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Age, Growth, and Mortality of Silvergray Rockfish (*Sebastes brevispinis*) from the Gulf of Alaska

T. T. TenBrink and C. M. Gburski

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U.S. DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration
National Marine Fisheries Service
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ABSTRACT

Silvergray rockfish (*Sebastes brevispinis*) inhabit oceanic waters in Alaska along the shelf and continental slope and is one of the most common rockfish species caught in research bottom trawl surveys off southeastern Alaska. Silvergray rockfish is federally managed within a rockfish multispecies complex in the Gulf of Alaska (GOA). Many rockfish species within this complex lack basic biological data in order to inform management. In this study, we provide initial region-specific information from the GOA on the age, growth, and natural mortality (*M*) of silvergray rockfish, based on 1,703 ages determined from sagittal otoliths. Precision of the assigned ages indicated no systematic biases with a coefficient of variation of 6.22% and percent agreement of 26.4%, suggesting that silvergray rockfish is one of the more difficult *Sebastes* spp. to age. Estimated ages ranged from 6 to 81 years. The maximum age of 81 years in this study represents a new estimate of longevity for this species in Alaska. Sexual dimorphism in growth existed, as females grew more slowly and reached larger asymptotic sizes (L_∞, cm) relative to males. Spatial differences in growth also existed between the eastern and western GOA, with those fish in the western GOA exhibiting larger asymptotic sizes and slower growth. Differences in weight-length relationships also suggest that silvergray rockfish are larger in the western GOA. Natural mortality (*M*) was generally variable with a mean estimate of 0.07 yr^{-1} depending upon the empirical method applied. This study represents the first comprehensive investigation of life history parameters of silvergray rockfish in Alaska and provides some of the information necessary to advance the species to Tier 4 management, which would provide species-specific fishing reference points.

INTRODUCTION

Silvergray rockfish (*Sebastes brevispinis*; Scorpaenidae) inhabit the northeastern Pacific Ocean, from coastal waters to the continental slope and are primarily found between 100 to 300 m (von Szalay and Raring 2018). The range of the species extends from the coastal Bering Sea down to Baja California, Mexico (Love et al. 2001). It is most common in the southeastern areas of the Gulf of Alaska (GOA), where it is one of the most abundant rockfish and groundfish species (von Szalay and Raring 2016, von Szalay and Raring 2018). Approximately 98% (42,106 t) of the total GOA-wide biomass for silvergray rockfish was concentrated in the eastern GOA in 2023 (Omori et al. 2023).

Silvergray rockfish is a non-target species managed within a multispecies rockfish complex in the GOA ("Other Rockfish"; Omori et al. 2023). Silvergray rockfish is one of five species that comprise > 95% of the "Other Rockfish" biomass estimates, including harlequin (*Sebastes variegatus*), redbanded (*S. babcocki*), redstripe (*S. proriger*), and sharpchin rockfish (*S. zacentrus*; Omori et al. 2023). Stock assessment methods and fishing reference points in Alaska are applied using a numbered tier system (1 to 6) that accommodates a range of data-rich to data-limited stocks (NPFMC 2020). The species belonging to the "Other Rockfish" complex are considered to be data-limited species and are managed as a group in tiers 4 to 6. This complex is assessed biennially to coincide with the availability of new trawl survey biomass estimates from the GOA. Silvergray rockfish is managed as a Tier 5 species, which is defined as those species with reliable estimates of biomass modeled and natural mortality rate (*M*). Rates of *M* are calculated from available life history information, such as age and growth parameters.

Fishing reference points for Tier 5 species, the overfishing level (OFL) and acceptable biological catch (ABC), are defined by the following: 1) OFL = Biomass × M; 2) ABC = 0.75 × OFL. The reliance on M in the reference points emphasizes the importance of this life history parameter for managing silvergray rockfish and other data-limited stocks in Alaska at the Tier 5 level (Sullivan et al. 2022).

There have been efforts in recent years to update or provide initial biological information for data-limited Tier 5 rockfishes in Alaska to improve the management of these species. For example, age, growth, and maturity of harlequin rockfish (*Sebastes variegatus*) were estimated in the GOA (TenBrink and Helser 2021, TenBrink et al. 2023) and dusky rockfish (*Sebastes variabilis*) growth was studied in the Aleutian Islands (TenBrink et al. 2023). An otolith shape analysis study was conducted to determine stock structure of dusky rockfish throughout its range in Alaska (TenBrink et al. 2024). An age validation study was completed for harlequin rockfish and redstripe rockfish to validate otolith growth zone counts and evaluate ageing error (Kastelle et al. 2020). This effort has also included an extensive literature review of available life history data that provided updated estimates of M for *Sebastes* spp. (Sullivan et al. 2022).

For silvergray rockfish, life history information has been primarily obtained from waters off British Columbia where it is also an important commercial species (Stanley and Kronlund 2005, Starr et al. 2016). Biological data for silvergray rockfish off waters of Alaska have remained limited. Bottom trawl surveys of the GOA have provided basic information such as distribution, location data, and sizes of silvergray rockfish caught. However, any detailed analyses on life history parameters specific to Alaska, such as age and growth, has yet to be published for silvergray rockfish. This document summarizes the effort to study age, growth, and estimated rates of *M* for this data-limited rockfish in the GOA.

METHODS

Study Area and Field Collections

Paired sagittal otoliths of silvergray rockfish were collected from bottom trawl surveys in the GOA (Table 1; Fig. 1). The extent of the survey was from the Islands of Four Mountains in the west to Dixon Entrance in the east (Fig. 1), and has occurred during late May through early August. This survey extends across a large longitudinal area and spans a known ecological boundary (Fig. 1). The western GOA is a large coastal ocean system dominated by the Alaska Coastal Current, while the eastern GOA has a narrow continental shelf influenced by the northward-flowing Alaska Current (Stabeno et al. 2004). These two areas have distinct downwelling regions (Coffin and Mueter 2016) and are separated near 147°W. Carbon (^{14}C) productivity, as measured through sea surface pigmentation from phytoplankton carbon fixation, also shows regional boundaries between the two areas (Behrenfeld and Falkowski 1997; Rooney et al. 2018). The survey was conducted on a biennial basis beginning in 2001 and every 3 years from 1993 to 1999. These surveys were conducted to assess groundfish resources and have provided a time series on distribution, abundance, and various biological characteristics of commercially important species for fisheries management. Bottom trawl surveys employed a random-stratified sampling design stratified by depth, bottom terrain, and area. Survey operations were conducted in compliance with national and regional protocols detailed in Stauffer (2004). Numbers and weights in catch of all taxa, including silvergray rockfish, were recorded for each haul. In hauls with catch of less than 150 silvergray rockfish, sex and fork length (cm) were recorded for each silvergray rockfish; otherwise, a random subsample was taken. Otoliths were extracted for subsequent age determination from a length-stratified sampling scheme that did not exceed two specimens per cm/sex/haul.

Age Determination and Image Acquisition

Silvergray rockfish ageing commenced at the Alaska Fisheries Science Center's (AFSC) Age and Growth Program in 2011 beginning with samples collected during the 2005 GOA bottom trawl survey. While the Age and Growth Program primarily supports essential work to provide ages and growth estimates for commercially important species in Alaska, the program also aims to expand the knowledge base for ageing additional *Sebastes* spp. with lesser known life history traits and limited age data, which included silvergray rockfish. In addition, this effort attempted to explore any spatial or temporal differences in growth. Prior to 2011, silvergray rockfish had been aged by AFSC-contracted personnel from the Alaska Department of Fish and Game (ADF&G) using the traditional break-and-burn method. These ages from ADF&G were recorded on samples collected in 1993, 1996, and 1999 and provided initial information for future research and analysis.

The initial effort from the AFSC's Age and Growth Program began experimenting with multiple ageing preparation techniques. Sagittal thin sections were prepared on a high-speed saw with a thickness of approximately 0.40 mm, slide mounted, and viewed under a stereo microscope.

Thin sectioning has been shown to produce more reliable age estimates for some *Sebastes* spp., providing an even reading surface that enhances both annual and sub-annual growth zones (Matta and Kimura 2012). However, these initial thin sections produced mixed results in interpretation. Otoliths were ultimately prepared primarily by the following methodology: 1) cutting in the transverse plane on a low-speed saw through the core (first year); 2) wet sanding the otolith half, if necessary, polishing the cut surface to remove deposits that might interfere with growth pattern interpretation; 3) either baking the otoliths in an oven at 450-500°F for 20 to 40 min. or alcohol flame; and 4) applying mineral oil to the prepped cut surface for viewing under a Leica MZ9.5 stereo microscope with reflected light. After a 10-year pause, ageing requests resumed in 2022 to supplement additional age data for this research study. To operationalize this effort, ageing criteria including early year (1 to 3) growth increment size (measurements in mm), was established between one age reader and one tester (authors of this document), both having many years of *Sebastes* spp. ageing experience. Intra-reader comparisons starting with 50 to 100% testing were performed to ensure consistency in ageing, comparisons and criteria, prior to testing 20% of the samples. The method of baking the otoliths (break and bake) was the preferred method for the more recent collections (2007, 2009, 2011, and 2013) due to it providing improved clarity throughout the age reading axes compared to the break- and-burn method.

Age reader precision was measured using standard statistical tools. This evaluation consisted of percent agreement, average percent error (Beamish and Fournier 1981), coefficient of variation, and age bias plots (Campana et al. 1995). A Bowker's test of symmetry to determine if significant differences existed between age readers was also conducted (Bowker 1948; Evans and Hoenig 1998). Specimens without agreement were re-examined, if needed. Age discrepancies from otoliths between the age reader and tester were resolved either by viewing under a double-stereo microscope or by images. For image acquisition, a single magnification of 25.0× was used (10× eyepieces; 2.5× zoom; 1.0× main objective). Images were captured with a digital microscope camera (Leica DMC4500) using Leica Application Suite (LAS) software (version 4.12.0). Ages were annotated independently using Photoshop Elements (version 18.0).

Growth Analysis

Silvergray rockfish growth was determined using the common three parameterization version of the von Bertalanffy growth function (Beverton and Holt 1957), using nonlinear least-squares estimation with length-at-age data:

$$L_t = L_\infty[1 - e\hat{}(-k(t - t_0)), \qquad (1)$$

where L_t is the expected length (cm) at age (t); L_∞ is the asymptotic length; k is the growth rate coefficient; and t_0 represents the theoretical age when length was zero. Growth parameters were estimated through the *nlsLM* function in R (version 4.0.4; R Core Team 2021) using the Levenberg–Marquardt algorithm (Elzhov et al. 2013; Ogle et al. 2018). The function was selected for its robustness to suboptimal starting values compared to the Gauss–Newton algorithm associated with the *nls* function (nlstools; Baty et al. 2015). Confidence intervals for each of the von Bertalanffy growth parameters were estimated using bootstrapping with 1,000 iterations based on normal distribution theory (Ogle et al. 2018). For growth analysis of length-at-age data, we analyzed GOA survey collections with age determinations (Table 2). An age–

length key was constructed from the length distributions where ages were assigned to individual fish when ages were not available, partitioned by year, area, and sex. Age–length keys were developed using the semi-random age assignment method of Isermann and Knight (2005) using length bins of 1 cm. Likelihood ratio tests were used to compare sex-specific or region-specific growth (Kimura 1980, Nelson 2018).

Length-Weight Relationships

Weight–length relationships for silvergray rockfish were based on the allometric equation:

$$W = aL^b, \tag{2}$$

where *W* is fish weight in kg; *L* is fork length in cm; and *a* and *b* are constants. An analysis of covariance (ANCOVA) was used to determine if there were significant differences in the regression models between sexes and regions (Zar 1999).

Estimation of Natural Mortality (M)

We applied several methods to calculate *M*. Then et al. (2015) used a comprehensive approach to evaluate the predictive performance of estimators based on combinations of life history parameters and found that maximum-age-based (t_{max}) estimators were superior to those methods associated with growth or water temperature (e.g., Alverson and Carney 1975, Pauly 1980, Jensen 1996). Then et al. (2015) updated methods based on modifications to the Hoenig (1983) method using linear (Equation 3) and nonlinear models (Equation 4). Additionally, we used Hamel's (2015) formula representing a median value for an *M* prior (Equation 5) currently used for U.S. West Coast *Sebastes* spp. This equation fits the Then et al. (2015) one-parameter estimate under a log–log transformation (Cope et al. 2021; Langseth et al. 2021).

$$\log(M) = 1.717 - 1.01\log(t_{max}) \quad (3)$$

$$M = 4.899t^{-0.916} \quad (4)$$

$$M = 5.4/t_{max}\ . \quad (5)$$

In addition to these maximum age-based methods, we applied an estimator based on a multivariate model of seven life history parameters and growth that was applied to a variety of fish taxa (Thorson et al. 2017; Cope and Hamel 2022). A mean *M* was calculated based on Cope and Hamel's (2022) inverse weighting method, which uses the variance of each method to weight the composite prior of *M*.

Statistical analysis and graphics were performed using the following packages in R version 4.4.1 (R Core Team 2023): *fsa* (Ogle et al. 2018), *ggFishPlot* (Vihtakari 2024), *ggplot2* (Wickham 2016), *sf* (Pebesma and Bivand 2023), *fishmethods* (Nelson 2018), and *minpack.lm* (Elzhov et al. 2013).

RESULTS

Age Determination

Length compositions for both sexes were similar, with sizes of males being slightly smaller (Fig. 2). For males, lengths ranged from 23 to 69 cm (mean = 48.8 cm; SD = 4.87). For females, lengths ranged from 25 to 74 cm (mean = 50.5 cm; SD = 6.31). Age compositions between sexes were also similar, with the majority of ages between 10 and 20 years (Fig. 3). Male ages ranged from 6 to 81 years (mean = 19.1 years; SD = 10.01), while female ages ranged from 6 to 74 years (mean = 19.5 years; SD = 9.64). The maximum age of 81 years was determined and resolved from three independent readings (Fig. 4). From these aged fish, a total of 405 age reader pairs were tested (Fig. 5; Table 2). Annuli interpretation on the otolith surface for the first 3 years and along the edge was similar to other *Sebastes* spp. Overall bias indicated that 77% of paired ages were within ± 2 years and 86% within ± 3 years (Fig. 5). Percent agreement was observed in 26.4% of the age reader pairs (Fig. 5). Average reader and tester age was 19.6 and 19.8 years, respectively. Results of precision tests indicated a coefficient of variation of 6.22 and an average percent error of 4.40. No systematic biases occurred between age readers, according to Bowker's test of symmetry (X^2 = 215.4; P = 0.305).

The coefficient of variation between age readers for silvergray rockfish was above the mean value estimated from a set of Alaska *Sebastes* spp. (6.22; Fig. 6), and the percent agreement was below the overall mean (27%; Fig. 7). The coefficient of variation for silvergray rockfish was most similar to that of the historical production of Pacific ocean perch (Fig. 6), while the percent agreement of silvergray rockfish was most similar to another limited-aged species, harlequin rockfish (Fig. 7). Silvergray rockfish is one of the more difficult Alaska rockfish species to age, with only rougheye rockfish (*Sebastes aleutianus*) and blackspotted rockfish (*S. melanostictus*) having a larger coefficient of variation and lower percent agreement.

Length-Weight Relationships

Regression models of the length-weight relationships indicated a significant difference between sex of silvergray rockfish (ANCOVA; F = 4.20; P = 0.041; Fig. 8) and between silvergray rockfish in the eastern and western GOA (ANCOVA; F = 122.9; P < 0.001). For example, silvergray rockfish at 45 cm are larger in the western GOA (females: east = 1,196 g, west = 1,248 g; males: east = 1,178 g, west = 1,291 g).

Growth Analysis

Females attained larger sizes and grew slower than males, most notably after an age of 15 years (Table 3; Fig. 9). Both sexes had sparse data for ages < 10 years; thus, the model fit to the early growth was poor (t_0 ranges from -2.810 to -8.376; Table 3; Fig. 9). Using likelihood ratio tests, significant growth differences were observed for sex and region (P < 0.001; Table 4). Silvergray rockfish in the western GOA attained larger sizes than those in the eastern GOA (Table 3; Fig. 10).

Estimation of Natural Mortality (M)

Estimates of *M* showed some variation among the methods. The composite estimate of *M* was 0.07 yr^{-1} (Table 5).

DISCUSSION

As we evaluate life history patterns among rockfishes of Alaska and the U.S. West coast, using size and age data, we find a continuum of larger-sized rockfish exhibiting older ages (Fig. 11). A positive relationship between the maximum lengths and longevities of the species reflects that larger species appear to be longer-lived (see Kuparinen et al. 2023), but also that for any given maximum body size there is a wide range of longevities among the *Sebastes* spp. examined. Among these life history traits, silvergray rockfish is most similar to canary rockfish (*Sebastes pinniger*). This demonstrates the need to account for differences in life history traits in the management of species within multispecies complexes.

Maximum age is a commonly used life history parameter for stock assessment and management. Thus, it is important for the recorded maximum age to be as accurate as possible. Prior to this study, the historical maximum age of silvergray rockfish recorded in Alaska was 79 years, but was only aged by a single reader. In this study, this particular specimen was re-examined for corroboration. The maximum age exceeded 80 years and was examined by multiple readers (authors of this document). The ages were estimated independently (81 and 83 years) and the final resolved age was determined to be 81 years. Due to the preparation (i.e., photographic image) and clarity of the otolith from this specimen, we believe that this updated maximum age of 81 years represents a more accurate depiction of longevity than the previously reported maximum age.

This study demonstrates the importance of age corroboration. In many cases, maximum ages have been reported from only a single source. These efforts have recently provided ages to other *Sebastes* spp. (e.g., redstripe rockfish = 46 years; rougheye rockfish = 144 years). At a minimum, ages of the oldest specimens should be conducted through paired readings for corroboration when possible. Depending upon the original preparation method and inherent challenges in interpretation of annuli in old fish, an additional level of quality control seems essential. The AFSC's Age and Growth Program is currently updating maximum ages for several species, including silvergray rockfish.

A longitudinal gradient was observed in silvergray rockfish growth, with varied size and growth rates observed between GOA regions. Although silvergray rockfish are not abundant in the western GOA, the larger sized fish observed in the western GOA may be the result of regional influences accounting for some level of spatial variability. Differences in growth of other rockfish species has similarly been reported between unique oceanographic boundaries along the U.S. West coast (splitnose rockfish *Sebastes diploproa*, Gertseva et al. 2010; greenstriped rockfish *S. elongatus*, Keller et al. 2012) and Alaska (harlequin rockfish, TenBrink and Helser 2021; northern rockfish *S. polyspinis*, Spencer and Laman 2023). For example, TenBrink and Helser (2021) similarly found larger harlequin rockfish in the western GOA compared to the rest of the GOA. Understanding the mechanisms involved in shaping these differences may be difficult, but analyzing possible sources of variation (e.g. bottom temperature, productivity) within the GOA ecosystem, could be a priority for an extended spatial analysis.

The effort to expand to additional *Sebastes* spp. ageing techniques and estimation has slowly increased in recent years, aside from those traditional methods, which can be labor intensive and subject to age reader variability. One such method, Fourier transform near infrared (FT-NIR) spectroscopy, can be used as a promising alternative for age estimation in long-lived species. Advances and operationalization in FT-NIR spectroscopy has explored northern rockfish ageing, demonstrating the potential for applying FT-NIR to long-lived rockfish species (Benson et al. 2024). This study also emphasized the necessity of incorporating biological and spatial data known to influence northern rockfish growth, which could be applied to other *Sebastes* spp. The FT-NIR method is considered a secondary approach for age estimation due to its reliance on the accuracy of reference ages obtained from a primary, traditional method. Although silvergray rockfish is not a priority species for this technology, due to its non-target status in the commercial fisheries, FT-NIR application to longer-lived species that require more resource-intensive methods and ageing challenges has become a promising alternative.

Effective management of silvergray rockfish in the GOA “Other Rockfish” complex has been hindered by a lack of data, and this study helps provide updated and critical life history information. An *M* estimate of 0.07 from this study represents an estimate based on GOA-specific information on age and growth parameters. In the current assessment of the “Other Rockfish” complex, silvergray rockfish is assigned an *M* of 0.05 (Omori et al. 2023), using a combination of the Alverson and Carney (1975) and Hoenig (1983) methods. This estimate could be updated with an incorporation of maximum-age based methods proposed by Then et al. (2015), which represents an update to Hoenig (1983). One of the objectives in *Sebastes* spp. management would be an upward movement within the management tier structure. A Tier 4 designation from Tier 5 would provide species-specific fishing reference points (Omori et al. 2023). However, Tier 4 requires the following parameters: von Bertalanffy growth curves, weight-length relationships, assumption on fishery selectivity age, a reliable estimate of *M* and age at 50% maturity with proportions (ogives). For the “Other Rockfish” complex, sharpchin rockfish is the only species managed in Tier 4, allowing managers to calculate the OFL and ABC based on a rate that reduces spawning biomass per recruit to 35% or 40% (F_{35}, F_{40}) of the unfished value. Information on size and maturity at age would allow target fishing mortality rates to be based upon the conservation of reproductive potential. This study provides some of the information necessary to advance the species from Tier 5 to Tier 4. However, maturity data do not exist for silvergray rockfish in Alaska, aside from proxy information from another region (i.e., Stanley and Kronlund 2005). Nevertheless, the age and growth parameters provided in this study represents an important step in improving management for this data-poor stock.

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CITATIONS

Alverson, D. L., and M. J. Carney. 1975. A graphic review of the growth and decay of population cohorts. J. Cons. Int. Explor. Mer. 36(2): 133–143.

Baty, F., C. Ritz, S. Charles, M. Brutsche, J.-P. Flandrois, and M.-L. Delignette-Muller. 2015. A toolbox for nonlinear regression in R: the package nlstools. J. Stat. Soft. 66(5).

Beamish, R. J., and D. A. Fournier. 1981. A method for comparing the precision of a set of age determinations. Can. J. Fish. Aquat. Sci. 38: 982–983.

Behrenfeld, M. J., and P. G. Falkowski. 1997. Photosynthetic rates derived from satellite-based chlorophyll concentration. Limnol. Oceanogr. 42: 1–20.

Benson, I. M., T. E. Helser, and B. K. Barnett. 2024. Fourier transform near infrared spectroscopy of otoliths coupled with deep learning improves age prediction for long-lived northern rockfish. Fish. Res. 278: 107116.

Beverton, R. J. H., and S. J. Holt. 1957. On the dynamics of exploited fish populations. Chapman and Hall, London.

Bowker, A. H. 1948. A test for symmetry in contingency tables. J. Am. Stat. Assoc. 43(244): 572–574.

Campana, S. E., M. C. Annand, and J. I. McMillan. 1995. Graphical and statistical methods for determining the consistency of age determinations. Trans. Amer. Fish. Soc. 124: 131–138.

Coffin, B., and F. Mueter. 2016. Environmental covariates of sablefish (*Anoplopoma fimbria*) and Pacific ocean perch (*Sebastes alutus*) recruitment in the Gulf of Alaska. Deep-Sea Res. Part II: Topical Stud. Oceanogr. 132: 194–209.

Cope, J. M., C. R. Wetzel, B. J. Langseth, and J. E. Budrick. 2021. Assessment of the squarespot rockfish (*Sebastes hopkinsi*) along the California U.S. west coast in 2021 using catch, length, and fishery-independent abundance data. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

Cope, J. M., and O. S. Hamel. 2022. Upgrading from M version 0.2: An application-based method for practical estimation, evaluation and uncertainty characterization of natural mortality. Fish. Res. 256: 106493. https://doi.org/10.1016/j.fishres.2022.106493.

Elzhov, T. V., K. M. Mullen, A. N. Spiess, and B. Bolker. 2013. minpack.lm: R interface to the Levenberg-Marquardt nonlinear least-squares algorithm found in MINPACK, plus support for bounds (R package). http://cran.r-project.org/package=minpack.lm

Evans, G. T., and J. M. Hoenig. 1998. Testing and viewing symmetry in contingency tables, with application to readers of fish ages. Biometrics 54(2): 620–629.

Gertseva, V. V., J. M. Cope, and S. E. Matson. 2010. Growth variability in the Splitnose Rockfish Sebastes diploproa of the northeast Pacific Ocean: pattern revisited. Mar. Ecol. Prog. Ser. 413: 125–136.

Hamel, O. S. 2015. A method for calculating a meta-analytical prior for the natural mortality rate using multiple life history correlates. ICES J. Mar. Sci. 72(1): 62–69.

Hoenig, J. M. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bull., U.S. 81: 898–903.

Isermann, D. A., and C. T. Knight. 2005. A computer program for age–length keys incorporating age assignment to individual fish. N. Am. J. Fish. Manage. 25:1153–1160.

Jensen, A. L. 1996. Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. Can. J. Fish. Aquat. Sci. 53(4): 820–822.

Kastelle, C., T. Helser, T. TenBrink, C. Hutchinson, B. Goetz, C. Gburski, and I. Benson. 2020. Age validation of four rockfishes (genera *Sebastes* and *Sebastolobus*) with bomb-produced radiocarbon. Mar. Freshw. Res. 71: 1355–1366.

Keller, A. A., K. J. Moltonb, A. C. Hicks, M. Haltuch, and C. Wetzel. 2012. Variation in age and growth of greenstriped rockfish (*Sebastes elongatus*) along the U.S. west coast (Washington to California). Fish. Res. 119-120: 80–88.

Kimura, D. K. 1980. Likelihood methods for the von Bertalanffy growth curve. Fish. Bull., U.S. U.S. 77: 765–776.

Kuparinen, A., E. Yeung, and J. A. Hutchings. 2023. Correlation between body size and longevity: New analysis and data covering six taxonomic classes of vertebrates. Acta Oecologica 119: 103917.

Langseth, B. J., C. R. Wetzel, J. M. Cope, T. S. Tsou, and L. K. Hillier. 2021. Status of quillback rockfish (*Sebastes maliger*) in U.S. waters off the coast of Washington in 2021 using catch and length data. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

Love, M. S., M. Yoklavich, and L. Thorsteinson. 2001. Rockfishes of the northeast Pacific, 406 p. Univ. Cal. Press, London.

Matta, M. E., and D. K. Kimura. 2012. Age determination manual of the Alaska Fisheries Science Center Age and Growth Program. U.S. Dep. Commer., NOAA Prof. Paper NMFS 13, 97 p.

Nelson, G. A. 2018. Fishmethods: fishery science methods and models. R package version 1.11-0. Available: https://cran.r-project.org/web/packages/fishmethods/fishmethods.pdf.

NPFMC 2020. Fishery Management Plan for the Groundfish of the Gulf of Alaska. North Pacific Fishery Management Council, 1007 West Third, Ste. 400, Anchorage, AK 99501. 152 p. https://www.npfmc.org/wp-content/PDFdocuments/fmp/GOA/GOAfmp.pdf.

Ogle, D. H., P. Wheeler, and A. Dinno. 2018. FSA: fisheries stock analysis. R package version (8): 22. https://github.com/droglenc/FSA.

Omori, K. L., C. A. Tribuzio, and B. Ferriss. 2023. Assessment of the Other Rockfish stock complex in the Gulf of Alaska. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Gulf of Alaska. North Pacific Fishery Management Council, 1007 West Third, Ste. 400, Anchorage, AK 99501.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. ICES J. Mar. Sci. 39(2): 175–192.

Pebesma, E., and R. Bivand. 2023. Spatial Data Science: With applications in R. Chapman and Hall/CRC. https://doi.org/10.1201/9780429459016.

Rooney, S., C. N. Rooper, E. Laman, K. Turner, D. Cooper, and M. Zimmermann. 2018. Model-based essential fish habitat definitions for Gulf of Alaska groundfish species. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-373, 370 p.

Spencer, P. D., and N. Laman. 2023. Assessment of the northern rockfish stock in the Bering Sea/Aleutian Islands. *In* Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea and Aleutian Islands. North Pacific Fishery Management Council, 1007 West Third, Ste. 400, Anchorage, AK 99501

Stabeno, P., N. A. Bond, A. J. Hermann, N. B. Kachel, C. W. Mordy, and J. E. Overland. 2004. Meteorology and oceanography of the northern Gulf of Alaska. Cont. Shelf Res. 24: 859–897.

Stanley, R. D. and A. R. Kronlund. 2005. Life history characteristics for silvergray rockfish (*Sebastes brevispinis*) in British Columbia waters and the implications for stock assessment and management. Fish. Bull. U.S. 103: 670-684.

Starr, P. J., R. Haigh, and C. Grandin. 2016. Stock assessment for silvergray rockfish (*Sebastes brevispinis*) along the Pacific coast of Canada. DFO Can. Sci. Advis. Sec. Res. 170 p.

Stauffer, G. 2004. NOAA protocols for groundfish bottom trawl surveys of the nation's fishery resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/SPO-65, 205 p.

Sullivan, J. Y., C. A. Tribuzio, and K. B. Echave. 2022. A review of available life history data and updated estimates of natural mortality for several rockfish species in Alaska. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-443, 45 p.

TenBrink, T. T., and T. E. Helser. 2021. Reproductive biology, size, and age structure of harlequin rockfish: spatial analysis of life history traits. Mar. Coast. Fish. 13: 463-477.

TenBrink, T. T., C. M. Gburski, and C. E. Hutchinson. 2023. Growth, distribution, and mortality of light dusky Rockfish and harlequin Rockfish in the Aleutian Islands. Mar. Coast. Fish. 15: e10268.

TenBrink, T. T., J. Y. Sullivan, and C. M. Gburski. 2024. Exploring the use of otolith shape analysis to identify the stock spatial structure of dusky rockfish (*Sebastes variabilis*). Fish. Res. 281: 107189.

Then, A. Y., J. M. Hoenig, N. G. Hall, and D. A. Hewitt. 2015. Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. ICES J. Mar. Sci. 72(1): 82–92.

Thorson, J. T., S. B. Munch, J. M. Cope, and J. Gao. 2017. Predicting life history parameters for all fishes worldwide. Ecol. Appl. 27: 2262-2276.

Vihtakari, M. 2024. ggFishPlots: Visualise and calculate life history parameters for fisheries science using ggplot2. https://deepwaterimr.github.io/ggFishPlots.

von Szalay, P. G., and N. W. Raring. 2016. Data report: 2015 Gulf of Alaska bottom trawl survey. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-325, 249 p.

von Szalay, P. G., and N. W. Raring. 2018. Data Report: 2017 Gulf of Alaska bottom trawl survey. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-374, 260 p.

Wickham, H. 2016. ggplot2: elegant graphics for data analysis. Springer-Verlag, New York.

Zar, J. H. 1999. Biostatistical Analysis. 4th ed. Prentice-Hall, New Jersey.

Table 1. -- Total numbers of aged silvergray rockfish (*Sebastes brevispinis*) from the Gulf of Alaska analyzed during this study.

		Sex		Region	
Year	N	Males	Females	East	West
1993	132	65	67	132	
1996	284	149	135	282	2
1999	308	151	157	268	40
2005	81	41	40	61	20
2007	172	76	96	163	9
2009	94	52	42	93	1
2011	442	214	228	338	104
2013	190	97	93	179	11
Total	1703	845	858	1516	187

Table 2. -- Age reader agreement table and associated statistical tests for aged silvergray rockfish (*Sebastes brevispinis*) in this study. Note: Reader refers to the primary age reader; N = number compared within each age class; SD = standard deviation; *t* = test statistic; Adj. *P* = adjusted *P*-value is based on the Holm's-Bonferonni method for multiple comparison testing. Age classes with N ≤ 2 do not have associated statistical tests.

Reader	N	Min	Max	Mean	SD	*t*	Adj. *P*
4	1	6	6	6			
6	1	6	6	6			
8	8	8	9	8.25	0.4639	1.528	1
9	20	8	12	9.35	0.9883	1.584	1
10	27	9	13	10.67	1.0392	3.338	0.0689
11	20	10	14	11.45	1.2343	1.63	1
12	18	11	18	13	2.2231	1.909	1
13	34	10	15	12.97	1.3353	-0.128	1
14	32	11	24	14.16	2.3589	0.375	1
15	24	12	18	15.33	1.4354	1.138	1
16	25	13	19	16.52	1.1950	2.177	0.9891
17	14	16	21	17.07	1.3283	0.201	1
18	8	14	20	17.5	2.2684	-0.624	1
19	10	16	26	19.6	3.1338	0.605	1
20	11	17	23	20.36	1.6285	0.74	1
21	11	15	30	21.18	3.8439	0.157	1
22	11	20	24	22.18	1.5389	0.392	1
23	14	16	31	23.21	3.8277	0.21	1
24	13	20	28	24.69	1.9758	1.264	1
25	16	21	31	25.56	2.7080	0.831	1
26	12	22	34	25.75	4.1604	-0.208	1
27	14	19	33	26.36	4.0485	-0.594	1
28	10	24	30	26.3	2.0586	-2.613	0.7317
29	8	25	32	27.88	2.3561	-1.35	1
30	4	29	31	29.75	0.9580	-0.522	1
31	4	26	33	30	3.1620	-0.632	1
32	4	27	34	29.75	2.9860	-1.507	1
33	3	27	68	41	23.388	0.592	1
34	2	30	32	31			
35	4	23	39	30.25	7.1820	-1.323	1
37	2	35	39	37			
38	2	39	42	40.5			
39	1	39	39	39			
41	1	45	45	45			
45	2	40	54	47			
48	1	48	48	48			

49	1	51	51	51
51	1	46	46	46
52	2	55	56	55.5
53	2	52	75	63.5
58	1	66	66	66
66	2	70	70	70
67	2	66	69	67.5
71	1	58	58	58
72	1	55	55	55

Table 3. -- Parameter estimates (mean ± 95% CI) for the von Bertalanffy growth function for silvergray rockfish (*Sebastes brevispinis*), according to sex and region. L_∞= asymptotic length; *K* is a growth coefficient, and t_0 is theoretical age at length 0 cm. Note: estimates are based on age-length key analysis calculated from the aged samples. WGOA = western Gulf of Alaska; EGOA = eastern Gulf of Alaska.

Data	L_{inf} (cm)	*K*	t_0	*N*
Combined	57.32 (56.91, 57.73)	0.091 (0.087, 0.098)	-5.163 (-6.018, -4.312)	7521
Males	54.44 (54.08, 54.79)	0.121 (0.113, 0.129)	-2.810 (-3.681, -2.008)	4190
Females	61.26 (60.47, 62.15)	0.069 (0.063, 0.077)	-7.679 (-9.392, -6.262)	3331
Combined - WGOA	68.37 (65.51, 71.79)	0.062 (0.052, 0.072)	-5.650 (-7.593, -4.016)	422
Males - WGOA	64.59 (60.13, 69.91)	0.075 (0.057, 0.101)	-3.865 (-6.456, -1.502)	224
Females - WGOA	70.52 (66.55, 75.11)	0.054 (0.043, 0.068)	-6.965 (-9.928, -4.495)	198
Combined - EGOA	57.39 (56.98, 57.80)	0.089 (0.083, 0.095)	-5.817 (-6.860, -4.893)	7099
Males - EGOA	54.52 (54.16, 54.91)	0.115 (0.107, 0.124)	-3.542 (-4.540, -2.595)	3966
Females - EGOA	61.31 (60.38, 62.33)	0.068 (0.060, 0.076)	-8.376 (-10.322, -6.642)	3133

Table 4. -- Results of likelihood ratio tests to assess differences in von Bertalanffy growth curves between silvergray rockfish (*Sebastes brevispinis*) based on sex and region. Bold denotes statistical significance ($P < 0.05$). Note: analyses based on comparing combined datasets.

Model	Tests	Hypothesis	Chi sq	*P*-value
Sex	H0 vs H1	Linf1=Linf2	3.61	0.057
	H0 vs H2	K1=K2	0.09	0.764
	H0 vs H3	t01=t02	0.02	0.888
	H0 vs H4	Linf1-Linf2, K1=K2, t01=t02	27.33	**0.000**
Region	H0 vs H1	Linf1=Linf2	1.85	0.174
	H0 vs H2	K1=K2	1.14	0.286
	H0 vs H3	t01=t02	2.21	0.137
	H0 vs H4	Linf1-Linf2, K1=K2, t01=t02	19.46	**0.000**

Table 5. -- Estimates of natural mortality (*M*) for silvergray rockfish (*Sebastes brevispinis*) from selected empirical methods.

Method	*M*
Then et al. 2015 LM	0.066
Then et al. 2015 NLS	0.087
Hamel 2015 age	0.067
Hamel 2015 growth	0.093
FishLife	0.046
Mean	0.07

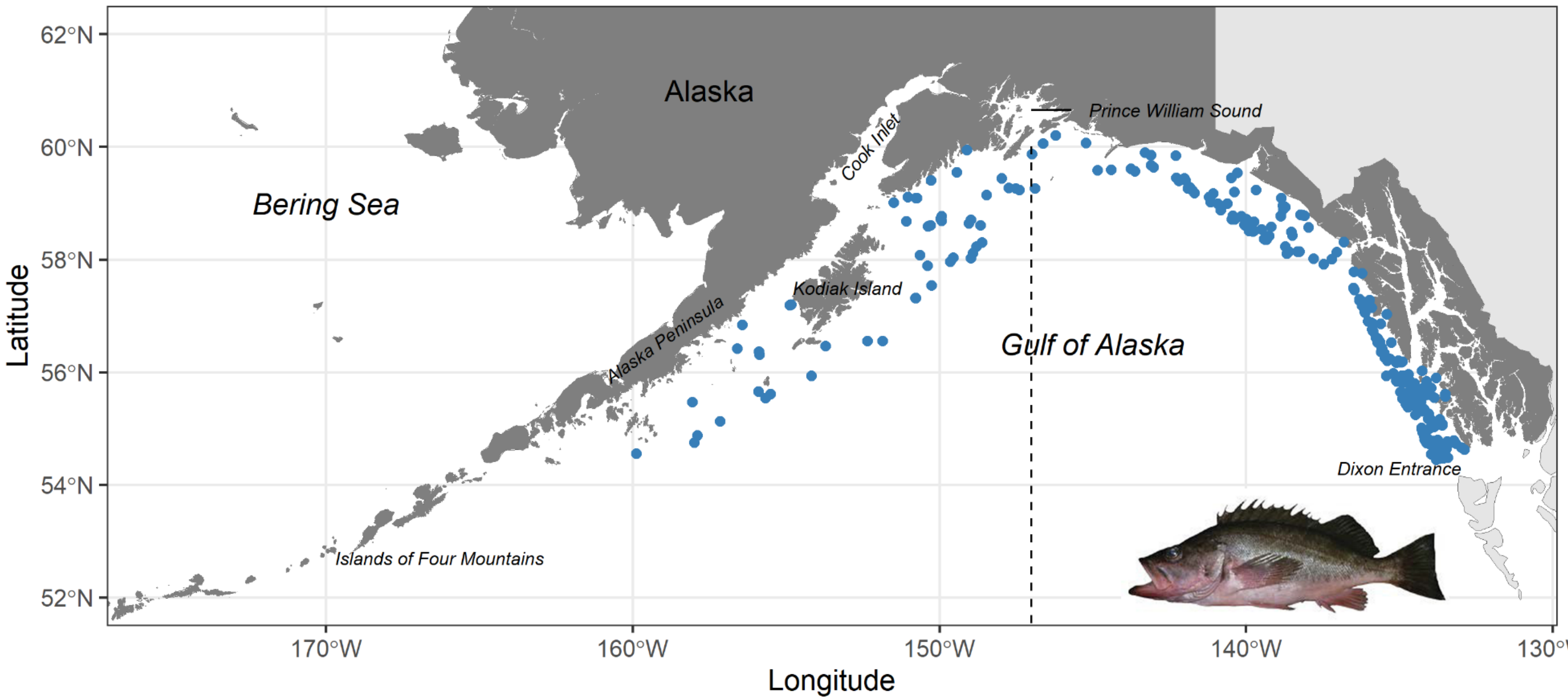


Figure 1. -- Map of sampling locations (blue) in the Gulf of Alaska of silvergray rockfish (*Sebastes brevispinis*) in this study. The dashed line represents the ecological boundary between eastern and western Gulf of Alaska (147°W; Stabeno et al. 2004, Coffin and Meuter 2016) used to investigate spatial differences in age and growth parameters.

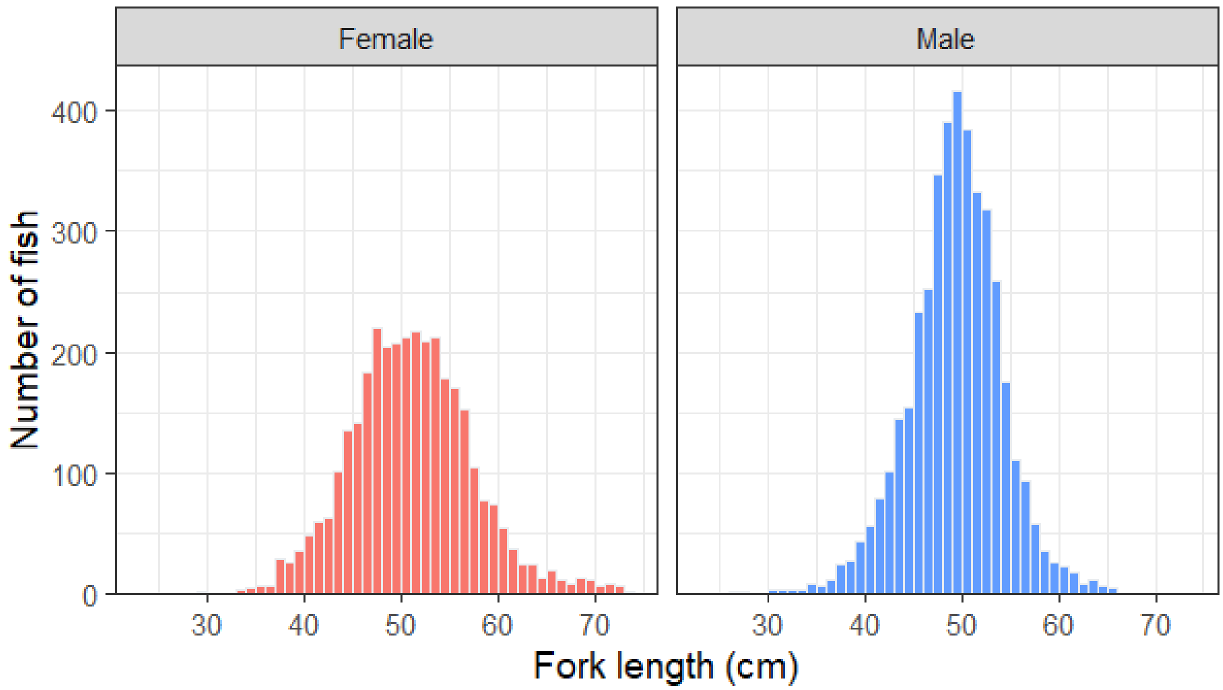


Figure 2. -- Length compositions by sex of silvergray rockfish (*Sebastes brevispinis*) used in this study.

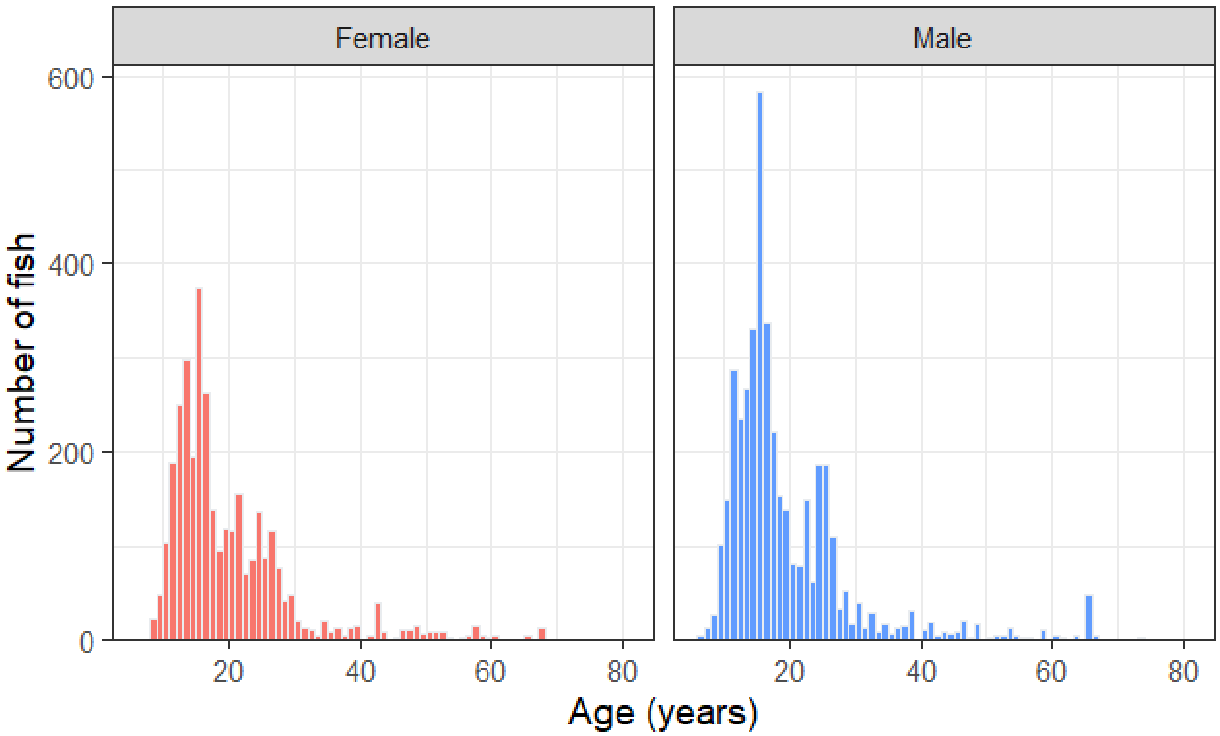


Figure 3. -- Age compositions by sex of silvergray rockfish (*Sebastes brevispinis*) used in this study, based on age-length key analysis.

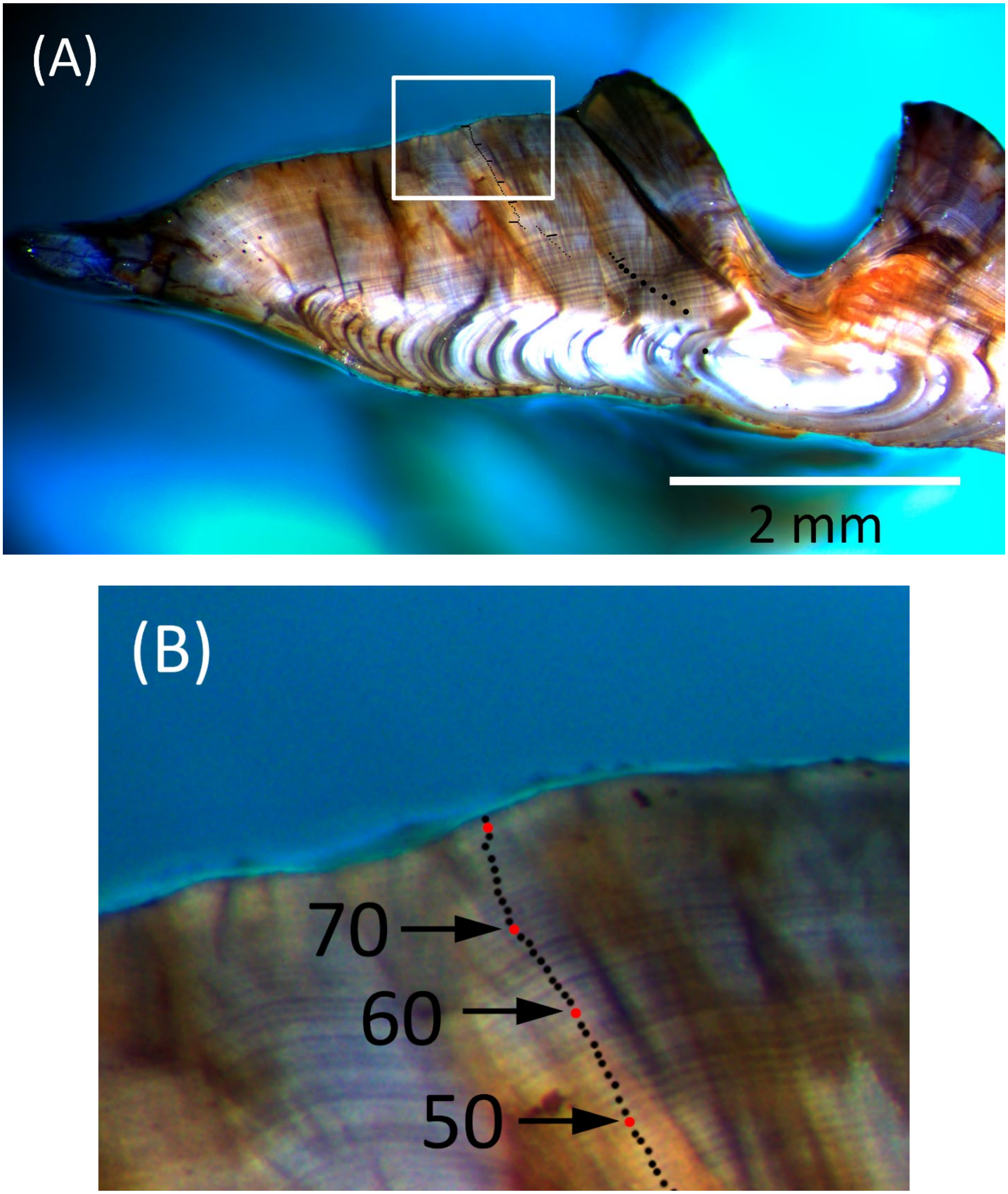
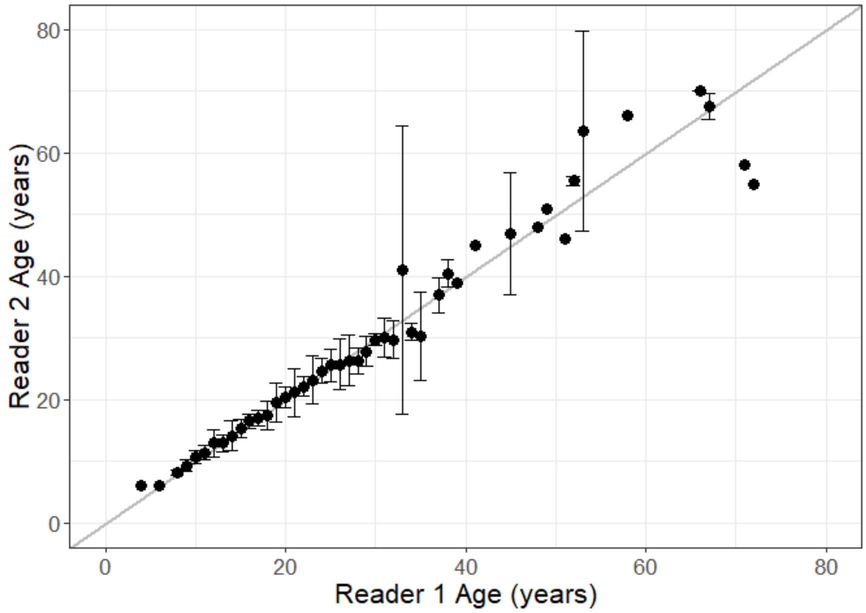


Figure 4. -- Image of the oldest silvergray rockfish (*Sebastes brevispinis*) in this study (81 years). A) view of otolith after preparation; and B) inset of the final 30+ years showing the annotated resolved age, based on three independent ages of 79, 81, and 83 years.



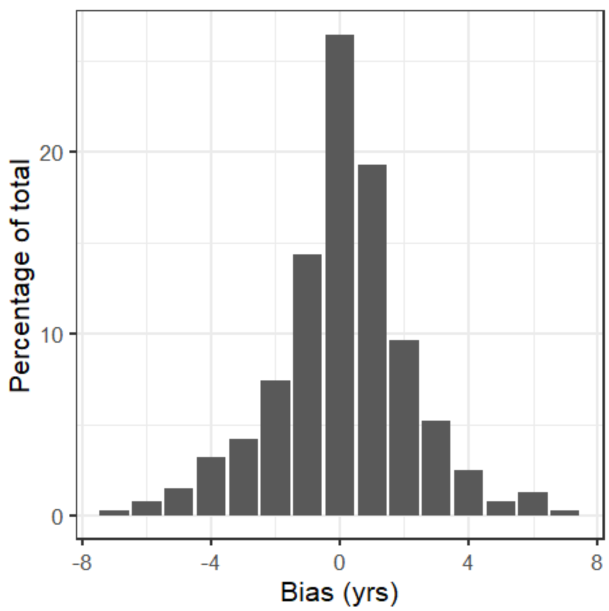


Figure 5. -- Top: Bias plot showing the precision between two age readers for all silvergray rockfish (*Sebastes brevispinis*) tested (n = 405). The 1:1 linear line represents agreement (± 0 years) between age readers. Error bars indicate ±1 standard deviation (SD). Bottom: Relative bias (± 8 years) for all samples combined (agreement = 26.42% of total).

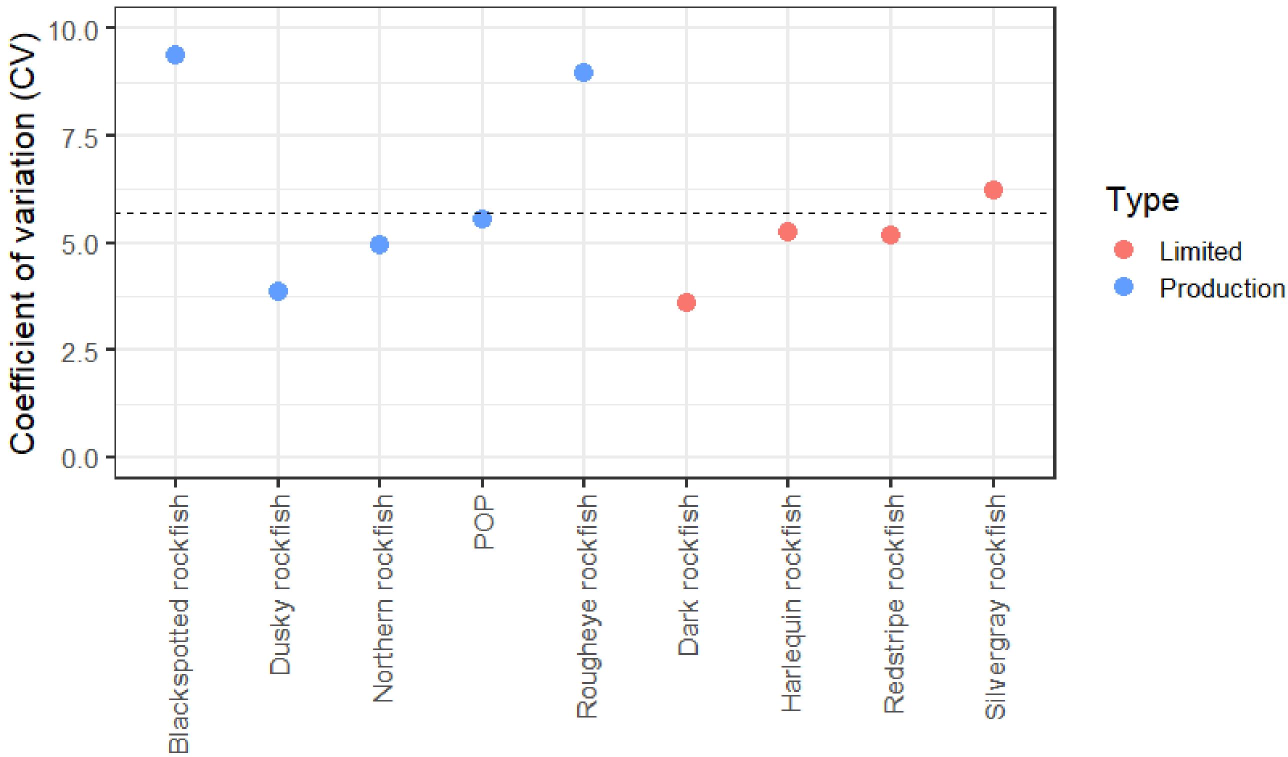


Figure 6. -- Historical comparison of the precision metric, coefficient of variation (CV; 2000 – 2023), of aged rockfish from the Age and Growth Program at the Alaska Fisheries Science Center (AFSC). Species are divided by type, which are the production-aged species that are given higher priority for ageing due to their importance in stock assessments, and those that have a limited number of recorded ages. The dashed line represents the combined overall mean CV for all rockfish ages with paired readings (n = 26,240; 2000 – 2023). Silvergray rockfish (*Sebastes brevispinis*) is listed at the far right.

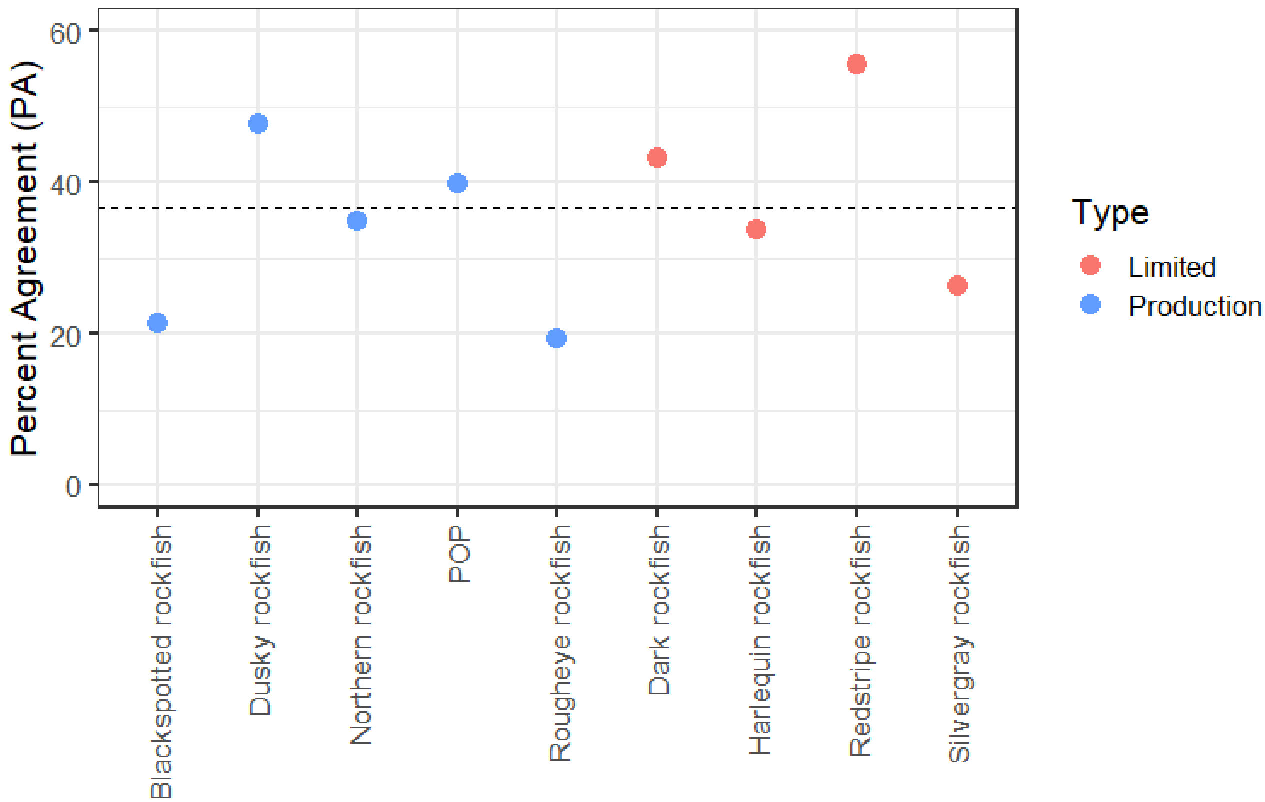


Figure 7. -- Historical comparison of the precision metric, percent agreement (PA; 2000 – 2023), of aged rockfish from the Age and Growth Program at the Alaska Fisheries Science Center (AFSC). Species are divided by type, which are the production-aged species that are given higher priority for ageing due to their importance in stock assessments, and those that have a limited number of recorded ages. The dashed line represents the combined overall mean PA for all rockfish ages with paired readings (n = 26,240; 2000 – 2023). Silvergray rockfish (*Sebastes brevispinis*) is listed at the far right.

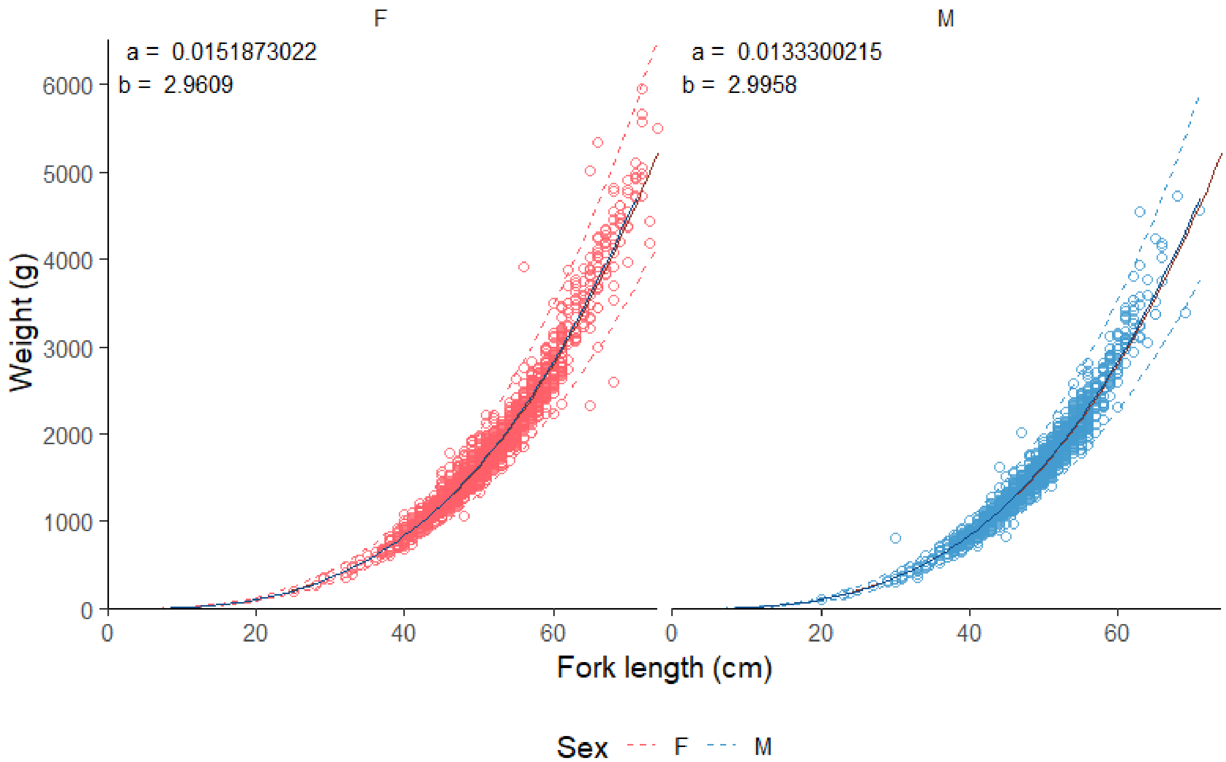


Figure 8. -- Length-weight relationships by sex for silvergray rockfish (*Sebastes brevispinis*) based on non-linear least square models. Parameters of the model (a, b) are included for each sex. Dashed-lines indicate the 95% confidence intervals.

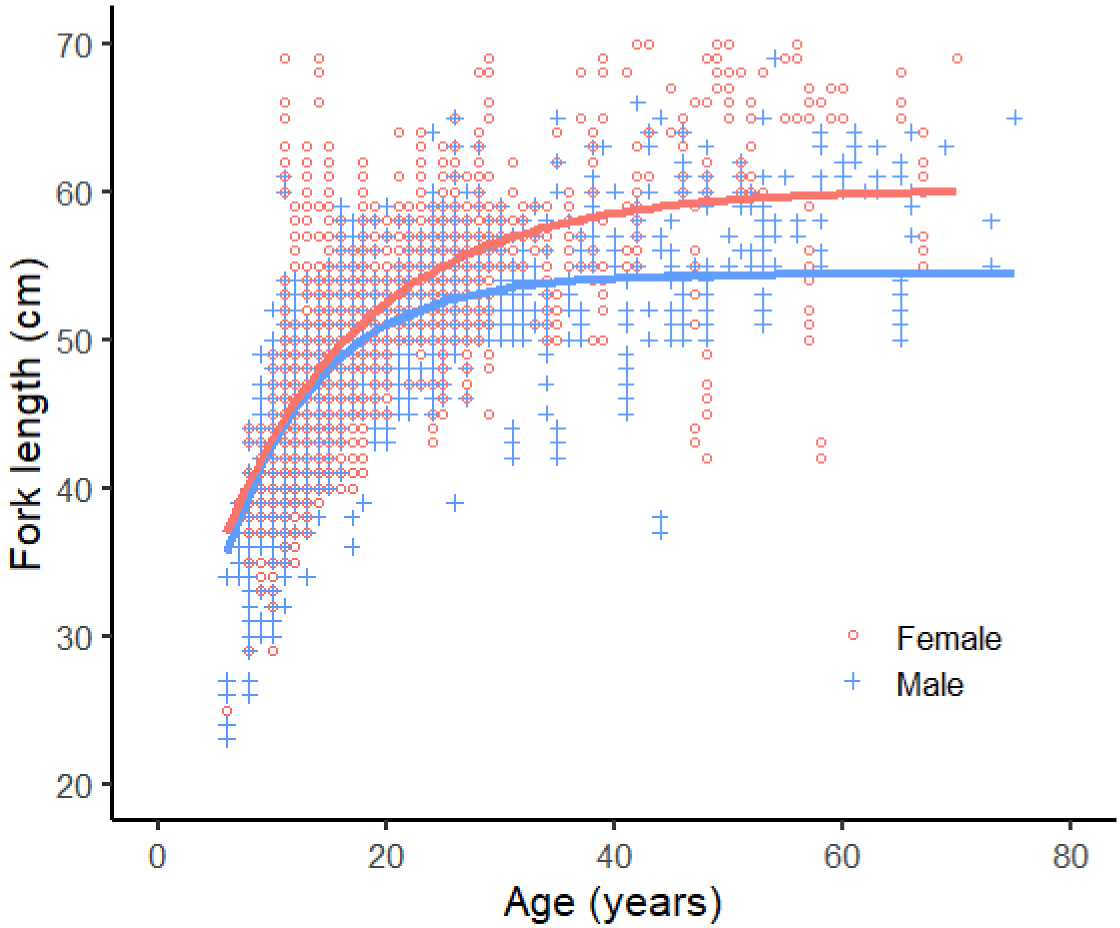


Figure 9. -- Plot of von Bertalanffy growth curves by sex of combined length at age data for silvergray rockfish (*Sebastes brevispinis*).

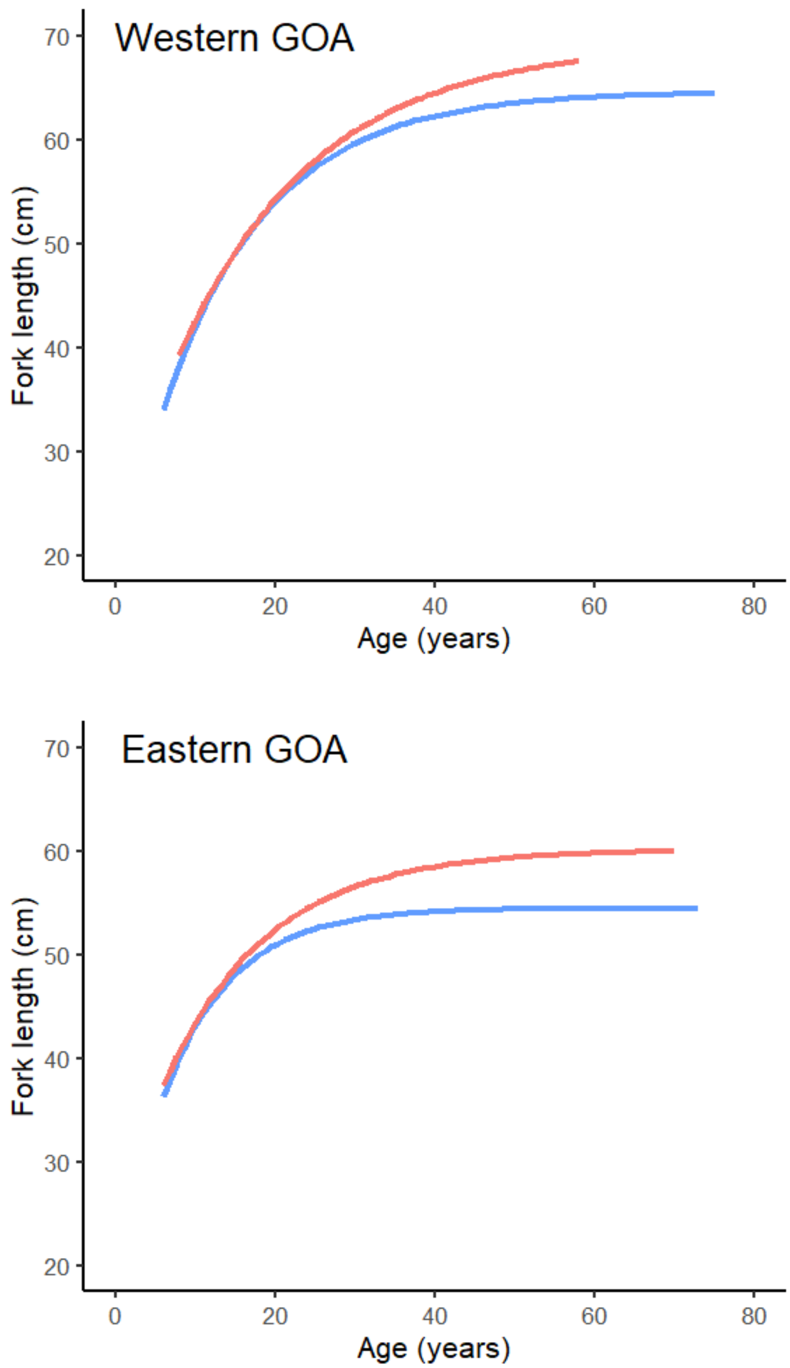


Figure 10. -- Plots of von Bertalanffy growth curves by Gulf of Alaska (GOA) region of length at age data for silvergray rockfish (*Sebastes brevispinis*). Females = red; Males = blue.

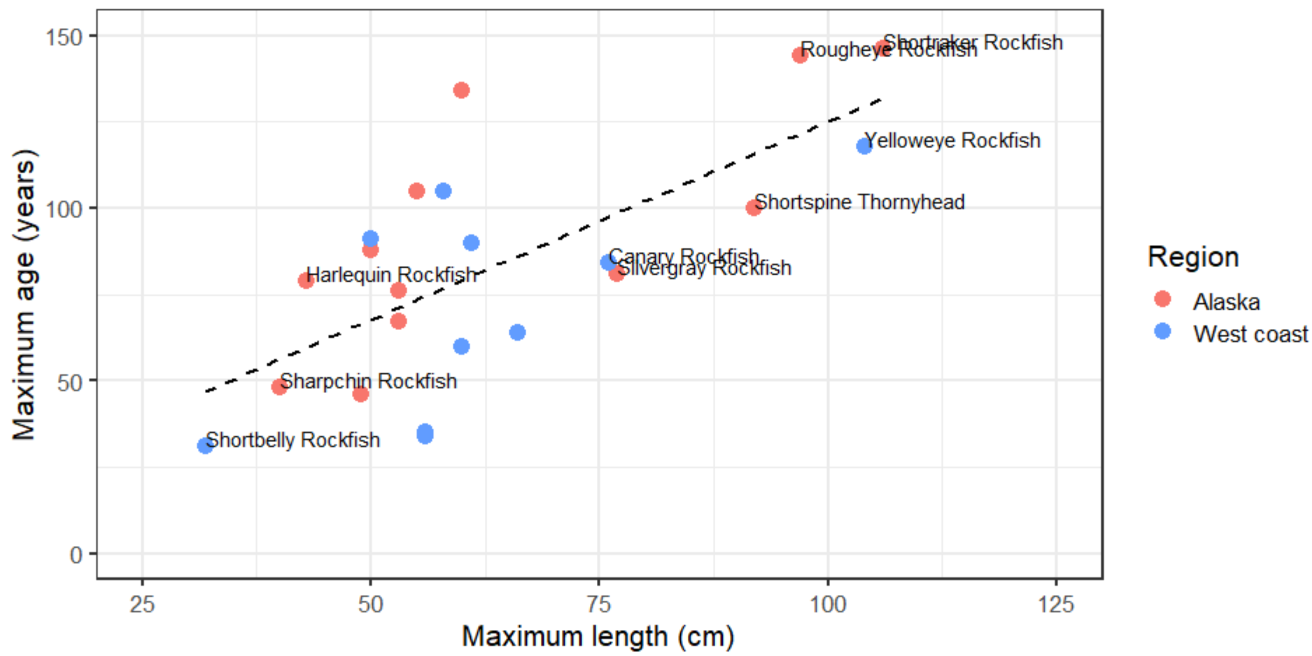


Figure 11. -- Life history variation along the small-large continuum showing the bivariate relationship between maximum length and maximum age across selected rockfish species of Alaska and the U.S. West Coast. Silvergray rockfish appears next to canary rockfish with a maximum length and age of 77 cm and 81 years, respectively. Note: Although there may be species with overlapping ranges (e.g., shortspine thornyhead), the data are specific to that region.

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