An investigation into the spatial distribution of use by charter fishermen and the size of sport-caught Pacific halibut in Seward, Alaska over the last two decades

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APPROVAL

of a writing project submitted by

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This writing project has been read by the writing project advisor and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the Statistics Faculty.

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1 Introduction

When asked about the change in the halibut fishery over her career as a charter boat captain out of Seward, Alaska, *Gusto* skipper Suzie Neuman says, "You don't get the big fish as often." I've always been interested in listening to older captains talk about how the fishing has changed over their time, and I've been listening to fish stories since I started deckhanding on charter boats out of Seward, Alaska in 2008. In 2014 I received my Merchant Mariner Credential and ran my own boat for the first time. I was a green captain, but nevertheless I felt compelled to start telling my own fish stories! It made me wonder whether seasoned fishermen paint a realistic picture of what the fishing was like $15 - 20$ years ago.

This project explores whether the fish stories of the past can be backed up by monitoring data. When seasoned charter boat captains out of Seward, Alaska are asked about how the fishing for bottomfish has changed over their time, they often say something to the effect of, "We travel farther for smaller fish." The goal of this project is to investigate this claim with available data.

First, I explore how the distance that Seward charter boats travel to fish for bottomfish changed over the years 1993 to 2014. To address this question, I look at the proportion of use over time in several areas purposely chosen to address this question (Section 2.3). Is there evidence that the proportion of charter boats traveling to fish for bottomfish in selected *indicator areas* has changed over the years 1993 through 2014? I then describe interviews with two charter boat captains who have been fishing out of Seward since the 1990s. The interviews paint a first-hand picture of how Seward fishermen view the change in the halibut fishing over time.

Second, I explore whether Seward boats are catching smaller fish. Is there evidence of a change in the mean length of halibut caught by Seward boats (private, charter, and military) over the years 1994-2013? To further investigate this question, I compare results with published literature about trends in size-at-age over time, and I briefly explore stock assessment data collected by the International Pacific Halibut Commission in area 3A.

2 Distance Traveled

In this section, I investigate how the distance Seward charter boats travel to fish has changed over the last two decades, given available data of fishing locations over years 1993 through 2014. To explore this question, I used two data sources—interview data and logbook data (ADF&G non-confidential data 1993-2014 and ADF&G Saltwater Logbook Database 2004–2013). The logbook data are generally considered census data (Section 2.1.1), and the interview data are collected from a sample of vessels. The logbook and the interview data are compared, and the interview data are used to investigate the question of interest (Sections 2.3.3 and 2.3.4).

First, I present my original explorations with the data. The initial exploratory plots showed general trends in use over time. To investigate the "distance traveled" question in a more rigorous way, I chose several specific *indicator areas* because of the quality of fishing in these areas and the distance from Seward (Section 2.3). The changes in the proportion of use in these carefully chosen indicator areas are intended to indicate whether Seward charter boats are truly traveling farther to fish.

2.1 Data Collection

2.1.1 Logbook Data 2004-2013

Charter fishermen are required to fill out a logbook page for each day paying clients are on board. Each logbook page requests information such as names and fishing licenses of paying clients in addition to the guide's license information. Additionally, the guide is given a map of statistical areas (Figure 1) and asked to record the statistical area fished for bottomfish "where the majority of fish species were caught" that day.

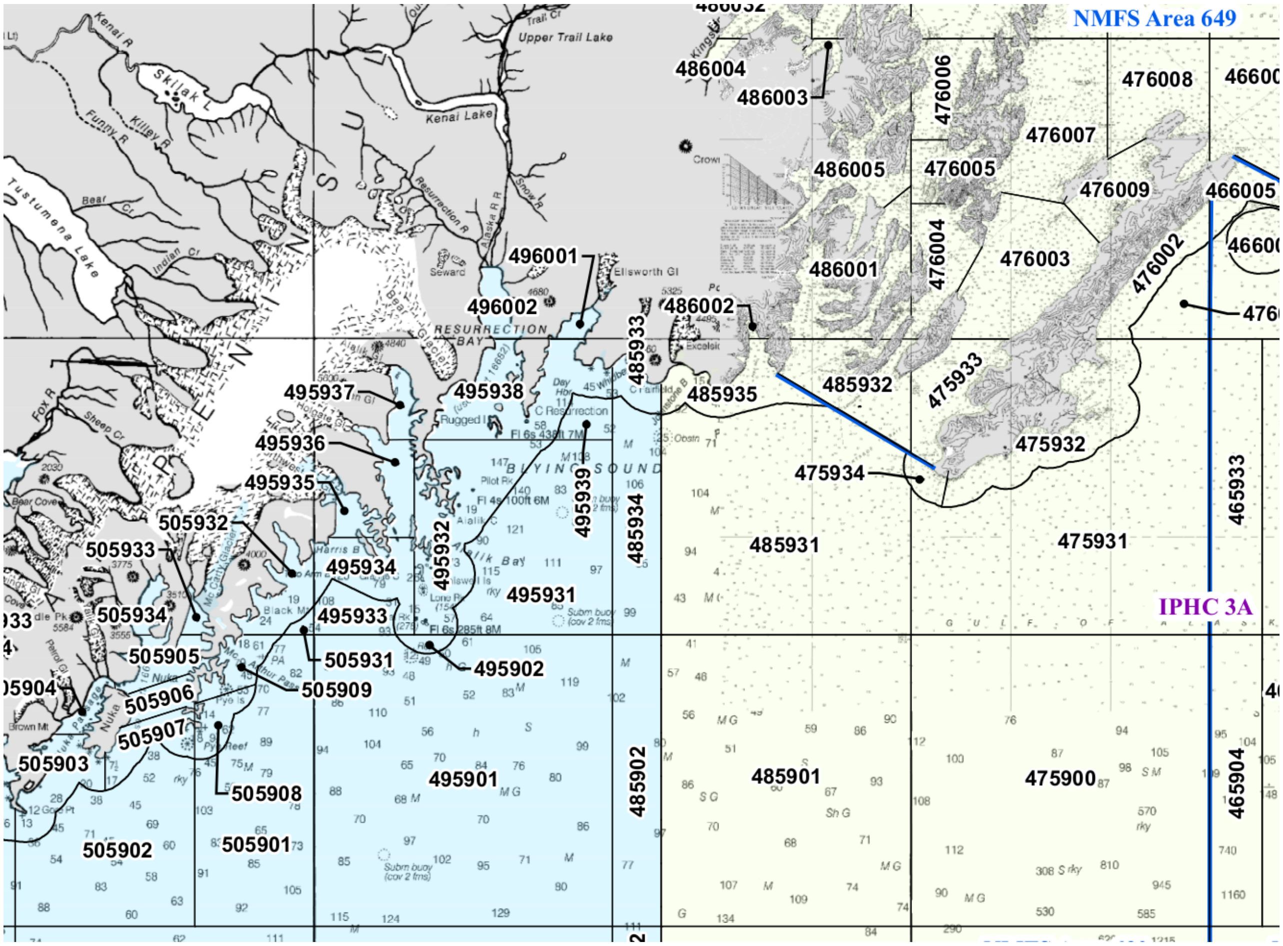

Figure 1: Alaska Department of Fish and Game map of statistical areas in the waters near Seward, Alaska.

Most of the statistical areas shown on the map in Figure 1 were used by charter fisherman offloading in Seward at least once between 1993 and 2014. The following thirteen areas, however, are some of the most commonly used, and for this reason I have assigned names to these areas according to geographical location. I will refer to these names in the following report. A key is provided here (Table 1) to connect the common names for the following statistical areas to the numbers used by Alaska Department of Fish and Game (ADF&G).

Table 1: A key for ADF&G statistical areas and the common names used in this report.

Common Name	ADF&G Statistical Area	Common Name	ADF&G stat area
Resday	495938	Elrington	485932
Aialik	495932	Mcarthur	505909
Whidbey	485933	Pye	505908
Junken	485935	Cape Cleare	475934
Granite	495934	Straits	475933
Twoarm	505932	Patton	475932
Nuka	505905, 505906, 505907		

ADF&G shared a compiled version of logbook data for years 2004 through 2013 (ADF&G Saltwater Logbook Database 2004–2013). The raw data could not be shared because it contains confidential information about specific businesses. The compiled dataset contains information about the number of trips in each statistical area within each year, as well as the proportion of null values for each year. Some null values exist in the raw data; these are truly missing values in which the guide did not fill out the statistical area fished. Other null values were assigned in the compilation process to preserve confidentiality. In the compilation processs, ADF&G combined areas with fewer than four businesses reporting in a given year with other areas to protect the privacy of the reporting businesses. Some areas were not able to be combined and in this case the number of trips was assigned a null value. The proportion of null values for each year are given in Table 2. There were relatively few null values in years 2005-2013, with the highest proportion of null values being approximately 4% in 2004.

The null values assigned due to privacy issues are not a concern, with one exception. Three of the four chosen *indicator areas* are very popular and have many more than four reporting businesses each year. The "Nuka" *indicator area*, however, is comprised of three smaller statistical areas and could have been altered in the compilation process. As a result, the logbook data are not displayed for area Nuka (Section 2.3.1).

The missing values are a concern, however, because the presence of these missing values means the logbook data are not truly census data. The missing values could introduce a bias in the data if there was a group of charter boat captains who purposefully did not fill in the location fished. I think this is unlikely because the statistical areas reported are very general and will not reveal secret fishing spots. I think it is more likely that the missing values are mistakes or oversights and not concentrated in one statistical area. Additionally, because I am interested in the change in the spatial distribution of use over time, if bias is present it won't affect the results of my investigation unless the bias itself changes over time. For these reasons, the logbook data are generally accepted and referred to as census data in this report.

Table 2: The total number of trips and the total number of null values in the logbook data for each year.

year	# NULL values	total trips	% NULL values
2004	158	3963	3.99
2005	39	3754	1.04
2006	18	3881	0.46
2007	13	4401	0.30
2008	27	4188	0.65
2009	12	3221	0.37
2010	21	3440	0.61
2011	8	3504	0.23
2012	11	3627	0.30
2013	15	3525	0.43

2.1.2 Interview Data 1993-2014

Dockside interview data are available for years 1993 through 2014. Two days a week are randomly selected for dockside interviews and three days a week are randomly selected for biological sampling (Section 4.1), with the constraint that there must be two consecutive days off per week.

Interviews are conducted between 2 and 9 p.m. each day, and the technician dedicates one hour of effort at each of the four harbor cleaning stations (J-dock, A-dock, B-float, and North Boat Ramp). The starting location rotates with each interview day. Technicians are instructed to conduct as many interviews as possible in the time frame and spread interview effort across sector and businesses within the charter sector. Only the charter sector is considered in this report.

The interview with the skipper begins with a question about what anglers on the vessel fished for that day. The interview proceeds only if bottomfish were kept or released, and the trip is recorded as one of seven trip types (Table 3). Only those trips that were recorded as a halibut only (H) or a combination trip (B or B+S) are considered in this report.

Table 3: *Trip types and abbreviations recorded in ADF&G interviews.*

abbreviation	trip type
H	halibut exclusively
R	rockfish exclusively
L	lingcod exclusively
B	any combination of bottomfish (hal, rockfish, lingcod, Pcod, sharks)
B+S	any combination of bottomfish and salmon (e.g. halibut+coho)
S	salmon only
SK	salmon shark

The charterboat captain is then asked to indicate the statistical area where the majority of bottomfish were caught. Information such as sector, charter name, logbook number, number of fishermen on the boat, and number of days out fishing are also recorded.

In the following exploratory analysis, I frequently use the phrase "proportion of use." In the context of the interview data, this phrase refers to the proportion of sampled charterboats that reported fishing for bottomfish in a given area. In the context of the logbook data, the phrase "proportion of use" refers to the proportion of all logbook compliant charterboats, with the exception of null values, that reported fishing for bottomfish in a given area. I chose to measure effort at the boat level, not the angler level, because the decision about where to fish on a charter trip is made by the skipper at the boat level.

2.2 Exploratory Plots

I started plotting the interview data to explore and compare the frequency of use across statistical areas and years. Side-by-side boxplots show the sample proportion of use over years 1993 through 2014 in thirteen of the most frequently used statistical areas, ordered by distance from Seward (Figure 2). The locations of these thirteen statistical areas are shown in Figure 3 and coded by color to match Figure 2.

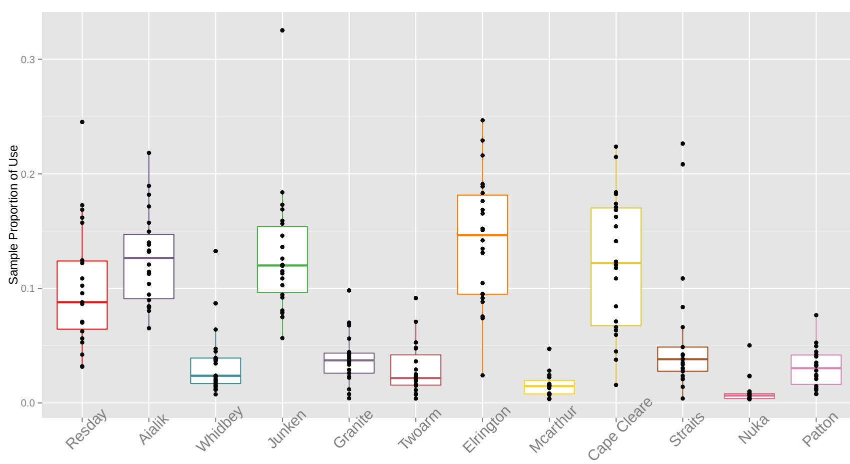

Figure 2: Side by side boxplots showing the sample proportions of use for thirteen of the most commonly used ADF&G statistical areas ordered by distance from Seward. Each point within an area represents a year ($1993 - 2014$*). Note the colors match those in Figure 3.*

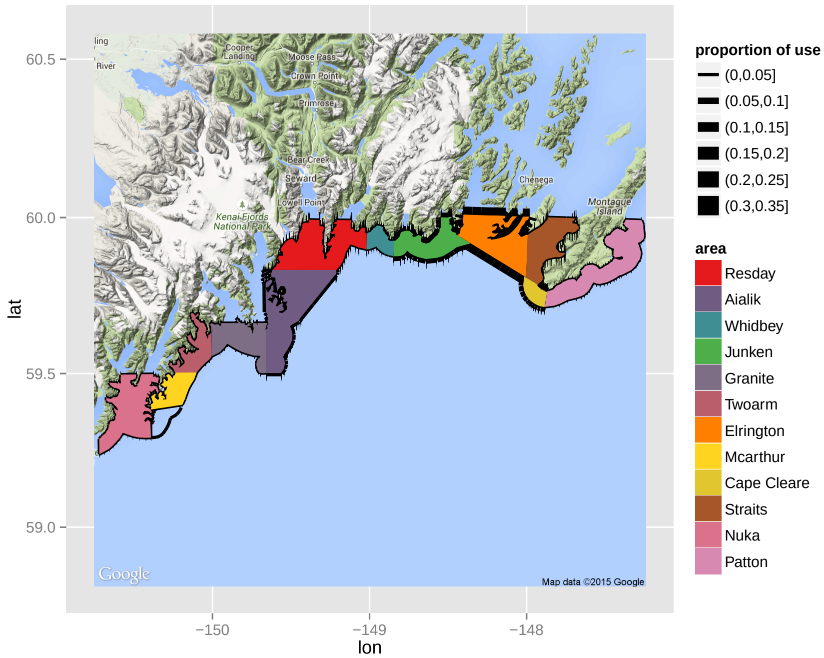

Figure 3: A map showing thirteen of the most commonly used ADF&G statistical areas coded by color. The sample proportion of use over years 1993 *through* 2014 *is coded by line width.*

The previous figures summarize use over all years, so I ordered statistical areas by distance and plotted the proportion of use by ordered area for each year to explore the spatial distribution of use over time (Figure 4). Four very popular statistical areas stand out in these plots. These areas were also identified in Figures 2 and 3 and correspond to areas Aialik, Junken, Elrington, and Cape Cleare. By boat, it is approximately 33 miles from Seward to the center of the statistical area named Aialik. Junken, Elrington, and Cape Cleare are approximately 42, 56, and 66 miles from Seward, respectively.

The initial exploratory plots do indicate that the distribution of use across statistical areas has changed over time. In the early period from 1993 to 1996, the distribution of use in the sample data is more heavily weighted towards the closer areas such as Resday, Aialik, Junken, and others. The areas farther from Seward see progressively more use in the subsequent periods, 1997 to 2000 and 2001 to 2004. After 2000, the peaks corresponding to the popular and faraway areas, Elrington and Cape Cleare, really begin to stand out. In the most recent period from 2010 to 2014, the distribution of use is more heavily weighted towards the areas farther from Seward (Figure 4). It is not clear whether these changes are due to sampling variability or true changes in the spatial distribution of use, however, and I will investigate this further in subsequent sections. It is important to note here that the number of interviews conducted vary across year, with the smallest sample sizes in the 1990s (Table 4).

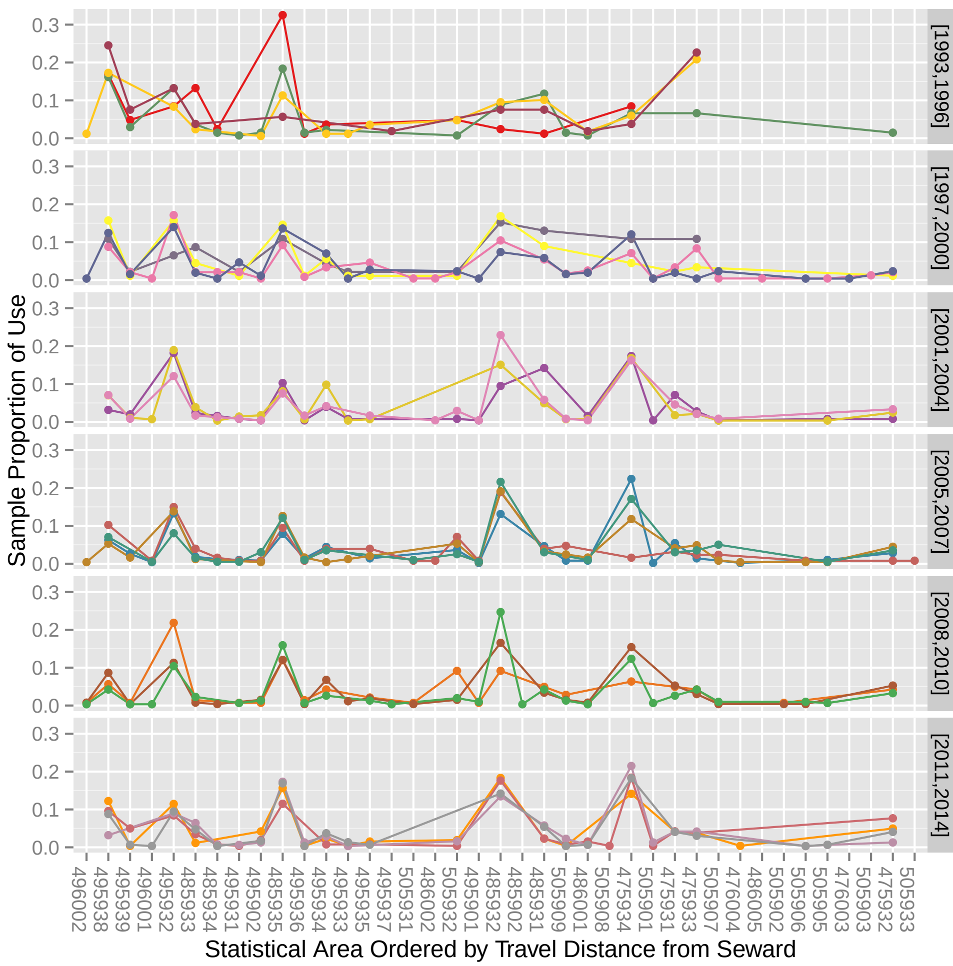

Figure 4: The proportion of use by charter boats offloading in Seward for five 3 *to* 4 *year periods between* 1993 *and* 2014*. All statistical areas are shown and ordered by travel distance by boat from Seward. Each point indicates the sample of proportion of use for the given statistical area within a year.*

Table 4: Number of interviews conducted each year.

1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
83	136	168	53	46	89	239	257	253	285	240
2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
496	127	246	199	142	266	308	262	261	312	296

2.3 Indicator Areas

In my experience working on and running a charter boat out of Seward, Alaska, I have found that Seward charter boat captains have certain "spots" where they like to fish, and the distance of each of these "spots" from Seward is taken into account when deciding where to fish on any given day. Cape Cleare, Patton Bay, and Nuka Bay are three fishing areas far from Seward where the fishing is stellar. I chose these three areas as *indicator areas* because I would expect the proportion of use in these areas to increase if Seward charter boats are traveling farther for fish. The fourth chosen *indicator area*, an area corresponding to Resurrection Bay and Day Harbor, is close to Seward, and the bottomfish fishing is mediocre. Here, I would expect the proportion of use to decrease over time if Seward charter boats are traveling farther for fish.

Cape Cleare describes the waters off the southern tip of Montague Island. The shallow shelf protruding from Cape Cleare is teeming with life and is excellent for halibut fishing because of shallow depths and abundant food sources for hungry halibut. Cape Cleare has long been known to have incredible fishing, and Seward fishermen have been traveling to fish in this area since they had access to boats that could make the journey. Cape Cleare (area 475934), however, is approximately 66 miles from Seward and takes approximately two and a half hours to reach depending on vessel speed and weather. Patton Bay (475932, "Patton") is another 15 miles past Cape Cleare. The third *indicator area*, Nuka Bay (505905, 505906, and 505907, "Nuka"), is an incredible fishing spot 70 to 80 miles southwest of Seward. This spot also has long been known to have abundant healthy halibut. The last *indicator area*, Resurrection Bay/Day Harbor (area 495938, "Resday") is between 10 and 25 miles. Again, I would expect the proportion of use in the faraway *indicator areas* to increase over time and the proportion of use in the *indicator area* close to Seward to decrease over time if the trend is to travel farther for fish.

In the logbook and interview data, the fishing area reported is the area where the majority of bottomfish were caught. The question I've chosen to address, then, is how the distance Seward charter boats travel to fish for *bottomfish* changed over the years 1993 to 2014. The question was motivated in part by the data that were available. I'm truly more interested in how the distance that Seward charter boats travel to fish for *halibut* has changed over the last two decades. But, at this point, given the data available to me, there is no way to tease apart the area fished for halibut and the area fished for rockfish, lingcod or other bottomfish.

That said, halibut are the most prized bottomfish, and most charter fishermen target halibut every day. If fishermen are driving all the way to Cape Cleare, Patton, or Nuka, I suspect that a main reason for traveling that far is to catch halibut. There is really no reason to drive that far just to catch rockfish, although there may be other motivating factors such as lingcod and king salmon. This is an observational study, so I won't venture to make causal inference, but in most cases I think the decision to make a long run to one of the faraway *indicator areas* is typically influenced (in whole or in part) by the goal of catching halibut. The motivating factors behind choosing a fishing spot for the day could be a topic of further study.

2.3.1 Logbook Data 2004-2013

The proportion of use in areas Cape Cleare, Resday, and Patton compiled from 2004 – 2013 logbook data are displayed over time (Figure 5). Refer to Section 2.1.1 for details on data collection.

In 2004, the proportion of use in Cape Cleare is higher than Resday and vice versa in 2005. In 2005, the proportion of use in Cape Cleare decreases to 0.080, the lowest value seen in this nine year span, and the proportion of use in Resday increases to 0.128. This change in 2005 could be due to bad weather. In long stretches of bad weather, boats are unable to make the run all the way to Cape Cleare and are forced to fish inside the bay to remain protected from wind and waves. For future studies, historical weather patterns could be examined and built into the analysis to help explain some of the year-to-year variability in use.

From 2006 to 2011, the proportion of use in Cape Cleare stays approximately constant, and then increases to 0.128 in 2012 and 0.168 in 2013. The proportion of use in Resday also stays approximately constant from 2006 to 2010, increases in both 2011 and 2012 and then decreases in 2013 to 0.079.

Patton generally increases in use across the nine-year span shown. There is a slight decrease in use in 2005, consistent with Cape Cleare, another drop in 2010, and then a peak at a high of 0.052 in 2012. Although there is an increase in Patton over time, the proportion of use remains relatively low overall, indicating the vast majority of fishermen are favoring other areas.

Note that logbook data for Nuka are not reported, due to privacy issues in sharing of data discussed in Section 2.1.1. ADF&G is not able to share logbook information when fewer than four businesses reported fishing in an area in a given year. This privacy issue does not affect Resday, Cape Cleare, and Patton areas. It could be a problem in Nuka however, because Nuka is a compilation of three smaller statistical areas, and a relatively small number of charter boats fish in these areas. For this reason, I leave Nuka out of the logbook data displays. The interview data are not modified due to confidentiality concerns, so I include Nuka in the analysis in Section 2.3.4.

Figure 5: The proportion of use for indicator statistical areas Resday, Cape Cleare, and Patton from 2004 − 2013 *logbook data. The figure panels indicate the expected change in use if charter fisherman are truly traveling farther to find fish.*

2.3.2 Interview Data 1993-2014

The sample proportions calculated from the interview data for years 1993 through 2014 are displayed in statistical areas Cape Cleare, Nuka, Patton, and Resday (Figure 6). The sample proportions of use in areas Cape Cleare and Patton generally increase over time. In Resday, use generally decreases between 1995 and 2001, and from 2002 on the sample proportion of use remains approximately constant. Nuka was not reported in any interviews until the year 1999, and for subsequent years the sample proportion of reported use remained relatively low.

Notice the dramatic decrease in the sample proportion of use in Cape Cleare in 2005. The 2005 spike shown in Figure 6 is a combination of process variability and sampling variability. The logbook data shows the proportion of use in Cape Cleare did truly decrease in 2005, but not as much as the interview data suggests. The difference in the logbook data and interview data is attributed to sampling error. In 2005, the process error and the sampling error is relatively large and negative. In the next section, I conduct a comparison of the interview and logbook data to further explore these two sources of variability.

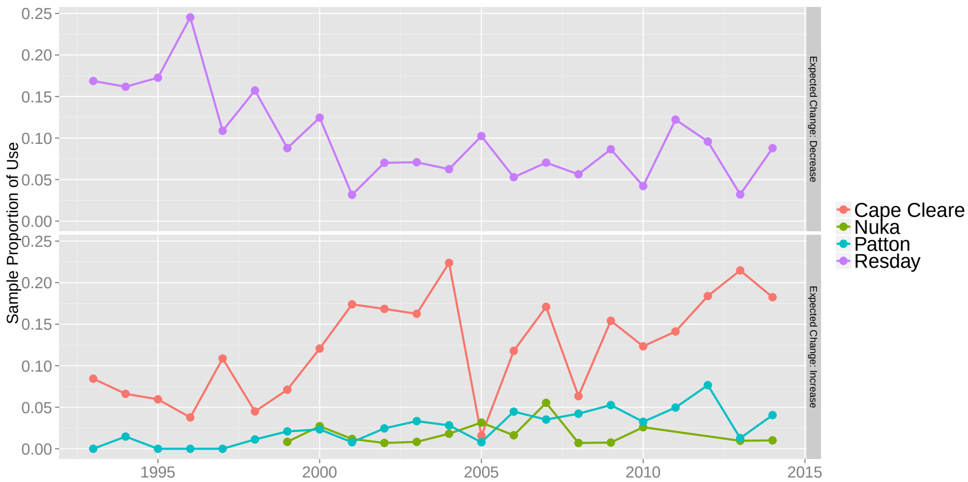

Figure 6: The proportion of use for each of the indicator statistical areas from the $1993 - 2014$ *interview data. The figure panels indicate the expected change in use if charter fisherman are truly traveling farther to find fish.*

2.3.3 Comparing Logbook and Interview Data

In this section, a graphical comparison of the interview and logbook data for the years in which logbook data are available, $2004 - 2013$, helps assess the proportion of the total variability in the interview data that can be attributed to true changes in use versus sampling error. This comparison can help the reader decide whether the trends seen in the interview data are real and improve trust in model results based on interview data.

I first used a locally weighted regression smoother built into the ggplot2 package to compare the general trend in the interview data to the logbook data (Wickham 2009). The graphical comparison is shown in Figure 7. For the most part, the interview data does a good job picking up the trend in the logbook data in all three *indicator areas*. The 95% pointwise confidence intervals for the census data capture the process variability, the "real" year-to-year changes in the proportion of use that aren't captured by the fitted model. The 95% confidence intervals for the interview data capture both the process variability and the sampling variability. In Patton and Resday, the sampling variability is approximately half of the total variability. In Cape Cleare, the sampling variability represents a larger proportion of the total variability.

Process variability depends on model choice, so it is important to assess the process and sampling variability in the model used for inference. A binomial logistic regression model is fit to the interview data in the next section and used to investigate trends in use over time (Section 2.3.4). I compare interview and logbook data again in Section 2.3.6, following an explanation of the binomial logistic regression model used for inference.

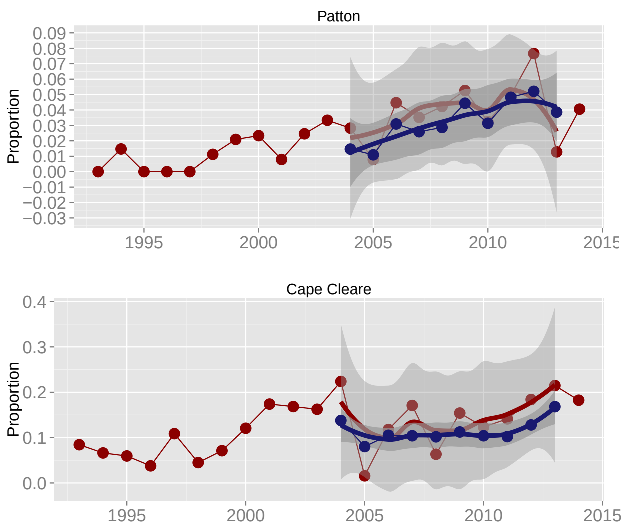

Figure 7: A locally weighted regression smoother was fit to both the interview and the logbook data in areas Patton, Resday, and Cape Cleare, and the 95% pointwise confidence intervals for the fitted proportions are shown. Note the scales vary across plots.

The multiplicative errors are shown over time in Figures 8. The errors were calculated by dividing the sample proportion of use in the interview data by the (presumed) true proportion of use in the logbook data. The average multiplicative errors in areas Cape Cleare and Patton are 1.19 and 1.20 respectively. That is, in Cape Cleare the sample proportions of use from the interview data are on average 19% higher than the true proportions of use in the logbook data. In Resday, the average multiplicative error is 0.70 meaning the sample proportions are on average 30% lower than the true proportions.

Patton and Cape Cleare are clearly more often biased high and Resday is more often biased low. There could be several reasons for this. Techicians conduct interviews between 2 and 9 p.m. each day, so they are missing the boats that arrive at the docks before 2 p.m. The $2-9$ p.m. shift may be causing the boats that fished far from Seward to be over-represented, and the boats that fished close to Seward to be under-represented. Additionally, those boats that fish in areas such as Cape Cleare and Patton Bay often make a big show out of the fish they caught that day. They bring their fish up to the hanging station for everyone to see, and maybe this is why they are more likely to be interviewed. Those who fish in Resurrection Bay generally get back to the docks earlier and make less of a show out of their catch. One method for accounting for known bias is to shift the regression line by a fixed amount. For this report, I make the assumption that the bias is constant over years 1993 to 2014 and does not affect results concerning the trend in use over time.

Figure 8: The differences shown are the multiplicative errors (interview proportion/logbook proportion) for years 2004 *to* 2013*.*

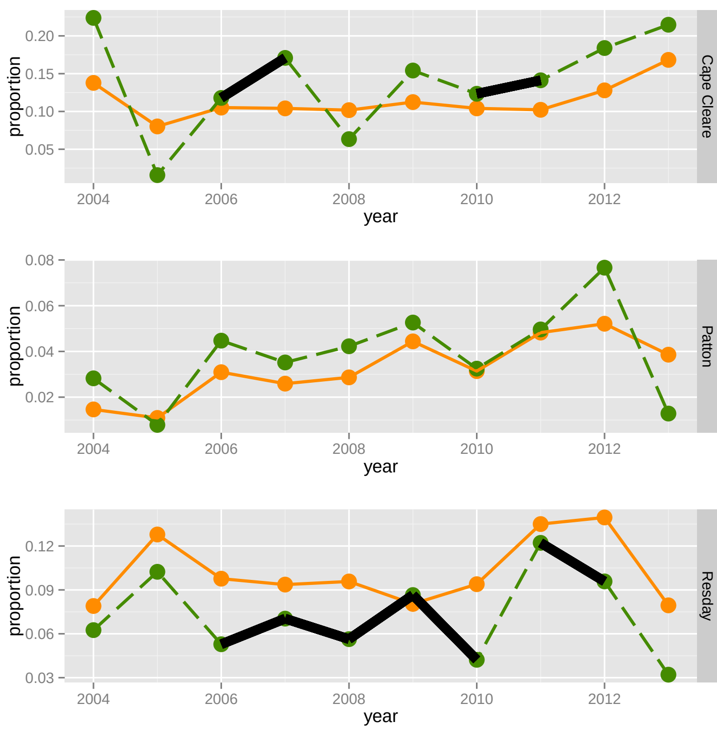

Figure 9: A plot showing the logbook proportions (solid orange line) and interview proportions (dashed green line) for areas Cape Cleare, Patton, and Resday for years 2004 *through* 2013*. Segments are colored black if the interview data do not capture the logbook trend (up or down) between years.*

The final graphical comparison highlights years when the change in the interview proportion from one year to the next does not reflect the change seen in the logbook data (Figure 9). The interview data mimics the logbook data extremely well in Patton Bay, and fairly well in Cape Cleare. Resday doesn't perform as well, with the sample data picking up the true between year change less than half the time.

Overall, this section gives the reader a general sense of how well the interview data capture the truth, under the assumption that the logbook data are very close to census data.

2.3.4 Analysis

In this section, I explain the reasoning and logic behind the final model used to investigate whether the proportion of charter boats traveling to fish for bottomfish in the *indicator areas* has changed over the years 1993 through 2014. I use a binomial logistic regression approach because the data provided are a count of trips out of a total number of trips per year, for each *indicator area*. The following rich binomial logistic regression model was considered.

$$\begin{aligned} logit(p_{ij}) &= \beta_{0j} + \beta_{1j} year_i + \beta_{2j} year_i^2 \\ y_{ij} &\sim bin(n_{ij}, p_{ij}) \\ i &\in (1993, 1994, ..., 2013) \\ j &\in (CapeCleare, Resday, Patton, Nuka) \end{aligned}$$

There was very strong evidence of extra-binomial variation (p-value$<$ 0.0001 from GOF-stat=221.85 on 76 df). I expected to see overdispersion because of several outliers (Figure 11) and a lack of independence among binary responses going into each count. In any given day, a charter boat captain's decision to fish in one of these indicator areas is not independent from another captain's decision. There are certain cliques among charter boat captains, and often captains talk with each other in the morning and decide to fish in the same area. This violation of the independence assumption could be contributing to the extra binomial variation. Additionally, there are some outlying observations identified in Figure 11 that could be driving overdispersion. The two observations that stand out are Cape Cleare in 2005 and Resday in 2001. I think these points are real, however, and there is no reason to consider them separately or exclude them. The 2005 observation in Cape Cleare was discussed in Section 2.3.2 and is a valid observation. It arises as a result of a combination of negative process error and negative sampling error. With a relatively small sample size, these points may appear to be outliers, but they provide useful and valid information when estimating overdispersion.

Next, I fit separate quasibinomial models for each statistical area. I chose to use separate models rather than the single interaction model above because I wanted to estimate the overdispersion parameter for each area separately. In the end, this decision did not did not affect inference in Resday, Patton, or Nuka, but it made the results more conservative in Cape Cleare.

I then checked for temporal autocorrelation in the residuals of the quadratic models for each area. There is no evidence of correlation across time in any of the areas.

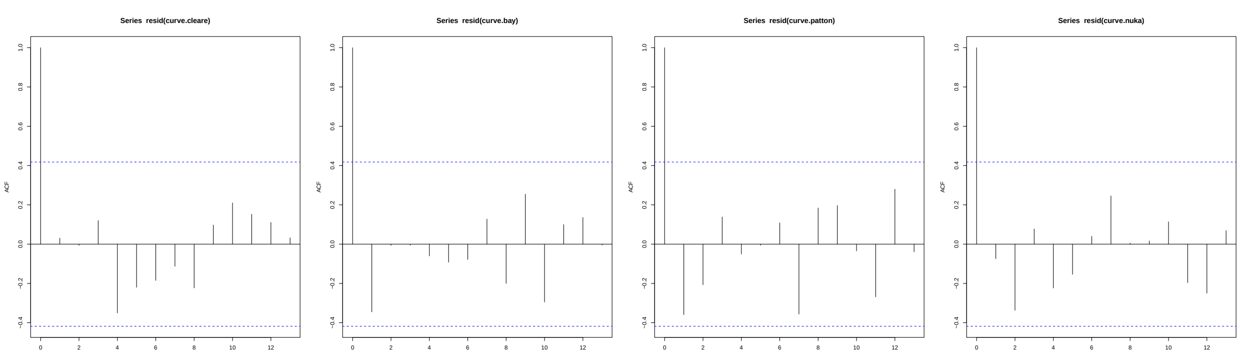

Figure 10: Autocorrelation function plots of the residuals of the quadratic model for each area.

A plot of empirical logits across year (Figure 11) showed that it could be reasonable to use a linear trend to model the relationship between year and the log odds of fishing in each of the four areas. I conducted a drop in deviance F-test as an informal lack of fit test to assess evidence of curvature in the relationship. In Cape

Cleare, there is no evidence of curvature (p-value= 0.2075 from drop-in-deviance F-stat=1.2880 on 1 and 19 df). In Resday, there is moderate to strong evidence of curvature (p-value= 0.0175 from drop-in-deviance F-stat=6.774 on 1 and 19 df). In Patton, there is also moderate evidence of curvature (p-value= 0.0460 from drop-in-deviance F-stat= 4.558 on 1 and 19 df). In Nuka, there is strong evidence of curvature (p-value= 0.00677 from drop-in-deviance F-stat= 9.229 on 1 and 19 df).

Despite the evidence for curvature in all areas except Cape Cleare, I chose to use a linear trend to model the relationship between year and the log odds of fishing in each of the four areas. I chose to ignore the curvature because the linear model is simpler than the quadratic model and adequate for my intended use. My ultimate goal is not to describe in detail the trend in use over time, instead I use the estimated model to compare the use in recent years to use in the 1990s. Ignoring the curvature actually makes the results more conservative because the extra variability arising from lack of fit increases the standard errors and inflates the estimates of the overdispersion parameters. As an informal check for the accuracy of the linear model, I compare results to the raw data in Section 2.3.5.

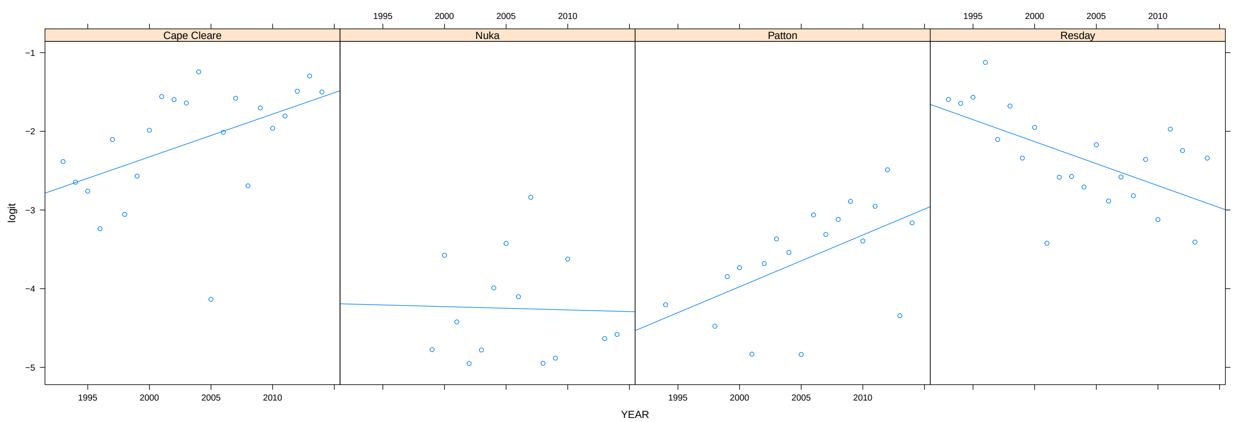

Figure 11: Empirical logits plotted over year for each area, with fitted linear regression lines.

The final model used for inference is as follows, with standard errors adjusted by the overdispersion parameter and a separate model fit for each statistical area.

$$logit(p_i) = \beta_0 + \beta_1 year_i$$
$$y_i \sim bin(n_i, p_i)$$
$$i \in (1993, 1994, ..., 2013)$$

2.3.5 Results

There is moderate to strong evidence that the odds of fishing in areas Cape Cleare, Patton, and Resday changes over time, assuming a linear trend over years 1993 to 2014 (p-values= 0.0248, 0.0021 and 0.0134 from drop in deviance F-stats=4.89, 12.53, and 7.35 respectively). There is no evidence that the odds of fishing in Nuka changed over time (p-value= 0.6309 from drop in deviance F-stat= 0.24). The fitted probabilities, with 95% pointwise confidence intervals are shown in Figure 12.

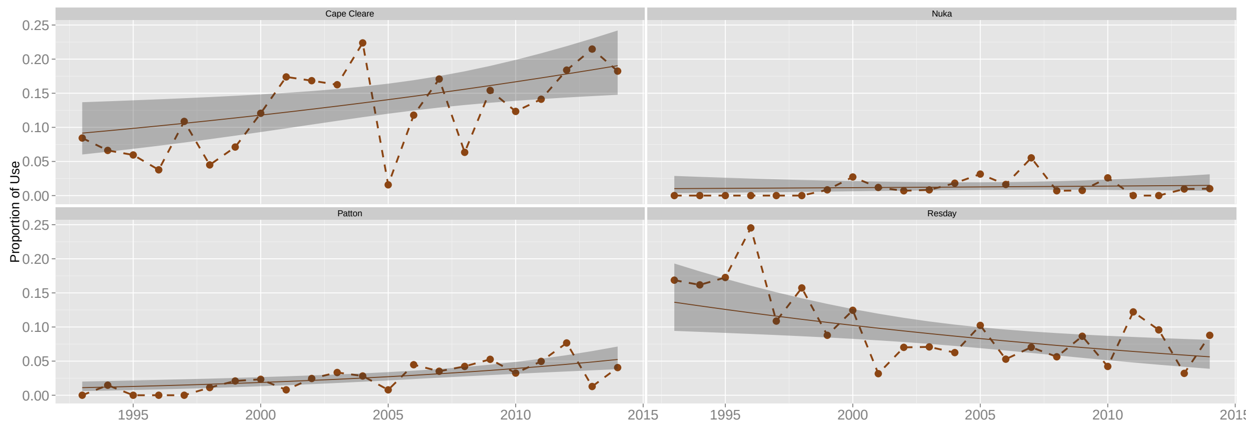

Figure 12: Fitted probabilities with 95% pointwise Wald confidence intervals.

Based on the linear trend, the odds of fishing in Cape Cleare in 2014 are estimated to be 2.43 times the odds of fishing in Cape Cleare in 1993, with a 95% likelihood based confidence interval from 1.22 to 4.92 times. The odds of fishing in Patton in 2014 are estimated to be 5.32 times the odds of fishing in Patton 1993, with a 95% likelihood based confidence interval from 2.29 to 12.84. The odds of *not* fishing in Resday in 2014 are estimated to be 2.78 times the odds of *not* fishing in Resday in 1993, with a 95% likelihood based confidence interval from 1.32 to 5.82 times. The odds of fishing in Nuka in 2014 are estimated to be 1.5 times the odds of fishing in Nuka in 1993, with a 95% confidence interval from 0.29 to 8.30 times (Figure 13).

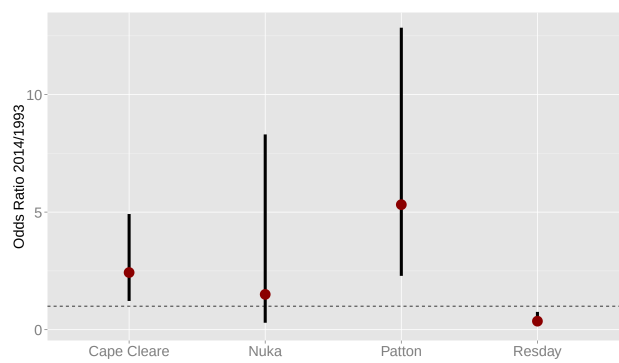

Figure 13: The estimated 2014/1993 odds ratio in each area, with likelihood based 95% confidence intervals.

Lastly, I compare the estimated odds ratios to an empirical odds ratio calculated by dividing the average sample proportion of use in $2013-2014$ by the average sample proportion of use in $1993-1994$ (Table 5). In all areas, the odds ratio estimated from the linear model was similar to the empirical odds ratio calculated from the raw data. This indicates that the linear model used for inference is capturing the overall trend seen in the data, thus validating my decision to use the simpler model for inference.

Table 5: The estimated odds ratios and empirical odds ratios for each area.

Area	Estimated 2014/1993 Odds Ratio	Empirical 2013-14/1993-94 Odds Ratio
Cape Cleare	2.43	2.64
Patton	5.32	3.63
Nuka	1.5	NA
Resday	0.36	0.36

Overall, there is evidence that use has increased in Cape Cleare and Patton, two areas that I expected to increase in use if Seward charter boats are truly traveling farther for bottomfish. There is evidence that use has decreased in Resday, the area I expected to decrease in use if Seward charter boats are traveling farther for bottomfish.

2.3.6 Comparing Logbook and Interview Data

A binomial logistic regression model was fit to the logbook data as well as the interview data for years 2004 to 2013, and Figure 14 shows 95% pointwise confidence intervals for the fitted probabilities for each area.

These plots again allow comparison of the variability quantified in the fitted model that can be attributed to sampling variability and process variability. A similar comparison was made with a non-parametric model fit in Section 2.3.3, and the results are similiar. These plots, however, show a higher proportion of process variability because the binomial logistic regression model does not fit as well as the locally weighted regression smoother. In this comparison, the process variability appears to make up more than half of the total variability for any given year.

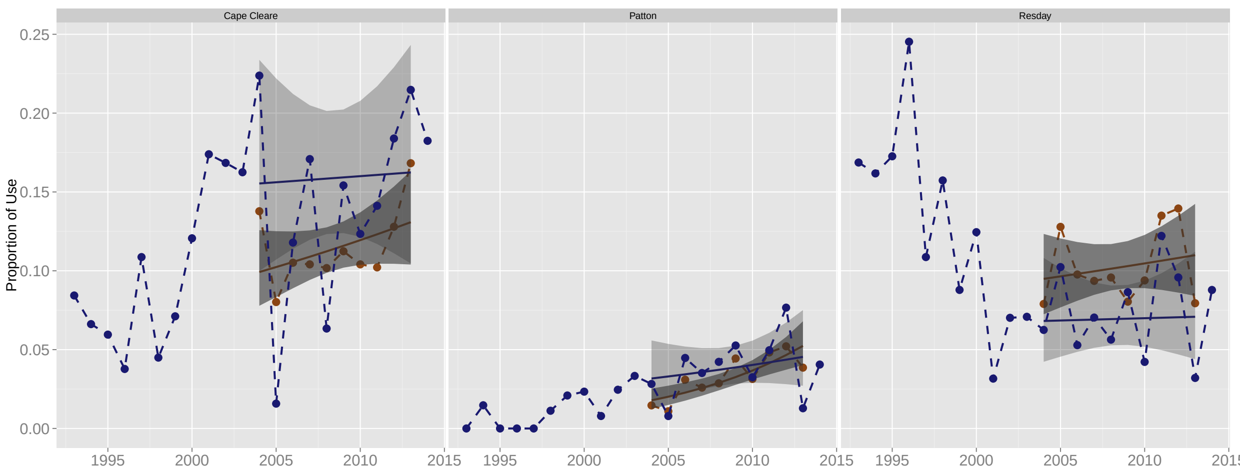

Figure 14: Binomial logistic regression models were fit to the interview and logbook data separately for years 2004 *to* 2013*, and the* 95% *pointwise confidence intervals for the fitted probabilities are shown for areas Cape Cleare, Patton, and Resday.*

2.3.7 Scope of Inference

The fishermen interviewed were not chosen at random and the design does not buy inference to all charter boats that offload their catch in the Seward harbor. For the most part, however, the interview data does a good job at capturing the overall trend seen in the logbook data for years 2004 to 2013 (Figures 7 and 9). The logbook data are presumed to be very close to the truth, and the trends discussed in Section 2.3.1 for years 2004 to 2013 are believed to be real. Under the strong assumption that the sampling design performed as well in the years prior to 2004, it is reasonable to conclude that the trends seen in the interview data do reflect the true trend in use among all charter boats offloading in Seward. The sample sizes as well as the technicians conducting the interviews vary across years, however, so it may be far-fetched to assume that the sampling design performed as well in years prior to 2004 (Table 4).

The results do suggest that the charter boats sampled are traveling farther for bottomfish than they did in the 1990s, but the reasons for the change are purely speculations. I personally think the shift is a result of a changing fishery combined with an increased level of competition among charter boats. These potential explanations could be topics of further study.

3 Interviews

3.1 Captain DeeJay, *Visitation*

Captain DeeJay started fishing on the ocean out of Seward in 1987. In 2006 he bought *Visitation* and started his own charter fishing business. Deejay recently took the time to talk with me and explain his views on how the halibut fishing out of Seward has changed over time.

It used to be that you could fish inside the bay and limit out, Deejay says, but now it's hard to limit out on halibut inside the bay in one day. The charter fleet today often travels 60 to 80 miles to fish for halibut at "Montague." "Montague" describes the fishing areas around Montague Island, including Cape Cleare and Patton Bay. He recalls that he did fish at Montague occasionally back in the 1990s, but the fishing at Montague has also gotten harder.

It was common to catch "45, 50, and 100" pounders in the well known, closer areas such as Cape Puget and Cape Junken, but today this is unusual. DeeJay estimates the average size halibut in the 1990s was 40 to 50 pounds and now, he says, the average size halibut is 20 pounds. Not only has DeeJay noticed a change in fish size; he has also noticed a change in the quality of halibut caught. Recently, he has been catching a 'thinnier' halibut with mushier flesh. He does not remember anything like this in the 90s.

DeeJay offers several explanations for why the halibut fishing has changed. He thinks it is due to overharvesting by commercial fishermen, environmental changes, and the impact of charter fishermen. He believes charter fishermen are the smallest contributing factor (Harvey).

3.2 Captain Suzie, *Gusto*

Captain Suzie, a retired PE, health and science schoolteacher, started fishing recreationally in the saltwater out of Seward in the early 1990s. In 1995, she started deckhanding on Seward charter boats and received her Merchant Mariner Credential in 1998. She bought *Gusto* in the winter of 1998 and has been running her own charter fishing business since then.

With the exception of the military boats (that were constrained by size and time), Suzie doesn't remember many charter boats fishing inside Resurrection Bay for halibut unless the weather was bad. But, she says, there were "lots and lots" of halibut all along the coastline from the east side of Day Harbor to Cape Puget (about 28 to 45 miles travel distance from Seward). She says that they would catch good fish there, and often big fish.

"We started going out to Montague," Suzie recalls, "because people were bringing back such big fish [from Montague]." She remembers they would often catch $4 - 5$ fish over 100 pounds on a typical day out at Montague. At that time, she felt the 60-plus-mile drive was worth it because of the amount of fish they would catch.

Overall, Suzie says, "you can't go East to the places you used to go, unless you go way far." But as fuel prices started increasing steadily in 2005, Suzie had to find closer fishing spots to maintain a sustainable business. In these areas, she says, the fishing has gotten more tactical. She says you have to hit the tide right and keep the fish you catch. There are still close range "chicken holes" where very small fish are plentiful, but bigger fish are harder to find and require patience. Often, she has to make the decision to move to a "chicken hole" in order to ensure that all of her clients catch their limit of two halibut.

Suzie talks specifically about Harris Bay, a spot about 40 miles southwest of Seward. "It used to be that you could always count on limiting out [in this area]." She says that a commercial fleet came in and hit this area really hard, and now it is very hard to catch halibut there.

With regard to halibut size, Suzie says, “You don’t get the big fish as often.” She recalls that they used to catch 200-pound halibut regularly, but in recent years the largest she has seen is 170 pounds. People used to bring in 70- to 80-pound fish all the time, she says, but now these fish are the “big fish” and 25- to 30-pound fish are more common (Neuman).

4 Biological Data

The following section explores the second part of the statement, “We travel farther for smaller fish.” I explore ADF&G biological data for trends in fish size over time (ADF&G non-confidential data 1994-2013) in the five most commonly used statistical areas (Cape Aialik, Cape Cleare, Cape Junken, Elrington, and Resurrection Bay). In these areas, is there evidence of a change in the mean length of halibut caught by Seward boats (private, charter, and military) over the years $1994 - 2013$?

4.1 Data Collection

ADF&G has conducted biological sampling of halibut offloaded in Seward since 1994. Sampling generally begins in late May or early June and ends in late August or early September. The sampling start and end dates for each year are shown in Table 6. 2005 was an unusual year in that sampling did not begin until June 30. Once sampling begins, three days a week are randomly selected for biological sampling. Recall that two days a week are randomly selected for dockside interviews, and overall there must be two consecutive days off per week. The second stage of the sampling design is vessel selection. The sampling is conducted during “major periods of landing” each day in which the technician collects samples from fishermen fileting their catch at the harbor cleaning stations. Vessels that clean some or all of their halibut at sea are not included in the sampling pool. Only those vessels with their entire catch available for study are sampled. If a vessel’s catch is selected, the fish cutters are instructed to place the halibut carcasses in a green ADF&G bin to await measurement and otolith removal (for determining the age of the fish). If a fish cutter accidentally discards a carcass, the technician abandons the entire catch and moves on to another vessel. Vessel selection is not random, although technicians “are instructed to spread sampling effort throughout the harbor cleaning stations as well as the military recreation camp cleaning facilities, with the goal of sampling all vessels in proportion to their annual harvest (Meyer).”

Three sectors are included in the dataset - private, charter, and Seward military. Prior to 2001, the military owned a few charter boats and about a dozen smaller boats that took active military, veterans, and families fishing for free on a lottery system. In 2001, they downsized and eliminated the free lottery boats. Today there are still a few military charter boats, but starting in 2001 the military boats are lumped into the charter sector (Meyer).

The lengths recorded are standard fork lengths. Fork length is a measurement from the tip of the snout to the middle of the tail fin (Fish Measurement). Measurements were recorded to the nearest mm through 1999, and the nearest cm since then (Meyer). In the following analysis, measurements are converted to inches because inches are more commonly referred to among Seward fishermen when comparing and discussing halibut lengths. Weight is also a common unit for comparing halibut sizes. A standard weight length table converts halibut fork lengths to pounds (Table 7).

Table 6: Biological sampling start and end dates for each year, 1994 *through* 2013.

Year	Start Date	End Date
1994	May 26	Sep 10
1995	May 27	Sep 4
1996	June 13	Sep 8
1997	May 24	Sep 1
1998	June 4	Sep 7
1999	May 28	Sep 6
2000	May 25	Sep 4
2001	May 27	Sep 1
2002	June 6	Sep 1
2003	May 31	Sep 2
2004	May 29	Sep 6
2005	June 30	Sep 4
2006	June 5	Sep 5
2007	June 9	Sep 1
2008	June 3	Aug 30
2009	May 25	Sep 6
2010	May 25	Aug 30
2011	May 25	Aug 29
2012	May 18	Sep 2
2013	May 18	Aug 31

Table 7: The standard halibut length weight table provided by the IPHC.

Halibut Length/Weight Chart (Imperial)

Length (inches), Net Weight (lbs, dressed, head-off, slime and ice deducted), Round Weight (lbs)

Length (inches)	Net wt (lbs)	Round Wt (lbs)	Length (inches)	Net wt (lbs)	Round Wt (lbs)
20	2.3	3.1	59	77.5	103.1
21	2.7	3.6	60	81.8	108.9
22	3.2	4.2	61	86.3	114.8
23	3.7	4.9	62	91	121.1
24	4.2	5.6	63	95.9	127.5
25	4.8	6.4	64	100.9	134.2
26	5.4	7.2	65	106.1	141.1
27	6.2	8.2	66	111.5	148.2
28	6.9	9.2	67	117	155.6
29	7.8	10.3	68	122.8	163.3
30	8.7	11.5	69	128.7	171.2
31	9.6	12.8	70	134.9	179.4
32	10.7	14.2	71	141.2	187.8
33	11.8	15.7	72	147.7	196.5
34	13	17.3	73	154.5	205.5
35	14.3	19	74	161.5	214.7
36	15.6	20.8	75	168.6	224.3
37	17.1	22.7	76	176	234.1
38	18.6	24.8	77	183.7	244.3
39	20.3	27	78	191.5	254.7
40	22	29.3	79	199.6	265.4
41	23.8	31.7	80	207.9	276.5
42	25.8	34.3	81	216.4	287.8
43	27.8	37	82	225.2	299.5
44	30	39.8	83	234.2	311.5
45	32.2	42.9	84	243.5	323.8
46	34.6	46	85	253	336.5
47	37.1	49.3	86	262.7	349.5
48	39.7	52.8	87	272.8	362.8
49	42.5	56.5	88	283.1	376.5
50	45.3	60.3	89	293.6	390.5
51	48.3	64.3	90	304.4	404.9
52	51.5	68.5	91	315.5	419.7
53	54.8	72.8	92	326.9	434.8
54	58.2	77.4	93	338.6	450.3
55	61.7	82.1	94	350.5	466.2
56	65.4	87	95	362.7	482.4
57	69.3	92.2	96	375.3	499.1
58	73.3	97.5			

There is a potential for sampling bias because vessels that clean fish at sea are not included in the sampling frame. The larger "party boats" fish eight to twenty people and often clean fish at sea. These boats will occasionally clean fish at the harbor on days when they caught large fish or days when the weather was bad. It is much harder to filet large halibut at sea because large fish do not fit on filet tables, and clients often want to take pictures with large halibut at the docks. Small boat fishermen, such as myself, often clean fish at sea when we catch small fish to save ourselves the embarrassment of bringing in a small catch. Overall, I expect the fish length data to be biased high across all years because boats generally clean more small fish at sea and more large fish at the docks. However, I evaluate the trend in fish lengths over time in this report, so the results will not be affected if the bias has not changed over time. While this is hard to evaluate, it is possible the bias *has* changed over time. Captain DeeJay mentioned that there seems to be a higher proportion of large "party boats" than there used to be, and fewer small "6-pack" boats (Harvey). If the proportion of party boats has increased, then I expect a higher proportion of small fish are being cleaned at sea. Following this logic, the observed results would be conservative in the sense that a bias corrected trend would be more extreme than what is observed. I suspect the true trend in fish size over time is in fact more extreme than the results suggest.

4.2 Exploratory Plots

The lengths of each fish sampled are plotted across years in each statistical area (Figure 15). Across all areas, the number of fish studied within each year was smaller in the 1990s and early 2000s. In particular, only 2 fish were studied from Elrington in 1997. In 2002, only 10 fish were studied from Resday. In 1994, 1995, and 2005, only 13, 13, and 15 fish were studied, respectively, from Cape Cleare. Nearly all other sample sizes were larger than 30.

The scale of Figure 15 is too large to detect changes in the average fish lengths over time, so the averages are plotted on a smaller scale (Figure 16). There appears to be evidence of a decreasing trend in the mean lengths over time in areas Aialik, Elrington, Junken, and Resday. There could be a trend in Cape Cleare, but I suspect it would be difficult to detect due to a large amount of unexplained variation in the average lengths.

I also examine the lower quartile, median, upper quartile, and 90th percentile of fish lengths plotted over time in Figure 16. It looks like the lower quartiles, medians, upper quartiles, and 90th percentiles capture the same general trend over time as the averages.

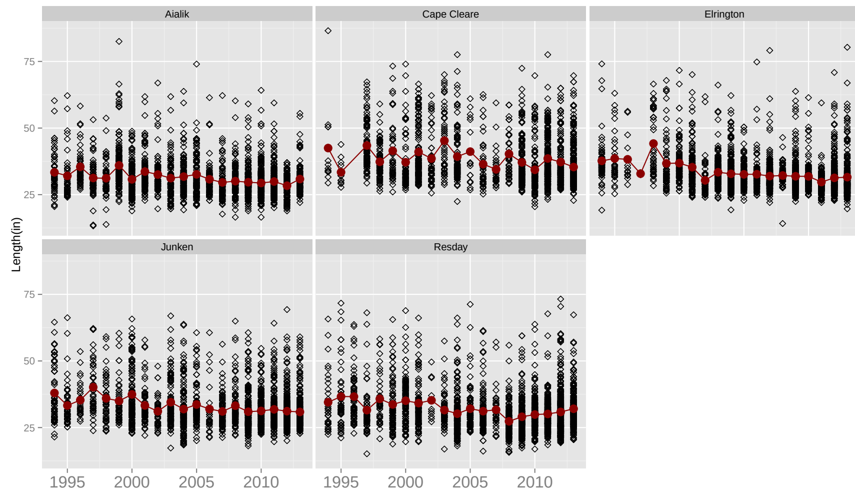

Figure 15: Individual fish lengths shown for years 1994 through 2013 with lines connecting the mean lengths.

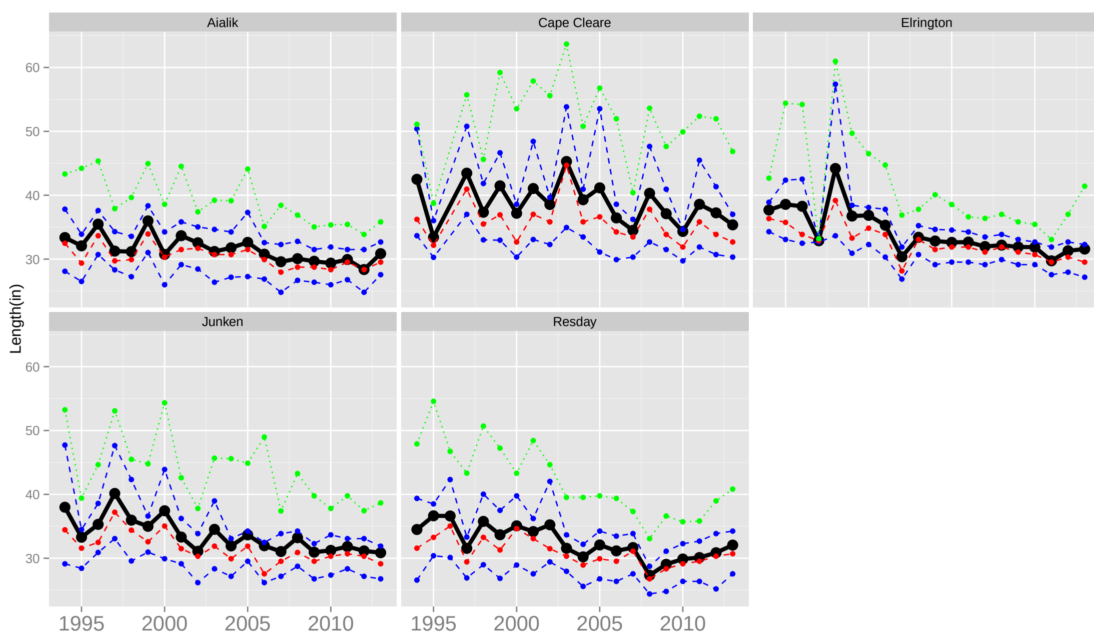

Figure 16: Average fish lengths of sport-caught fish offloaded in Seward plotted over years 1994 through 2013. The dashed lines indicate the lower quartile, median, upper quartile, and 90th percentile of fish lengths plotted over time.

4.3 Methods

4.3.1 Linear Model with Weighted Least Squares

I fit a linear model with average fish lengths per year as the response variable. The number of fish studied in each area varies across year, so weighted least squares is used to estimate the regression line where the weights are proportional to the sample sizes, giving more weight to years with more measured fish.

Each statistical area of interest was analyzed separately because both the sampling variability and the process variability are expected to depend on statistical area. I would expect both sources of variability to be larger in areas where the fish are larger. The data support this hypothesis, showing more variability in average fish lengths over time in areas Cape Cleare and Elrington where the fish are larger on average. The following simple linear regression model was fit separately in each statistical area.

$$log(\overline{length}_i) = \beta_0 + \beta_1 year_i + \epsilon_i$$
$$\epsilon_i \stackrel{iid}{\sim} N(0, \sigma^2)$$

The results from the weighted least squares approach are not used to make conclusions. I think a mixed model approach is more appropriate for inference because it uses a different method than weighted least squares for taking sample size size into account when estimating the regression line. The advantages of the mixed effects model are discussed in detail in Section 4.3.2. Model choice does not affect conclusions in areas Aialik, Elrington, Junken and Resday. In Cape Cleare, however, conclusions could change with model choice and this is discussed further in Section 4.5.1.

A log transformation was applied to the average fish lengths for consistency with the mixed effects analysis in Section 4.3.2. The transformation is used because the normality of residuals assumption in the mixed effects model is severely violated (Section 4.3.2). I ran the models with and without the log transformation and the results do not change, but the log transformation is preferred because it allows results to be interpreted in terms of multiplicative changes in the median halibut length over time rather than additive changes in the mean. The estimated multiplicative changes in median fish lengths over years 1994 through 2013 are shown for each area, with 95% confidence intervals (Figure 18), for later comparison with the mixed effects approach (Section 4.5.1).

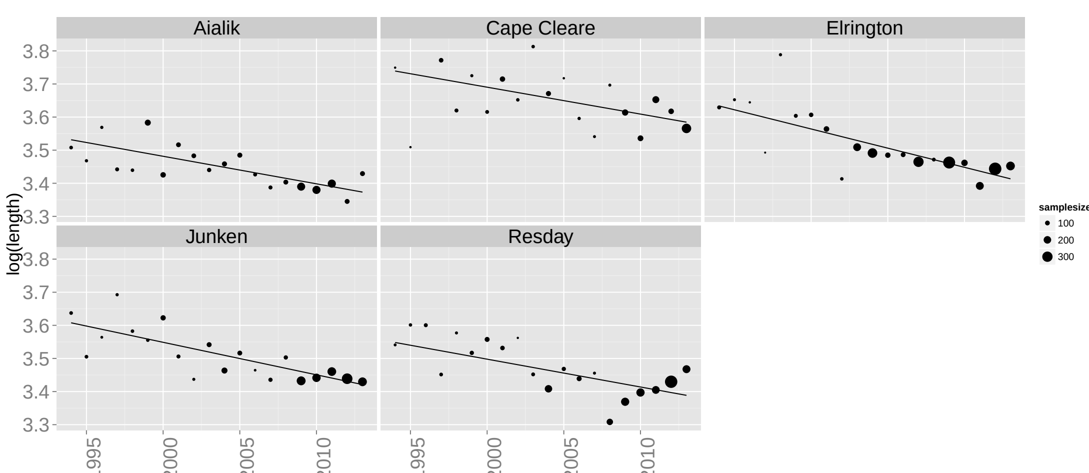

Figure 17: Average fish lengths for each year on the log scale in each area with the fitted regression line from the weighted least squares linear model. The size of the point indicates the relative sample size.

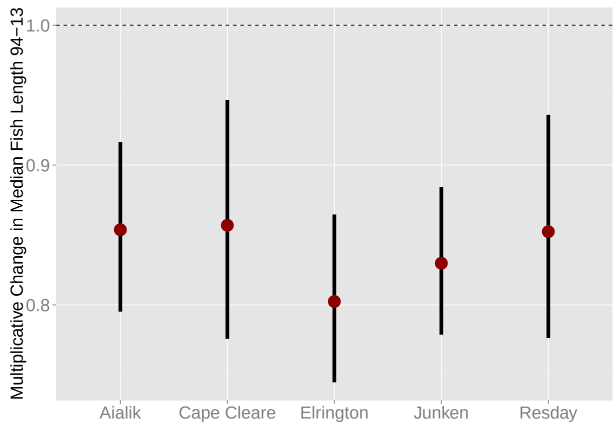

Figure 18: The estimated multiplicative change in median fish lengths between 1994 *and* 2013 *in each area with* 95% *confidence intervals. Estimates and confidence intervals are from the weighted least squares approach.*

4.3.2 Mixed Effects Model

I now approach the same analysis using a mixed model with a random effect for year. That is, I now assume the yearly deviations from a linear trend over time come from a common normal distribution with a mean of 0 and an unknown variance, σ^2_α. The following mixed effects model was fit to each area. Year is treated as a continuous fixed effect to capture a linear trend over time, and a random effect, α_i, is included for each year to avoid pseudoreplication and account for the fact that fish were sampled within years.

$$log(length_{ij}) = \beta_0 + \beta_1 year_i + \alpha_i + \epsilon_{ij} \tag{1}$$

$$\begin{aligned} \epsilon_{ij} &\sim N(0, \sigma^2) \\ \alpha_i &\overset{iid}{\sim} N(0, \sigma^2_\alpha) \\ i &\in (1994, 1995, ..., 2013) \\ \alpha_i &\text{ and } \epsilon_{ij} \text{ are independent} \end{aligned}$$

I checked the assumptions of constant variance, normality, and independence among years. Before the transformation, the normal QQ plots suggested that the assumption of normality was severely violated because the distribution of residuals is clearly right skewed (Figure 19). A log transformation was applied to fish lengths and the assumption of normality looks better in the residuals of the mixed effects model after the log transformation (Figure 20), but the distribution of residuals is still clearly right skewed in all areas except Cape Cleare. The violation of the normality assumption could artificially inflate the estimate of σ^2, which would cause the weights on the yearly averages going into the "partially pooled" estimated fish lengths to be slightly smaller than they "should" be (Section 4.3.3). I am not worried about the potential effects, however, because the results are very conclusive in the areas that show the most severe violations of normality.

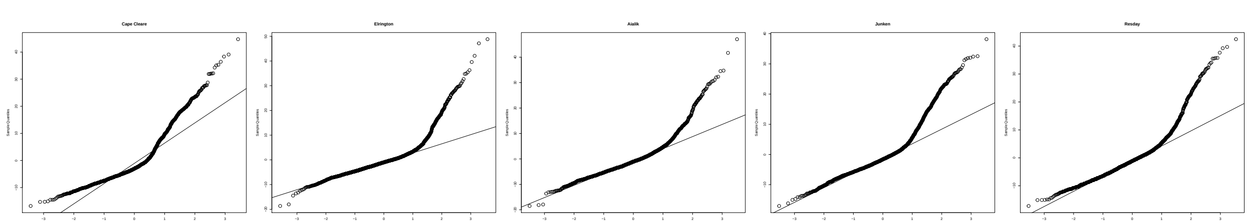

Figure 19: Normal QQ plots of the residuals of the mixed effects models for each area before log transformation.

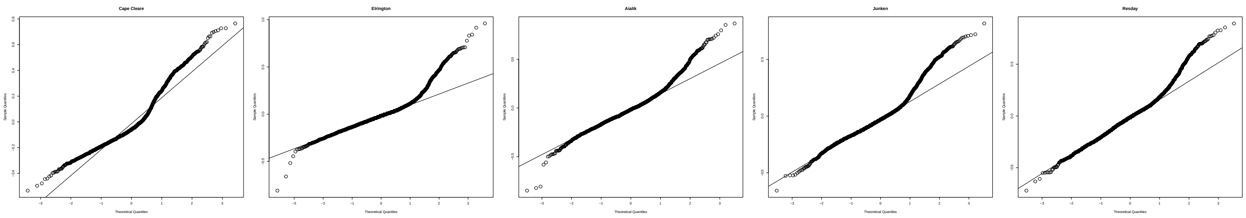

Figure 20: Normal QQ plots of the residuals of the mixed effects models for each area after a log transformation on fish lengths.

A plot of the Pearson residuals shows that the assumption of constant variance in fish lengths across years does not appear to be violated (Figure 21). Additionally, there is no evidence of quadratic curvature in any of the five areas (p-values= 0.7389, 0.3291, 0.5497, 0.2072, and 0.3018 for Aialik, Cape Cleare, Junken, Resday, and Elrington respectively). Lastly, I checked the assumption of independence among years. The autocorrelation function plot of the year level residuals from the mixed effects model showed no evidence of correlation across time for any of the areas (Figure 22). Therefore, there is no need to adjust the covariance structure of the models to account for temporal autocorrelation.

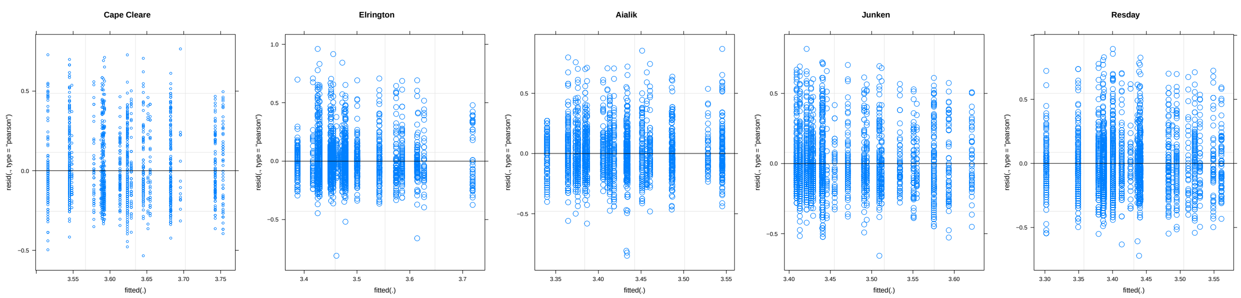

Figure 21: Pearson residuals of the mixed effects model for each area, after the log transformation.

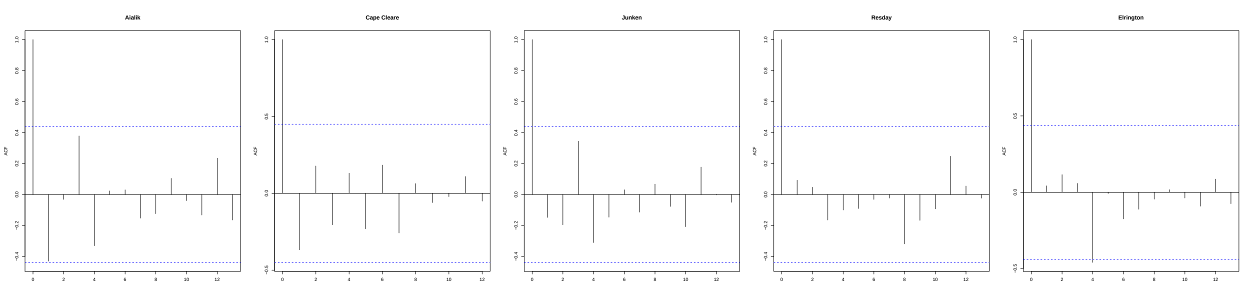

Figure 22: Auto correlation function plots of the year level residuals from the mixed effects models for each area.

4.3.3 Advantages of the Mixed Effects Model

There are two main advantages of treating the yearly deviations as random effects. First, the variability of fish lengths within years (assumed constant over all years) as well as the year to year variability in mean fish lengths, on the log scale, will be estimated simultaneously and automatically in the model output.

The second advantage of treating the yearly deviations as random effects is the "partial pooling" method of estimation. In the "no pooling" analysis, the estimated mean fish lengths for each year are simply the yearly empirical averages. In the "complete pooling" analysis, the estimated mean fish lengths for each year are the predicted values from a simple linear regression of the average fish lengths on year. "Partial pooling" uses a weighted average of the "no pooling" and "complete pooling" estimates, and the weights depend on sample size and the variability of fish lengths within a year (assumed constant over all years). Years with smaller sample sizes are weighted more towards the "complete pooling" estimate. The estimated mean fish lengths for each year are calculated as follows (Gelman and Hill 2007),

$$\widehat{length}_i \approx \frac{\frac{n_i}{\sigma^2}\overline{length}_i + \frac{1}{\sigma_\alpha^2}\widehat{length}_{SLR}}{\frac{n_i}{\sigma^2} + \frac{1}{\sigma_\alpha^2}} \tag{2}$$

where $\widehat{length}_i$ is the estimated mean fish length for year i from the mixed effects model, $i \in (1994, 1995, ..., 2013)$, n_i is the number of fish sampled in year i, $\overline{length}_i$ is the average fish length for year i, $\widehat{length}_{SLR}$ is the estimated mean fish length for year i from a simple linear regression model of the average fish lengths on time, and σ^2 and σ_α^2 are as given in Equation 1.

The estimated mean fish length for a year with a large sample size is very similar to the empirical average for that year. The estimated mean fish length for a year with a small sample size is closer to the predicted value from the simple linear regression of the average fish lengths on time (Figure 23). Note that I ignored the log transformation here, and in the previous paragraph, for the purpose of explaining partial pooling. Keep in mind this estimation procedure happens on the log scale.

The estimated trend line used for inference is then the simple linear regression line of the "partially pooled" estimated mean fish lengths, on the log scale, on year. In contrast, the weighted least squares linear model fits a simple linear regression of the yearly average fish lengths, on the log scale, on year and then de-emphasizes years with smaller sample sizes so they have less influence on the estimated regression equation. Results from the weighted least squares and mixed effects models are compared in Section 4.5.1.

4.4 Results

The estimated yearly means on the log scale from the random effects model as well as the estimated regression line for each area are shown in Figure 23. Only 13 fish were studied from Cape Cleare in years 1994 and 1995, and the fitted values for these years are clearly pulled away from the empirical log averages and toward the regression line. The effect of partial pooling appears more dramatic in Cape Cleare in 1995 because the empirical average deviates farther from the regression line for this year. The partial pooling effect is also observed in Resday in 2002 ($n = 10$), Elrington in 1997 ($n = 2$), and Cape Cleare in 2005 ($n = 15$). Nearly all other years had sample sizes larger than 30.

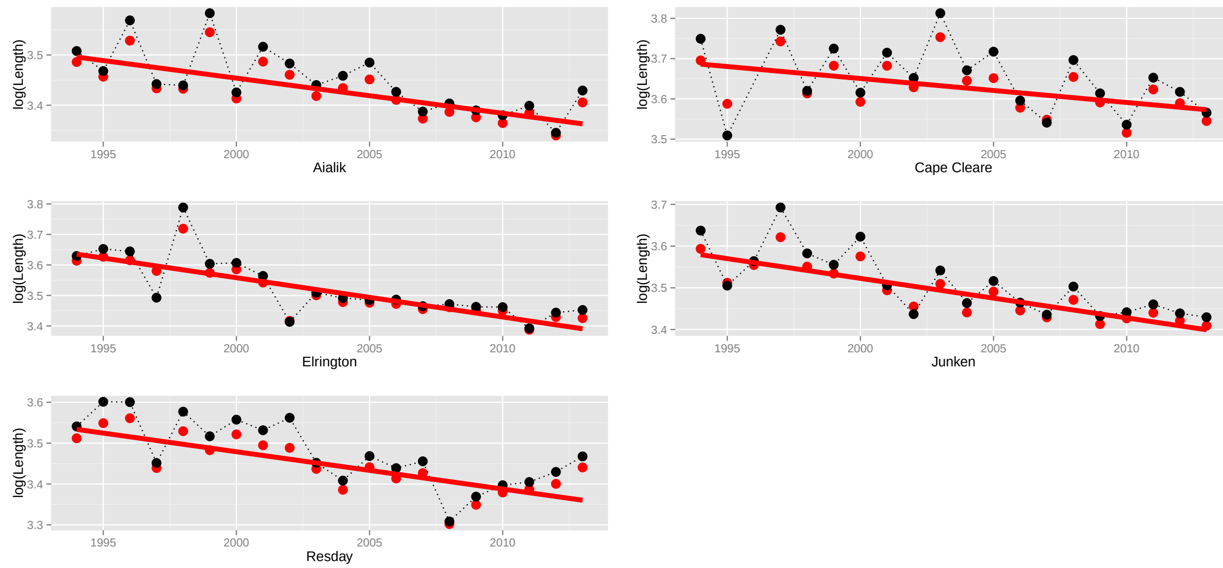

Figure 23: The red points are estimates for the mean fish lengths per year, on the log scale, in each statistical area from the mixed effects model. The black points are the empirical log average fish lengths per year. The fitted trend lines are shown for each statistical area.

The estimated year coefficient, backtransformed to the original scale, and variance parameter estimates are given in Tables 8 and 9. Estimates and 95% likelihood based confidence intervals for the multiplicative changes in median fish lengths between 2013 and 1994 are displayed in Figure 24.

Table 8: The estimated coefficient on year, backtransformed to the original scale, with p-values from the mixed effects model and 95% likelihood based confidence intervals.

Area	Estimate	95% CI	T-stat	DF	Two-sided p-value
Elrington	0.9872	$(0.9831, 0.9913)$	-5.983	18	< 0.0001
Cape Cleare	0.9941	$(0.9885, 0.9998)$	-2.059	17	0.0552
Aialik	0.9930	$(0.9896, 0.9965)$	-3.985	18	0.000868
Junken	0.9906	$(0.9872, 0.9939)$	-5.520	18	< 0.0001
Resday	0.9909	$(0.9867, 0.9951)$	-4.209	18	0.000528

Table 9: Variance parameter estimates on the log scale from the mixed effects model for the statistical areas of interest.

Area	Residual SD	95% CI	Year to Year SD	95% CI
Elrington	0.164	$(0.0160, 0.169)$	0.050	$(0.031, 0.070)$
Cape Cleare	0.219	$(0.211, 0.227)$	0.063	$(0.038, 0.090)$
Aialik	0.192	$(0.187, 0.198)$	0.040	$(0.025, 0.057)$
Junken	0.203	$(0.197, 0.209)$	0.038	$(0.021, 0.056)$
Resday	0.219	$(0.213, 0.225)$	0.048	$(0.033, 0.071)$

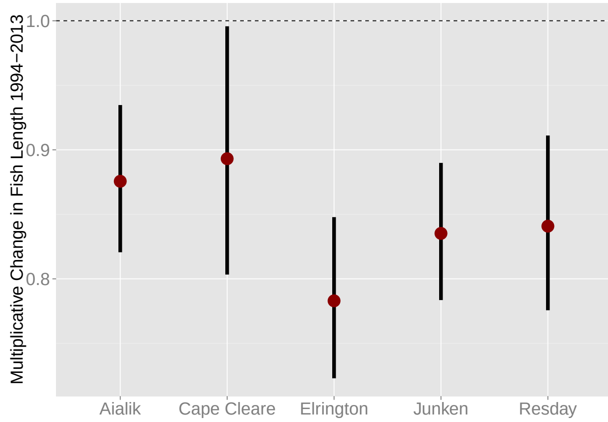

Figure 24: The estimated multiplicative change in median fish lengths between 2013 *and* 1994 *in each area with* 95% *likelihood based confidence intervals. Estimates are from the mixed effects model.*

4.5 Conclusions

There is strong evidence of a change in the mean length of halibut caught by Seward boats over the years 1994-2013, on the log scale, in areas Aialik, Elrington, Junken, and Resday (Table 8). In Cape Cleare, there is weak evidence of a change in the mean length of halibut caught by Seward boats over the years $1994 - 2013$ on the log scale (two-sided p-value= 0.055 from t-stat= -2.059 on 17 df). Cape Cleare also has the largest estimated variability of fish lengths within a year and across years (log scale estimates given in Table 9).

Overall, it is estimated that true median fish lengths decreased by about 0.5% to 1.2% every year, assuming a linear trend in log fish lengths over years 1994 to 2013. The estimated multiplicative changes in median fish lengths over years 1994 to 2013 are shown in Figure 24. The median fish length in Junken in 2013 is estimated to be 16.5% less than the median fish length in Junken in 1994, with a 95% confidence interval from 11.0% to 21.6% less. According to the IPHC length weight table (Table 7), a 36-inch halibut weighs 20.8 pounds and a 30-inch halibut (a 16.5% reduction in size) weighs 11.5 pounds. For smaller halibut, a 16.5% reduction in length translates to a 44.7% reduction in weight! The relationship is even more extreme for larger halibut. A 62-inch halibut weighs 121.1 pounds according to the length-weight table, and a 52-inch halibut (about a 16.5% reduction in size) weighs 64.3 pounds. For larger halibut, a 16.5% reduction in length translates to a 46.9% reduction in weight!

A 16.5% reduction in length over a 20-year span is meaningful, and I would expect sport fishermen to notice this change. The results are similar in the other areas except Cape Cleare. The median fish length in Cape Cleare in 2013 is estimated to be 10.7% less than the mean fish length in Cape Junken in 1994, with a 95% confidence interval from 0.43% to 19.7% less. The confidence interval for Cape Cleare is so wide that it contains values that are small enough to be not practically meaningful and large enough to be practically meaningful. A reduction in length of 0.7% for a 35-inch halibut translates to a reduction in weight of less than 1 pound. Therefore, the results are inconclusive in Cape Cleare. There is insufficient evidence to say that the median length of Cape Cleare halibut has decreased over years 1994 to 2013.

4.5.1 Comparing Results from Different Methods

The results are very conclusive in areas Resday, Aialik, Junken, and Elrington, and model choice does not affect inference in these four areas. As I discussed in the previous section, however, the results were inconclusive in Cape Cleare and results could depend on model choice in this area. The fitted lines from the ordinary least squares (OLS), weighted least squares (WLS), and mixed effects models are compared in Figure 25. The results are the most conclusive in the WLS model. The estimated reduction in median fish length over years 1994 to 2013 in Cape Cleare is estimated to be 14.3% in the WLS model, with a 95%

confidence interval from a 5.34% to a 22.4% reduction (Table 10). The upper end of this confidence interval is still a large enough reduction to be practically meaningful. A reduction in length of 5.34% translates to a reduction in weight of about 3 pounds. Biologists may consider this a meaningful change, and if I had used weighted least squares for inference, I could have concluded a meaningful change took place in Cape Cleare. The results are most conservative in the ordinary least squares approach in that the decrease in fish size over the 20 year time span is estimated to be only 9.1%, with a 95% confidence interval from a 20.4% decrease to a 3.8% increase (Table 10). The results of the mixed effects model are intermediate between these two approaches.

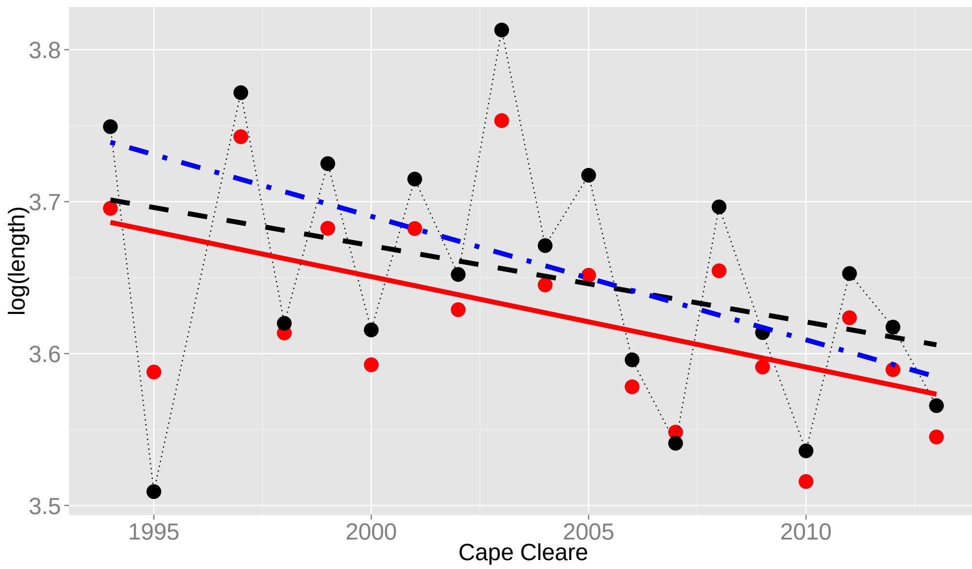

Figure 25: A comparison of the fitted lines across OLS, WLS, and mixed effects models. The black dots are the yearly averages, and the red dots are the fitted values from the mixed effects model on the log scale. OLS is the black dashed line, mixed effects is the red solid line, and WLS is the blue dot-dashed line.

Table 10: The estimated slope coefficient for area Cape Cleare (backtransformed to the original scale), with p-values and confidence intervals for the multiplicative changes in median fish lengths over $1994 - 2013$*. The OLS, WLS, and mixed effects models are compared.*

	Estimate	P-value	95% CI
OLS	0.9090	0.1567	(0.7964, 1.0376)
WLS	0.8569	0.0045	(0.7757, 0.9466)
Mixed Effects	0.8931	0.0551	(0.8033, 0.9957)

4.5.2 Scope of Inference

Since the halibut sampled were not randomly selected, the design does not buy inference to all halibut offloaded in Seward. However, the dockside interview data captured the true trend in use over time (Section 2.3.3) for years $2004 - 2013$. Although the biological sampling procedures were slightly different than the dockside interviews, both samples were collected by the same technician. Under the strong assumption that the biological sampling design performed as well as the $2004 - 2013$ dockside interviews, it is likely that the trends seen in the biological sample data do reflect the true trend in fish size over time.

This was an observational study intended to observe changes in lengths of halibut over time. Although I do not venture to make causal statements, I do suspect that the trends in the lengths of sport-caught halibut observed in this report are related to the decline in size-at-age over the last two decades documented by the International Pacific Halibut Commission.

5 IPHC

The International Pacific Halibut Commission (IPHC) was established in 1923, and fluctuations in the size-at-age relationships in Pacific halibut over the last century have been documented in IPHC publications and peer-reviewed literature. The size-at-age was estimated to be low in the 1920s and 1930s and very high in the middle of the 20th century. Sometime between the mid 1970s and 1990, it is estimated that the size-at-age of Alaska halibut began decreasing and since then it has been steadily declining (Leaman et al 2013).

In IPHC area 3*A*, for example, the length at 50% maturity was estimated to be 110–125 cm in the 1970s and 90–100 cm in 1999 (Clark et al 1999). In a 2002 publication, Clark and Hare state, "Older fish today weigh only about a third of what fish of the same age did 20 years ago." And then in a 2008 IPHC publication, Clark and Hare state, "Compared to 20 years ago, mean size-at-age has decreased at least 50% for all ages over 10." Even more recently, in a 2012 IPHC publication, the size-at-age is said to have "declined markedly" over the last decade (Loher 2012). The earlier papers suggested that the size-at-age is a reflection of halibut growth rates, but in the 2012 publication, Loher suggested, "the change in size-at-age could be a result of other factors such as size-dependent mortality instead of a change in growth rate."

The abundance of Alaska halibut is estimated to have increased in the last two decades, and the populations of favorable prey have decreased. These patterns are attributed to environmental changes, and the decline in size-at-age is thought to be directly related to the decrease in food supply as well as the growing abundance of halibut and other competing species such as arrowtooth flounder (Hare and Clark 2002). More recent studies suggest that other factors such as size-selective fishing could be causing the decline in size-at-age (Loher 2012).

5.1 IPHC Stock Assessments

The IPHC hires commercial fishing vessels to conduct halibut stock assessment surveys. The surveys are conducted sometime between June 1st and August 31st each year, and the survey stations are arranged in a grid with ten nautical miles between stations.

"The purpose of the setline survey is to collect standardized data used for halibut stock assessment (IPHC stock assessment survey data 1998 – 2014)." Commercial fishermen are contracted by the IPHC to conduct the surveys. In a typical year, the fishermen are instructed to fish five skates at each station, and the middle of the set coincides with the station coordinates. Each skate consists of 1,800 feet of groundline with circle hooks on gangions spaced every eighteen feet. Each set soaks for at least five hours.

The IPHC emphasizes that the goal of surveying fishing is "not to find the best spot with the most fish but to adhere to the standards of the survey, such as location, soak-time, bait size, and gear setup (IPHC stock assessment survey data 1998 – 2014)."

Stock assessment survey data is available on the IPHC website from 1998 to 2014 (IPHC stock assessment survey data 1998 – 2014). For each year, the reports include total pounds of legal and sublegal halibut. Sublegal halibut are less than 32 inches long. Each halibut caught is measured, and the weight is then calculated from a standard weight length table. Total pounds are calculated by summing these weights. Starting in 2001, the survey data also include the total number of legal and sublegal halibut caught as well as the total pounds.

Data from IPHC stock assessment surveys for station ID 4184 are shown in Figure 26. Station 4184 is close to the ADF&G statistical area that I refer to as "Cape Cleare" in this report. In this area and nearby areas, the proportion of sublegal halibut (less than 32 inches) has increased among the survey catch since 1998.

The biological patterns I observed in the ADF&G data are consistent with the data observed here as well as the reported change in the size-at-age relationships published by the IPHC. For future studies, I think it would be helpful to conduct a further comparison of the sport catch and the commercial catch to gain a better understanding of the change in the halibut fishery over time.

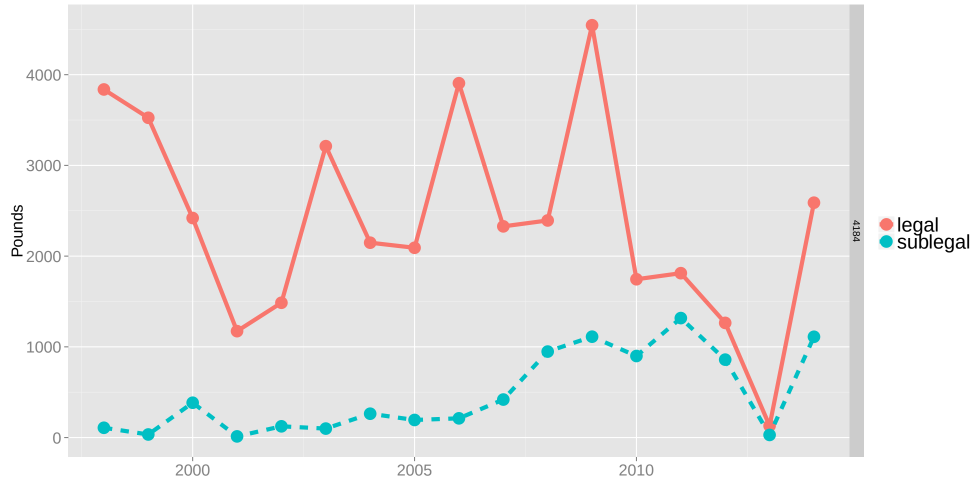

Figure 26: The total pounds of legal and sublegal halibut caught in the annual IPHC stock assessment survey for years 1998 *to* 2014*. Station* 4184*, near Cape Cleare, is shown.*

6 Conclusions

I find compelling evidence that the sport fishery out of Seward, Alaska has changed over time, both in the distance Seward fishermen travel to fish for bottomfish and in the median size of halibut brought back to the docks. The conclusions are corroborated by anecdotal evidence from seasoned Seward fishermen as well as IPHC publications about changes in size-at-age over time.

Fishermen tell stories and sometimes they exaggerate. They are very observant, however, and I started this project with the goal of exploring whether the stories of fishermen can be backed up by available data. In this case, the observations of Seward fishermen are consistent with the trends seen in the data. I think this study shows that the opinions and experiences of fishermen can help academics identify and understand patterns they wouldn't otherwise see. I believe science can benefit by listening to what fishermen have to say and by weaving their personal input into studies and publications.

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