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WCPFC Projects 117 & 118:
The Development Of Biological Sampling Plans For Tuna & Billfish

WCPFC Projects 125 & 126

Billfish biology & Optimised sampling for shark biological data collection

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Executive summary

Biological sampling underpins the stock assessments of tuna and billfish in the Western and Central Pacific Ocean (WCPO), both in informing external estimates of biological parameters that are then used as an input to assessment models, or informing the assessment model directly as data inputs.

In this context, WCPFC SC recommended the development of biological sampling plans for tuna, billfish and shark species to help guide collections. Given the need to continually collect biological samples, and some of the significant gaps across size and spatial strata, such plans will need to be highly collaborative.

The Scientific Services Provider convened an online meeting with interested parties in October 2024 to discuss potential approaches to developing the biological sampling plans. Following discussions at the meeting it was proposed that: the development of the sampling plan should take an iterative approach, starting with a relatively simple power analysis building on the approach used to develop sampling plans for North Pacific billfish; the method be developed initially for two tuna species with differing life history and fisheries characteristics; an initial sampling plan be presented at WCFPC SC21; future work should continue to define priority hypotheses regarding life history parameters.

This Working Paper summarises the power analysis that was applied to skipjack and bigeye, parameterised from the 2022 and 2023 stock assessments respectively, focussed on estimation of growth. Proportional Otolith Sampling generally resulted in minimal bias in estimates of growth rate parameters, whereas Fixed Otolith Sampling resulted in systematic overestimation of the size of the oldest fish. The results of the power analysis are then used to scope out a biological sampling plan, focussed on the estimation of growth rates, with consideration of maturity.

The findings of this work have implications for the sampling plans of tuna, billfish and sharks, and hence this report represents an output for the four related SC Projects 117, 118, 125 and 126.

With regards Project 125, activity since project formalisation in March 2025 has focussed on preparation of course material to be pursued once SC21 guidance is provided to Project 118.

With regards Project 126, a no cost extension will be required to develop the sampling plan for sharks. SC21 guidance provided to Projects 117 and 118 will guide this plan development.

Finally, we note that for billfish and sharks, while an optimum sampling design may be developed, there will remain challenges in implementing the design given the practical limitations of observer coverage in the face of the encounter rates of what are often bycatch species, and non-retention management interventions for some sharks.

Introduction

The Western and Central Pacific Ocean has accounted for over 50% of the global tuna catch in recent years (Williams & Ruaia, 2023), with tuna fisheries in the region making substantial contributions to the economies of Pacific Island countries and territories (Ruaia et al., 2020). WCPFC supports the collection and storage of biological samples through the WCPFC Pacific Marine Specimen Bank (PMSB), which as of 30 June 2024 had samples collected from 100,000+ individuals covering more than 160 species ranging from micronekton through to tuna and billfish (SPC-OFP, 2023). However, there is no formal sampling plan for the PMSB, with samples collected on a more opportunistic basis primarily by observers and port samplers, as well as SPC-led tagging cruises. The collection of representative biological samples underpins the effective management of tuna and tuna-like species in the region.

In this context, WCPFC SC19 and SC20 recommended the development of biological sampling plans for tuna, billfish and shark species. Given the need to continually collect biological samples, and some of the significant gaps across size and spatial strata, such plans will need to be highly collaborative. The Pacific Community held an online meeting in October 2024 with interested parties to discuss the potential approaches that could be taken for developing a biological sampling plan for WCPO tuna, billfish and shark species, and to agree on the necessary specifics and potential priorities. Following the discussions of the online meeting, it was proposed that:

1. Design of biological sampling plans should take an iterative approach, focused initially on relatively simple power analyses building on the approach used for North Pacific billfish species (Kinney et al., 2023) and focussed primarily on estimation of growth curves, with consideration of maturity.
2. The method be developed initially for two tuna species with differing life history and fisheries characteristics, including selectivity shapes for key fisheries.
3. An initial sampling plan be presented at WCFPC SC21.
4. Defining the priority hypotheses regarding life history parameters should be continued over a longer period of time, to inform sampling plans tailored to the specific needs of each species.

In this report, we summarise the power analysis conducted to support development of the initial sampling plan, as well as the existing data holdings in the Pacific Marine Specimen Bank.

Power analysis

As described in the Introduction, a power analysis was conducted to support the development of sampling plans for tuna, billfish and shark species in the WCPFC. There are a range of studies that provide guidance on sampling approaches and sample sizes in the literature which could be used to support development of the sampling plan (e.g., Goodyear, 2019). However, there is also recognition that the optimal sampling design depends on the specifics of the species and fishery in question. As such, a power analysis exercise was undertaken, applied to two tuna species with varying life history characteristics and which are exploited by different fisheries.

Method

The power analysis was conducted using a simulation modelling framework, consisting of an operating model and estimation model, implemented in *R* version 4.4.1 (R Core Team, 2024). The operating model, representing the underlying population and associated fisheries, was parameterised using

MFCL input and output files from the most recent skipjack (Castillo Jordán et al 2022) and bigeye assessments (Day et al 2023). The operating model for skipjack was parameterised using information from the last five years of the assessment (2017 to 2021), with the last three years used for bigeye (2019 to 2021). The estimation model represents the sampling of catch and estimation of von Bertalanffy growth parameters. The inputs to the operating model, and examples of simulated catches and age-length samples are provided in the Appendix (Figure 5Figure 5 to Figure 12Figure 12).

The following were calculated from the MFCL files, taking the mean across the time period of parameterisation:

1. Numbers at-age per assessment model region, quarter, $n_{r,j,a}$ where subscripts r, j and a represent region, quarter and age-class respectively (Figure 6Figure 6 & Figure 12Figure 12).
2. The probability of a fish of age-class a being in length class l, $p_{a,l}$, estimated from the assessment's von Bertalanffy growth curve, including the assumed relationship between age class and the standard deviation of length at age (Figure 5Figure 5 & Figure 11Figure 11).
3. The numbers by age-class and length class, per region and quarter, $N_{r,j,a,l}$, calculated deterministically from 1. and 2. (Figure 6Figure 6 & Figure 12Figure 12).
4. Fishery (f) specific effort per quarter, $E_{f,j}$
5. Fishery specific selectivity at age, $s_{f,a}$, scaled to have a maximum of 1 (Figure 7Figure 7 & Figure 13Figure 13).
6. Fishery-specific catchabilities ($q_{f,j}$) required to recover the reported catch tonnage (per quarter).
7. Probability of capture of a fish per age-class, $\rho_{f,j,a}$, calculated as function of catchability, selectivity and effort, where $\rho_{f,j,a} = q_{f,j} s_{f,a} E_{f,j}$

The following steps were then undertaken 100 times, to obtain 100 sets of conditional age-at-length data and a corresponding set of estimated von Bertalanffy growth parameters:

8. Draw replicates of catch (individuals) per age class and length class, $C_{f,r,j,a,l}$ from numbers per age class and length class, by taking a random draw from the binomial distribution $B(N_{r,j,a,l}\,,\ \rho_{f,j,a})$
9. Across fisheries where sampling was assumed to occur, calculate the total estimated catch per age and length class, $C^s_{a,l} = \sum_{f,r,j} C_{f,r,j,a,l}$ (Figure 9Figure 9, Figure 15Figure 15).
10. Apply both fixed otolith sampling (FOS) and proportional otolith sampling (POS) to the catch data replicate for fisheries with sampling, by drawing samples at random from age and length class specific catch data ($C^s_{a,l}$) to achieve the target sampling rate (Figure 10Figure 10 & Figure 16Figure 16). This implicitly assumes no errors in ageing.
11. For both FOS and POS samples, fitting a von Bertalanffy model to the conditional age at length data using the *R* package TMB (Kristensen et al., 2016; Figure 10Figure 10 & Figure 16Figure 16).

The estimated growth curves and growth curve parameters were then compared against the 'true' values used to parameterise the operating model. There were 54 2cm length classes for skipjack, covering the size range 2 to 110cm, with 16 quarterly age classes (1 to 16 quarters). For bigeye, there were 33 6cm length classes, covering the size range 6 to 204cm, with 40 quarterly age classes (1 to 40 quarters). Target sampling rates were: 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12 and 15 samples per length class.

This process was repeated with selectivities defined as a function of length rather than age ($v_{f,l}$), by taking the weighted mean of the selectivities at age (weighted by the numbers at age in the population). Catchabilities for length-based selectivities were re-estimated to preserve the total estimated catch per fishery (Figure 8~~Figure 8~~ & Figure 14~~Figure 14~~).

Skipjack fisheries with sampling were assumed to be the 'all-flag' purse seine fisheries in regions 5 to 8 (fishery IDs 14, 15, 29, 20, 25, 26, 29 & 30 from Castillo Jordán et al 2022). Bigeye fisheries with sampling were assumed to be a selection of major longline fisheries in regions 1 to 9 (fishery IDs 1 to 12 and 27 from Day et al 2023), and 'all-flag' purse seine fisheries in regions 3, 4 and 8 (fishery IDs 13 to 16, 25 and 26 from Day et al 2023).

Results & Discussion

For skipjack, Fixed Otolith Sampling resulted in systematic bias in von Bertalanffy parameter estimates and growth curves, with an overestimation of mean length for fish older than 3 quarters and vice versa, when selectivities were a either a function of age (Figure 1~~Figure 1~~) or length (Figure 2~~Figure 2~~). Proportional Otolith Sampling resulted in unbiased estimates of von Bertalanffy parameters for skipjack when selectivities were a function of age (Figure 1~~Figure 1~~). However, Proportional Otolith Sampling resulted in systematic bias in estimates of von Bertalanffy parameters when selectivities were a function of length, though the bias was relatively weak in comparison to that resulting from Fixed Otolith Sampling (Figure 2~~Figure 2~~).

For bigeye, Fixed Otolith Sampling also resulted in systematic bias in von Bertalanffy parameter estimates and so growth curves, with an overestimation of mean length for fish older than 10 quarters and vice versa, when selectivities were either a function of age (Figure 3~~Figure 3~~) and length (Figure 4~~Figure 4~~). Proportional Otolith sampling resulted in unbiased estimates of von Bertalanffy parameters for bigeye when selectivities were a function of age (Figure 3~~Figure 3~~), with a relatively weak bias when selectivities were a function of length (Figure 4~~Figure 4~~).

Fixed Otolith Sampling resulted in more precise estimates of growth rate parameters and growth curves than Proportional Otolith Sampling for both species and both approaches to assumed selectivities (Figure 1~~Figure 1~~ to Figure 4~~Figure 4~~), though as described above the estimates were also systematically biased. We note that, for both species, Proportional Otolith Sampling also resulted in less biased, or in some cases unbiased, estimates of the relationship between the standard deviation of length-at-age and age-class (not provided).

For a given sampling rate, expressed as an average samples per length class, estimated growth curves for bigeye were more precise than for skipjack, despite there being fewer length classes for bigeye (33, compared to 54 for skipjack). This reflects the weaker variation in the assumed distributions for length at age for bigeye (Figure 5~~Figure 5~~) compared to skipjack (Figure 11~~Figure 11~~).

There was a relatively limited increase in precision of parameter estimates with effective sampling rates greater than 5 individuals per length class, equating to 165 total samples for bigeye and 270 samples for skipjack. These sampling rates are broadly in line with guidance in the literature, ranging from 200 to 500 samples (e.g., Kritzer et al., 2001; Brouwer & Griffiths, 2005; Chang et al., 2019; Schemmel et al., 2022).

With selectivities as a function of length, the stronger systematic bias in von Bertalanffy parameters for skipjack with Proportional Otolith Sampling (relative to bigeye) appears to be due to samples from the youngest age classes, which have a larger average size in the catches relative to the underlying population (i.e., the fastest growing individuals are selected at a younger age). For skipjack, samples were drawn from purse seine catches, which have relatively high selectivities for small fish and vice versa (Figure 8~~Figure 8~~). In contrast, for bigeye samples were also drawn from longline fisheries which select larger fish (Figure 14~~Figure 14~~), resulting in a lower proportion of samples from small bigeye.

Proportional Otolith Sampling performed markedly better than Fixed Otolith Sampling for both skipjack and bigeye, regardless of whether selectivities are a function of length or age. This suggests that the size composition of catches are sufficiently representative of the population (Schemmel et al., 2022), regardless of whether selectivities were predominantly dome shaped, rather than of a logistical form.

The strength of bias resulting from Fixed Otolith Sampling may reflect the fact that samples were drawn from all length classes in the catch, if there were sufficient individuals to sample, resulting in samples from length classes that are very rarely observed in reality. As such, the realised performance of Fixed Otolith Sampling may not be as poor as suggested in the power analysis.

Biological sampling plan

Introduction

The proposed approach is to collect samples by observers across the relevant fleets in order to achieve proportional representation of the catch by fleet, within predetermined strata. The biological sampling plan should provide sufficient information to obtain robust estimates of growth curves and maturity schedules for each species, and provide sufficient information to test for differences between sex. Additionally, the samples should provide sufficient information to test for broad-scale spatial variation in these processes (e.g., Williams et al., 2012), which will be helpful in informing sampling requirements to explore more detailed hypotheses of spatial variation in the future. Finally, the collection of all sample types from all fish would provide a powerful "paired" dataset for future studies related to the biology of tuna, billfish and shark species in the WCPFC.

We note that the biological sampling plan is intended to support independent estimation of growth and maturity parameters, i.e., external to stock assessments. These can then be used to validate estimates from stock assessments.

Sampling approach

Proportional Otolith Sampling is the recommended approach for application to WCPFC tuna and billfish samples given its superior performance over Fixed Otolith Sampling in the power analysis regardless of species, and whether selectivities are assumed to be a function of age or length, as well as the difficulties in implementing other sampling approaches (e.g., Random Otolith Sampling). This is consistent with earlier studies applied to a range of species (e.g., Chang et al, 2019, Goodyear, 2019), as well as the sampling design for North Pacific billfish (Kinney et al., 2023).

Proportional Otolith Sampling relies on information on the length composition of the catch, in order to allocate the target sample size amongst the length classes. Length compositions of tuna and tuna like species typically exhibit both spatial and temporal variation in size compositions, at least in cases where sufficient size samples are available (e.g., Teears et al., 2024). In this context, we propose calculating an overall size composition from available samples based on the last 5 years (2019 – 2023, to allow sufficient time for submission of longline size data). This reflects the assumption that this should provide a sufficiently accurate estimate of length compositions during the time period of sampling such that any biases would be less than those expected with Fixed Otolith Sampling.

The power analysis results suggest a target sample size in the region of 200 to 250 for estimation of growth curves, which is broadly in line with target sample sizes in the literature which range from 200 – 500 (see discussion in the Power analysis section). Following Kinney et al. (2023), a target sample size of 300 would appear to be appropriate. These samples should be allocated between sexes to allow testing of variation in growth rates between sex. As a general rule, the target number of samples in each length class should be spit 50:50 between the two sexes. For length classes with a target sample size of one, we recommend that this be assigned to either sex at random.

The target sample sizes should be specific to coarse spatial strata, i.e., a target of 300 samples to be collected from each area. Assessment regions from the latest assessment, or that of a proxy species, represents a pragmatic approach to defining spatial strata. This should allow sufficient samples to explore spatial variation in growth at a broad-scale, and also collect information that should be helpful to design sampling plans to test more detailed hypotheses in the future. Within each area, we recommend that the target sample size be distributed amongst the corresponding fleets broadly in proportion to their catch. This should ensure that the spatial distribution of samples within each spatial strata is reflective of the spatial distribution of the population. The catch proportions per fleet should be calculated over the same time period used to estimate the length composition of catches, i.e.., 2019 – 2023).

The estimation of maturity will require additional samples of smaller individuals to be collected, to ensure sufficient samples of immature fish. Following Kinney et al. (2023), we recommend collection of samples specifically for maturity estimation for length classes up to ⅔ L_{∞} to ensure a minimum of 10 samples per length class. The lower size limit for these supplemental samples is less influential; the smallest length class requiring a sample for estimation of growth represents a pragmatic solution.

As noted above, we recommend that observers are responsible for the sampling effort. The power analysis assumed that sampling was restricted to large scale purse seine and longline fisheries in the WCPFC Convention Area. This, in combination with sampling by observers, implies that there would be no sampling effort directed at domestic fisheries in the WCPFC Convention Area. These domestic fisheries represent an appreciable proportion of total catches of tuna in the Convention Area, and operate in a geographically distinct region (the Western Pacific East Asia region, WPEA). The collection of samples from these fisheries would allow for a more complete spatial coverage of sampling effort, and in doing so allow for testing whether growth curves in the WPEA region western sector differ to the rest of the WCPFC Convention Area. This additional sampling effort could build on existing sampling capacity in the WPEA region (e.g., see CSIRO et al, 2025).

An alternative approach would be to collect a pre-determined number of samples across all the key fleets, again using Proportional Otolith Sampling with samples also distributed in proportion to the catch. This would result in a larger and more comprehensive bank of otoliths and fin spines, which could then be subsampled appropriately (and processed) to estimate WCPO-level growth curves, or subsampled (and processed) for testing of a wide range of hypotheses on variability in growth curves.

Project 125: Biology of South Pacific striped marlin, blue marlin, black marlin, shortbill spearfish and sailfish in the WCPO from longline fisheries

Activity since project formalisation in March 2025 has focussed on preparation of course material once SC21 guidance is provided to Project 118.

Project 126: Developing a statistically robust and spatial/temporal optimized sampling strategy for biological data collection

A no cost extension will be required to develop the sampling plan for sharks. SC21 guidance provided to Project 117 and 118 will guide this plan development.

Current biological samples held in the PMSB for sharks are limited to 522 (collected from 275 individuals) with sparse representation temporally and spatially. A sampling programme for shark species would essentially need to commence from scratch.

References

Anon. 2023. Report of the 19th Regular Session of the Scientific Committee of the Western and Central Pacific Fisheries Commission. 16–24 August 2023, Koror, Palau.

CSIRO, Indonesia, Philippines, Vietnam, SPC. 2025. Understanding connectivity of key tuna species in the Western Pacific and East Asia region with the WCPFC Convention Area: results of Project 128. WCPFC-SC21-2025/SA-WP-13.

Brouwer, S. L., & Griffiths, M. H. (2005). Influence of sample design on estimates of growth and mortality in *Argyrozona argyrozona* (Pisces: Sparidae). *Fisheries Research*, **74(1-3)**, 44-54.

Castillo Jordán, C., Teears, T., Hampton, J., Davies, N., Scutt Phillips, J., McKechnie, S., Peatman, T., MacDonald, J., Day, J., Magnusson, A., Scott, R., Scott, F., Pilling, G., Hamer, P. 2022. Stock assessment of skipjack tuna in the western and central Pacific Ocean: 2022. WCPFC-SC18-2022/SA-WP-01.

Chang, Y. J., Hsu, J., Shiao, J. C., Chang, S. K. 2019. Evaluation of the effects of otolith sampling strategies and ageing error on estimation of the age composition and growth curve for Pacific bluefin tuna *Thunnus orientalis*. *Marine and Freshwater Research*, **70(12)**, 1838-1849.

Day, J., Magnusson, A., Teears, T., Hampton, J., Davies, N., Castillo Jordán, C, Peatman, T., Scott, R., Scutt Phillips, J., McKechnie, S., Scott, F., Yao, N., Natadra, R., Pilling, G., Williams, P., Hamer, P. 2023. Stock assessment of bigeye tuna in the western and central Pacific Ocean: 2023. WCPFC-SC19-2023/SA-WP-05.

Farley, J., Krusic-Golub, K., Eveson, P., Clear, N., Roupsard, R., Sanchez C., Nicol, S., Hampton, J. 2020. Age and growth of yellowfin and bigeye tuna in the western and central Pacific Ocean from otoliths. WCPFC-SC16-2020/SA-WP-02.

Goodyear, C. P. (2019). Modeling growth: consequences from selecting samples by size. *Transactions of the American Fisheries Society*, **148(3)**, 528-551.

Kinney, M., Chang, Y., Ijima, H., Kanaiwa, M., Schemmel, E., O'Malley, J. 2023 Length-Based Proportional Sampling for Life History Research: Establishing Uniform Sampling for North Pacific Billfish Species. WCPFC-SC19-2023/SA-IP-11.

Kristensen, K., Nielsen, A., Berg, C.W., Skaug, H., Bell, B.M. 2016. TMB: Automatic Differentiation and Laplace Approximation. Journal of Statistical Software, 70(5), 1-21. doi:10.18637/jss.v070.i05

Kritzer, J. P., Davies, C. R., Mapstone, B. D. 2001. Characterizing fish populations: effects of sample size and population structure on the precision of demographic parameter estimates. *Canadian Journal of Fisheries and Aquatic Sciences*, **58(8)**, 1557-1568.

R Core Team. 2024. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>.

Ruaia, T., Gu'urau, S., Reid, C. 2020. Economic and development indicators and statistics: Tuna fisheries of the Western and Central Pacific Ocean. Forum Fisheries Agency (FFA), Honiara.

Schemmel, E., Bohaboy, E. C., Kinney, M. J., O'Malley, J. M. 2022. An assessment of sampling approaches for estimating growth from fishery-dependent biological samples. *ICES Journal of Marine Science*, **79(5)**, 1497-1514.

Senina, I., Lehodey, P., Calmettes, B., Nicol, S., Caillot, S., Hampton, J., Williams, P. 2015. SEAPODYM application for yellow tuna in the Pacific Ocean. Western and Central Pacific Fisheries Commission Scientific Committee, Information Paper. WCPFC-SC11-2015/EB-IP-01.

SPC-OFP. 2023. Project 35b: WCPFC Pacific Marine Specimen Bank. WCPFC-SC19-2023/RP-P35b-01.

Teears, T., Hampton, J., Peatman, T., Vidal, Williams, P., Xu, H., Hamer, P. 2024. Background analyses for the 2024 South Pacific stock assessment. WCPFC-SC20-2024/SA-IP-05.

Williams, A. J., Farley, J. H., Hoyle, S. D., Davies, C. R., Nicol, S. J. 2012. Spatial and sex-specific variation in growth of albacore tuna (Thunnus alalunga) across the South Pacific Ocean. *PloS one*, ***7*(6)**, e39318.

Williams, P., Ruaia, T. 2023. Overview of tuna fisheries in the western and central Pacific Ocean, including economic conditions - 2022. WCPFC-SC19-2023/GN-WP-01.

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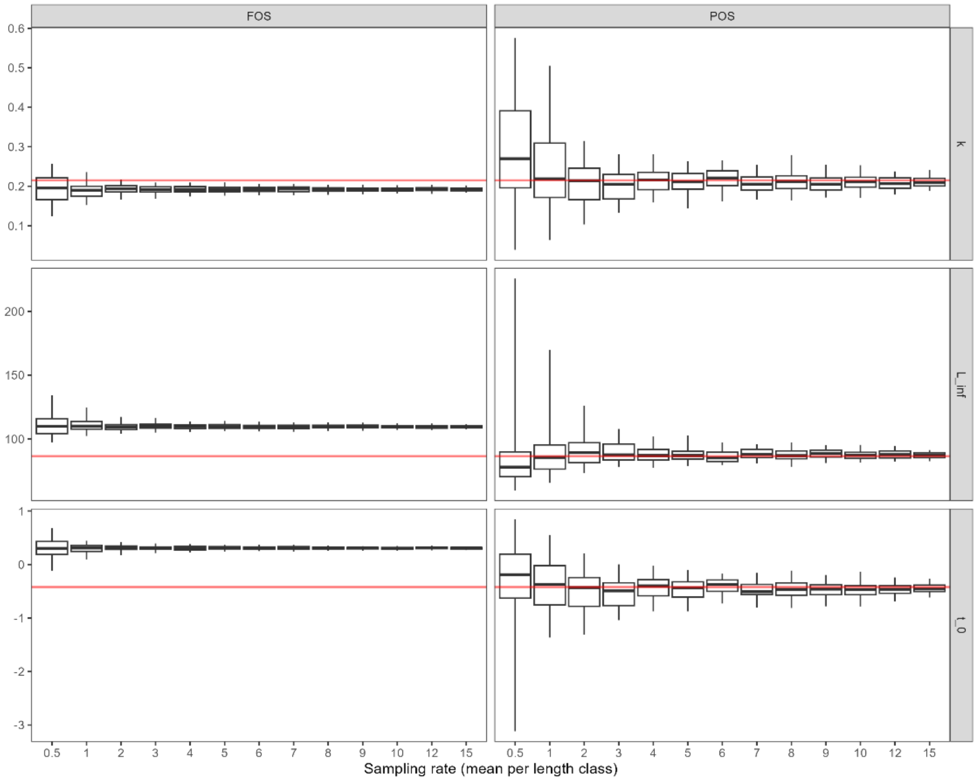
Figures

a) von Bertalanffy parameters (medians, IQR and 95% quantiles)



b) Growth curves

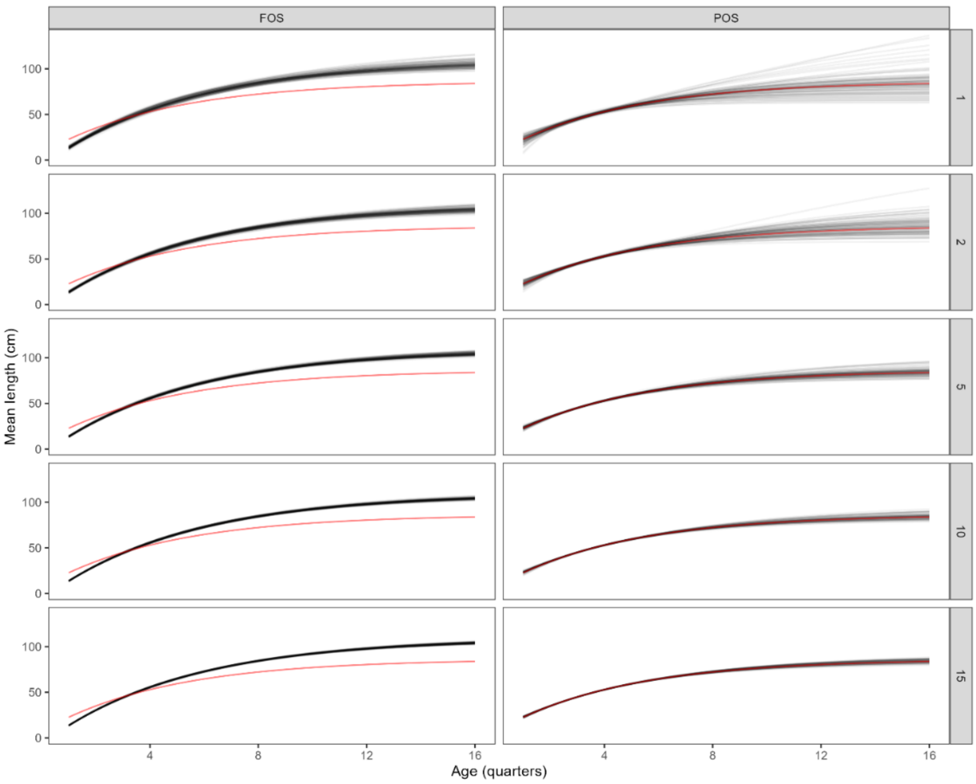
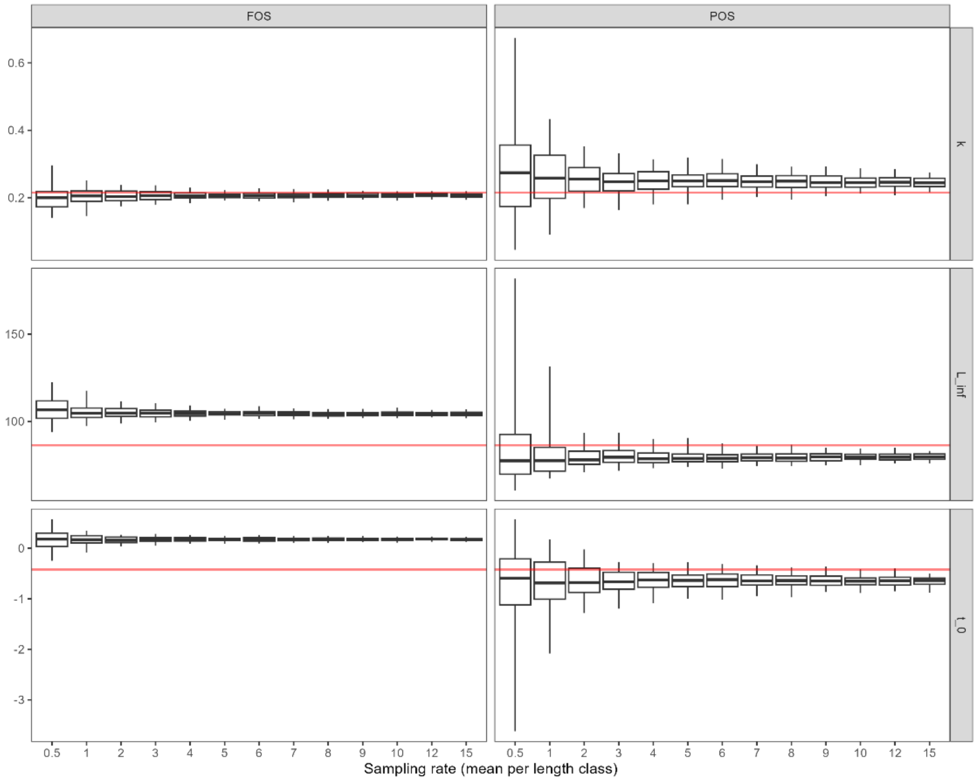


Figure 1 Estimated von Bertalanffy a) growth curve parameters and b) growth curves for skipjack with fixed otolith sampling (FOS) and proportional otolith sampling (POS), with varying sampling rates (x axis – expressed in terms of mean samples per 2cm length class, with 54 length classes) and selectivity a function of age. Red lines = assumed values in operating model.

a) von Bertalanffy parameters (medians, IQR and 95% quantiles)



b) Growth curves

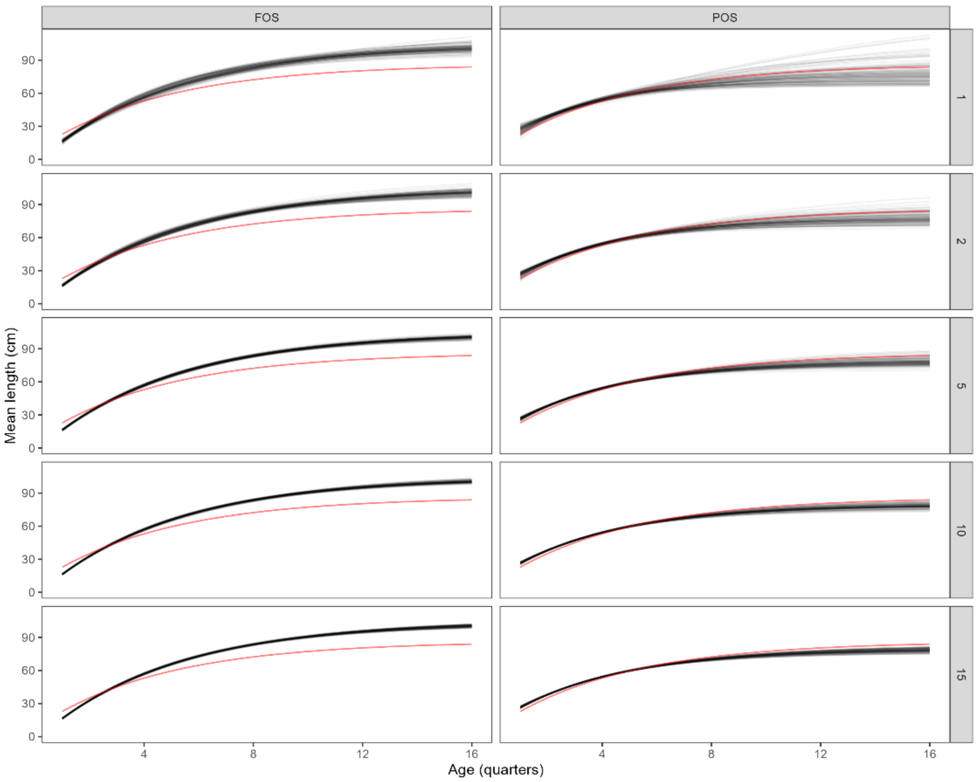
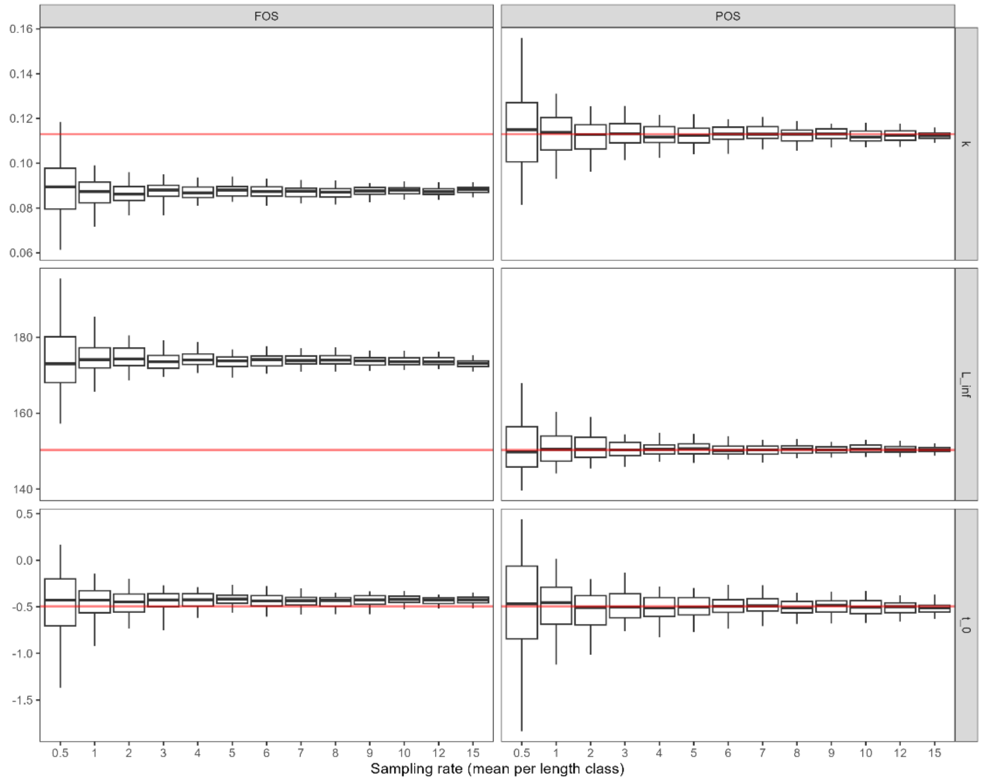


Figure 2 Estimated von Bertalanffy a) growth curve parameters and b) growth curves for skipjack with fixed otolith sampling (FOS) and proportional otolith sampling (POS), with varying sampling rates (x axis – expressed in terms of mean samples per 2cm length class, with 54 length classes) and selectivity a function of length. Red lines = assumed values in operating model.

a) von Bertalanffy parameters (medians, IQR and 95% quantiles)



b) Growth curves

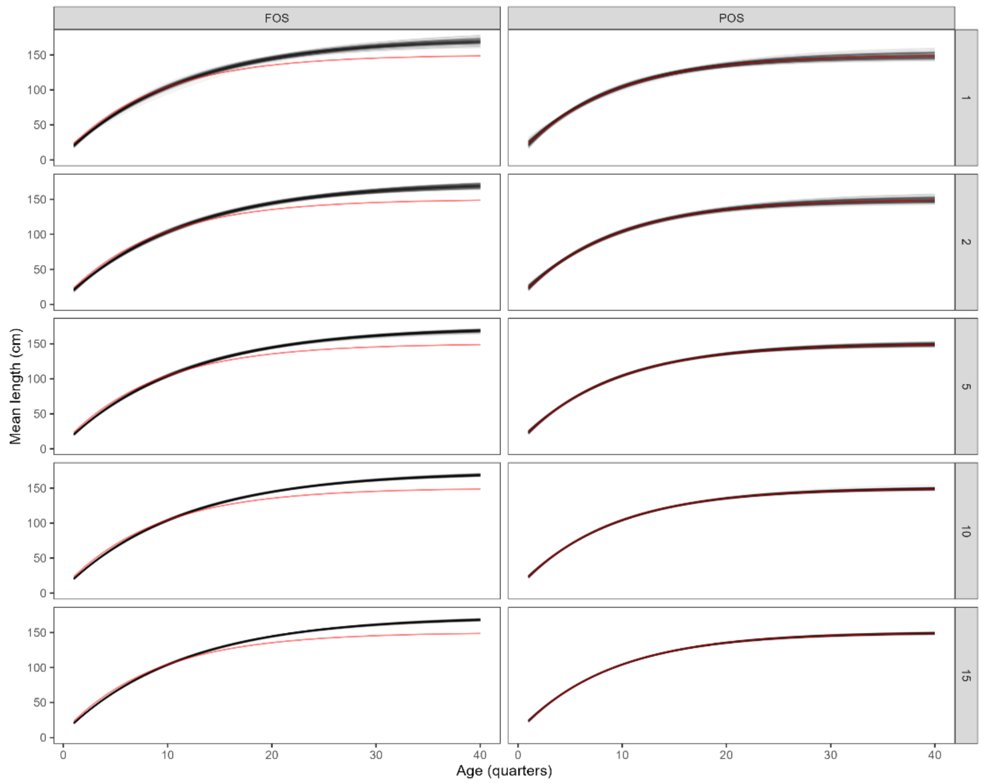
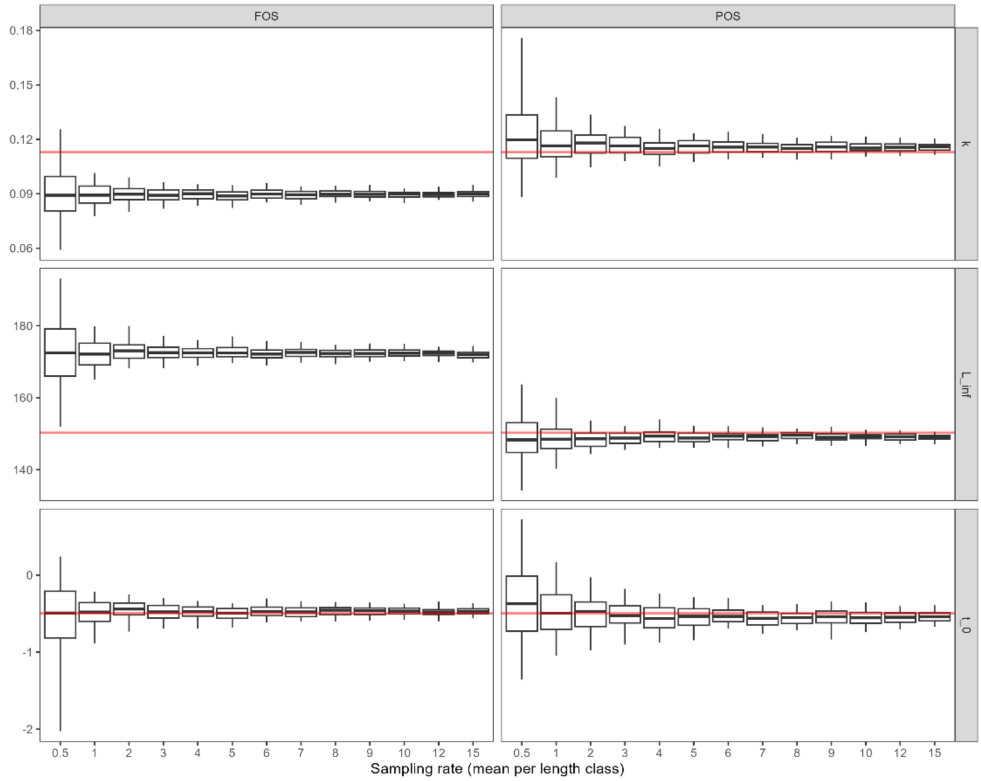


Figure 3 Estimated von Bertalanffy a) growth curve parameters and b) growth curves for bigeye with fixed otolith sampling (FOS) and proportional otolith sampling (POS), with varying sampling rates (x axis – expressed in terms of mean samples per 6cm length class, with 33 length classes) and selectivity a function of age. Red lines = assumed values in operating model.

a) von Bertalanffy parameters (medians, IQR and 95% quantiles)



b) Growth curves

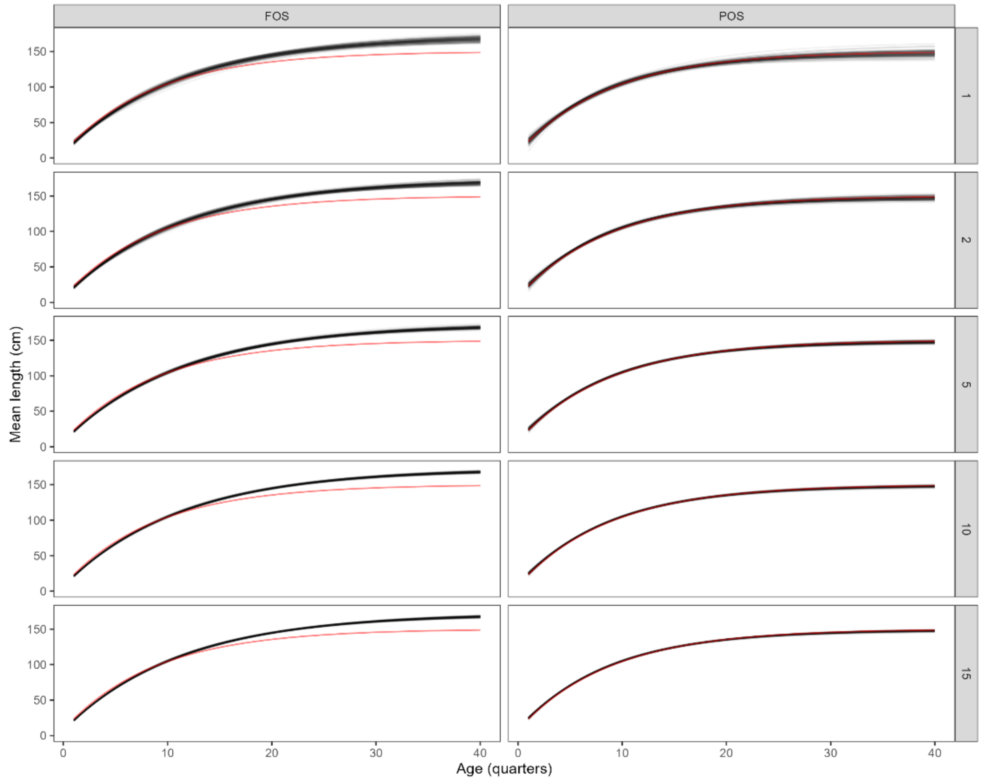


Figure 4 Estimated von Bertalanffy a) growth curve parameters and b) growth curves for bigeye with fixed otolith sampling (FOS) and proportional otolith sampling (POS), with varying sampling rates (x axis – expressed in terms of mean samples per 6cm length class, with 33 length classes) and selectivity a function of length. Red lines = assumed values in operating model.

Appendix

Inputs for skipjack power analysis

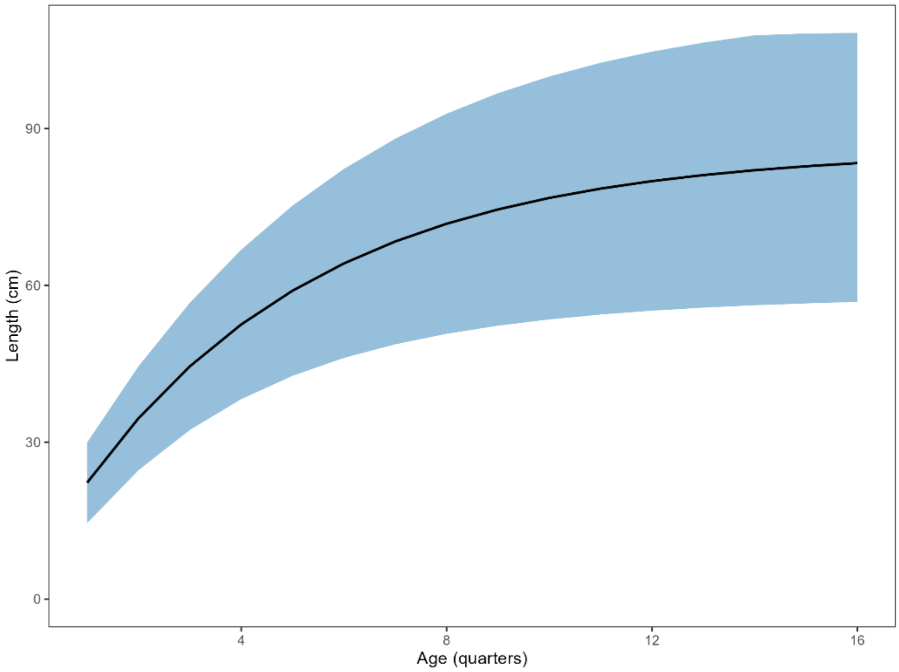
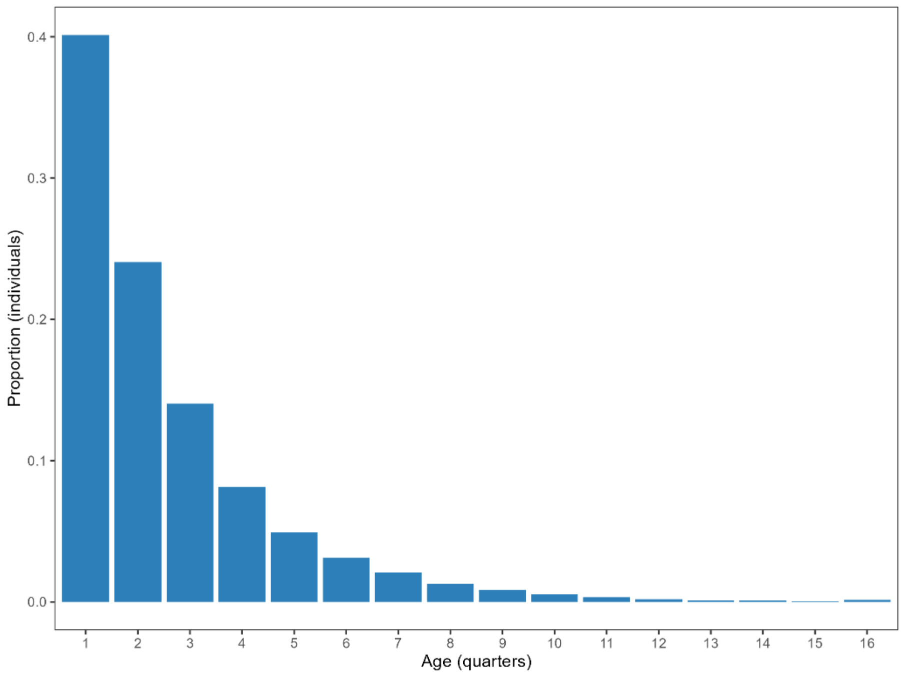


Figure 5 Assumed growth curve for skipjack (mean and 95% confidence interval).

a) Age class



b) Length class

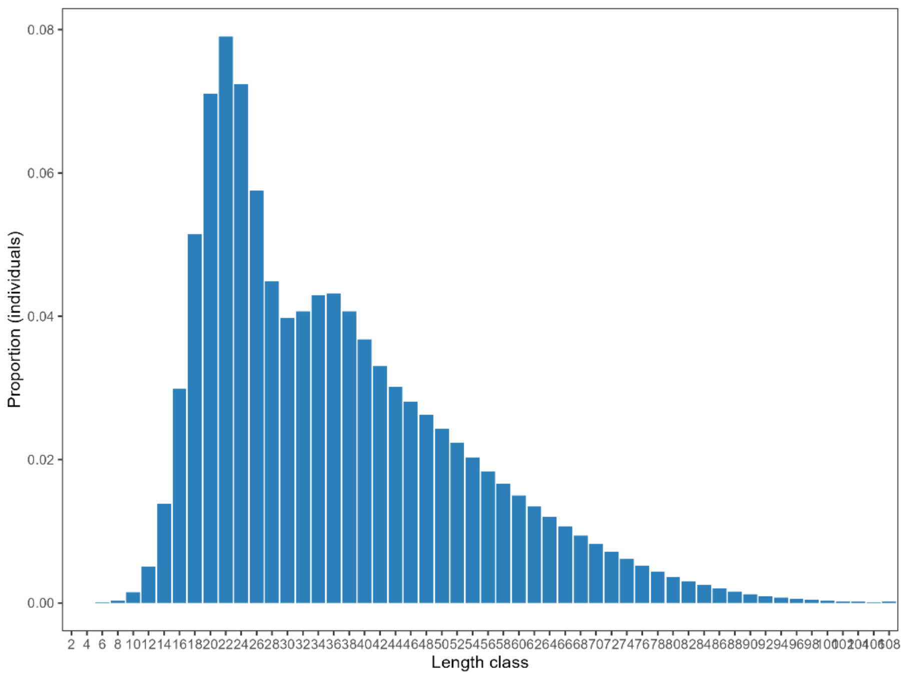


Figure 6 Assumed numbers of skipjack per a) age class and b) length class in the population.

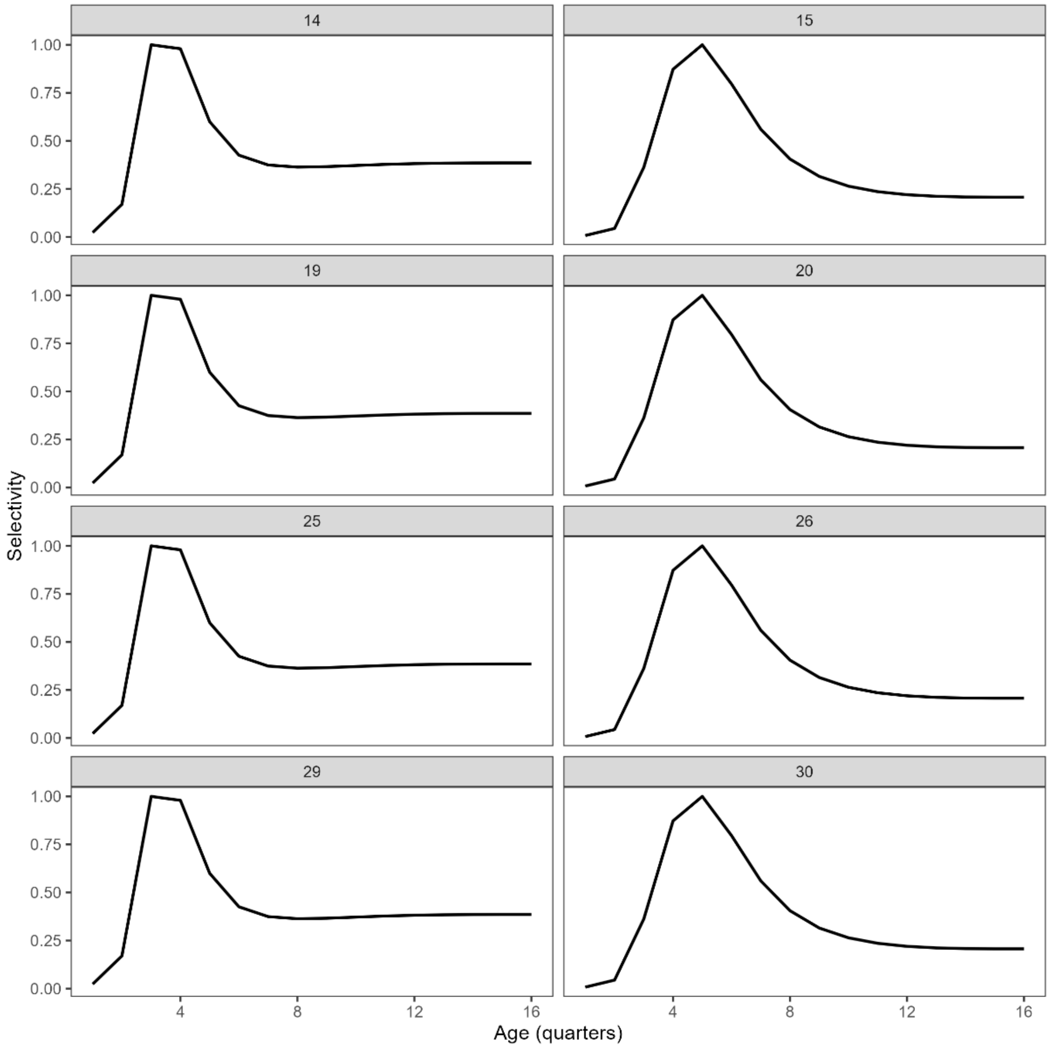


Figure 7 Assumed selectivities at age for skipjack per fishery (see Castillo Jordán et al., 2022 for fishery IDs).

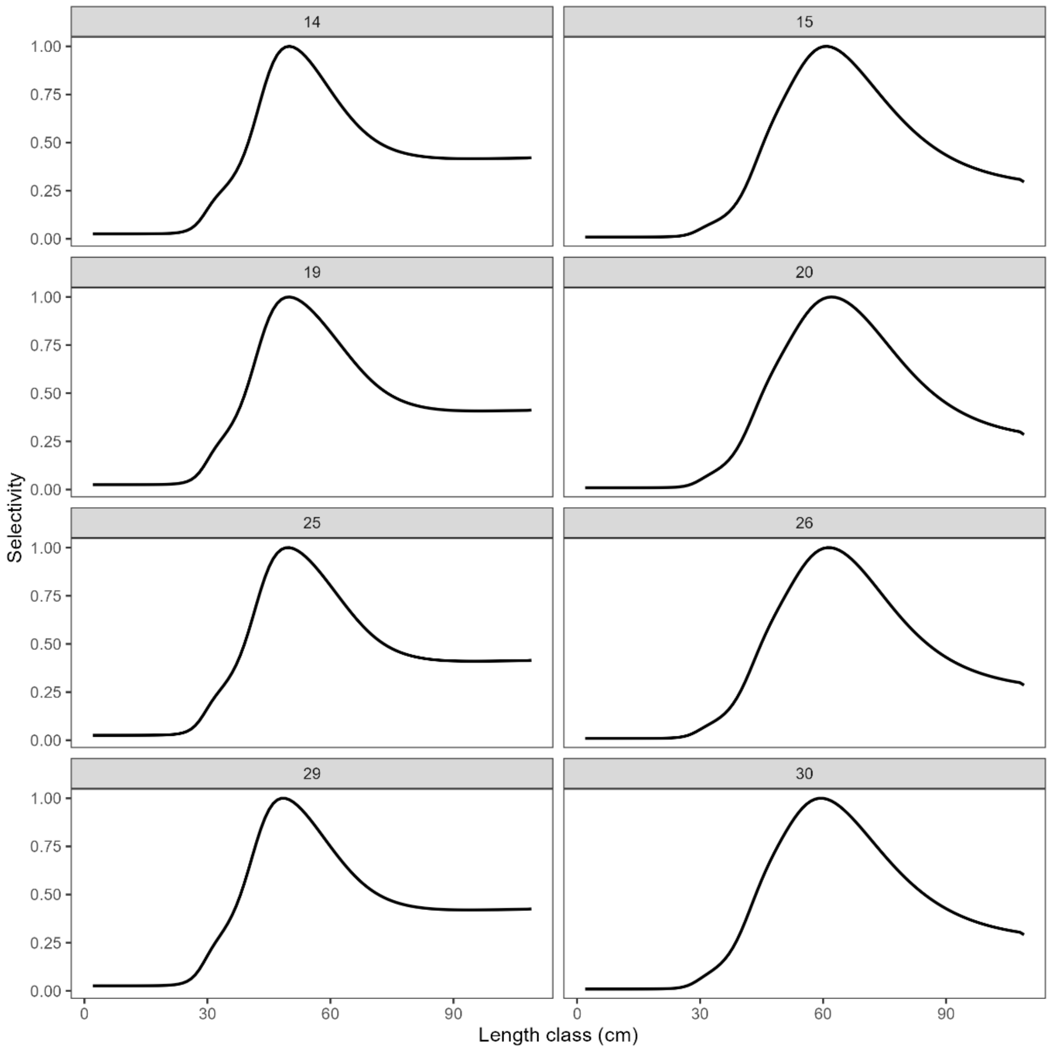
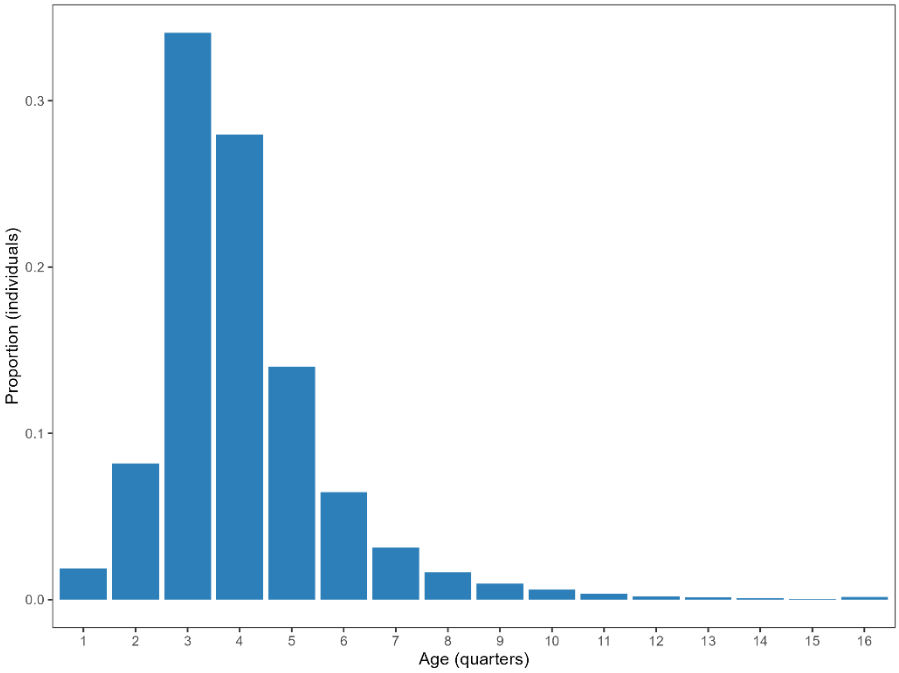


Figure 8 Assumed selectivities at length for skipjack per fishery (see Castillo Jordán et al., 2022 for fishery IDs).

a) Catch at age



a) Catch at length

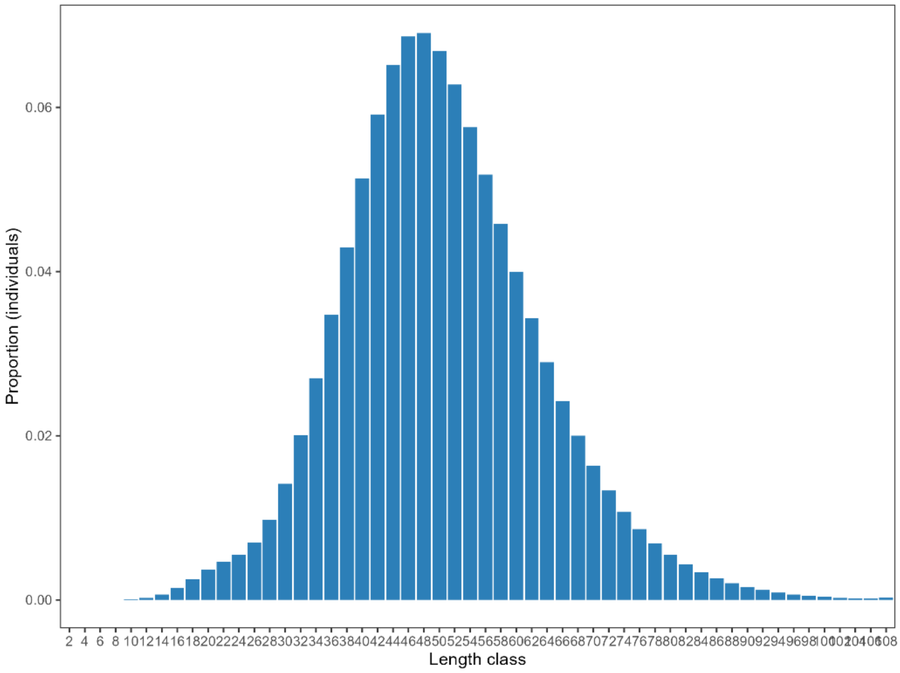


Figure 9 An example replicate of estimated a) catch per age class and b) catch per length class for skipjack with selectivities at age, from fisheries assumed to have sampling.

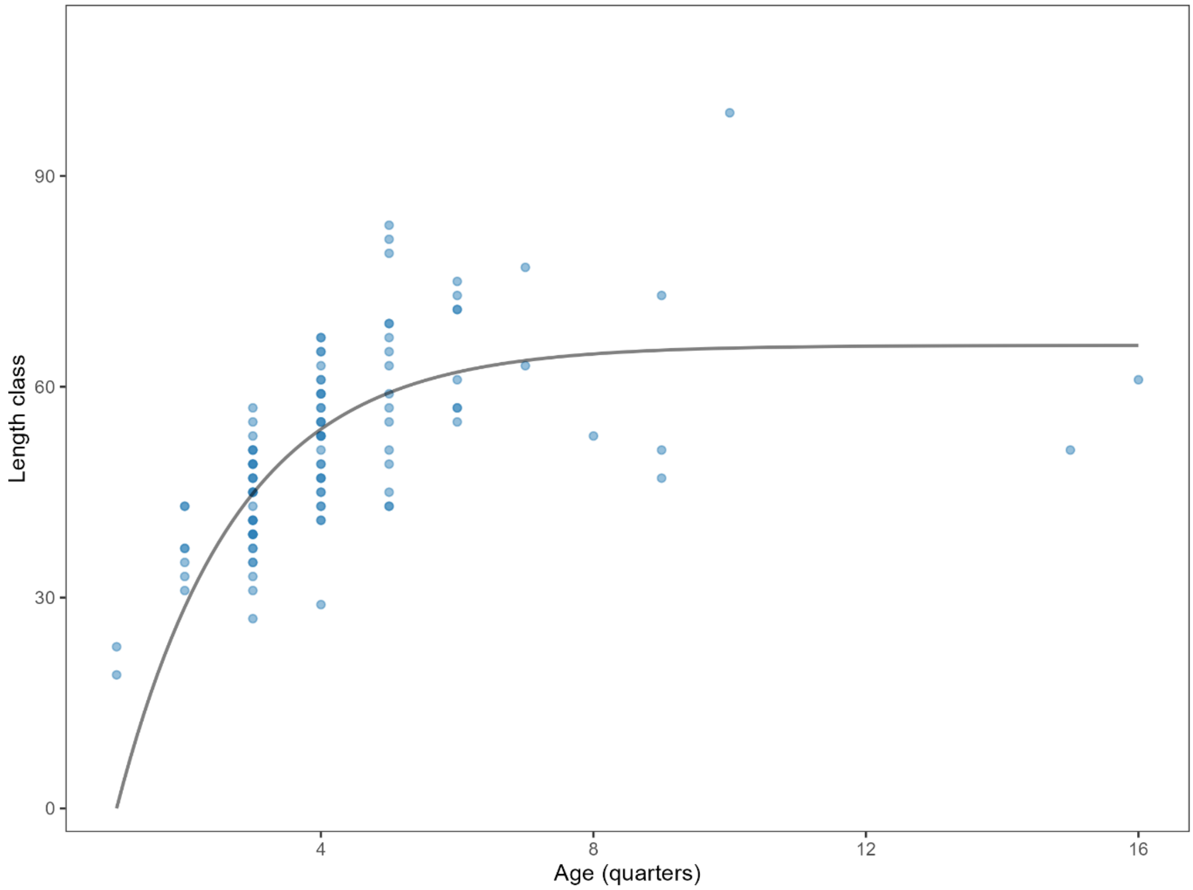


Figure 10 An example replicate of estimated age-length samples for skipjack with proportional otolith sampling (POS, 2 samples per 2cm length bin) and selectivities at age, and the resulting estimated von Bertalanffy growth curve.

Inputs for bigeye power analysis

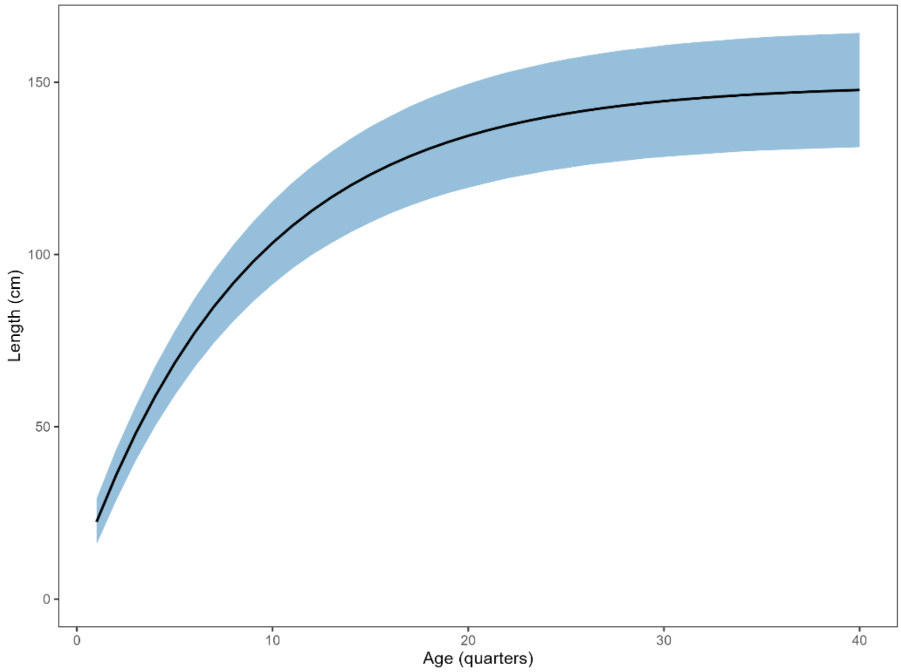
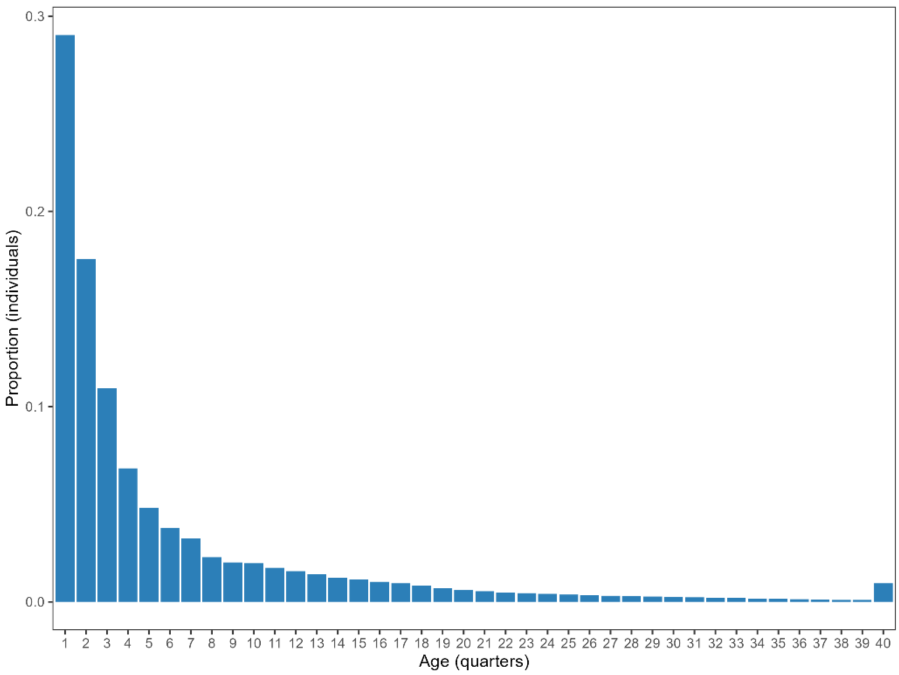


Figure 11 Assumed growth curve for bigeye (mean and 95% confidence interval).

c) **Age class**



d) **Length class**

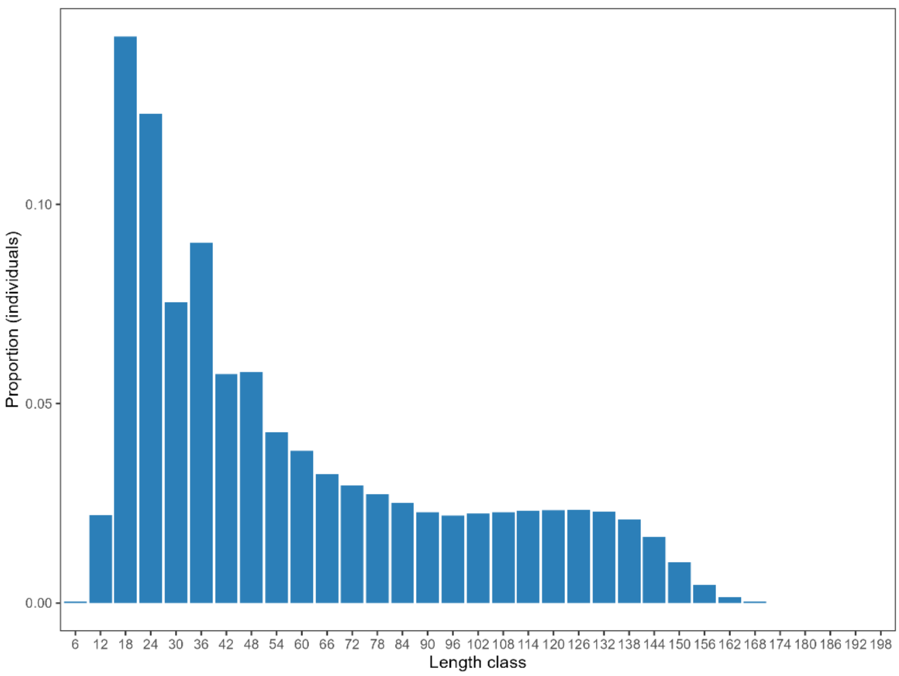


Figure 12 Assumed numbers of bigeye per a) age class and b) length class in the population.

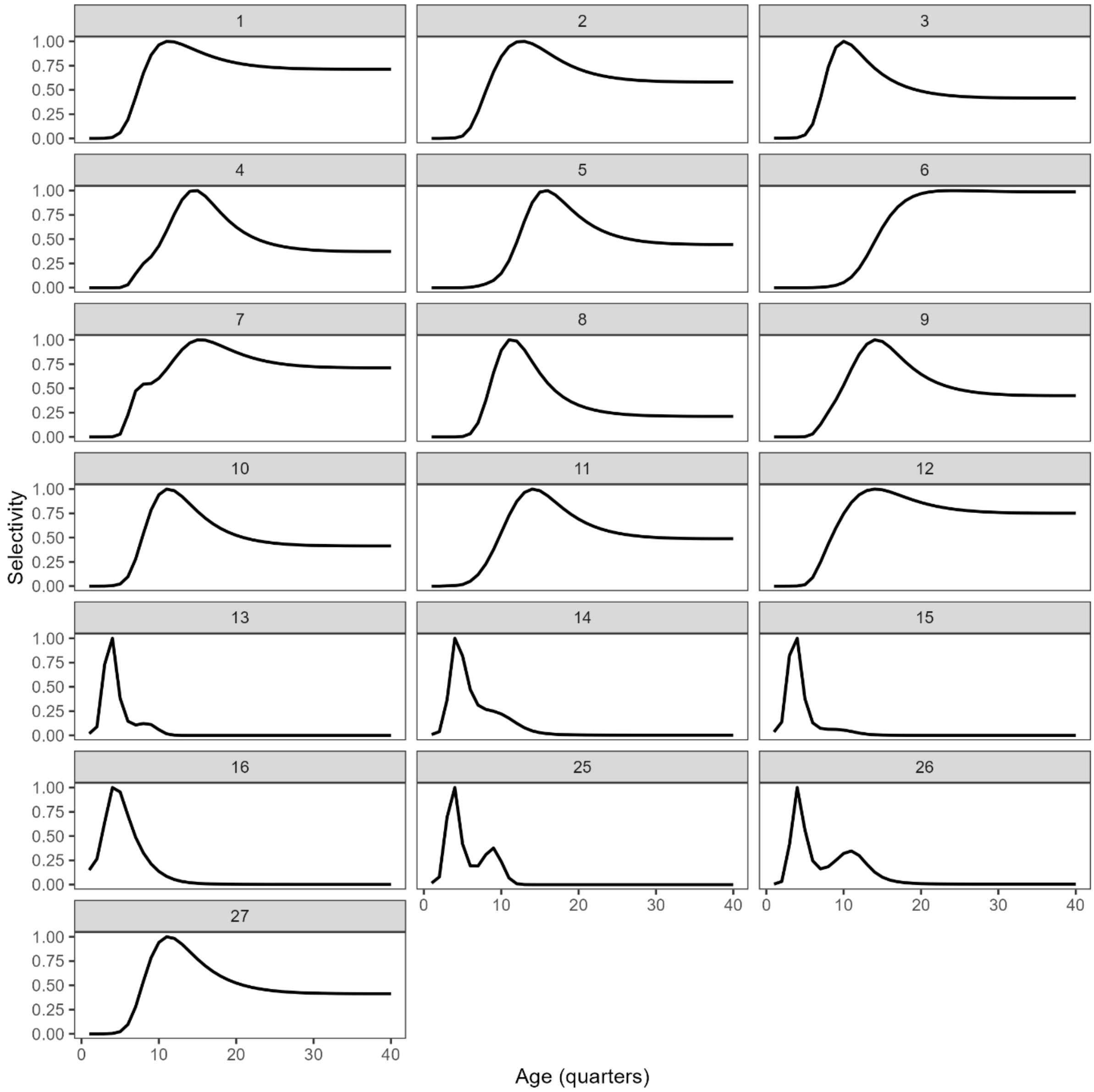


Figure 13 Assumed selectivities at age for bigeye per fishery (see Day et al., 2023 for fishery IDs).

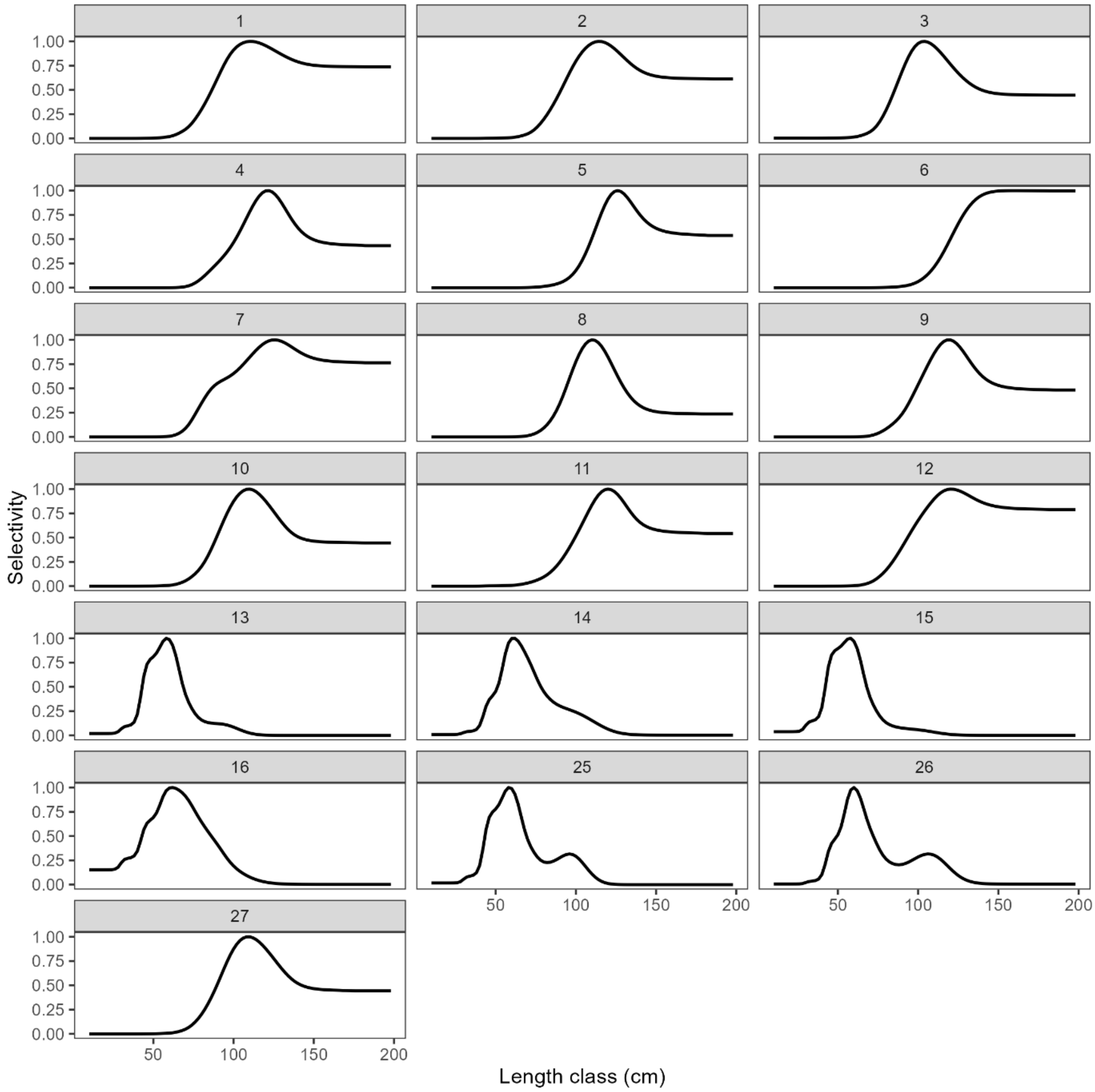
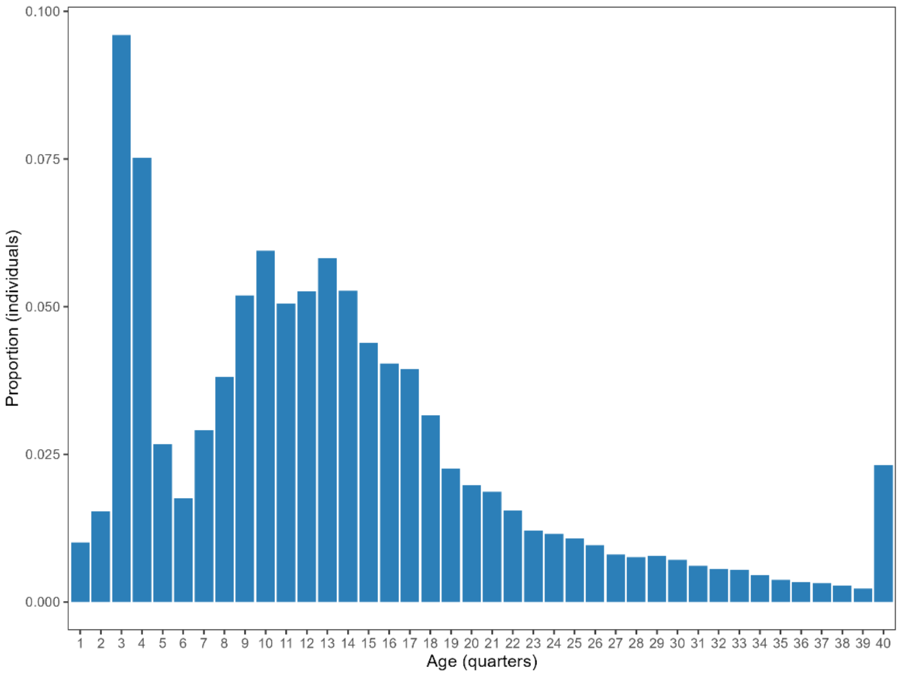


Figure 14 Assumed selectivities at length for bigeye per fishery (see Day et al., 2023 for fishery IDs).

b) Catch at age



b) Catch at length

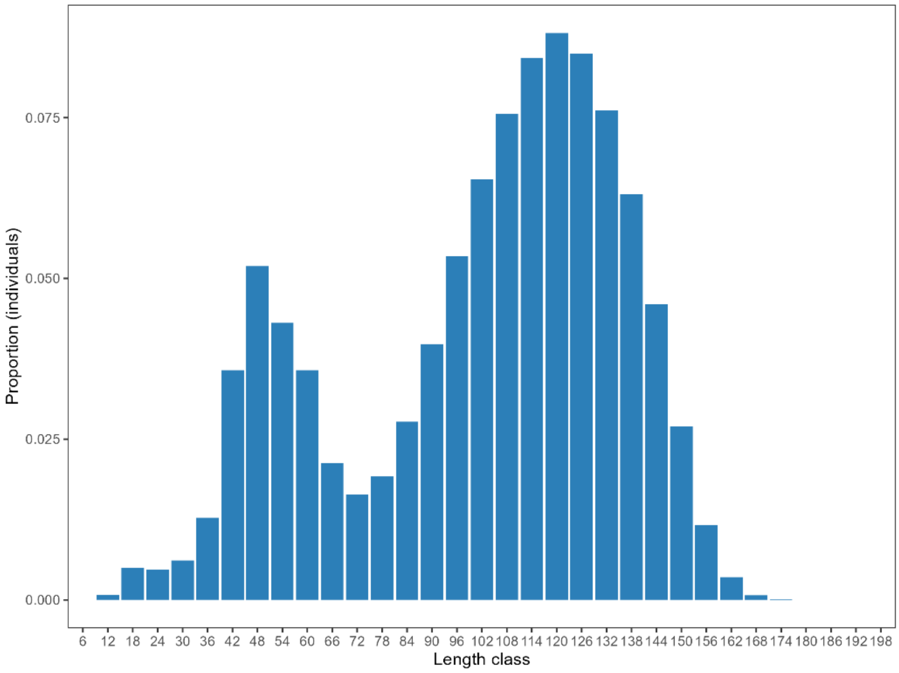


Figure 15 An example replicate of estimated a) catch per age class and b) catch per length class for bigeye with selectivities at age, from fisheries assumed to have sampling.

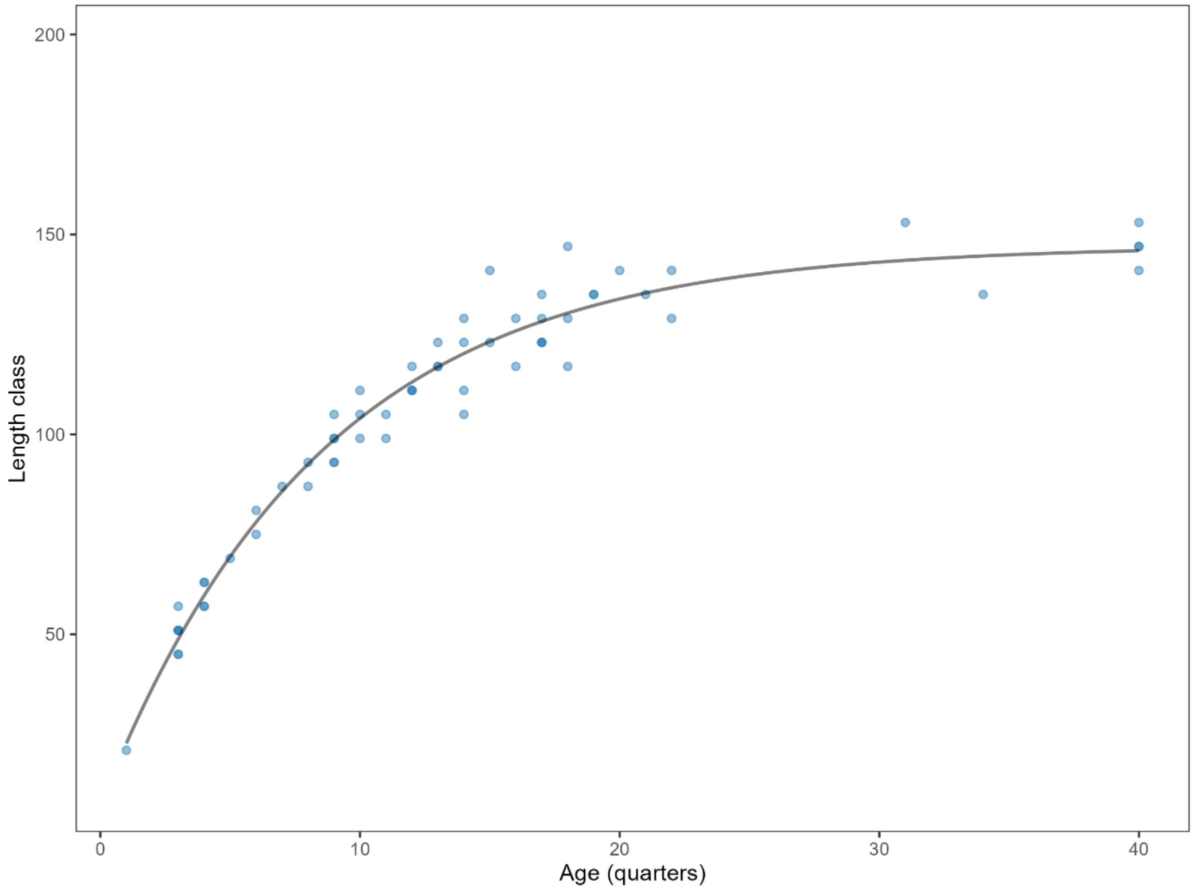


Figure 16 An example replicate of estimated age-length samples for bigeye with proportional otolith sampling (POS, 2 samples per length class) and selectivities at age, and the resulting estimated von Bertalanffy growth curve.