *Econometrica*, 61(4), 821-856.  
doi:10.2307/2951764
- Engle, R. (2001). GARCH 101: The Use of ARCH/GARCH Models in Applied Econometrics. *The Journal of Economic Perspectives*, 15(4), 157-168.
- Guttormsen, A. G., Myrland, Ø., & Tveteras, R. (2011). Innovations and Structural Change in Seafood Markets and Production: Special Issue Introduction. *Marine Resource Economics*, 26(4), 247-253.

- Griffith, D. (2008). The Ecological Implications of Individual Fishing Quotas and Harvest Cooperatives. *Frontiers in Ecology and the Environment*, 6(4), 191-198. Retrieved from <http://www.jstor.org/stable/20440871>
- Kaplan, I. C., Levin, P. S., Burden, M., & Fulton, E. A. (2010). Fishing Catch Shares in the Face of Global Change: A Framework for Integrating Cumulative Impacts and Single Species Management. *Canadian Journal Of Fisheries & Aquatic Sciences*, 67(12), 1968-1982. doi:10.1139/F10-118.
- Hansen, B. (2012). Advanced Time Series and Forecasting Lecture 5 Structural Breaks. *Advanced Summer School in Economics and Econometrics*. Department of Economics, University of Wisconsin-Madison. Retrieved from [assee.soc.uoc.gr](http://assee.soc.uoc.gr)
- Hinkley, D. V. (1970) Inference About the Change-Point in a Sequence of Random Variables, *Biometrika* **57**, 1–17.
- Levy, S. (2010). Catch Shares Management. *BioScience*, 60(10), 780-785. doi:1. Retrieved from <http://www.jstor.org/stable/10.1525/bio.2010.60.10.3>  
doi:1
- NOAA Fisheries Service. (2009). Central Gulf of Alaska Rockfish. *Fisheries Service Office of Policy*. Retrieved from [http://www.nmfs.noaa.gov/sfa/management/catch\\_shares/about/documents/goa\\_rockfish.pdf](http://www.nmfs.noaa.gov/sfa/management/catch_shares/about/documents/goa_rockfish.pdf)
- NOAA Fisheries Service. (2009). Pacific Sablefish Permit Stacking Program. *Fisheries Service Office of Policy*. Retrieved from [http://www.nmfs.noaa.gov/sfa/management/catch\\_shares/about/documents/pacific\\_sablefish\\_permitstacking.pdf](http://www.nmfs.noaa.gov/sfa/management/catch_shares/about/documents/pacific_sablefish_permitstacking.pdf)
- NOAA Fisheries Service. (2010). West Coast Groundfish Trawl Catch Share Program. *NOAA Fisheries Service Office of Policy*. Retrieved from [http://www.westcoast.fisheries.noaa.gov/publications/fishery\\_management/rawl\\_program/catch-shares-final-comp.pdf](http://www.westcoast.fisheries.noaa.gov/publications/fishery_management/rawl_program/catch-shares-final-comp.pdf)
- NOAA Fisheries Service. (2016). Electronic Monitoring and Reporting. *Office of Science and Technology*. Retrieved from <https://www.st.nmfs.noaa.gov/advanced-technology/electronic-monitoring/index>
- NOAA Fisheries Service. (2017). NOAA Catch Share Policy. *U.S. Dept. of Commerce*. Retrieved from [http://www.nmfs.noaa.gov/sfa/management/catch\\_shares/about/documents/noaa\\_cs\\_policy.pdf](http://www.nmfs.noaa.gov/sfa/management/catch_shares/about/documents/noaa_cs_policy.pdf)
- Northwest Fisheries Science Center. (2015). West Coast Groundfish Trawl Catch Share

- Program. *NOAA Fisheries*. Retrieved from [https://www.nwfsc.noaa.gov/research/divisions/fram/catch\\_shares.cfm](https://www.nwfsc.noaa.gov/research/divisions/fram/catch_shares.cfm)
- NOAA Fisheries Service. (2017). The Community Development Quota Program. *Alaska Regional Office*. Retrieved from <https://alaskafisheries.noaa.gov/sites/default/files/cdqprogsummary.pdf>
- Organisation For Economic Co-Operation and Development (OECD). (2006). *Using Market Mechanisms to Manage Fisheries*. 287-321.
- Parkes, Swasey, Underwood, Fitzgerald, Strauss, & Agnew. (2016). The Effects of Catch Share Management on MSC Certification Scores. *Fisheries Research*, 182, 18-27.
- Rieser, A. (1997). Property Rights and Ecosystem Management in U.S. Fisheries: Contracting for the Commons. *Ecology Law Quarterly* 24(4), 813-832.
- Scott, A. J. and Knott, M. (1974) A Cluster Analysis Method for Grouping Means in the Analysis of Variance, *Biometrics* **30(3)**, 507–512
- Seifert, B. and Gasser, T. (2006). Local Polynomial Smoothing. *Encyclopedia of Statistical Sciences*. 7.
- Sigler, M., & Lunsford, C. (2001). Effects of individual quotas on catching efficiency and spawning potential in the Alaska sablefish fishery. *Canadian Journal of Fisheries and Aquatic Sciences*, 58(7), 1300-1312.
- Squires, Campbell, Cunningham, Dewees, Grafton, Herrick, . . . Vestergaard. (1998). Individual transferable quotas in multispecies fisheries. *Marine Policy*, 22(2), 135-159.
- Thébaud, O., Innes, J., & Ellis, N. (2012). From anecdotes to scientific evidence? A review of recent literature on catch share systems in marine fisheries. *Frontiers in Ecology and the Environment*, 10(8), 433-437.
- Tokotch, Meindl, Hoare, & Jepson. (2011). Stakeholder Perceptions of the Northern Gulf of Mexico Grouper and Tilefish Individual Fishing Quota Program. *Marine Policy*.
- U.S. Department of Commerce. (2014). NOAA: Review of NOAA Catch Share Programs. *Office of Inspector General, Office of Audit and Evaluation*. Retrieved from [http://www.westcoast.fisheries.noaa.gov/publications/fishery\\_management/rawl\\_program/oig-report.pdf](http://www.westcoast.fisheries.noaa.gov/publications/fishery_management/rawl_program/oig-report.pdf)
- Wand, M., & Jones, M. C. (1995). *Kernel smoothing* (1st ed., Monographs on statistics and applied probability (Series) ; 60). London ; New York: Chapman & Hall.

