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Growth Modelling and Catch-Curve Residual Analysis of Lake Trout

Yukon's Southern Lakes System

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Growth Modelling and Catch-Curve Residual Analysis of Lake Trout: Yukon's Southern Lakes System

Government of Yukon
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Abstract

To support the Monitoring and Adaptive Management Plan for the Whitehorse Rapids Generation Station, we analyzed long-term growth dynamics and recruitment patterns of lake trout (*Salvelinus namaycush*) in the Yukon's Southern Lakes system (Lake Laberge, Marsh Lake, Tagish Lake and Bennett Lake). Long-term age and length datasets derived from Index Netting and Summer Profundal Index Netting programs were analyzed using von Bertalanffy Growth Models (VBGM) and weighted catch-curve residuals.

- Growth analyses showed that VBGM parameters (asymptotic length, L_∞ and growth coefficient, *k*) exhibited substantial overlap in bootstrapped confidence intervals across all lakes and survey periods, indicating no biologically meaningful temporal shifts in growth. Predicted age-at-length curves similarly overlapped within observed ages. Differences in some years were attributable to variation in sampling methodologies and representation of older age classes rather than true changes in growth trajectories.
- Catch-curve analyses produced consistently low instantaneous mortality (*Z*) across lakes and years, with weighted studentized residuals showing that most age cohorts fell within expected limits. Only occasional strong or weak year classes were detected, with no directional trend in cohort deviations based on generalized linear models. These results indicate consistent adult survival and broadly consistent recruitment through time.

Overall, the combined results from growth modelling and catch-curve residual analyses suggest that lake trout populations in the Southern Lakes system have remained consistent over the study period. Observed variability among individual cohorts appears episodic and is likely associated with environmental or operational factors rather than long-term population change. Further evaluation linking cohort-specific deviations to water-level or flow conditions may help identify potential drivers of recruitment variability.

Contents

Table of figures

Table of tables

Introduction

The Whitehorse Rapids Generating Station (WRGS), located in Whitehorse and operated by Yukon Energy Corporation (YEC), was relicensed on July 31, 2025, for a 20-year term under Water Licence HY24-061 (Yukon Water Board, 2025). Prior to licence issuance, the Government of Yukon released a Decision Document requiring the development and implementation of a Monitoring and Adaptive Management Plan (MAMP) (Government of Yukon, 2025). The purpose of the MAMP is to define mitigation measures to reduce or eliminate adverse project effects, including the establishment of clear goals, objectives, indicators and adaptive management triggers for fish and fish habitat. Lake trout (*Salvelinus namaycush*) is a valued freshwater species within this system, which may be impacted by project effects.

Since 1991, the Government of Yukon Fisheries section has periodically monitored lake trout populations in Lake Laberge, Marsh Lake, Tagish Lake and Bennett Lake to assess abundance and harvest pressure (Figure 1). These long-term monitoring programs have also generated age and length information suitable for evaluating growth and recruitment dynamics.

At the request of YEC, and to assist the WRGS technical working group, we analyzed these datasets using growth models and catch-curve residuals, to independently evaluate potential project related effects.

Datasets and limitations

The lake trout datasets used in this analysis were derived from two Government of Yukon fisheries monitoring programs, Index Netting and Summer Profundal Index Netting (SPIN) (Government of Yukon, 2023). Both programs follow standardized protocols for capturing and measuring fish, yielding datasets appropriate for growth modelling (VBGM) and catch-curve residual analysis.

Although both programs produce representative biological samples for lake trout, methodological differences, such as mesh distributions, soak times, seasonal timing and depth coverage, can influence capture probabilities for specific size and age classes. In particular, size-selective sampling can bias growth parameters estimates by under- or over-representing smaller, younger fish or the oldest individuals, which are rare but influential in VBGM parameterization and mortality estimation (Gwinn, et. al., 2010).

These design and operational differences introduce limitations, including:

- potential bias in VBGM parameters (especially $L\infty$ and K) when older fish are sparse or unevenly sampled;
- reduced precision in catch-curve estimates if fully recruited age classes are inconsistently represented; and
- challenges in direct inter-annual comparisons where effort, habitat strata, or targeted collection of large fish differed among surveys.

Accordingly, point estimates are interpreted alongside their uncertainty, with emphasis on overlap in bootstrap confidence intervals and agreement of predicted age-at-length curves within observed ages. This interpretive framework helps ensure that conclusions about growth and recruitment reflect biological signal rather than sampling-method artifacts.

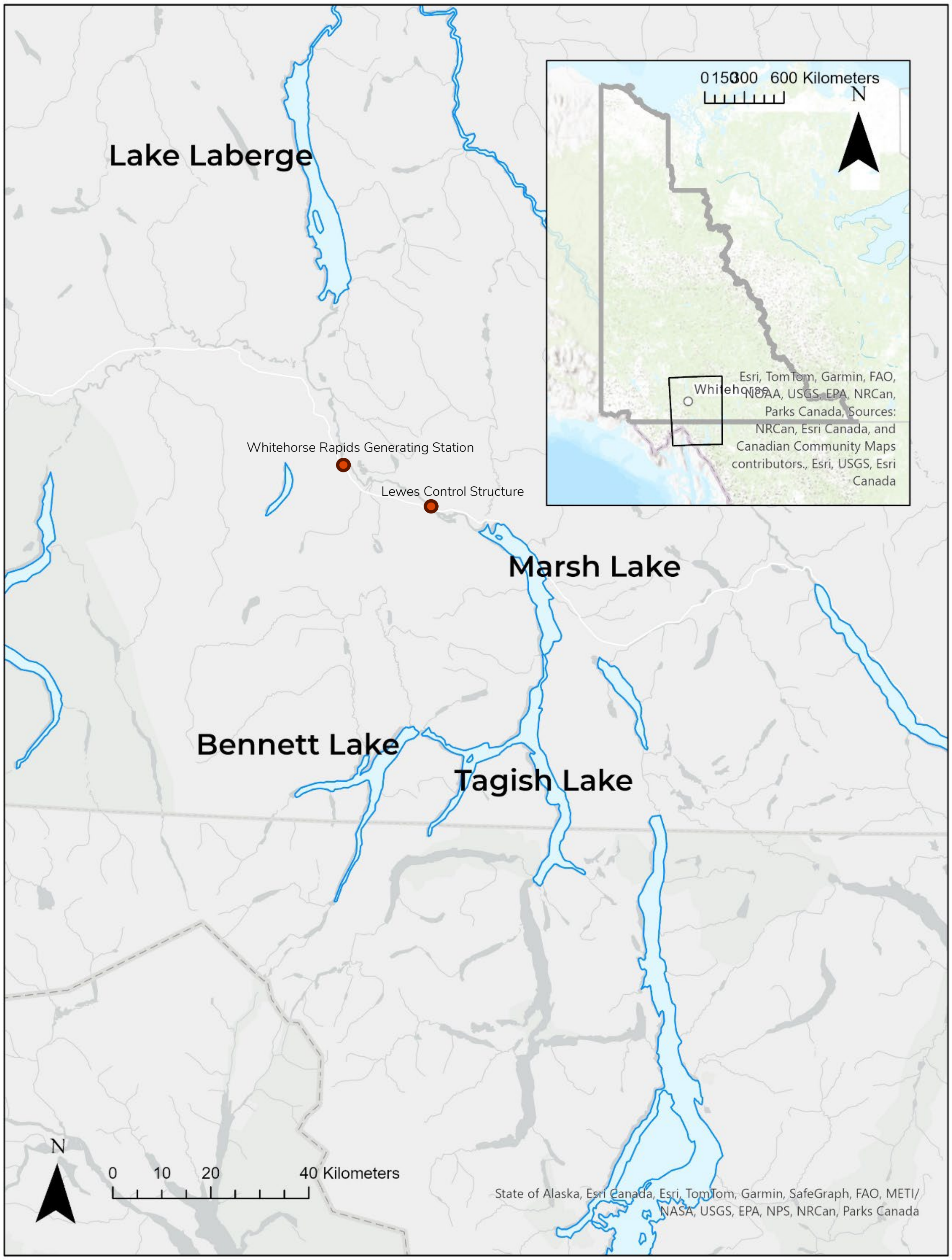

Figure 1. Location of the Southern Lakes complex, including: Lake Laberge, Marsh Lake, Tagish Lake and Bennett Lake. The Whitehorse Rapids Generating Station and the Lewes Control Structure are indicated on the map.

Methods

Growth models

Age and growth analysis of lake trout was conducted by nonparametric distribution comparisons and modeling using the von Bertalanffy Growth Model (VBGM), which defines asymptotic length ($L\infty$), growth rate coefficient (K), and the theoretical age at zero length (t_0). Application of these growth parameters within fisheries population dynamics follows Beverton and Holt (1957) and von Bertalanffy (1938).

Age distributions

Age data were summarized for each survey year by using mean age and distribution. Differences in age structure among years was evaluated using nonparametric tests (Wilcoxon rank-sum for two-group comparisons and Kruskal-Wallis for multiple groups). Differences in mean age were assessed using Welch's t-test, which accommodates unequal variance and sample sizes and is robust to deviations in normality. This combination of tests allowed evaluation of both distributional differences and changes in mean age across survey periods.

Growth parameters

Bootstrapping

Bootstrap resampling was applied to all survey years to quantify uncertainty in VBGM parameters under a consistent inferential framework (Guy & Brown, 2007). For datasets with sample sizes below 100, bootstrapping was particularly important because parameter estimates can be unstable and disproportionately influenced by a small number of large or old individuals. However, bootstrapping was also implemented for years with sample sizes greater than 100 to maintain methodological consistency across lakes and survey periods. Accordingly, age-length pairs were resampled with replacement for 10,000 replicates, and the VBGM was refit to each resampled dataset.

Resulting parameter distributions were summarized using means and percentile-based, bias-corrected 95% confidence intervals. This approach preserves the empirical structure of the data, avoids reliance on normality assumptions, and ensures that inter-annual differences in growth reflect biological variation rather than differences in statistical treatment or sample size.

Modelled parameters

Age data was dominated by fish older than age 4, with young age classes poorly represented in the dataset, an artifact of the sampling methods, resulting in weak identification of the VBGM parameter t_0. When estimated freely, t_0 assumed unrealistic negative values and increased parameter instability due to strong covariance with L_∞ and K. Accordingly, t_0 was fixed at −1 for all analyses to improve model stability, remove bias from estimates, and ensure to consistent comparisons of growth parameters across years and lakes (Goodyear, 2019).

To limit the influence of occasional bootstrap refits that produced implausibly large asymptotic lengths due to L_∞–K trade-offs, bootstrap replicates were filtered using an a priori biological plausibility criteria of $L_\infty \leq 1.4 \times L_{\mathbf{max}}$, prior to summarizing VBCM parameters. Filtering removed only a small proportion of bootstrap replicates and did not alter central estimates, but prevented biologically unrealistic inflation of L_∞.

Formal hypothesis testing among periods was not emphasized because sampling methods varied among surveys, potentially influencing size and age selectivity. Instead, inference was based on overlapping parameter confidence intervals and separation of predicted VBGM curves to evaluate biological differences among periods. This approach acknowledges that observed variation in length-at-age may reflect sampling differences.

Predicted length-at-age

Growth comparisons among periods are presented using predicted length-at-age curves derived from bootstrapped estimates. Each bootstrap replicate was used to calculate predicted fork length across ages, allowing uncertainty in the model to be reflected directly into the predicted growth curve. The predicted curves integrate estimates from all ages (1 to 45), to provide a standardized, biologically interpretable basis for comparison.

Catch-curve residuals

Catch-curve analysis was used to estimate total mortality (Z) and evaluate relative recruitment patterns among cohorts. Catch-curve analysis assumes constant recruitment and mortality overtime, across ages (Nelson, 2019). Catch curves were fitted using weighted linear regression of log-transformed numbers-at-age for fully recruited age classes, consistent with established fisheries approaches to mortality estimation based on catch-curve analysis (Chapman & Robson, 1960; Robson & Chapman, 1961).

Catch-curve analysis was conducted by fitting a weighted linear regression of the natural log of numbers-at-age against age for fully recruited age classes following the model:

$$\ln (N_a) = \alpha - Za,$$

In this model, N_a is the number of fish at age a and Z is instantaneous total mortality. The regression was weighted by the number of fish in each age class ($w_a = N_a$) to reduce the influence of sparsely sampled age classes and improve stability of the mortality estimate.

Recruitment was evaluated using catch-curve analysis rather than the cohort method, as the latter requires several sequential years of composition data, which was not available (Tetzlaff, et. al., 2011).

Studentized residuals

Studentized residuals were calculated to evaluate deviations of individual cohorts from the expected mortality model. Studentized residuals represent standardized differences between observed and predicted log catch-at-age, adjusted for model variance, allowing direct comparison among age classes and survey years, even when sample sizes differ.

Residual values near zero indicate agreement with expected mortality patterns. Positive residuals indicate relatively strong age cohorts, while negative residuals indicate weak cohorts. Reference lines at ± 2.0 were included to aid interpretation. Under model assumptions, approximately 95% of studentized residuals are expected to fall within this range if variation reflects sampling variability alone. Residuals exceeding ± 2.0 are interpreted as unusually large departures from expectations and were treated as diagnostic indicators of potential issues with recruitment or survival.

No secondary regression or trend statistics applied to residuals, as residuals are derived from the fitted regression model and are not expected to exhibit a linear trend.

Generalized linear model

To assess whether age-cohort deviations showed directional change over time, a weighted generalized linear model (GLM) was fitted with studentized residuals as the response and recruitment year as a continuous predictor (normal distribution, identity link, weighted by sample size). This analysis provides a complimentary statistical test to the diagnostic interpretation of catch-curve residuals, however, the GLM should be used with caution as it is limited in the output of the model, rather than direct observations.

Results

Growth models

Lake Laberge

Length-at-age data were analyzed across four time periods: Index Netting collected in both 1991 and 1993, and SPIN data collected from 2016 and 2024.

The 1991 and 1993 datasets were analyzed separately for age-distribution comparisons to avoid confounding captures between the two surveys. However, because these surveys occurred in close temporal proximity, and thus were unlikely to reflect meaningful population-level changes in VBGM parameters, these two datasets were pooled for growth-parameter estimation.

Age distributions

Age frequency distributions differed significantly among survey years (Kruskal–Wallis χ^2 = 15.24, df = 2, p = 0.0016), indicating temporal variation in population age structure within the lake (**Figure 2**, **Table 1**). Post-hoc pairwise comparisons using Wilcoxon rank-sum tests showed that fish sampled in 2024 were significantly older than those sampled in both 2016 (Z = 3.24, p = 0.0065).

The Hodges–Lehmann estimates indicated that median ages in 2024 were approximately 3 years higher than in 2016 and 2 years higher than in both 1991 and 1993, although not statistically significant.

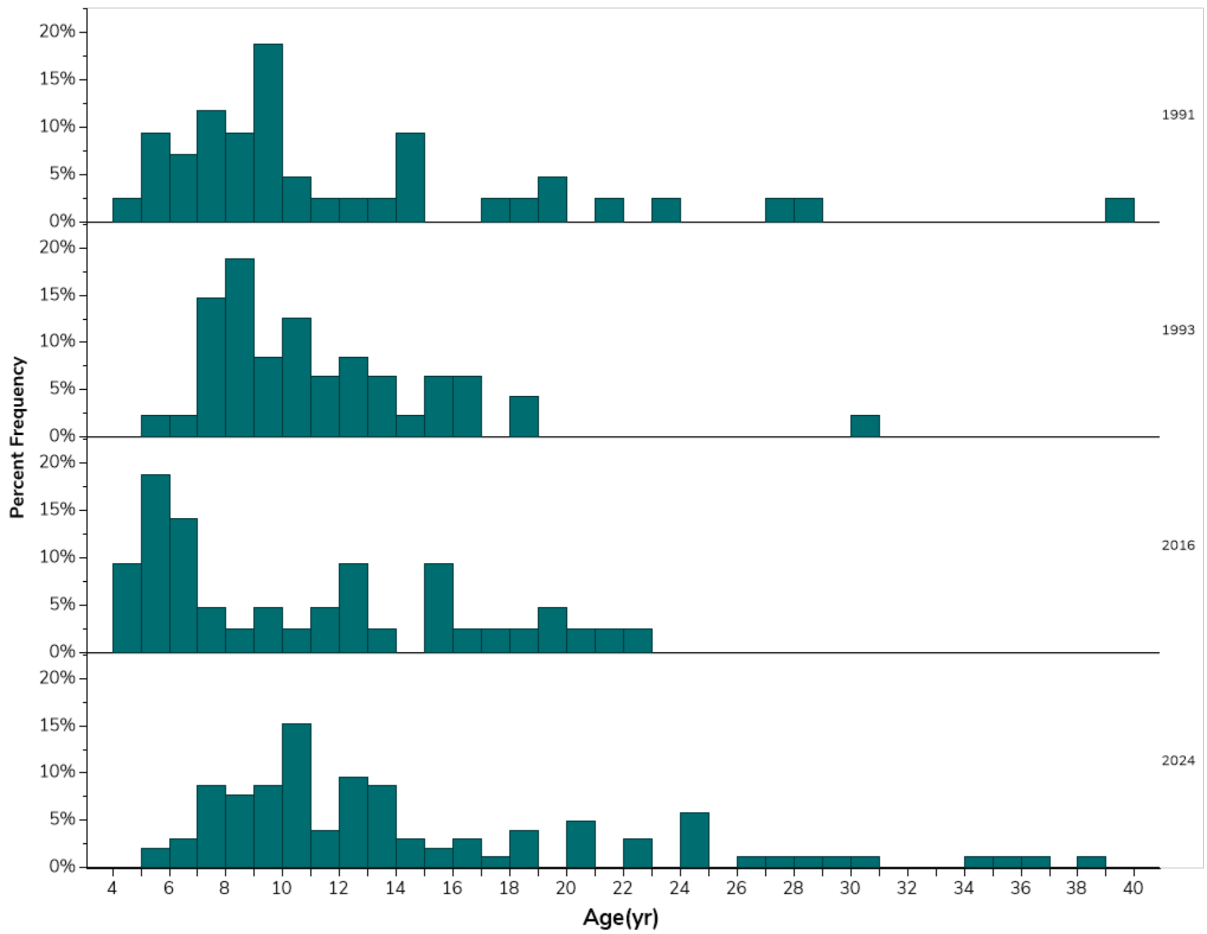

Figure 2. Age frequency distribution of age-analyzed lake trout in Lake Laberge for survey years 1991 (n = 43), 1993 (n = 78), 2016 (n = 43), and 2024 (n = 106).

Table 1. Lake Laberge, lake trout age summary statistics, *n* (sample size), mean, IQR (Interquartile age) and min-max for survey years from 1991/93, 2016, and 2024.

Survey year	*n*	*Mean*	*IQR*	*Min-max*
1991	43	11.72	7	4 – 39
1993	48	10.85	5	5 - 30
2016	43	10.16	10	4 - 22
2024	106	13.95	9	5 - 38

Growth parameters

Bootstrapped von Bertalanffy growth parameters are presented in Table 2. Asymptotic length (L_∞) estimates were similar between 1991, 1993 and 2016, with overlapping bootstrap 95% confidence intervals. In contrast, the 2024 L_∞ estimate was higher, and its confidence interval did not overlap that of the early 1990s period. Bootstrap confidence intervals for the growth coefficient (K) overlapped among all periods, indicating no clear evidence of temporal change in growth rate. Parameter uncertainty in k was greater in the earlier datasets.

Predicted length-at-age curves derived from bootstrapped VBGM parameters overlapped substantially among survey periods across most observed ages (Figure 3). Divergence among curves became more apparent at older ages, where sample sizes were limited and associated uncertainty was highest.

Table 2. Modelled von Bertalanffy growth parameters (L∞ = asymptotic length, K = growth coefficient) with bootstrapped confidence intervals for Lake Laberge, lake trout for survey years from 1991/93, 2016 and 2024.

Survey year	*L∞*	*L∞ (95% CI)*	*K*	*K (95% CI)*
1991 + 1993	562	483 - 574	0.18	0.15 – 0.81
2016	553	517 - 617	0.23	0.09 – 0.69
2024	632	586 - 671	0.11	0.09 – 0.17

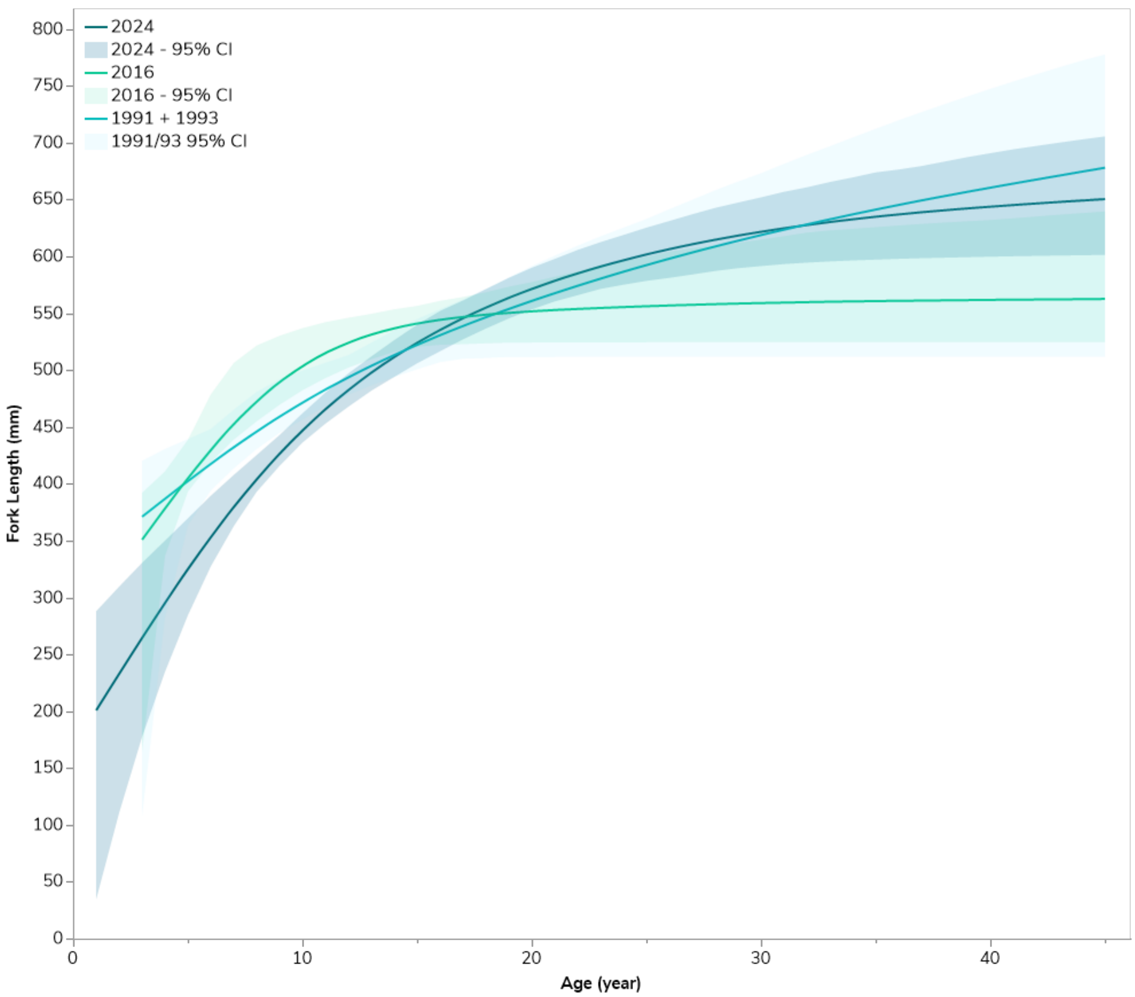

Figure 3. Predicted age-at-length, von Bertalanffy growth curves for Lake Laberge, lake trout for survey years 1991+1993, 2016 and 2024. VBGM curves include 95% confidence intervals (2.5 and 97.5 quantiles).

Marsh Lake

Length-at-age data for Marsh Lake were analyzed from Index netting in 1993, and SPIN data from 2015 and 2024.

Age distributions

Age distributions were not significantly different among survey years (Kruskal–Wallis χ^2 = 1.68, df = 2, p = 0.4319), indicating no statistically detectable temporal shift in population age structure across sampling periods. (Figure 4). Despite this, mean age declined from 15.03 in 1993 to 12.46 in 2024, corresponding to a reduced representation of older fish in the 2024 (Table 3).

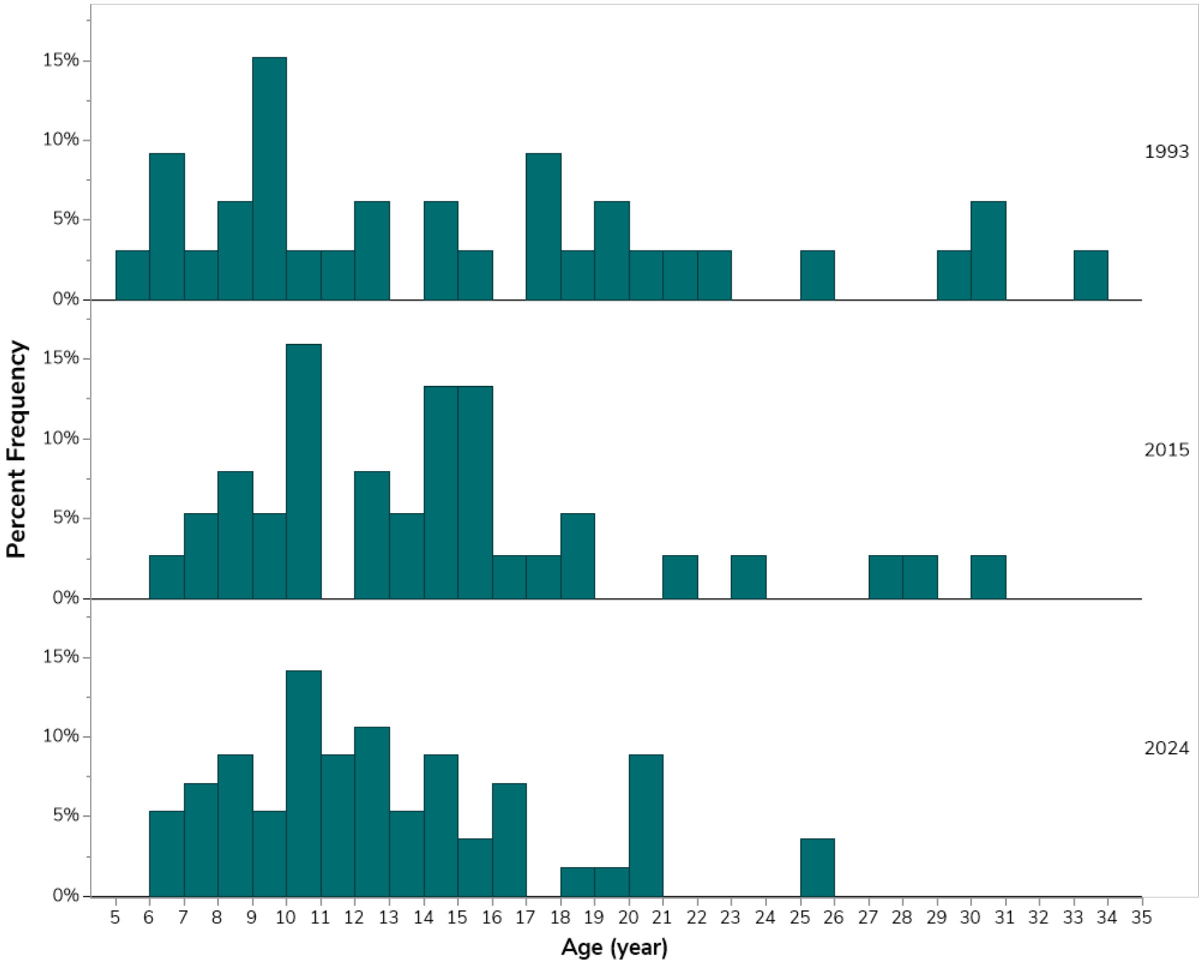

Figure 4. Age frequency distribution of age-analyzed lake trout in Marsh Lake for survey years 1993 (*n* = 33), 2015 (*n* = 38) and 2024 (*n* = 57).

Table 3. Marsh Lake, lake trout age summary statistics, *n* (sample size), mean, IQR (Interquartile age) and min-max for survey years from 1993, 2015, and 2024.

Survey year	*n*	*Mean*	*IQR*	*Min-max*
1993	33	15.03	10.5	5 - 33
2015	38	13.87	5.25	6 - 30
2024	57	12.46	6	6 - 25

Growth parameters

Bootstrapped von Bertalanffy growth parameters fitted to the Marsh Lake data indicated broadly similar growth trajectories among surveys, with overlapping parameter confidence intervals (Table 4). Although the 2015 data produced the highest L_∞ estimate, its confidence interval was substantially wider than the other surveys, reflecting uncertainty associated with the limited representation of older fish.

Predicted age-at-length curves derived from bootstrapped parameters (L_∞, K) overlapped across all survey years and all ages over 20 (Figure 5). Minor divergence occurred at younger ages, where sampled cohort sizes were small. Overall, predicted growth trajectories were similar across surveys, with no detectable temporal divergence in age-at-length.

Table 4. *Modelled von Bertalanffy growth parameters (L_∞ = asymptotic length, K = growth coefficient) with bootstrapped confidence intervals for Marsh Lake, lake trout for survey years from 1993, 2015, and 2024.*

Survey year	*L_∞*	*L_∞ (95% CI)*	*K*	*K (95% CI)*
1993	578	546 - 582	0.17	0.10 – 0.56
2015	607	592 - 897	0.19	0.02 – 0.24
2024	598	575 - 655	0.19	0.05 – 0.23

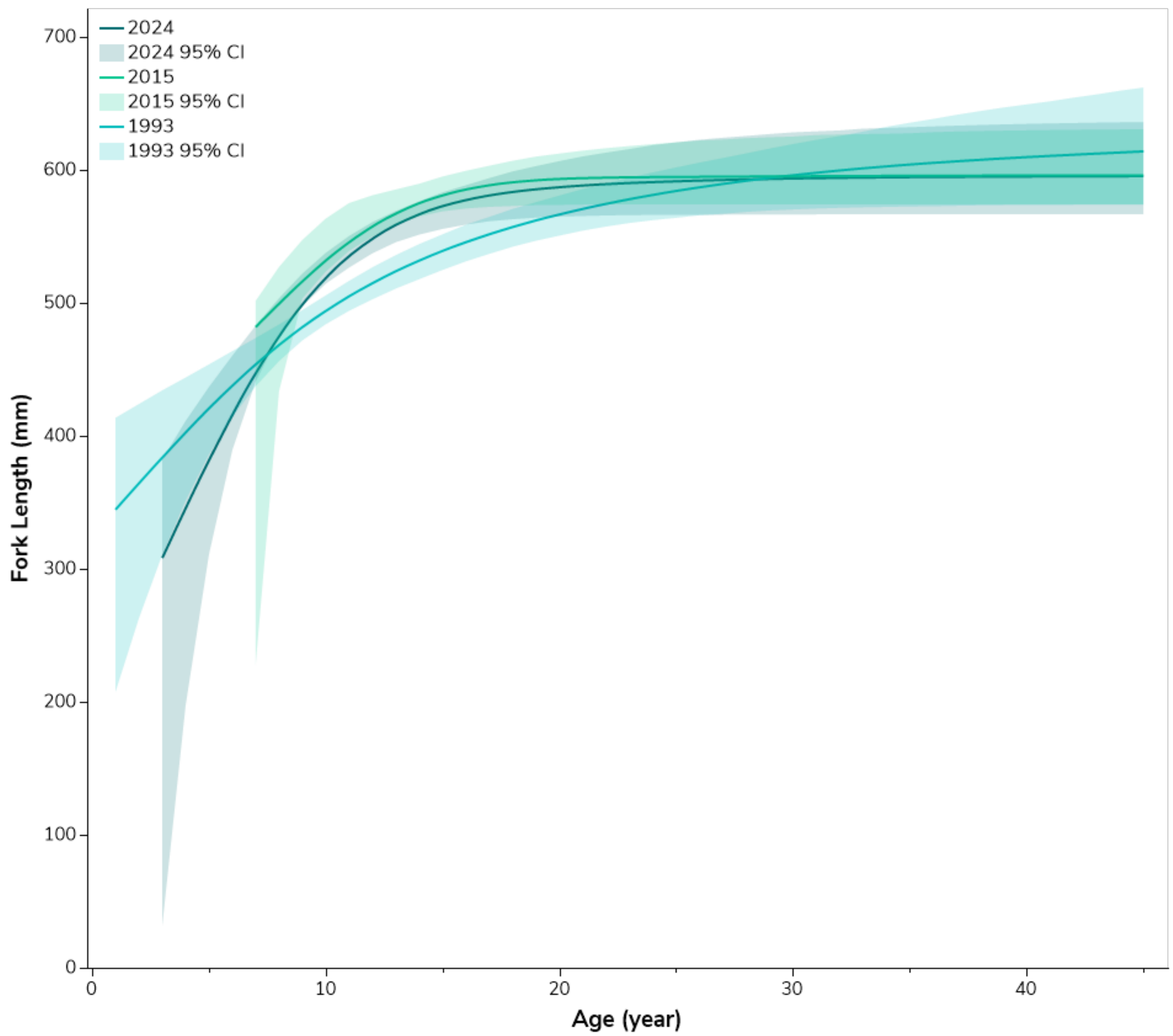

Figure 5. *Predicted age-at-length, von Bertalanffy growth curves for Marsh Lake, lake trout for survey years 1993, 2015 and 2024. VBGM curves include 95% confidence intervals (2.5 and 97.5 quantiles).*

Tagish Lake

Length-at-age data for Tagish Lake were analyzed from Index netting in 1993, and SPIN data from 2015.

Age distributions

Age distributions did not differ significantly between 1993 (n = 202) and 2015 (n = 37), (Wilcoxon rank-sum test: Z = -1.45, p = 0.148), indicating substantial overlap between surveys and no detectable shift in age structure (**Figure 6**). In contrast, mean age differed between surveys (Welch's t-test, p = 0.0275), declining from 12.66 years in 1993 to 10.7 years in 2015., suggesting that the observed difference reflects a modest change in average age, rather than a broad shift in overall age distribution (**Table 5**).

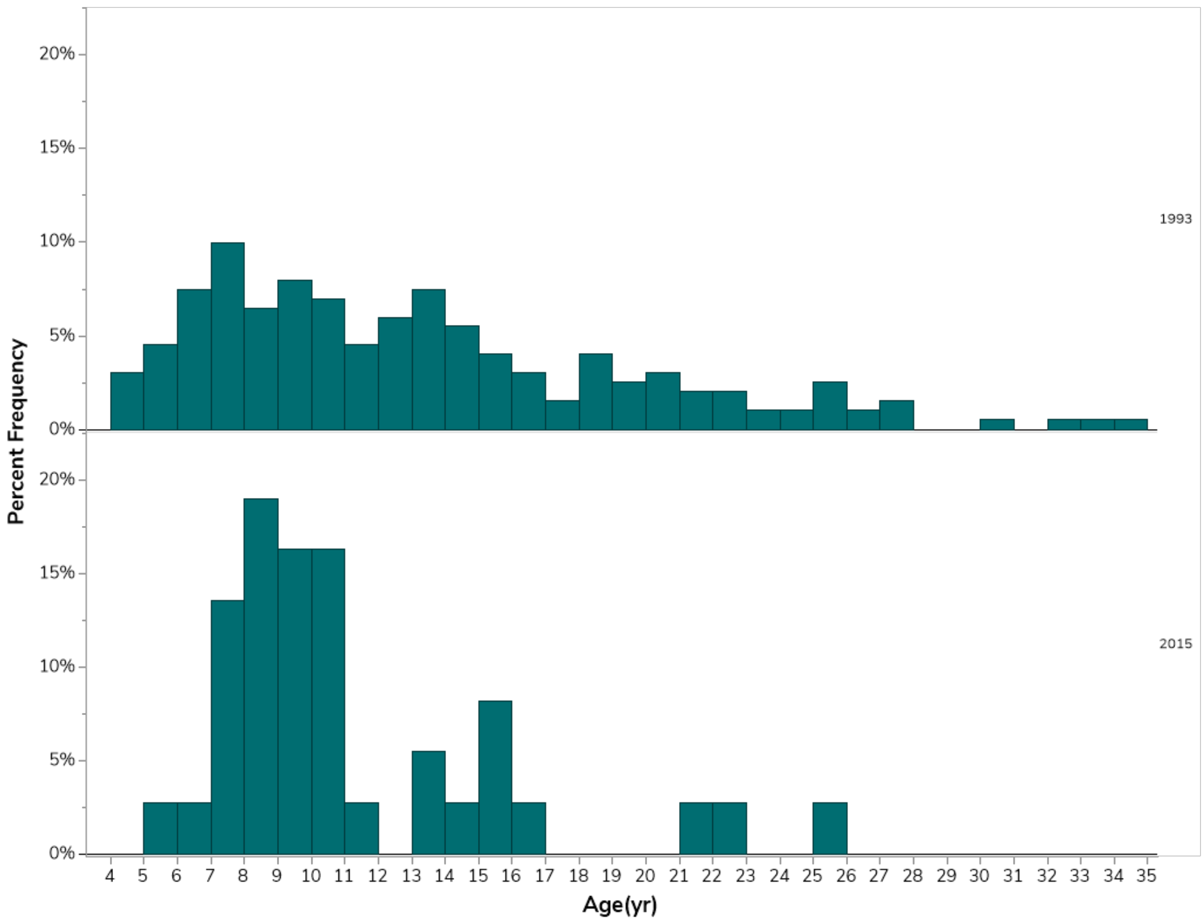

Figure 6. Age frequency distribution of age-analyzed lake trout in Tagish Lake for survey years 1993 (n =202) and 2015 (n = 37).

Table 5. Tagish Lake, lake trout age summary statistics, n (sample size), mean, IQR (Interquartile age), and min-max for survey years from 1993 and 2015.

Survey year	*n*	*Mean*	*IQR*	*Min-max*
1993	202	12.66	8.25	4 - 34
2015	37	10.7	5	5 - 25

Growth parameters

Bootstrapped von Bertalanffy growth parameters fitted to the Tagish Lake data indicated similar growth trajectories between the 1993 and 2015 surveys, with overlapping 95% confidence intervals for both L∞ and K (Table 6). Bootstrapped estimates of L∞ were nearly identical between years, although the 2015 survey produced substantially wider confidence intervals, indicating reduced precision in parameter estimation. Estimates of K showed the same pattern, with similar central values but greater uncertainty in 2015.

Predicted age-at-length curves derived from bootstrapped parameters overlapped across the observed age range (Figure 7). Minor divergence was evident at older ages; however, prediction intervals widened substantially in this region. Overall, predicted growth trajectories were similar between surveys, with no detectable temporal difference in age-at-length.

Table 6. Modelled von Bertalanffy growth parameters (L∞ = asymptotic length, K = growth coefficient) with bootstrapped confidence intervals for Tagish Lake, lake trout for survey years from 1993 and 2015.

Survey year	*L∞*	*L∞ (95% CI)*	*K*	*K (95% CI)*
1993	554	548 - 577	0.17	0.15 – 0.16
2015	546	504 - 756	0.18	0.03 – 0.51

Figure 7. Predicted age-at-length, von Bertalanffy growth curves for Tagish Lake, lake trout for survey years 1993 and 2015. VBGM curves include 95% confidence intervals (2.5 and 97.5 quantiles).

Bennett Lake

Length-at-age data for Bennett Lake was analyzed from the only survey (SPIN) conducted ion this lake in 2014.

Age distribution

Bennett Lake ages ranged from 3 – 22, with a mean of 10.34 (Table 7). No individuals older than 22 were observed (Figure 8), however, the 2014 survey design targeted large lake trout only incidentally for ageing. As a result, the absence of fish older than 22 years may reflect sampling limitations rather than a true absence of older individuals in the population.

Table 7. Bennett Lake, lake trout age summary statistics, n (sample size), mean, IQR (Interquartile age), and min-max for survey year 2014.

Survey year	*n*	*Mean*	*IQR*	*Min-max*
2014	56	10.34	5	3 - 22

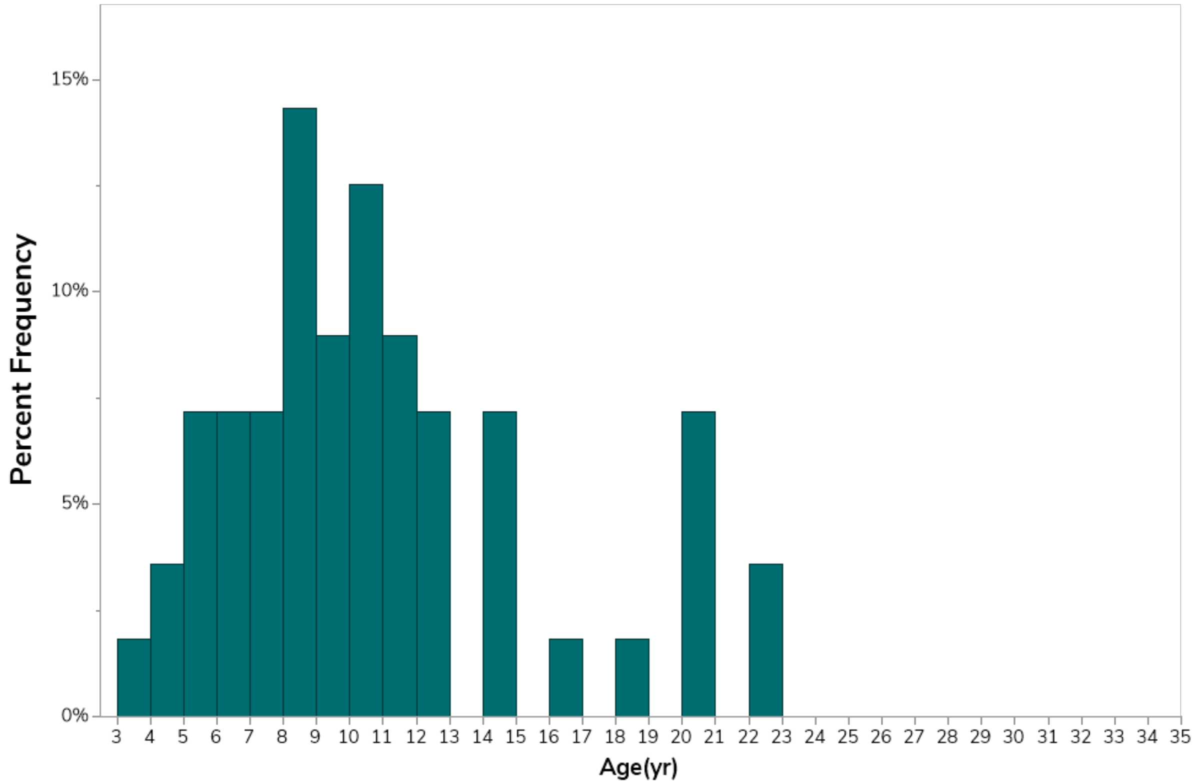

Figure 8. Age frequency distribution of age-analyzed lake trout in Bennett Lake for survey year 2014 (n = 56).

Growth parameters

Von Bertalanffy growth parameters were estimated for Bennett Lake using bootstrapped length-at-age data from the 2014 survey (**Table 8**). The predicted age-at-length curve showed increased divergence among older ages (**Figure 9**). As noted previously, uncertainty at older ages likely reflects limited representation of larger, older individuals in the data set rather than true biological variability. Overall, the model provides a reasonable description of growth for the sampled population.

Table 8. Modelled von Bertalanffy growth parameters (L∞ = asymptotic length, K = growth coefficient) with bootstrapped confidence intervals for Bennett Lake, lake trout for survey year 2014.

Survey year	*L∞*	*L∞ (95% CI)*	*K*	*K (95% CI)*
2014	563	543 - 851	0.16	0.03 – 0.20

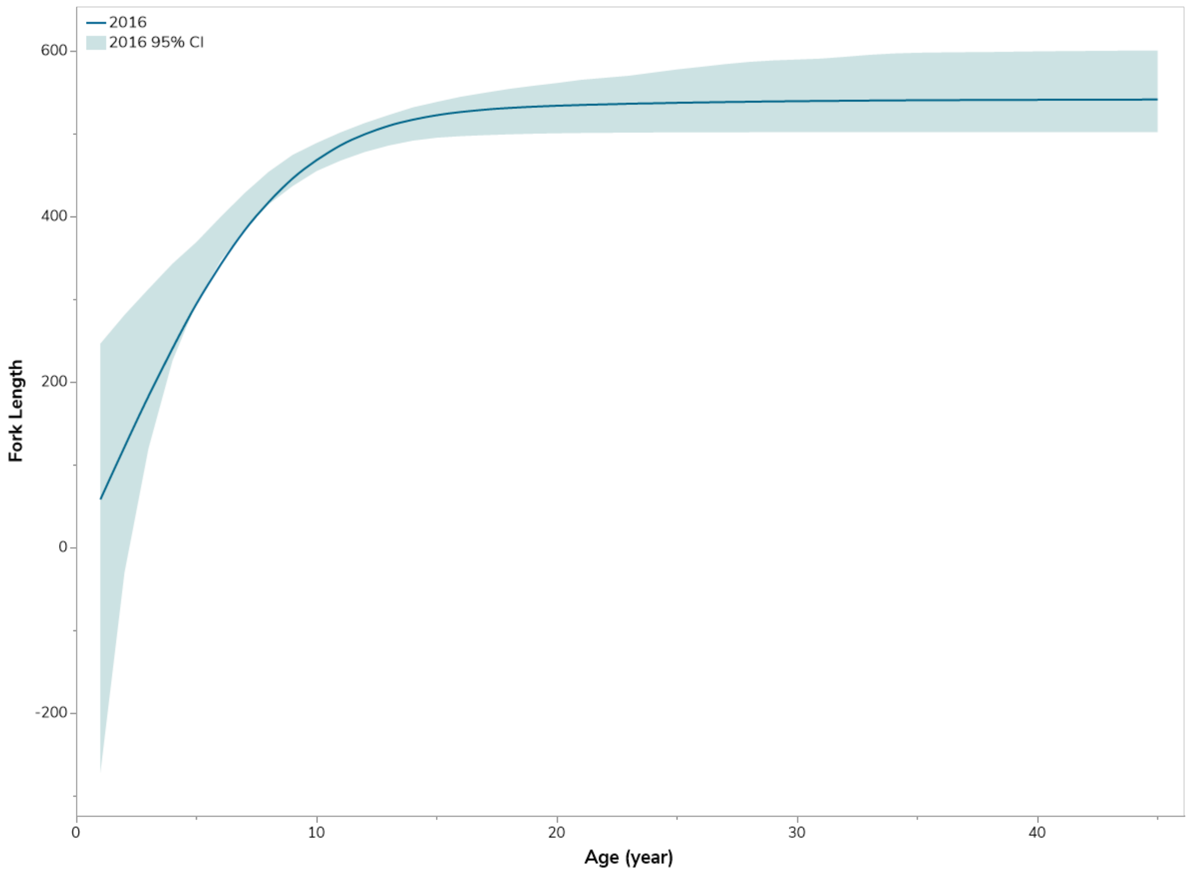

Figure 9. Predicted age-at-length, von Bertalanffy growth curves for Bennett Lake, lake trout for survey year 2016. VBGM curves include 95% confidence intervals (2.5 and 97.5 quantiles).

Catch-curve residuals

Lake Laberge

Studentized residuals

Catch-curve analysis produced statistically significant estimates of instantaneous total mortality (Z) for all survey years, with Z ranging from 0.079 to 0.111, indicating consistent adult survival through time (Table 9). Model fit was moderate (R^2 = 0.44 – 0.67), supporting the reliability of the mortality estimates. Studentized residuals showed that most cohorts fell within the ±2.0 standard deviations, with only sporadic strong or weak cohorts (Figure 10).

Table 9. Lake Laberge year-specific weighted catch-curve results, including instantaneous mortality (Z), model fit (p-value and R^2), and age ranges used in analysis.

Survey year	*Z*	*p-value*	*R^2*	*Age range*
1991	0.079	0.010	0.44	9 - 39
1993	0.111	0.002	0.67	8 – 30
2016	0.104	0.001	0.51	5 – 22
2024	0.099	<0.0001	0.63	10 - 38

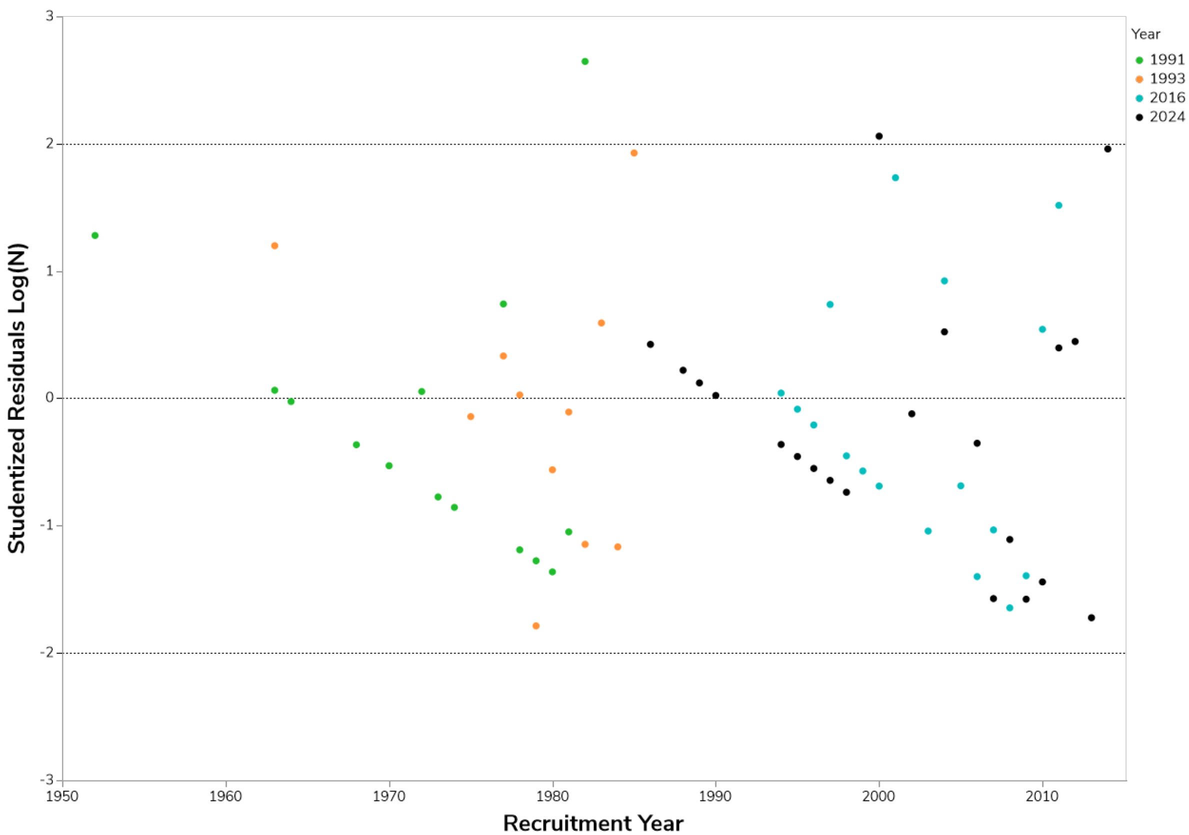

Figure 10. Lake Laberge weighted catch-curve studentized residuals, as sampled in 1991, 1993, 2016 and 2024. ± 2.0 reference lines represent 95% model probability.

Generalized linear model

The weighted generalized linear model showed no evidence of directional change in cohort deviations through time (β = 0.005, SE = 0.010, p = 0.605, 95% CI = -0.015 – 0.025). The estimated slope was small and not significantly different from zero, indicating that recruitment variability did not exhibit a systematic temporal trend.

Marsh Lake

Studentized residuals

Catch-curve analysis produced low estimates of instantaneous total mortality across all survey years, with Z ranging from 0.045 to 0.103, showing no clear evidence of sustained change over time (Table 10). However, estimates should be interpreted with caution for years where model fit was modest (i.e. 1993; $R^2 = 0.28$). Studentized residuals showed that most cohorts fell within the ±2.0 standard deviations, with only sporadic strong or weak cohorts (Figure 11).

Table 10. Marsh Lake year-specific weighted catch-curve results, including instantaneous mortality (Z), model fit (p-value and R^2), and age ranges used in analysis.

Survey year	*Z*	*p-value*	*R^2*	*Age range*
1993	0.045	0.034	0.28	9 – 33
2015	0.103	0.002	0.61	10 – 30
2024	0.071	0.045	0.38	10 - 25

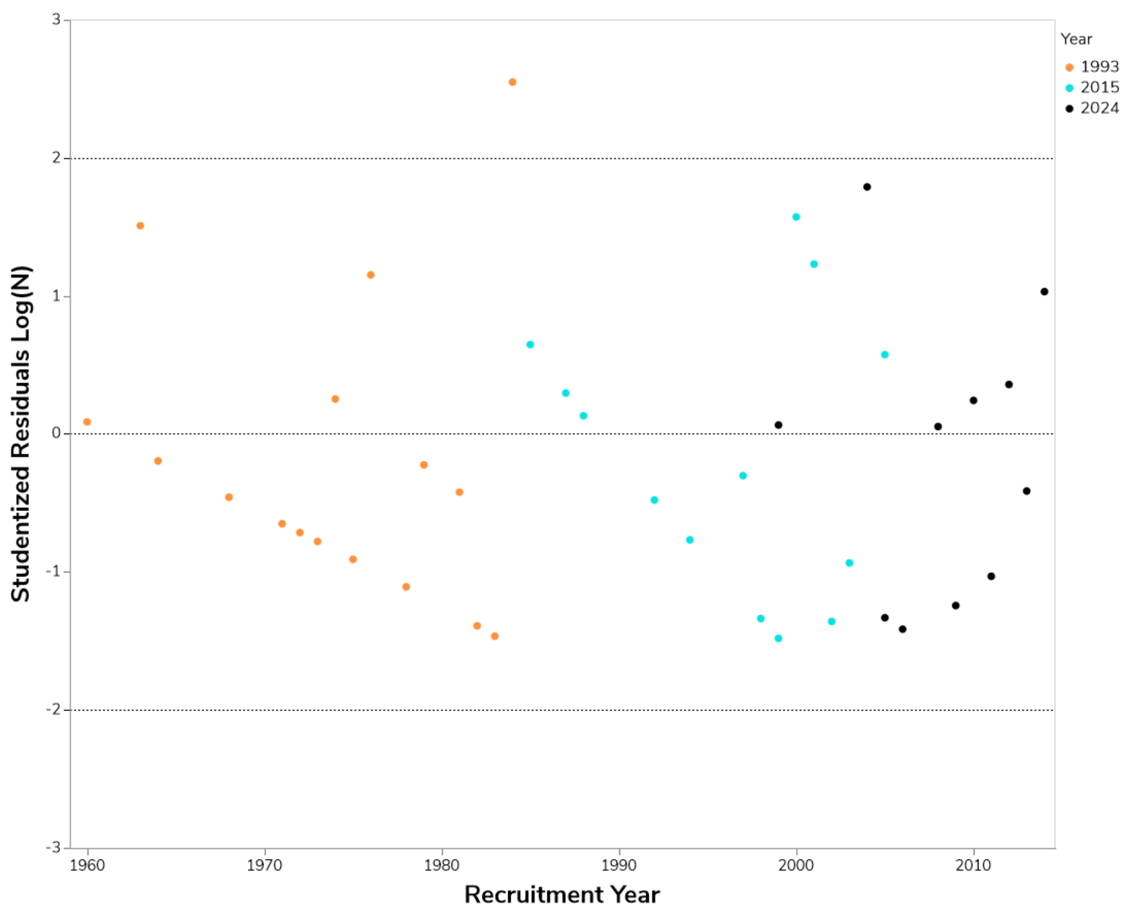

Figure 11. Marsh Lake weighted catch-curve studentized residuals, as sampled in 1993, 2015 and 2024. ± 2.0 reference lines represent 95% model probability.

Generalized linear model

A weighted generalized linear model detected no evidence of directional change in cohort deviations through time (β = 0.00177, SE = 0.011, p = 0.875, 95% CI = -0.024 – 0.021). The estimated slope was near zero and not significantly different from zero, indicating that recruitment variability did not exhibit a systematic temporal trend. This supports the interpretation that cohort strength varies among years, rather than reflecting a gradual change in recruitment.

Tagish Lake

Studentized residuals

Catch-curve analysis produced statistically significant and low estimates of instantaneous total mortality across all survey years, with Z ranging from 0.103 to 0.142, showing no clear evidence of sustained change over time (Table 11). Studentized residuals showed that most cohorts fell within the ±2.0 standard deviations, with only sporadic strong or weak cohorts (Figure 12).

Table 11. Tagish Lake year-specific weighted catch-curve results, including instantaneous mortality (Z), model fit (p-value and R^2), and age ranges used in analysis.

Survey year	*Z*	*p-value*	*R^2*	*Age range*
1993	0.103	<0.0001	0.86	7 – 34
2015	0.142	0.001	0.71	8 - 25

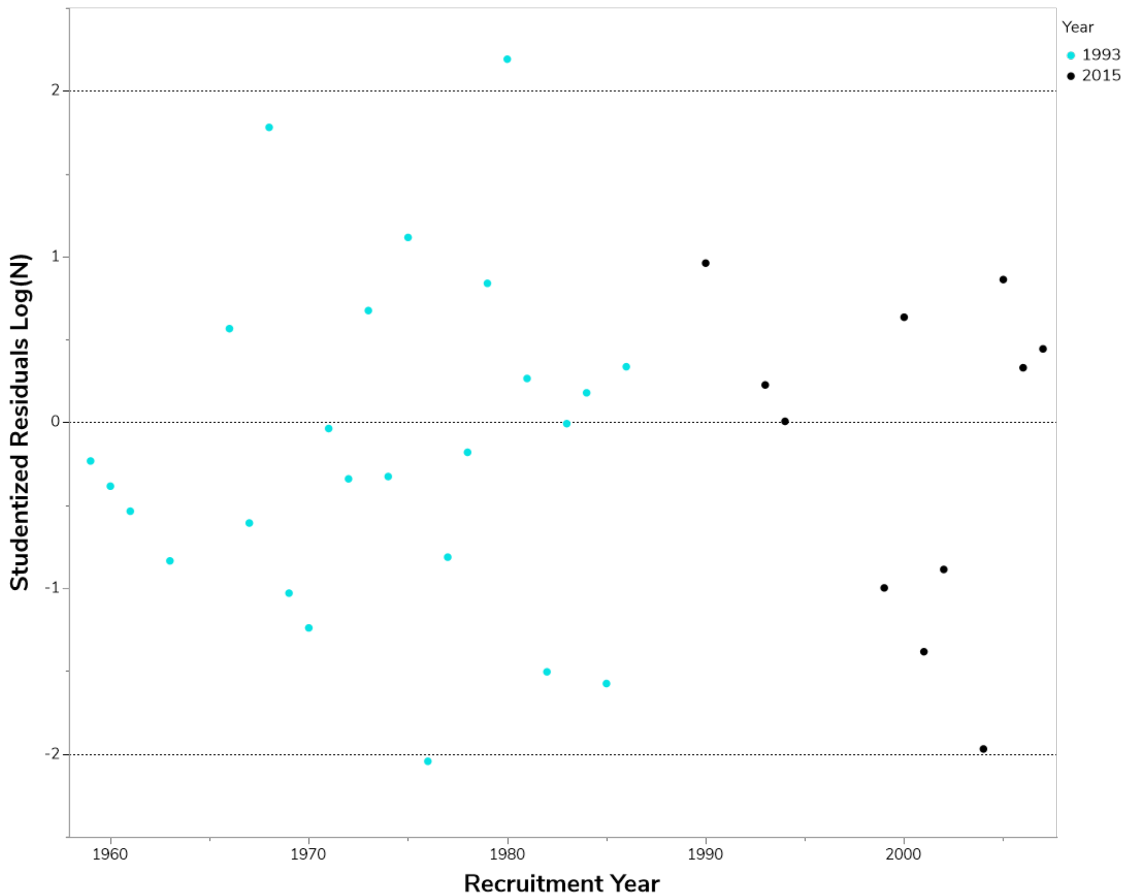

Figure 12. Tagish Lake weighted catch-curve studentized residuals, as sampled in 1993 and 2015. ± 2.0 reference lines represent 95% model probability.

Generalized linear model

A weighted generalized linear model detected no evidence of directional change in cohort deviations through time ($\beta = 0.0008$, SE = 0.016, $p = 0.961$, 95% CI = -0.033 – 0.032). The estimated slope was near zero and not significantly different from zero, indicating that recruitment variability did not exhibit a systematic temporal trend. This supports the diagnostics of the weighted catch curve that cohort strength varies among years, rather than reflecting a gradual change in recruitment.

Bennett Lake

Studentized residuals

Catch-curve analysis of the 2014 survey on Bennett Lake, produced a low estimate of instantaneous total mortality ($z = 0.086$) (Table 12). However, as this estimate is from a single survey, no temporal mortality trends can be determined. Studentized residuals showed that cohorts fell within the ±2.0 standard deviations (Figure 13).

Table 12. *Bennett Lake year-specific weighted catch-curve results, including instantaneous mortality (Z), model fit (p-value and* R^2*), and age ranges used in analysis.*

Survey year	*Z*	*p-value*	R^2	*Age range*
2014	0.086	0.015	0.56	8 - 22

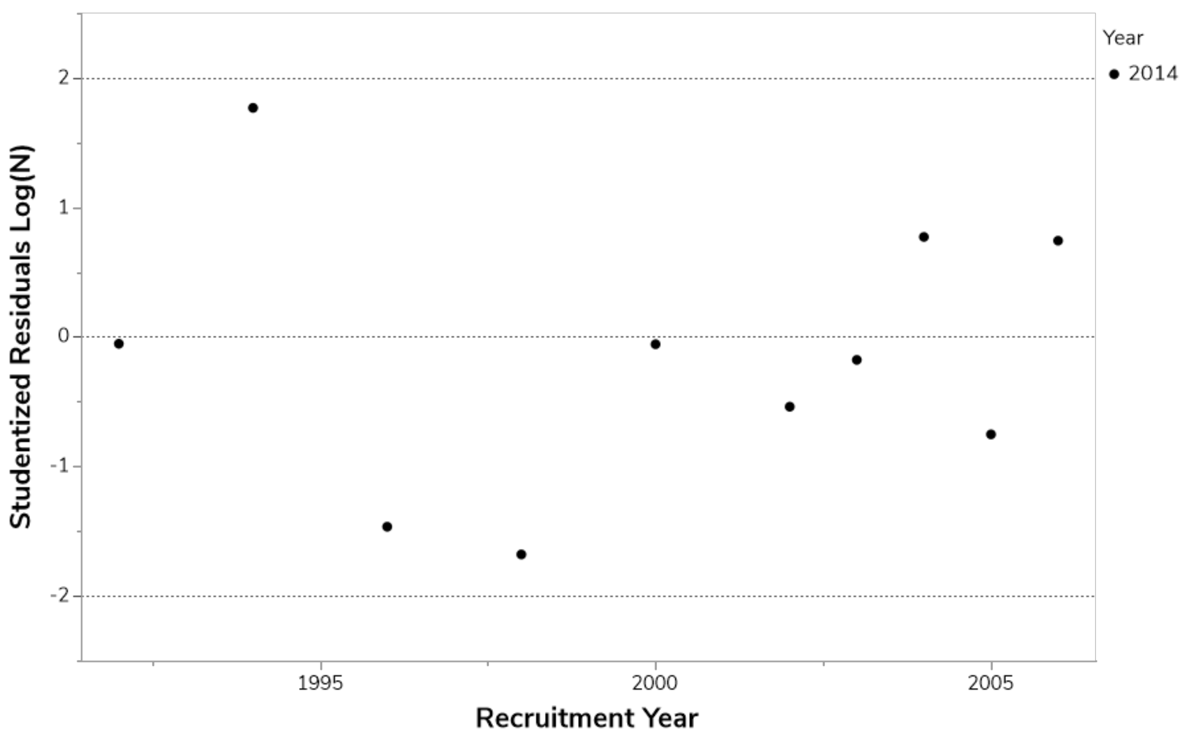

Figure 13. *Bennett Lake weighted catch-curve studentized residuals, as sampled in 2014. ± 2.0 reference lines represent 95% model probability.*

Generalized linear model

A weighted generalized linear model detected no evidence of directional change in cohort deviations through time (β = 0.022, SE = 0.06, p = 0.719 95% CI = -0.157 – 0.112). The estimated slope was near zero and not significantly different from zero, indicating that recruitment variability did not exhibit a systematic temporal trend. Similarly to the catch-curve diagnostics, this supports that cohort strength varies among years.

Discussion

Growth models

Bootstrapped von Bertalanffy growth model results indicate that lake trout growth has remained consistent across lakes and survey periods, when parameter uncertainty is considered. Although estimates of L_∞ and K varied among surveys, bootstrapped confidence intervals overlapped broadly in all lakes. Predicted age-at-length curves also overlapped extensively within the observed age ranges, indicating no consistent or biologically meaningful temporal shifts in growth trajectories.

In Lake Laberge, the higher L_∞ estimate in 2024 did not correspond to a distinct change in growth trajectory, as K was lower and confidence intervals overlapped among all periods. Predicted age-at-length curves were largely indistinguishable across observed ages, suggesting that the apparent increase in asymptotic size is best explained by the greater representation of older and larger individuals in the 2024 dataset, which exerted stronger leverage on the VBGM asymptote. This interpretation is supported by the fact that the 2024 survey sampled proportionally more older fish than the 2016 SPIN survey and the 1991/1993 index-netting surveys, indicating that the elevated L_∞ is a sampling-driven outcome rather than a biological shift in growth potential. Taken together, these patterns indicate that the difference in L_∞ reflects both stronger anchoring of the curve by older age classes and the typical L_∞–K trade-off inherent in VBGM fitting, rather than a biological signal of changing growth

For Marsh and Tagish lakes, variation in estimates among surveys was accompanied by substantial overlap in confidence intervals, particularly where age structure was limited or representation of older fish was sparse. In both systems, predicted age-at-length curves overlapped strongly, indicating consistent growth dynamics through time despite differences in parameter precision. The wider confidence intervals observed in some years likely reflect uneven sampling of older age classes rather than underlying biological variation, reinforcing the importance of interpreting VBGM parameters in combination with predicted growth curves.

The single Bennett Lake estimate was characterized by wide confidence intervals for both L_∞ and K, limiting inference regarding temporal trends. This estimate is best interpreted as a baseline characterization rather than evidence of growth change, and should not be compared directly to multi-year datasets without additional sampling to characterize older age classes more fully.

Overall, overlapping bootstrap confidence intervals and closely aligned predicted growth trajectories indicate no robust evidence of temporal change in lake trout growth across the study system. The difference in bootstrapped parameter estimates among surveys are most likely attributable to differences in sampling methodologies and sampled age structure, rather than underlying changes to growth dynamics. Accordingly, inference about temporal stability in growth should rely primarily on overlap of predicted curves within observed ages and on biological context, rather than on point estimates of VBGM parameters alone.

Catch-curve residuals

Across the four sampled lakes and survey years, catch-curve analysis consistently produced low estimates of instantaneous mortality, and although model fit varied across lakes and surveys, we did not detect any evidence of sustained change in mortality over time. Weighted studentized residuals further showed that most cohorts were within expected limits, with only occasional strong or weak year classes. Weighted generalized linear models also detected no directional trends in cohort deviations. Combined, these results suggest that adult survival and long-term recruitment dynamics have broadly remained consistent for the duration of the available datasets.

While we did not observe population-level trends, variability in individual cohorts was evident in all lakes. These interannual variations can be common and attributable to environmental conditions, spawning success, early survival, or habitat availability. The lack of a defined trend across all lakes indicates that any drivers of this variability may be episodic in nature. However, interpreting recruitment patterns solely from temporal trends will risk overlooking environmentally meaningful cohort-specific responses. However, the absence of a directional trend should not be interpreted as evidence of recruitment stability; rather, it reflects the limits of inference from single-year age-composition datasets and the assumptions underlying catch-curve methods. Interpreting recruitment patterns solely from temporal trends risks overlooking environmentally meaningful cohort-specific responses.

Accordingly, further evaluation of these results should focus on whether individual strong or weak cohorts correspond to historical water-level conditions or operational changes. A more detailed analysis linking cohort-specific residuals to hydrologic conditions would provide a clearer understanding of whether deviations reflect natural variability or potential project related effects.

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