Evidence of range-wide patterns in growth for northeast pacific sablefish

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# Introduction

Sablefish (*Anoplopoma fimbria*) are a highly mobile, long-lived, valuable groundfish that have high movement rates (10 – 88% annual movement probabilities across Alaska, Hanselman et al. 2015) and range from Southern California to the Bering Sea. Concurrent sablefish population declines across the entire range during the past few decades have increased concern about the populations’ status and causes of this downward trend. Traditionally, sablefish stock assessment and management has occurred independently at regional scales, namely Alaska, British Columbia, and the US West Coast, assuming that these are closed stocks. However, recent genetic work has shown that NE Pacific sablefish are not genetically distinct between these traditional management areas (Jasonowicz et al., 2017), though there is evidence for differences in growth rate and size-at-maturity throughout the range (McDevitt, 1990). This suggests that the current delineation of assessment and management regions is incongruent with the stock’s actual spatial structure and motivates research that would enable the construction of a population dynamics model which represents the spatial heterogeneity of sablefish throughout their range.

Growth rates of fish within a population, which are generally parameterized using the von Bertalanffy growth function (VBGF, von Bertalanffy, 1957) can influence stock assessment results (Punt, 2003). Parameter estimates for sablefish are usually based on survey data acquired from chartered commercial trawl or longline vessels (Table 1). It is preferable to obtain estimates from a survey, because fishery-dependent information can be heavily biased due to targeting or gear selectivity (Ricker, 1969).

There has been a resurgence of efforts to quantify spatial growth variability for several managed species, including Gulf Sheepshead (Adams et al., 2018) and northern rock sole (Hurst and Abookire, 2006), as well as sablefish (James et al., 2002). Though a robust volume of survey data is available for this species for all management regions, researchers have not yet analyzed available length and age data for the entire range for evidence of spatial patterns.The objective of this study was to investigate variation in growth rates for sablefish across the Northeast Pacific. We present the results of this evaluation with the intention of informing future sablefish modeling work in the northeast Pacific.

# Methods

We obtained fishery-independent length and age data from the Bering Sea and West Coast trawl surveys conducted annually by the National Oceanic and Atmospheric Administration. Data from each region included measured length, sex, age, and the starting latitude and longitude which determined the survey station. We also obtained length and age records from the Canadian Department of Fisheries and Oceans, which has performed an annual trap-based survey since 1991. Due to computational constraints, we randomly subsampled 8,000 records from each of the three management regions.

The modeling workflow was designed to identify significant spatiotemporal break-points in the age-length relationship and did not consider *a priori* hypotheses of spatial stratification. We employed a Generalized Additive Model (GAM) with smooth functions for latitude and year using the mgcv package (Wood, 2011) in R (R Development Core Team, 2011). The first derivatives of the GAM were evaluated to identify areas of significant change (i.e., break points) in in growth parameter estimates.

We fit a GAM with the vector of observed lengths as the response predicted by separate smoother for year and latitude. Non-smoothed predictors included age and sex so that smooth functions represented all variation not explained by these factors. We investigated the use of an AR1 temporal structure with lags of 1 to 3 years, but these models did not improve AICc over the initial model without autoregressive structure.

Once the best-fit model was identified, we used the method of finite differences (as in Simpson, 2018) to locate periods and/or locations of statistically significant change in growth. The finite differences approach approximates the first derivative of the spline generated from the GAM function. We calculated uncertainty in derivative estimates by computing the sum of the square root of the fixed-effects covariance matrix. We then identified years or latitudes where the confidence interval of the first derivative was outside the 5th to 95th percentiles of the entire dataset and designated these as “break points”. Once identified, we re-aggregated the data to match these breakpoints and estimated the parameters of the VGBF using maximum likelihood in Template Model Builder (Kristensen et al., 2016). This was performed on the entire data set, separately for each sex.

The VBGF is parameterized by *L∞* (asymptotic length), *k* (the rate at which asymptotic length is approached) and *t0* (the estimated age at length zero). The prediction for length at age is subject to an error term ε that is assumed to be lognormally distributed with zero mean and variance σ. Our model estimates values for the three biological parameters at each of six strata for two sexes (fish of “unknown” sex were removed from the analysis beforehand); the additive error term is assumed universal across strata and sex and normally distributed with mean zero.

Equation 4

2)

We executed a maximum of 1000 iterations. Initial parameters were t0 = 0, = 0, with L∞ = 70, K = 0.

# Results

Our best-fit GAM produced a positive definite Hessian and converged after 10 iterations. It explained 42.4% of deviance. The latitude smoother suggested a general increasing cline with latitude, with a significant breakpoint centered around 49˚N (approximately Vancouver, Canada), which corroborates results in Gertseva et al. (2017). The temporal smoother did not exhibit a strong one-way trend, though the quantile analysis identified a significant change in slope centered on years 2004-2005 (Figure 3). We therefore split the data collected during or after 2005 (hereafter referred to as “late”; prior data is “early”) and at 49˚N (hereafter referred to as “north”; data collected south of this point is designated as “south”). Parameter estimation for the VBGF generated estimates for mean and standard deviations of t0, log(*k*) and log(L∞) for unique combinations of north/south, early/late and male/female populations, and associated predictions for length at age (Figure 4). The error term was estimated for all data to be 6.13 (standard deviation = 0.027). There was considerable overlap in parameter estimates for the growth rate *k,* whereas L∞ and its confidence intervals were quite spread out at the stratification indicated by the GAM derivative analysis (Figure 5).

# Discussion

Previous work with sablefish data has utilized an *a priori* approach, wherein length data were aggregated into pre-hypothesized spatial zones and compared via Akaike’s Information Criterion. This ‘information-theoretic’ (Guthery et al., 2003) approach is fairly straightforward computationally, and has been implemented separately for the California Current (Gertseva et al., 2017) and Alaska fisheries (Echave et al., 2012). The CC analysis identified a statistically significant break in von Bertalanffy growth parameters for sablefish at approximately 30 degrees N, between Point Conception and Monterey, CA, with additional evidence for an increasing cline in L∞ with increasing latitude. That work also observed an increase in *k* estimates from the Vancouver sampling region (ca. 49˚N), which was posited to be the result of samples coming from the “southern end of a faster-growing northern stock”, a suggestion supported by our findings. The authors of that study described how sablefish have been shown to highly migratory, with ontogenetic movements off the coastal shelf; such combined, complex life patterns could yield higher growth rates in northern regions that interacts with a more generalized shelf-slope pattern observed in groundfish overall. For Alaska, a GLM analysis of length as a function of pre-specified zones and time blocks was used to diagnose a ‘regime change’ in sablefish growth occurring in year 1995, though the authors explain this is likely more attributable to changes in sampling strategy that occurred in that year’s survey. In the recent AK sablefish assessments, the parameters of the VBGF are time-blocked accordingly (see Table 1). While the first derivative was not zero in this year (which included data for all regions), the value thereof was not an outlier.

The consideration of temporal variation in sablefish growth is further complicated by the exploitation history of the fishery, which has steadily marched north- and west-ward over the last several decades, encountering ‘larger’ fish (M. Haltuch, pers. comm.). This suggests that differences in mean length across the region could be attributable to different degrees and duration of fishing pressure, and not inherent population differences alone. Importantly, the L∞ estimates for both sexes and regions show a decline from the ‘early’ to ‘late’ periods, resulting in nearly equivalent values for north and south regions for females and males, respectively.

**[Further discussion of movement following analyses by Luke Rodgers, DFO postdoc, to be continued].**

# Figures

Figure 1. Histogram of raw length data from three regional surveys, colored by sex.



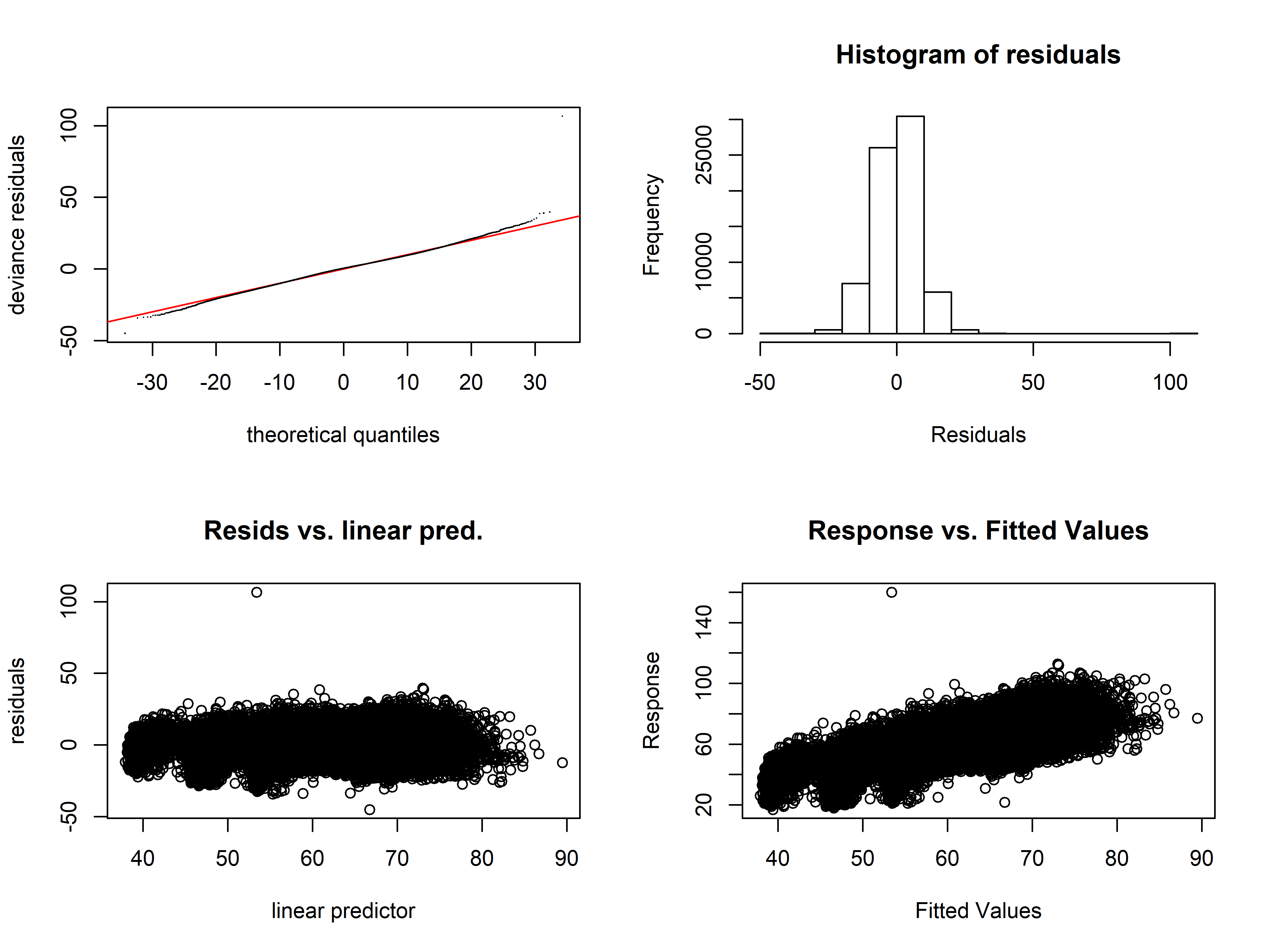


Figure 2. Diagnostic plots of best-fit GAM model. Clockwise from top left: quantile-quantile plot of deviance residuals; histogram of residuals; observed response values (lengths, in cm) vs predicted values, and model-predicted residuals vs linear predictor.

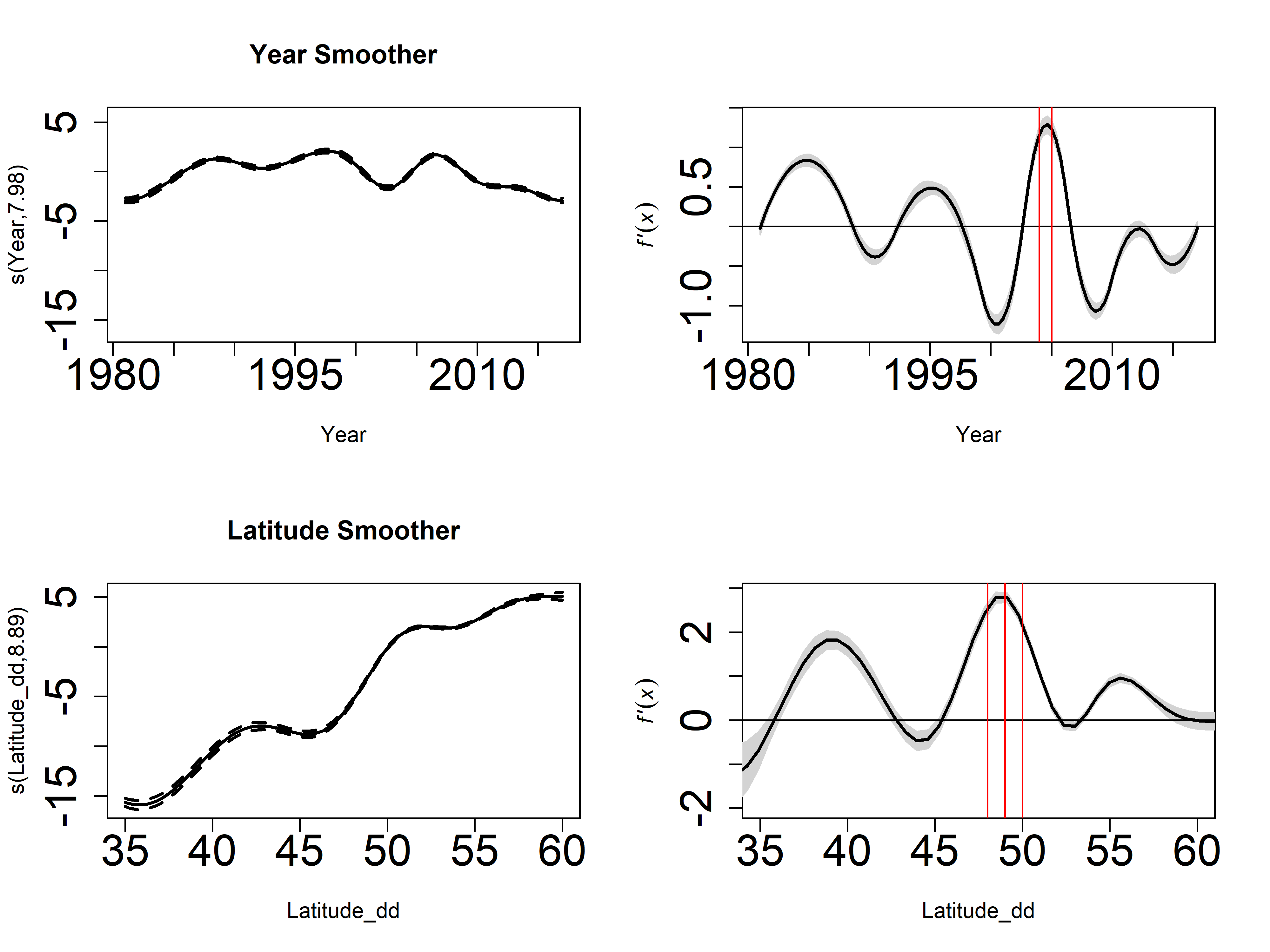


Figure 3. Plots of smoothers for Year and Latitude, and first derivatives thereof. Red lines indicate years or latitudes where the value of the first derivative was outside of the 95th percentile of values in the dataset.



Figure . Fits of von Bertalanffy growth function to data stratified at values determined using the derivative analysis of the GAM. Panels marked “early” are data obtained prior to 2005; “Northern” datapoints were collected north of 45˚N latitude. Predicted values are color-coded by sex.



Figure . Comparative boxplot of estimated parameters from spatiotemporally stratified data. The error term (not shown) was estimated universally for all regions and sexes.

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Region** | **Survey Method** | **Sample size used in this analysis** | | **VBGF parameters from recent assessments** | | | | | |
| **M** | **F** | **L∞** | | **K** | | **t0 (years)** | |
| **M** | **F** | **M** | **F** | **M** | **F** |
| West Coast of US (Johnson et al., 2015) | Trawl on chartered commercial fishing vessels | 4056 | 4183 |  |  | 0.415657 | 0.326787 |  |  |
| British Columbia | Stratified trap survey | 3725 | 4514 | 68.99 | 72.00 | 0.29 | 0.25 | 32.50 | 32.50 |
| Alaska Federal ( Hanselman et al., 2015) | Longline on chartered commercial fishing vessels | 3531 | 4551 | \*67.8  ⁑65.3 | \*80.2  ⁑75.6 | \*0.29  ⁑0.28 | \*0.22  ⁑0.21 | \*⁑2.27 | \*⁑1.95 |

# Tables

Table 1. Overview of survey methods, data available and most recent VBGF parameters used for sablefish in stock assessments. \*Time-blocked VBGF parameters for AK Federal assessment 1996-current; ⁑Time-blocked VBGF parameters from 1960-1995 (Hanselman et al., 2017).

\*The WC assessment , which is written in Stock Synthesis, does not specify L∞ nor t0, but instead an age-length key. Values were back-converted via xx for presentation here.

|  |  |  |
| --- | --- | --- |
| Predictor | Estimated Degrees of Freedom | Proposed Breaks |
| s(Year) | 7.984 | 2004, 2005 |
| s(Latitude) | 8.888 | 48˚ to 50˚N |

Table . Description of predictors (smoothers denoted with s()) and locations along each where the first derivative lay outside the 5th to 95th percentile.

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