Striped Bass in the San Joaquin River Restoration Area: Population and Bioenergetics Modeling

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Self-Certification of Peer Review

This proposal has been peer reviewed by the following two individuals, at least one of whom is from outside my work group:

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1.0 Introduction

1.1 Background

The San Joaquin River Restoration Program (SJRRP) aims to establish sustainable Chinook Salmon (*Oncorhynchus tshawytscha*) populations within the mainstem San Joaquin River below Friant Dam to the confluence of the Merced River (referred to as the SJRRP Restoration Area; SJRRP 2018). Predation of juvenile salmon is identified as a “critical stressor” to the population within the San Joaquin River and the SJRRP’s success (SJRRP 2018). In addition to the SJRRP’s priorities of providing adequate flows, volitional passage, habitat restoration and reintroductions, the Fisheries Management Plan and Fisheries Framework identified the importance of understanding and managing predators for the restoration of Chinook Salmon (SJRRP 2010 and SJRRP 2018). Assessing predation levels, identifying impacts to juvenile salmon survival, and detecting areas of high predation to adjust management actions will also be a component of the Long-Term Monitoring Plan (SJRRP *In Draft*).

Striped Bass (*Morone saxatilis*) are non-native to California but have well-established populations throughout the San Joaquin/Sacramento Delta and adjacent rivers systems (Nobriga et al. 2021, Sabal et al. 2019). Within the Restoration Area, Striped Bass are the dominant piscivore caught during annual steelhead (*O. mykiss*) and adult Chinook Salmon monitoring (Sutphin and Root 2021, Root and Sutphin 2021). They are mobile, schooling and often found where juvenile salmon congregate (Sabal et al. 2016, Nobriga et al. 2021). As juveniles, Striped Bass feed mostly on invertebrates but become predominantly piscivorous after two years (Lindley and Mohr 2003). Migration patterns and behavior are variable, and not well understood within the San Joaquin River (Sabal et al. 2019, Goertler et al. 2021). However, it appears Striped Bass often make upriver spawning migrations and spend more time in rivers during the spring compared to delta or bay areas (Sabal et al. 2019). Spawning occurs between April and June, which overlaps with juvenile spring- and fall-run Chinook Salmon emigration (Sabal et al. 2019, Satterthwaite et al. 2017). Striped Bass reportedly leave riverine habitats and move towards Bay-Delta habitat in the winter (January – March; Le Doux-Bloom et al. 2021) but are frequently observed within the Restoration Area during this time (Root and Sutphin 2021).

Using data collected during SJRRP’s Central Valley Steelhead Monitoring and Adult Spring-Run Chinook Salmon Monitoring, Trap and Haul programs, we present a hierarchal approach using two Striped Bass models (a population model and a bioenergetics model) where results from the population model will be used to inform results of the bioenergetics model. Results from these simplistic preliminary models help describe the potential impact of Striped Bass to native fish, like juvenile salmon, and highlight the value of increased data collection to improve the accuracy and relevance of these models.

2.0 Methods

2.1 Striped Bass Captures and Recaptures

Data from Striped Bass captured during SJRRP's Central Valley Steelhead Monitoring and Adult Spring-Run Chinook Salmon Monitoring, Trap and Haul efforts (Root and Sutphin 2021, Sutphin and Root 2021) were used as model inputs. Central Valley Steelhead Monitoring occurs annually between December and March/April. This is followed seamlessly by Adult Spring-Run Chinook Salmon Monitoring, Trap and Haul, which continues until water temperatures or flow create unsuitable habitat for salmon and adults are no longer being captured (typically late-May/early-June). Both sampling/monitoring efforts are completed in the lower reaches of the San Joaquin River Restoration Program's Restoration Area (Reaches 4b and 5) and employ 8- or 10-foot (ft) wire fyke traps or 4- or 6- ft fyke nets designed to capture large fish moving through or adjacent to the thalweg. The upstream extent of sampling during these efforts can change year-to-year depending on flows, but sample sites in Reach 5 are generally consistent. During Steelhead Monitoring, electrofishing within Reach 5 supplements the trapping effort to increase the probability of detecting Steelhead.

Throughout standardized steelhead and adult Chinook Salmon monitoring efforts, all non-target species, including Striped Bass, are recovered from sample gear, identified to species, measured for total length (millimeters; mm), and released upstream of sample gear to minimize likelihood of recapture. In addition, to support on-going efforts by FISHBIO to study distribution and movements of non-native piscivores in the San Joaquin River, all captured Striped Bass were scanned for a Passive Integrated Transponder (PIT) tag. If no PIT tag was present, a new tag was implanted.

2.2 Striped Bass Population Model

All data analyses for the population model were conducted in program MARK (Cooch and White 2020) using R statistical program (version 4.3.1; R Core Team 2024). Individual capture histories (captured = 1, not captured = 0) were created for each day of sampling between the months of (December-June) of each sample year (2019–2024) using PIT tagged Striped Bass collected during Winter/Spring seasons from December 2018 to May 2024 (1,415 unique PIT tags, 61 recapture events). After release, each fish was considered independent and remixed back into the population. Year and monthly time intervals were used as a covariate since it is thought that Striped Bass demonstrate migratory behavior temporarily (Sabal et al. 2019). Striped Bass population estimates were generated using the POPAN model (Schwarz and Arnason 1996) for open populations based on the Jolly-Seber method using the link function mlogit. Three primary parameters are estimated using the POPAN model: probability of an animal surviving between occasions i and i+1 (φ); the probability of capture at occasion i (p); and the probability that an animal from the super-population (N) would enter the population between occasions i and i + 1 and survive to the next sampling occasion i + 1 (pent). Pent can also be considered a combination of birth and immigration into the population. The POPAN model produces a super-population estimate which is a total abundance estimate of the population of individuals that occupy the sample area during the entire sampling effort as well as individuals who only inhabit the sampling area for a limited portion of the sampling time. In the context of this project, the Striped Bass super-population estimate is considered the individual Striped Bass that both inhabit and “visit/migrate” into the sampling area during the sampling period.

Three population models were tested with different combinations of fixed and random φ and pent time (month, year). Model creation was limited and reflected ecologically probable situations that could occur in the San Joaquin River. Model selection was based on an information theory approach, using the corrected Akaike information criterion (AICc) and calculated weight. The top model was considered the model with the lowest AICc and where the difference between that model’s AICc and the AICc of the other models (ΔAIC_c) was greater than 2.00 (Burnham and Anderson 2002).

Correlations between total monthly Striped Bass catch and monthly average San Joaquin River flow (in cubic feet per second [cfs]) were calculated using the Pearson’s correlation in the R statistical program (version 4.4.2; R Core Team 2024) and the rstatix package (Kassambara 2023).

2.3 Striped Bass Bioenergetics Model

Bioenergetics simulations were conducted using Fish Bioenergetics 4.0 (FB4; Deslauriers et al. 2017). The model design file was structured and formatted in RStudio (R Core Team 2024), and simulation outputs were subsequently imported back into RStudio for analysis (dplyr package; Wickham et al. 2023), integration with the Striped Bass population model (Section 2.2), and data visualization (ggplot2 package; Wickham 2016). Model parameters were sourced from available scientific literature or derived from SJRRP monitoring data (Section 2.1). Monthly average biomass of juvenile Chinook Salmon was estimated using measurements from rotary screw trap (RST) monitoring conducted in the upper Restoration Area over multiple years (Hutcherson and Sutphin 2023). San Joaquin River water temperatures used for the model were downloaded from California Data Exchange Center Newman (SMN) gauging station (available online at: California Data Exchange Center). Full details of model and post-processing inputs are provided in Appendix A.

Striped Bass were delineated into three age-classes by total length: Age-1 (150 to <300 mm), Age-2 (300 to <400 mm), and Age-3+ (Adult; ≥400 mm; Mansueti 1961). Individuals smaller than 150 mm were excluded from the model (n = 3). Model simulations were conducted for each age-class during each month and year in which individuals of that age-class were captured. To evaluate seasonal trends, simulations were also run for each age-class using input data that was averaged by month (December - May) across all years. All simulations assumed an initial population size of one individual.

Each simulation was fit to a P-value, representing the proportion of maximum consumption rate (Cmax) at which the fish was assumed to be feeding (Hanson et al. 1997). P-values were assigned by age-class and the average river temperature for that month (Hartman and Brandt 1995). Average daily river temperatures were also incorporated into each simulation using an accessory input file. Initial weights for each simulation were averaged from individuals of that age-class collected in the respective sampling month and year. These were derived from Striped

Bass captured during SJRRP monitoring (Section 2.1) by converting total length to fork length (Porter et al. 2017) and applying length-weight relationships from Nobriga (2009). Age-specific energy density values for Striped Bass (predator energy density) were help constant at: 5659.5 J/g (Age-1), 6860 J/g (Age-2) and 7,681 J/g (Age-3+; Loboschefsky et al. 2012). Prey Energy Density of Chinook Salmon was set to 4,800 Joules per gram (J/g; Adrean 2011). The oxycalorific coefficient used to convert oxygen consumption to energy was 13,560 J/g O2; Loboschefsky et al. 2012). Indigestible prey was set to three percent to reflect the proportion of fish body that cannot be digested (Hanson et al.1997).

To simulate how different proportions of Chinook Salmon in the Striped Bass diet impact net consumption, three diet scenarios were tested: 10 percent (Sabal et al. 2016), 50 percent (an estimated midpoint) and 80 percent (Blackwell and Juanes 1998). When modeling diet scenarios, unadjusted average daily river temperatures were used.

To simulate how rising temperatures may influence net consumption rates of Chinook Salmon, average daily river temperatures measured at the SMN gauging station were increased by 1 and 2 degrees Celsius (°C). When modeling temperature scenarios, the proportion of Chinook Salmon in the Striped Bass diet was fixed at 10 percent and P-values were adjusted to reflect the temperature increases.

Predicted consumption of Chinook Salmon was reported in grams (g). To estimate the number of individual Chinook Salmon (n) consumed by Striped Bass, the total biomass consumed was divided by the average weight of juvenile spring-run Chinook Salmon captured during five seasons (2017 to 2022) of RST monitoring in the upper reaches of the Restoration Area (Hutcherson and Sutphin 2023). Length-at-date regressions were developed from genetically identified spring-run individuals collected during the first three years of effort (2017/2018 through 2019/2020). These regressions were applied to the raw data set, and values outside the 99 percent prediction interval were excluded prior to averaging by collection month (December to May). Live fish whose total length was less than 45 mm were not weighed due to the potential measurement error by residual water clinging to the fish. As a result, early season (e.g., December) weights primarily reflect deceased fish, which may have gained or lost water post-mortem.

Monthly age-class structure of the Striped Bass population was calculated from length data collected between 2018 and 2024 during SJRRP steelhead and adult Chinook Salmon monitoring (Section 2.1), excluding duplicate recaptures of PIT tagged individuals recaptured within the same month. Age-class structure was combined with averaged monthly results from the POPAN population model (Section 2.2) to estimate total monthly consumption of Chinook Salmon.

3.0 Results

Striped Bass were the most frequently captured piscivore most years, averaging 48 percent of piscivore catch between December 2018 and May 2024 of SJRRP's Central Valley Steelhead Monitoring and Adult Spring-Run Chinook Salmon Monitoring, Trap and Haul seasons (Figure 1). In 2020/2021 and 2022/2023, Channel Catfish were the most frequently encountered (32 and 38 percent, respectively) and Striped Bass were the second most frequently encountered (30 percent both seasons). Most Striped Bass captured were considered Age-class 3+, being between 400- and 500-mm total length (35 percent on average; Figure 2) and between 500 and 600 mm (26 percent on average).

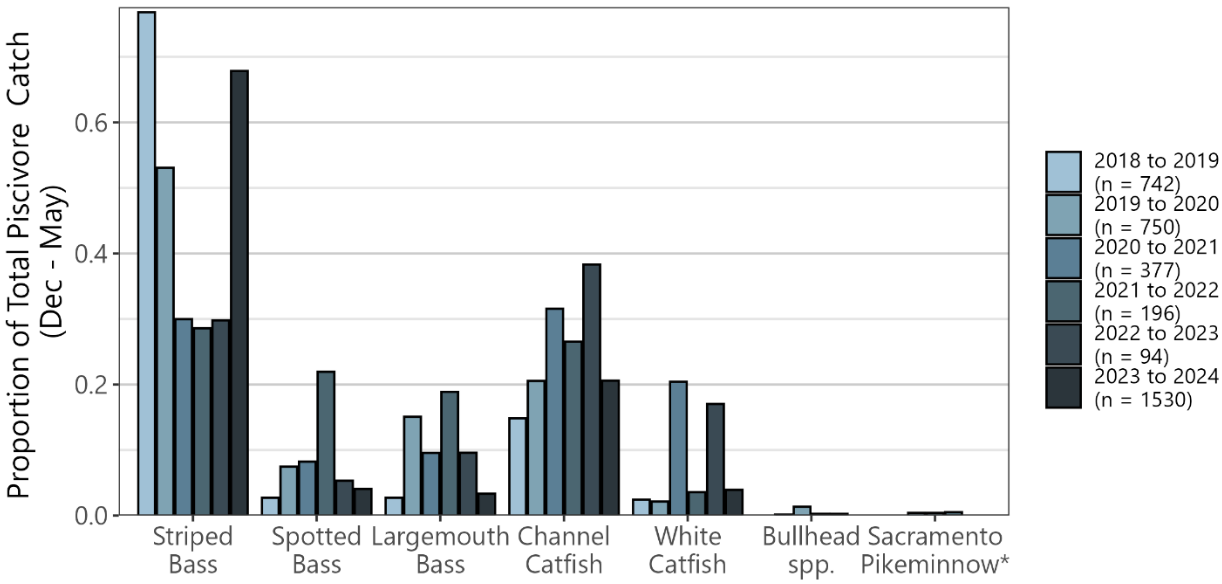

Figure 1. Proportion of total annual large piscivore catch by species and sampling season (December to May) during SJRRP's Central Valley Steelhead Monitoring and Adult Spring-Run Chinook Salmon Monitoring, Trap and Haul programs using electrofishing, Fyke nets and Fyke traps. *Native species to the San Joaquin River (2018/2019 to 2023/2024; n = 3692). Data excludes same-month recaptures (29 Striped Bass, 2 Channel Catfish).

Average Striped Bass size across the 2018/2019 through 2023/2024 seasons did not vary much between months, although it was highest in March (Figure 3). However, there was a broader range of sizes between March and May. Striped Bass catch typically peaks in April. This observance is most pronounced in 2019 and 2024 (Figure 4).

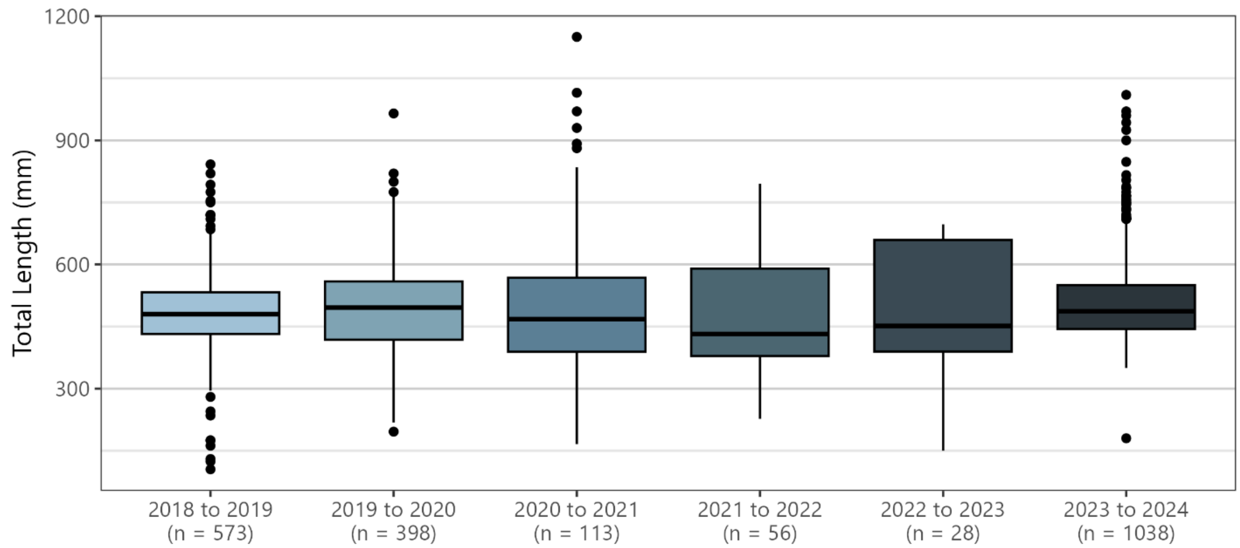

Figure 2. Distribution of Total Length (mm) by sampling season (December to May) of Striped Bass during SJRRP's Central Valley Steelhead Monitoring and Adult Spring-Run Chinook Salmon Monitoring, Trap and Haul programs (2018/2019 to 2023/2024; n = 2206). Length data includes 765 individuals that were not PIT tagged and excludes 29 same-month recaptures.

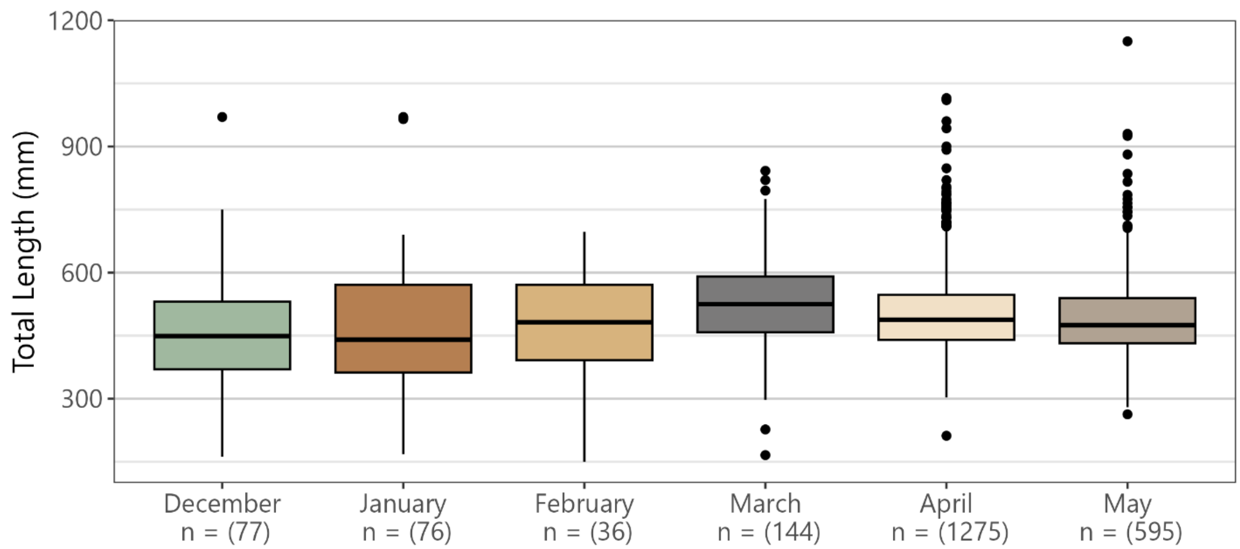

Figure 3. Distribution of Total Length (mm) by sampling month (December to May) of Striped Bass during SJRRP's Central Valley Steelhead Monitoring and Adult Spring-Run Chinook Salmon Monitoring, Trap and Haul programs (2018/2019 to 2023/2024; n = 2206). Length data includes 765 individuals that were not PIT tagged and excludes 29 same-month recaptures.

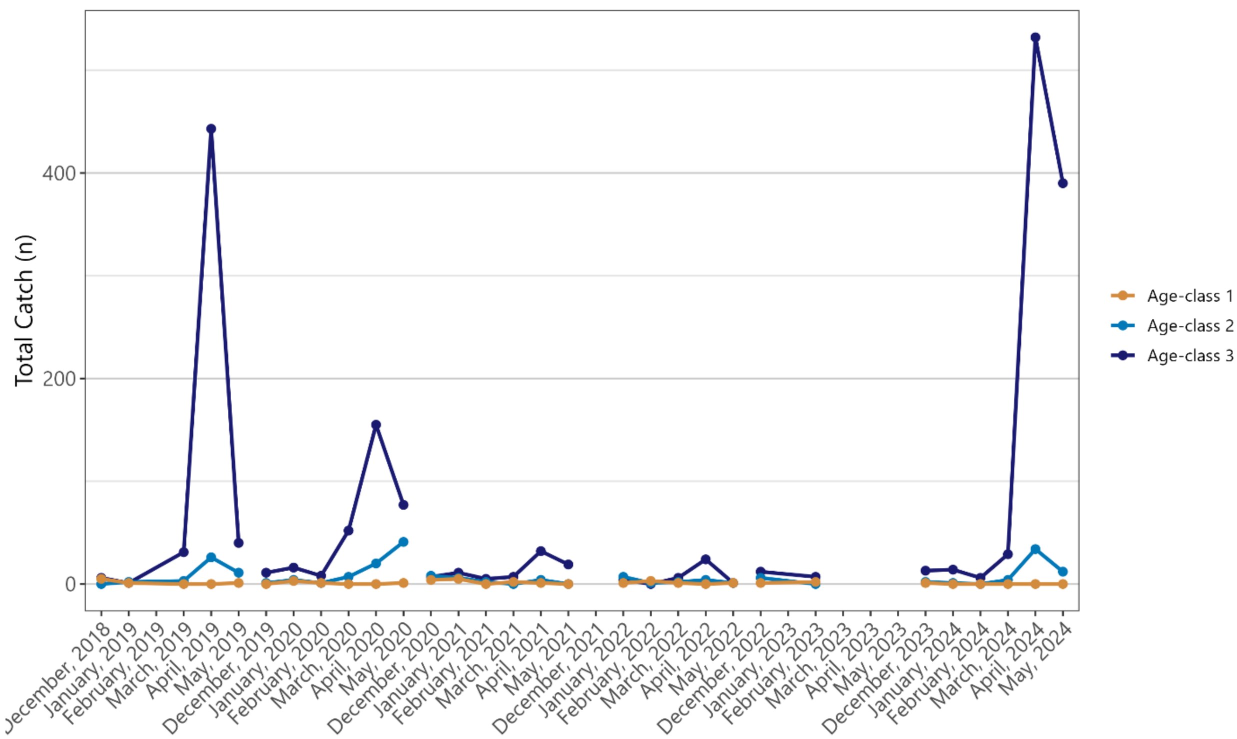

Figure 4. Striped Bass catch by age-class (n) for sampling season December 2018 to May 2024. PIT-tagging occurred from December 2019 – May 2024 in the San Joaquin River, CA during annual SJRRP's Central Valley Steelhead Monitoring and Adult Spring-Run Chinook Salmon Monitoring, Trap and Haul programs.

3.1 Striped Bass Population Model

Striped Bass were encountered on 328 days, and 1,410 PIT tags were deployed across all years evaluated. During these sampling days, there was a recapture rate of 3.8 percent (n = 53). In addition, 8 individuals captured that were previously tagged by other entities were included in the model. Forty-five models were tested. The top model, with all the weight, allowed φ and p to vary by the additive effects of month and year, and pent to vary by day (Table 1).

Table 1. Top five models tested for Striped Based population estimation using the POPAN model. The total number of parameters (npar), Akaike's information criterion (AIC_c), increase over the lowest AIC_c (ΔAIC_c), and Akaike model weight (weight).

Model	npar	AICc	∆AICc	weight
φ (~Month + Year) p(~Month + Year) pent(~time) N(~1)	29	6082.80	0.00	1.00
φ (~Month + Year) p(~time) pent(~Month + Year) N(~1)	37	6245.78	162.97	0.00
φ (~Flow) p(~Month + Year) pent(~time) N(~1)	65	6269.09	186.29	0.00
φ (~Flow) p(~Flow) pent(~time) N(~1)	73	6269.42	186.62	0.00
φ (~Month + Year) p(~Flow) pent(~time) N(~1)	100	6474.54	391.73	0.00

The results of the model showed the estimated population maximum occurred in April 2024 (N = 1936; SE ± 141.71) and the minimum in December 2019 (N = 56; SE ± 15.59; Figure 5). Average monthly river flow was highest during the 2022/2023 and 2023/2024 sampling seasons, but no sampling occurred during April and May of 2023. Striped Bass catch is typically lower between December and March, with no apparent correlation to river flow. April and May catch appears to correlate with average river flow during both the current and previous months (Table 2). This suggests that both seasonality, likely reflecting migration patterns, and flow play important roles in striped bass abundances in the Restoration Area.

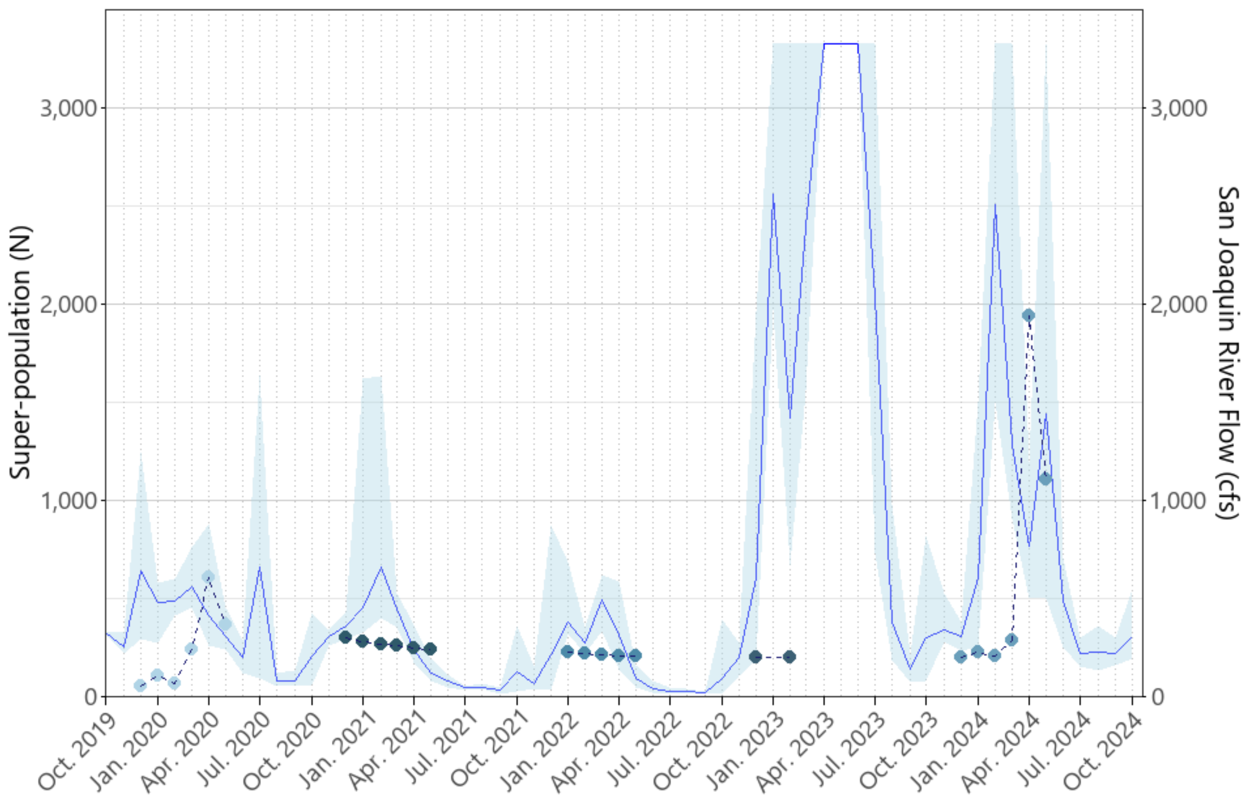

Figure 5. Striped Bass super-population estimates (N; solid dot) for each sampling month Striped Bass were encountered. Sampling and PIT-tagging occurred from December 2019 – May 2024 in the San Joaquin River, CA during annual SJRRP's Central Valley Steelhead Monitoring and Adult Spring-Run Chinook Salmon Monitoring, Trap and Haul programs. No Striped Bass were encountered December of 2021 or January, March – May 2023. The secondary axis shows average monthly San Joaquin River flow (cfs; line) measured at SMN gauge near Newman with minimum and maximum values (shaded area). Flow reported as "above available rating table [ART]" were substituted with 3,325 cfs, representing 1 cfs above the maximum reported during this period.

Table 2. Pearson's correlations between total monthly Striped Bass catch and average daily flow of the current month or previous month. Only sampled month-years included between December 2019 – May 2024. Correlations of a significant level (p-value = ≤0.01, grey; p-value = ≤0.05, blue) are highlighted.

Month	Current month flow (cfs)	p-value	Previous month flow (cfs)	p-value
December	−0.370	−0.628	−0.063	0.937
January	0.070	0.930	0.830	0.172
February	−0.011	0.986	0.440	0.460
March	0.260	0.740	0.160	0.839
April	0.990	0.009	0.990	0.015
May	0.990	0.009	0.990	0.012
Combined	*0.180*	*0.385*	*0.210*	*0.323*

Note: Flow reported as "above available rating table [ART]" were substituted with 3,325 cfs, representing 1 cfs above the maximum reported during this period.

3.2 Striped Bass Bioenergetics Model

Simulated consumption of Chinook Salmon biomass (g) by Striped Bass increased in February (Figure 6A), likely due to rising water temperatures, while consumption of individuals (total fish; N; Figure 6B) is higher in December when juvenile salmon are modeled to be nearly 10 times smaller than in January. The peak of consumption - both individuals and biomass – in April reflects the large increase in super-population levels. Plots by year are available in Appendix B.

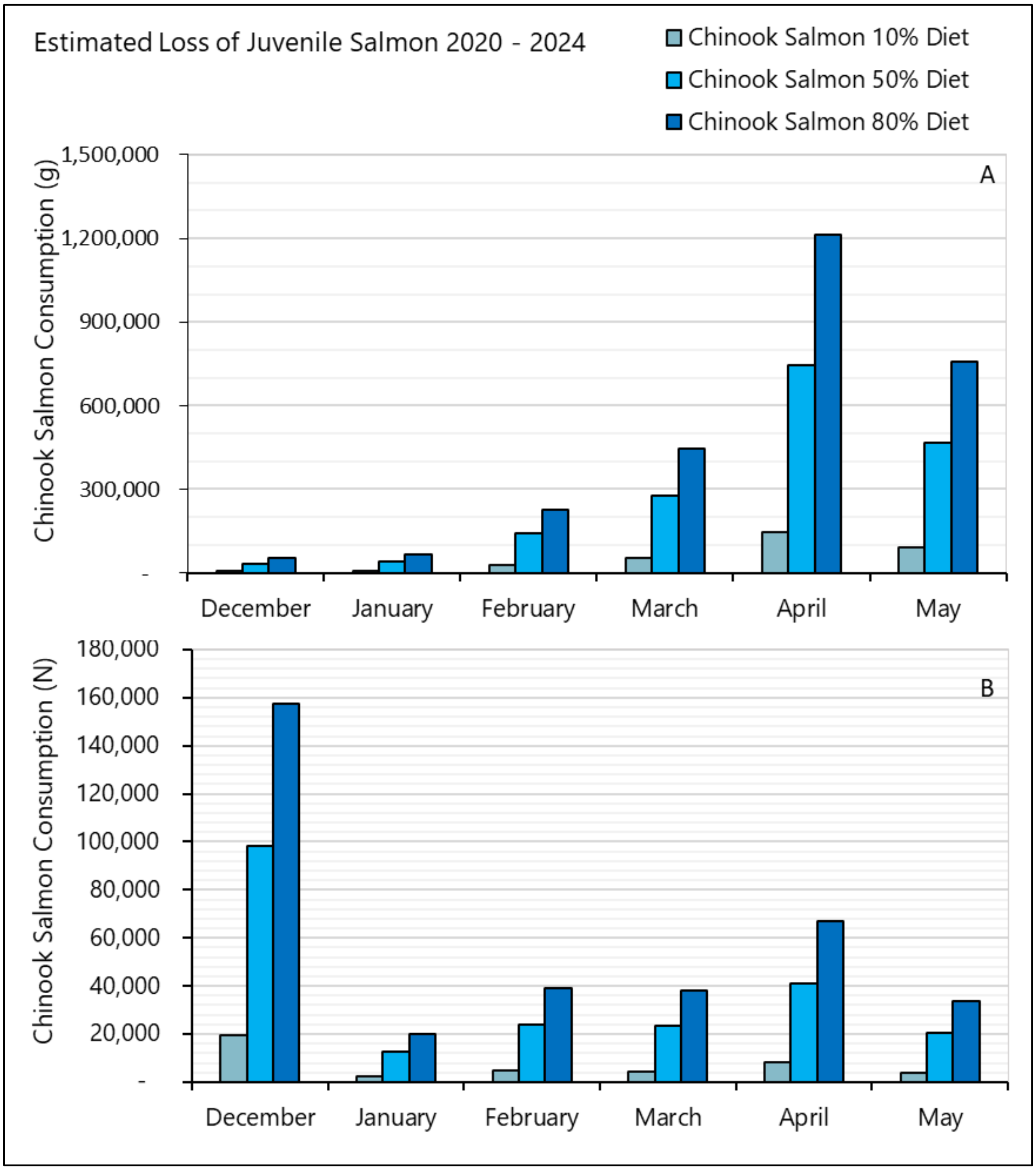

Figure 6. Simulated Chinook Salmon consumption by Striped Bass in the San Joaquin River, CA over three different percentages of Striped Bass Diet across average monthly population estimates (2020 to 2024). A: Biomass of Chinook Salmon consumed (g). B: Number of individual Chinook Salmon consumed (N) calculated from Biomass consumed and average Chinook Salmon weight (g).

Increasing average river temperature by 1 or 2°C only impacted consumption when altering the proportion of maximum daily food consumed (p-value of Cmax; Figure 7). Average water temperatures from March to May are typically between 11 and 30°C (Appendix A), where the model assumes Striped Bass are feeding close to their maximum rate (P-Value = 0.98; Appendix A).

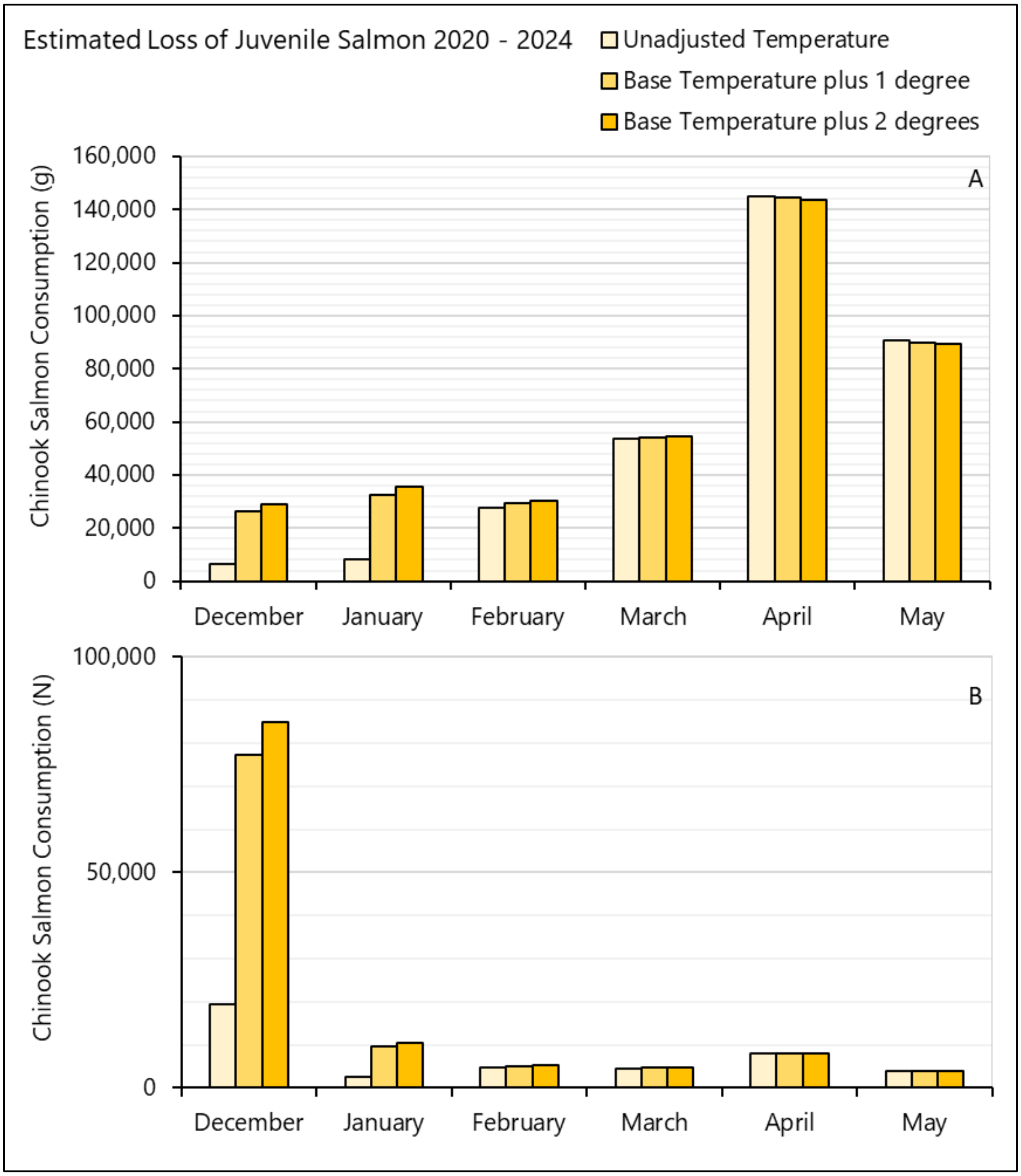

Figure 7. Simulated Chinook Salmon consumption by Striped Bass in the San Joaquin River, CA over three different San Joaquin River temperatures regimes (measured temperature with no adjustment, adding 1°C and adding 2°C) across average monthly population estimates (2020 to 2024). A: Biomass of Chinook Salmon consumed (g). B: Number of individual Chinook Salmon consumed (N) calculated from Biomass consumed and average Chinook Salmon weight (g).

4.0 Discussion

The population and bioenergetics models presented here represent simplistic estimates of Striped Bass population and salmon consumption within the lower reaches (4b and 5) of the Restoration Area from 2019 to 2024. Model results should be interpreted cautiously because they are based on a small dataset within a brief temporal scope. The estimates of juvenile salmon consumption did not account for prey availability or predator interactions and were scaled using population estimates. Despite these limitations, the models provide valuable insights into predator-prey interactions within the San Joaquin River system.

Understanding the dynamics of the Striped Bass population and estimated consumption of Chinook Salmon over changing conditions (e.g., water temperature) could help improve conceptual models and identify the most effective periods and locations for management actions, such as predator removals, juvenile Chinook Salmon releases, etc. Within the Sacramento/San Joaquin Delta (Delta), increasing water temperature and decreasing conductivity showed a significant positive association with Chinook Salmon being found in the stomach and gut samples of Striped Bass (Brandl et al. 2021). Energetic studies suggest that Striped Bass are tolerant of a wide range of environmental conditions, and that growth is possible between 6°C and 30°C (Hartman and Brandt 1995).

As the population model (Figure 5) and catch data demonstrate, the population of the Striped Bass in Reach 5 of the Restoration Area was highest in April and May. This overlaps with peak juvenile salmon smolt emigration (Hutcherson et al. 2020), and actions to reduce predator effects during this time may have the greatest impact on reducing salmon loss. In 2024, large numbers of Striped Bass were captured, but the recapture rate remained low and could indicate a large source population and/or substantial migration within the system. Striped Bass recapture rates using fyke nets have also been relatively low near the Stanislaus inlet (Lamb et al. 2024). Striped Bass have been documented traveling downstream of the restoration area from Hills Ferry Barrier to the Stan Weir PIT tag array (approximately 80.1 river miles) within an average of 209 days. Also, tagged fish were recaptured in a fyke trap 55.6 river miles downstream 823 days after release (Sonke, personal communication, 16 January 2025).

The bioenergetics model suggests consumption of individuals (N) is highest during winter months (Figure 6B) when salmon are smaller and less developed. However, juvenile salmon are not likely present in abundance in Reaches 4b and 5 during that timeframe as juvenile salmon monitoring in Reach 1 indicates most salmon initiate downstream emigration in March and April (Hutcherson et al. 2020). As these estimates are based on the caloric requirements of fixed diets and not prey availability, until competing data is presented, the SJRRP should focus data interpretation to what is presented for March – May timeframe. Decreased Chinook Salmon consumption in May (Figure 7) could be attributed to reduced metabolic efficiency driven by increased river temperatures and, to a larger extent, the fewer Striped Bass in the area as predicted by the POPAN model.

To enhance confidence in modeled Chinook Salmon consumption rates, more data on Striped Bass feeding frequency, diet composition, and stomach fullness (particularly from recaptured individuals) are needed. Additionally, understanding the temporal and size-dependent effects of these factors will improve the accuracy of consumption estimates. Studies examining the metabolic efficiency of Striped Bass and temperature-related consumption in the San Joaquin

River could further refine these models and explore temperature-driven changes in prey preference. Non-lethal stomach content sampling, such as gastric lavage, combined with DNA or physical analysis, would provide valuable data. Fish sampled by FishBio frequently have empty stomachs in the south Delta, with an average of 43.1 percent in 2024 (Lamb et al. 2024). While Striped Bass appeared to feed most frequently on invertebrates (66 percent), they also had the highest frequency occurrence of native fish in stomach content analyses (Lamb et al. 2024). Variability in Striped Bass behavior and diet has been observed (Sabal et al. 2016), and more data from individuals in the San Joaquin River will help to refine management models.

Striped Bass were selected as the primary species of interest due to their frequency of capture during other SJRRP studies and reported impacts on salmon, but other species should also be considered if a complete understanding of salmon predation loss in the Restoration Area is of concern. For example, Michel et al. (2018) reported salmonids comprised over 30 percent of the diets of Channel Catfish (*Ictal urus punctatus*) from the San Joaquin River. Channel Catfish are the second most frequently encountered large piscivore during steelhead and adult Chinook Salmon monitoring (Figure 1). Additional common piscivores within the Restoration Area include Largemouth Bass (*Micropterus salmonids*), White Catfish (*Ameiurus catus*), Green Sunfish (*Lepomis cyanellus*), and Black Crappie (*Pomoxis nigromaculatus*); Michel et al. 2018, Sutphin and Root 2021). Smallmouth Bass (*Micropterus dolomieu*) are also documented predators of Chinook Salmon within the Delta system (Brandl et al. 2021). The interaction between these predators and Striped Bass, as well as their direct or indirect influence on juvenile salmon should be considered.

As the population and biogenetic models suggest, Striped Bass in the Restoration Area have the potential to consume large amounts of juvenile salmon during their emigration. Further data are needed to portray the risk by Striped Bass and other predators on juvenile salmon with more precision and to inform management actions.

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Appendix A:

Model Variables and Parameters

Table A-1. Fish Bioenergetics 4.0 standard inputs (see Hanson et al.1997 and Deslauriers et al. 2017)

Initial Settings	
Species	*Striped Bass (select target Age-class)
Initial Day	Each season sampling day started at 1 on December 1 *See Table A-2 (Model Input Parameters)*
Final Day	Each year Day 1 is December 1 *See Table A-2 (Model Input Parameters)*
Initial Weight (g)	*Monthly average weights by age-class. Derived from average TL (n = 2203) of Striped Bass captured 2019-2024 (Root and Sutphin 2021; Sutphin and Root 2021), converted to Fork Length (Porter et al. 2017) and Fork Length-weight relationships (Nobriga and Branch 2009). *See Tables A-2 (Model Input Parameters) and A-3 (Size Class)*
Oxycalorific Coefficient (J/g 02)	13,560 (J/g) O2 (Loboschefsky, et al. 2012)
Fit to	p-value (proportion of Cmax)
(Fit to Value)	*Binned Cmax values from literature determined by average monthly temperature and age-class *See Table A-4 (Cmax)* **Experimental Simulations: Adding 1 or 2°C to monthly temperature.**
Input Files (.csv)	
Water Temperature	Average daily temperature between 2019 and 2024 collected from California Data Exchange Center SMN gauging station. All-Years cumulative model averaged daily temperatures across 2019 to 2024. *See Table A-2 (Model Input Parameters) for monthly averages* **Experimental Simulations: Adding 1 or 2°C to monthly temperature.**
Prey Composition (Diet_prop)	*Standard 10% (Sabal et al. 2016) **Experimental Simulations: 50% (Sabal et al. 2016), 80% (Blackwell and Juanes 1998)**
Prey Energy Density (Prey_E)	Chinook Salmon = 4800 J/g (Adrean 2011) Other = 3500 J/g (Loboschefsky, et al. 2012; Decapods/Isopods [4181 J/g], Mysids [3140 J/g], Other [2025 J/g])
Predator Energy Density (Pred_E)	*Determined by Age-class (Loboschefsky, et al. 2012) *See Table A-3*
Indigestible Prey	3 % (Hanson et al. 1997)

*Input dependent on simulation (Month, Age-class, Diet, Temperature Change)

Table A-2. Fish Bioenergetics 4.0 Model Input Parameters used in all monthly simulations.

Input Parameter	**Month**					
	December	*January*	*February*	*March*	*April*	*May*
2019/2020						
*Striped Bass Age-1 Weight (g)***		179.2	66.7			160.7
Striped Bass Age-2 Weight (g)	298.9	324.6	392.0	450.7	454.7	424.4
Striped Bass Age-3+ Weight (g)	1,360.3	1,706.6	1,304.5	1,723.4	1,311.3	1,129.6
*San Joaquin River Temperature (°C)****	11.0	10.6	12.6	15.4	19.1	23.3
2020/2021						
Striped Bass Age-1 Weight (g)	132.0	83.7		135.7	84.4	
Striped Bass Age-2 Weight (g)	419.4	410.5	518.2		338.5	
Striped Bass Age-3+ Weight (g)	2,119.9	1,367.2	1,304.6	1,249.2	1,766.1	2,619.5
San Joaquin River Temperature (°C)	9.4	9.9	12.5	14.5	20.1	23.2
2021/2022						
Striped Bass Age-1 Weight (g)		131.7	150.0	103.6		228.5
Striped Bass Age-2 Weight (g)		426.2	395.3	514.3	485.4	347.9
Striped Bass Age-3+ Weight (g)		2,402.3		2,046.1	1,440.3	720.8
San Joaquin River Temperature (°C)		10.2	11.7	16.2	19.0	21.8
2022/2023						
Striped Bass Age-1 Weight (g)	73.1		53.1			
Striped Bass Age-2 Weight (g)	488.7					
Striped Bass Age-3+ Weight (g)	1,641.5		1,751.1			
San Joaquin River Temperature (°C)	9.2		10.4			
2023/2024						
Striped Bass Age-1 Weight (g)	51.7					
Striped Bass Age-2 Weight (g)	474.8	457.6		491.6	485.3	510.8
Striped Bass Age-3+ Weight (g)	1,466.0	1,921.2	1,456.1	1,189.5	1,280.8	1,220.7
San Joaquin River Temperature (°C)	11.1	11.5	13.4	16.2	19.6	21.2
2020 thru 2024						
Striped Bass Age-1 Weight (g)	109.9	113.5	103.8	125.0	84.4	194.3
Striped Bass Age-2 Weight (g)	443.3	408.6	455.9	477.4	471.4	439.6
Striped Bass Age-3+ Weight (g)	1,510.9	1,726.3	1,459.7	1,561.6	1,247.8	1,242.6
San Joaquin River Temperature (°C)	10.3	10.5	12.1	15.1	19.3	21.7
Leap Year and All Years						
First Day	1	32	63	92	123	153
Last Day	31	62	91	122	152	183
Other Years						
First Day	1	32	63	91	122	152
Last Day	31	62	91	121	151	182

*Striped Bass weight calculated from measured lengths based on Nobriga and Branch (2009) from Striped Bass captured between 2019 and 2024 (Root and Sutphin 2021, Sutphin and Root 2021). Used as Initial Weight for each month.

**Temperature measured in SJRRP and recovered from California Data Exchange Center SMN gauging station. Used to assign Cmax value for the month.

Table A-3. Size Class and Energy Density for Striped Bass. Adapted from *Mansueti (1961) and **Loboschefsky et al. (2012).

Species	Minimum Total Length (mm)*	Maximum Total Length (mm)*	Energy Density (J/g)**
Striped Bass Age-1	150	< 300	5659.5
Striped Bass Age-2	300	< 400	6860
Striped Bass Adult/Age-3+	400	+	7681

Table A-4. Proportion of Cmax (Maximum Consumption) Variable (P-Value). Adapted to bin categories from Hartman and Brandt (1995).

Parameter Value	**P-Value**		
Temperature Range	*Age-1*	*Age-2*	*Age-3+*
6° to 10°C	0.262	0.255	0.323
11° to 30°C	0.980	0.980	0.980
> 30°C	0.850	0.900	0.850

Table A-5. Total Striped Bass encounters, individuals that were PIT tagged and recaptured individuals between December 2018 and May 2024 captured during SJRRP's Central Valley Steelhead Monitoring and Adult Spring-Run Chinook Salmon Monitoring, Trap and Haul efforts.

	Month						
Years	*December*	*January*	*February*	*March*	*April*	*May*	*Annual Total*
2018/2019							
Encounters	13	6		34	470	52	*575*
Tags Deployed							*0*
2019/2020							
Encounters	12	23	10	60	179	125	*409*
Tags Deployed	8	21	10	59	148	19	*265*
*Recapture Events**	0 (4)	0	0	1	10	9	*21 (4)*
2020/2021							
Encounters	19	22	7	9	37	19	*113*
Tags Deployed	17	21	7	6	34	18	*103*
Recapture Events	1 (1)	0	0	1	1	1	*4 (1)*
2021/2022							
Encounters		13	4	9	30	3	*59*
Tags Deployed		13	4	8	25	3	*53*
Recapture Events		0	0	1	4		*5*
2022/2023							
Encounters	19		10				*29*
Tags Deployed	17		9				*26*
Recapture Events	0		0				*0*
2023/2024							
Encounters	16	15	6	33	581	403	*1054*
Tags Deployed	15	15	6	32	543	352	*963*
Recapture Events	0	0	0	0	17 (3)	6	*23 (3)*
Grand Totals							
Encounters							*2239*
Tags Deployed							*1410*
Recapture Events							*61*

*Recapture events include any recapture of Striped Bass whose tag had been previously deployed on this project and may include multiple recaptures of a single individual. Values in parentheses are recaptures of tagged individuals from other projects (n = 8). Tagging of Striped Bass began in the 2019/2020, so recaptures occurred in 2018/2019 season.

Table A-6. Metrics used in post-processing of bioenergetics data to extrapolate consumption estimates.

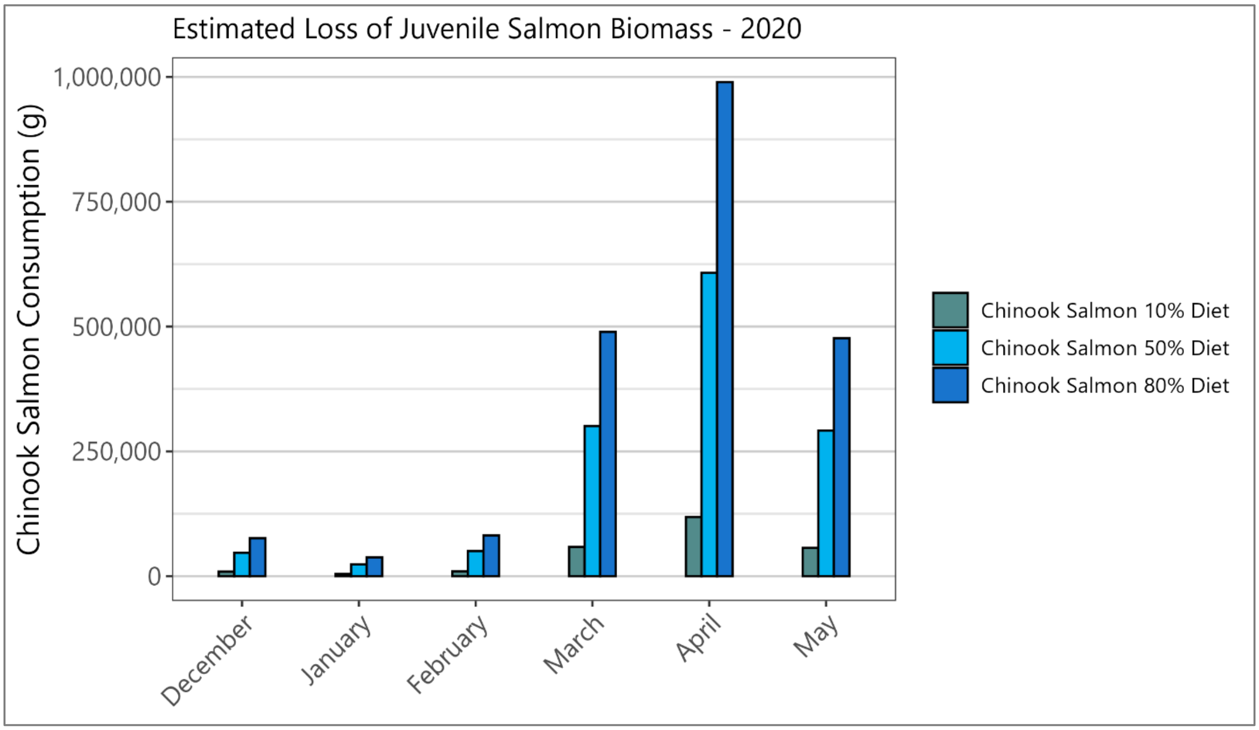
	Month					
Extrapolated Metrics	*December*	*January*	*February*	*March*	*April*	*May*
All Years						
*Chinook Salmon weight (g)**	0.34	3.36	5.81	11.75	18.03	22.51
2019/2020 (n = 398)						
*Proportion of Age-1***		0.13	0.1			0.01
Proportion of Age-2		0.17	0.1	0.12	0.11	0.34
Proportion of Age-3+		0.7	0.8	0.88	0.89	0.65
*N-hat****		49.49	37.12	98.23	359.03	28.54
± Standard Error		± 4.7	± 8.2	± 4.9	± 20.5	± 0.9
2020/2021 (n =113)						
Proportion of Age-1	0.21	0.23		0.22	0.03	
Proportion of Age-2	0.42	0.27	0.29		0.11	
Proportion of Age-3+	0.37	0.5	0.71	0.78	0.86	1
N-hat	58.58	64.06	38.65	23.48	121.12	28.17
± Standard Error	± 4.4	± 8.0	± 8.4	± 3.1	± 11.6	± 1.6
2021/2022 (n = 56)						
Proportion of Age-1		0.08	0.75	0.11		0.33
Proportion of Age-2		0.58	0.25	0.22	0.14	0.33
Proportion of Age-3+		0.33		0.67	0.86	0.33
N-hat		29.28	19.38	18.93	64.82	7.82
± Standard Error		± 3.2	± 4.8	± 1.7	± 5.5	± 0.8
2022/2023 (n = 28)						
Proportion of Age-1	0.05		0.22			
Proportion of Age-2	0.32					
Proportion of Age-3+	0.63		0.78			
N-hat	32.06		40.56			
± Standard Error	± 2.9		± 10.0			
2023/2024 (n = 1038)						
Proportion of Age-1	0.06					
Proportion of Age-2	0.13	0.07		0.12	0.06	0.03
Proportion of Age-3+	0.81	0.93	1	0.88	0.94	0.97
N-hat	37.83	45.17	32.85	69.15	1572.97	416.77
± Standard Error	± 6.4	± 4.8	± 7.0	± 5.1	± 78.4	± 14.0
2020 through 2024*						
Proportion of Age-1	0.16	0.16	0.2	0.05	0	0.01
Proportion of Age-2	0.25	0.25	0.14	0.13	0.07	0.13
Proportion of Age-3+	0.58	0.59	0.66	0.82	0.93	0.86
N-hat	42.82	47.00	33.71	52.45	529.48	120.32

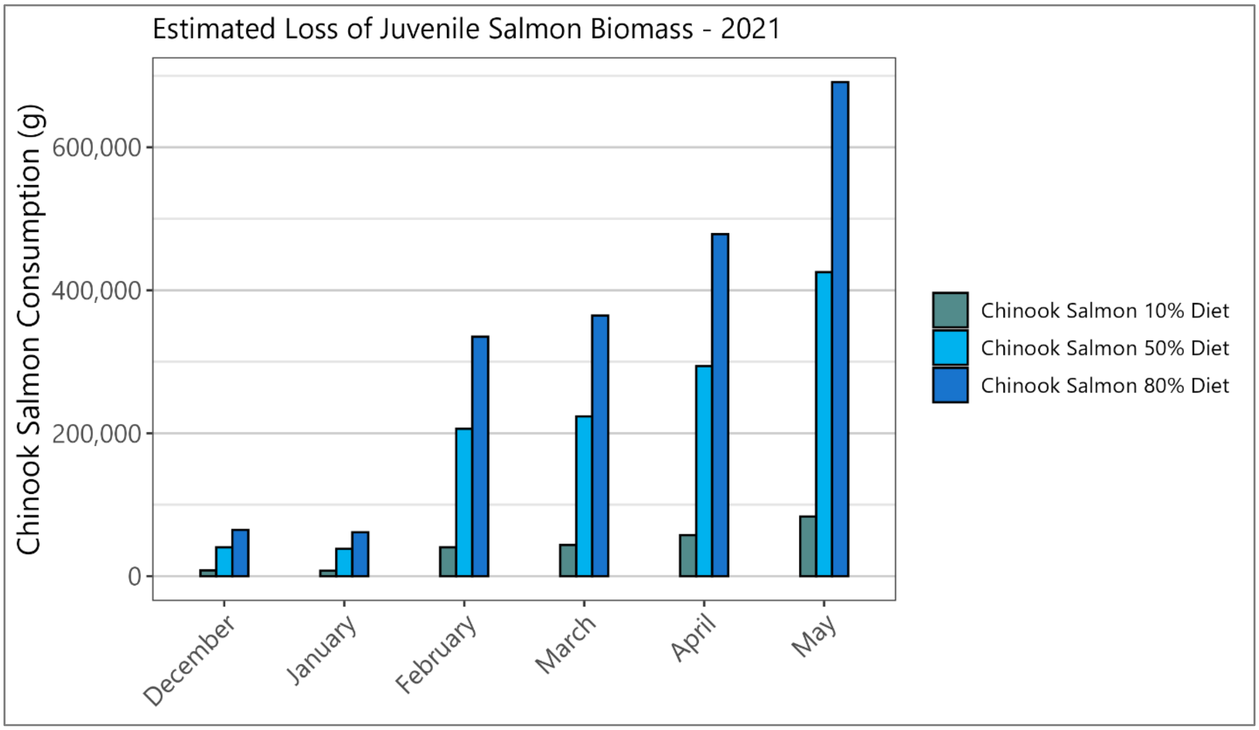
*Chinook Salmon Weight measured in RST operations between 2017 and 2019 (Hutcherson and Sutphin 2023).
**Proportion by month of captured Striped Bass of age-class.
***Average Population Size from POPAN Model
****Monthly catches averaged across years before calculating proportions

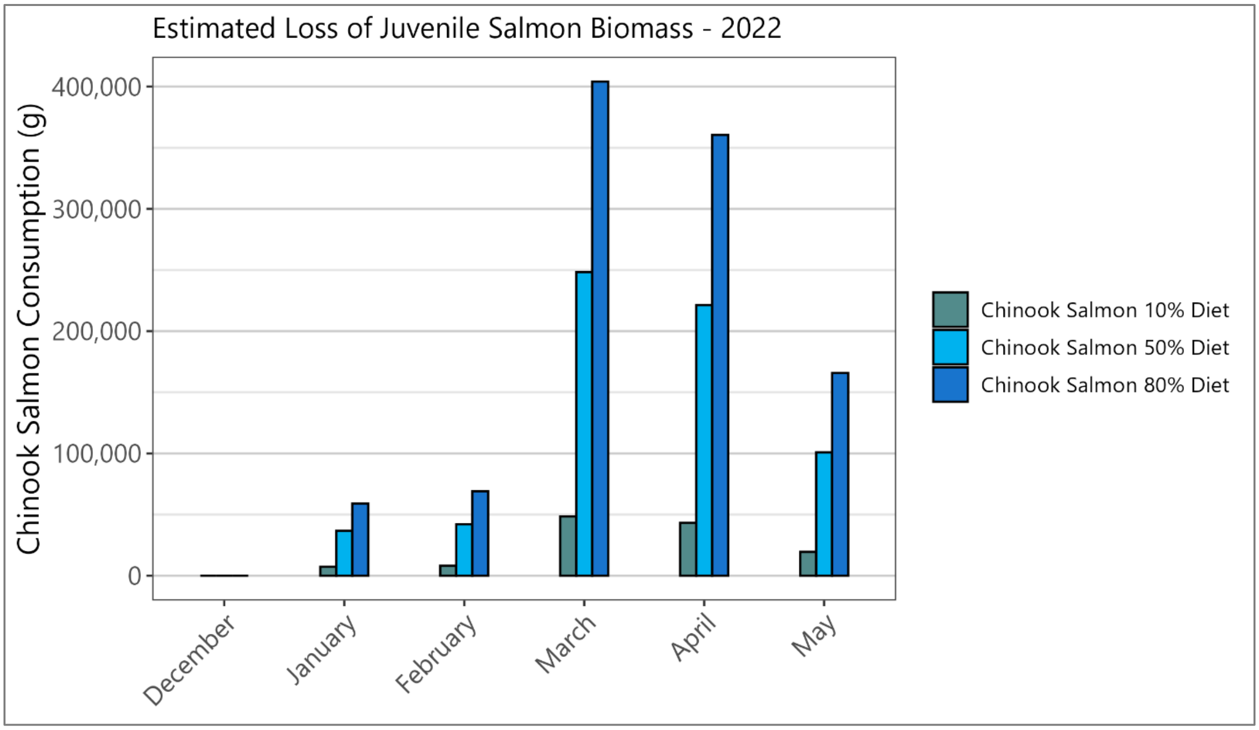
Appendix B:

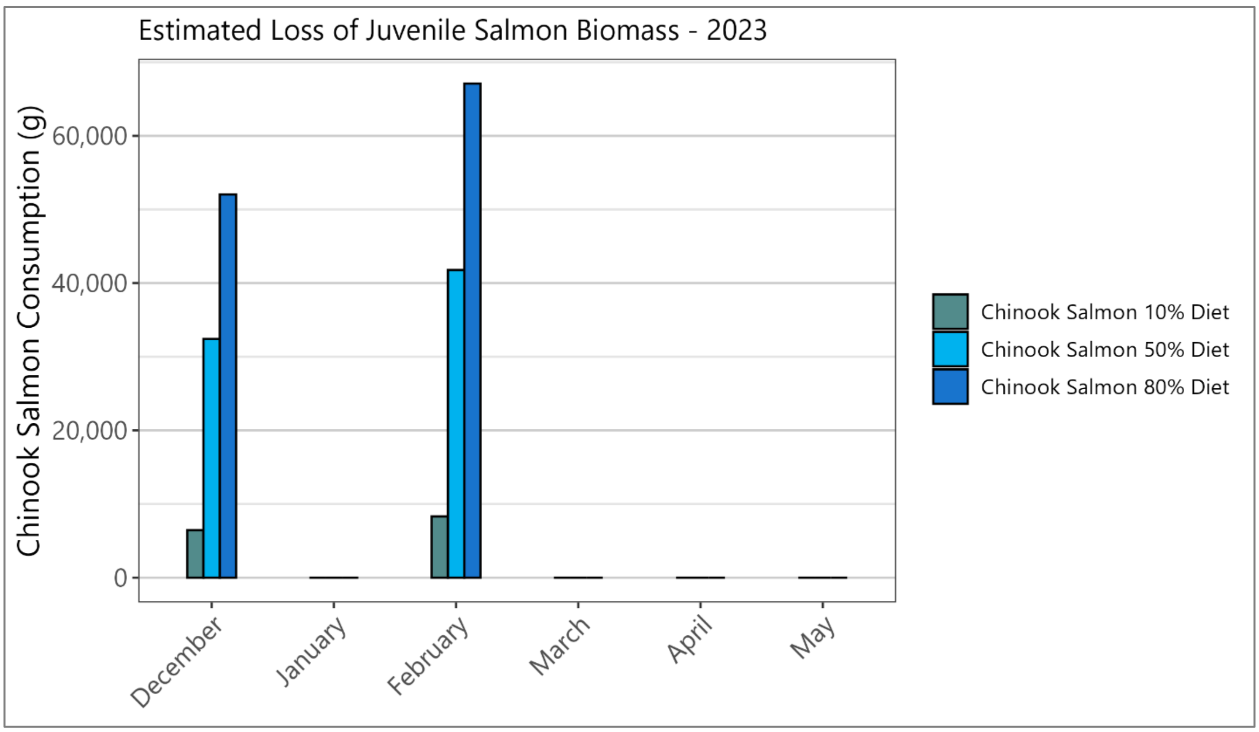
Simulation Output Graphs by Year

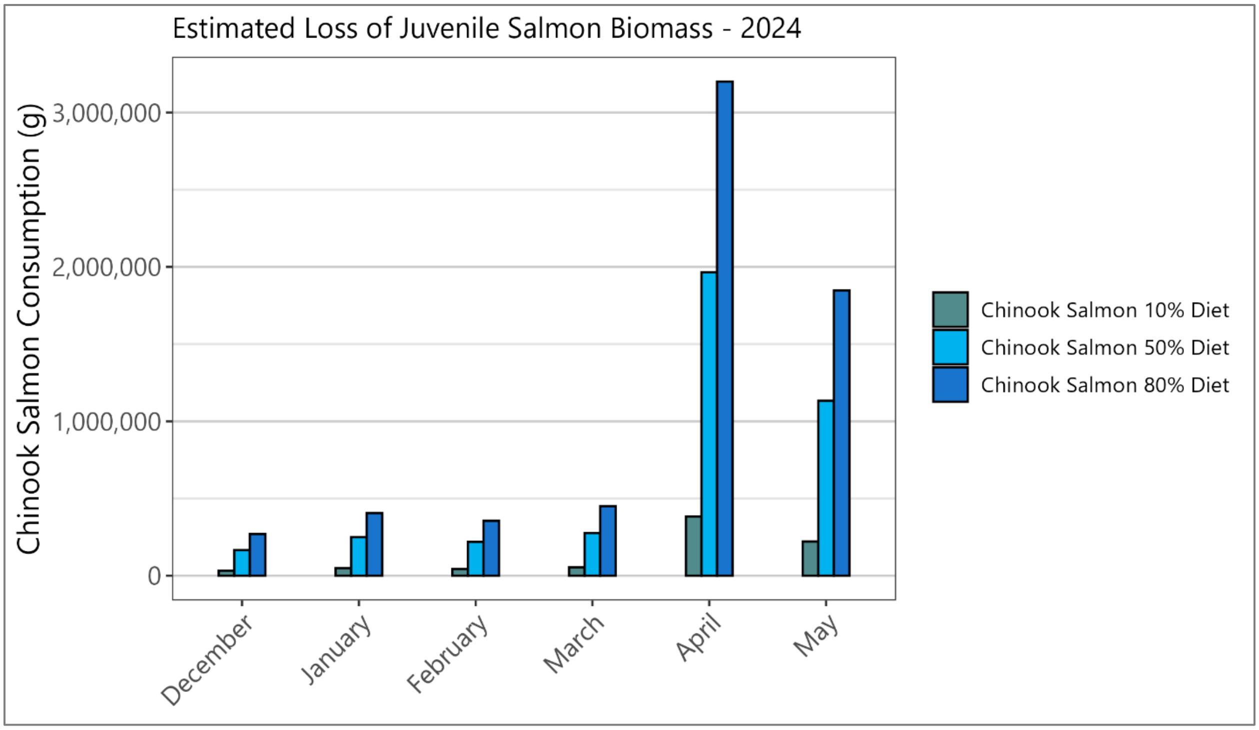
Estimated Consumption of Chinook Salmon Mass (g) by Diet



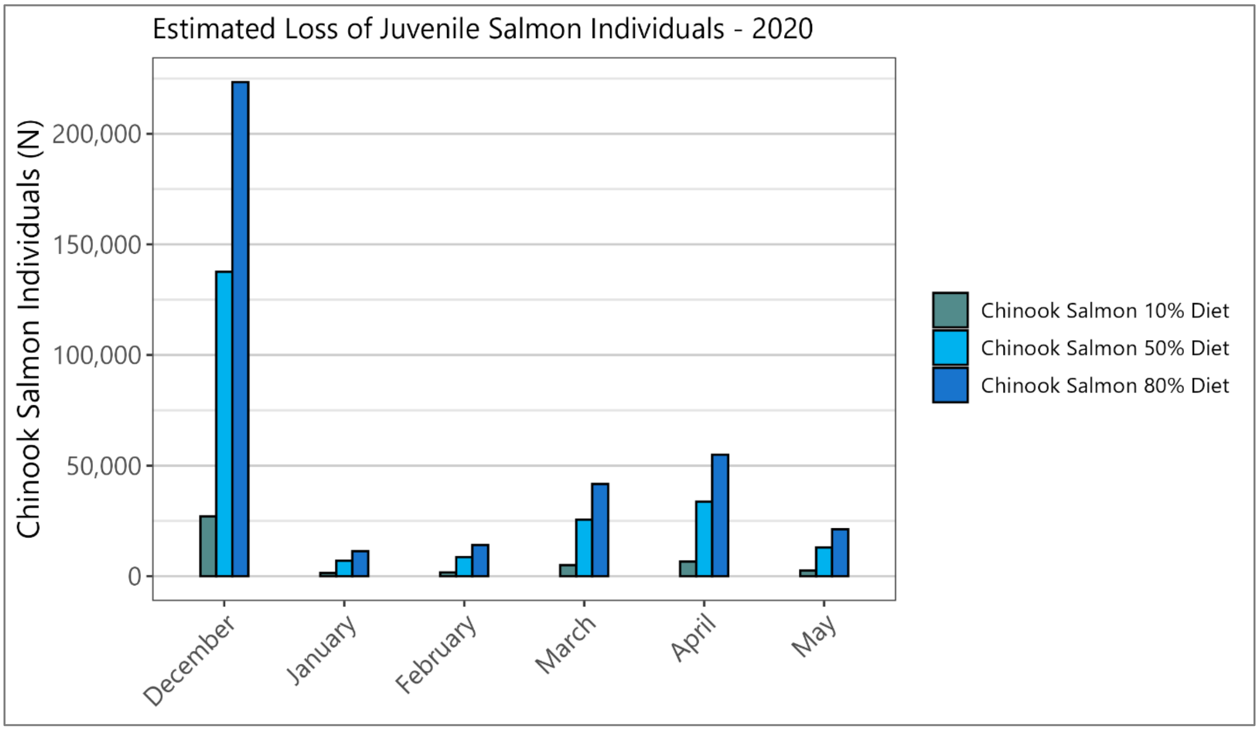


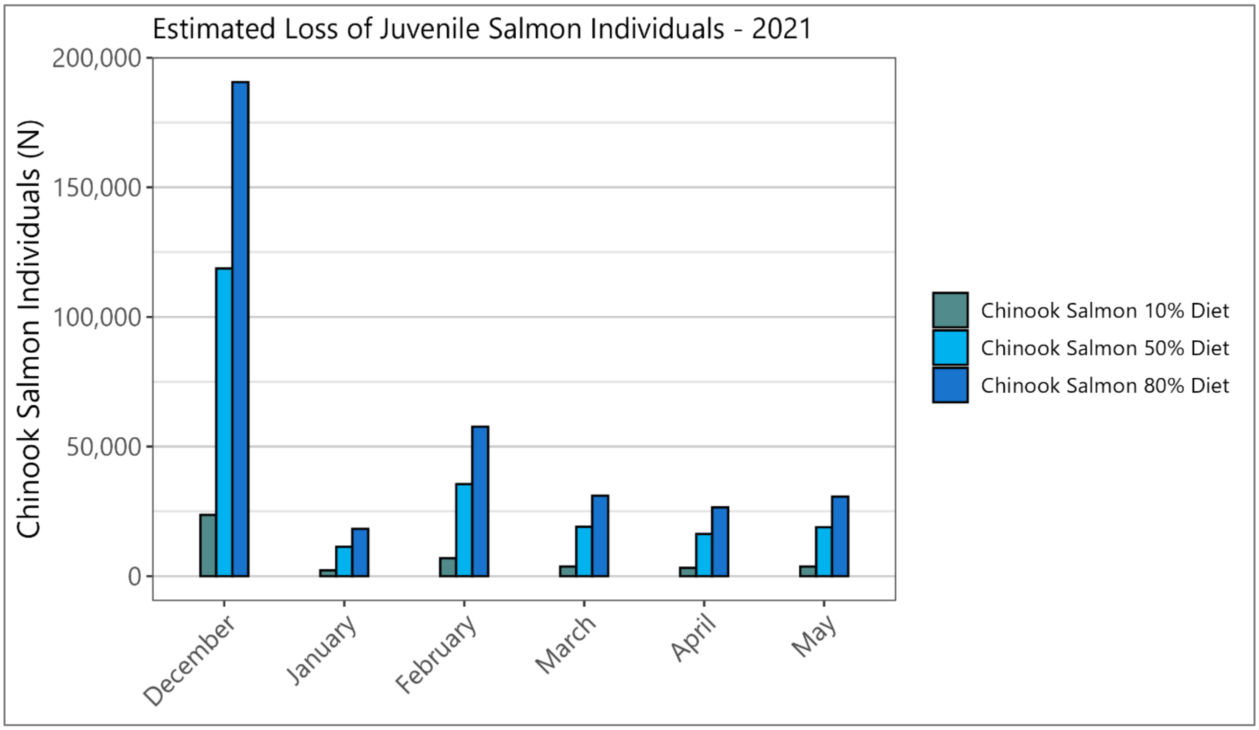

Estimated Loss of Juvenile Salmon Biomass - 2022
Chinook Salmon Consumption (g)
400,000
300,000
200,000
100,000
0
December
January
February
March
April
May
Chinook Salmon 10% Diet
Chinook Salmon 50% Diet
Chinook Salmon 80% Diet

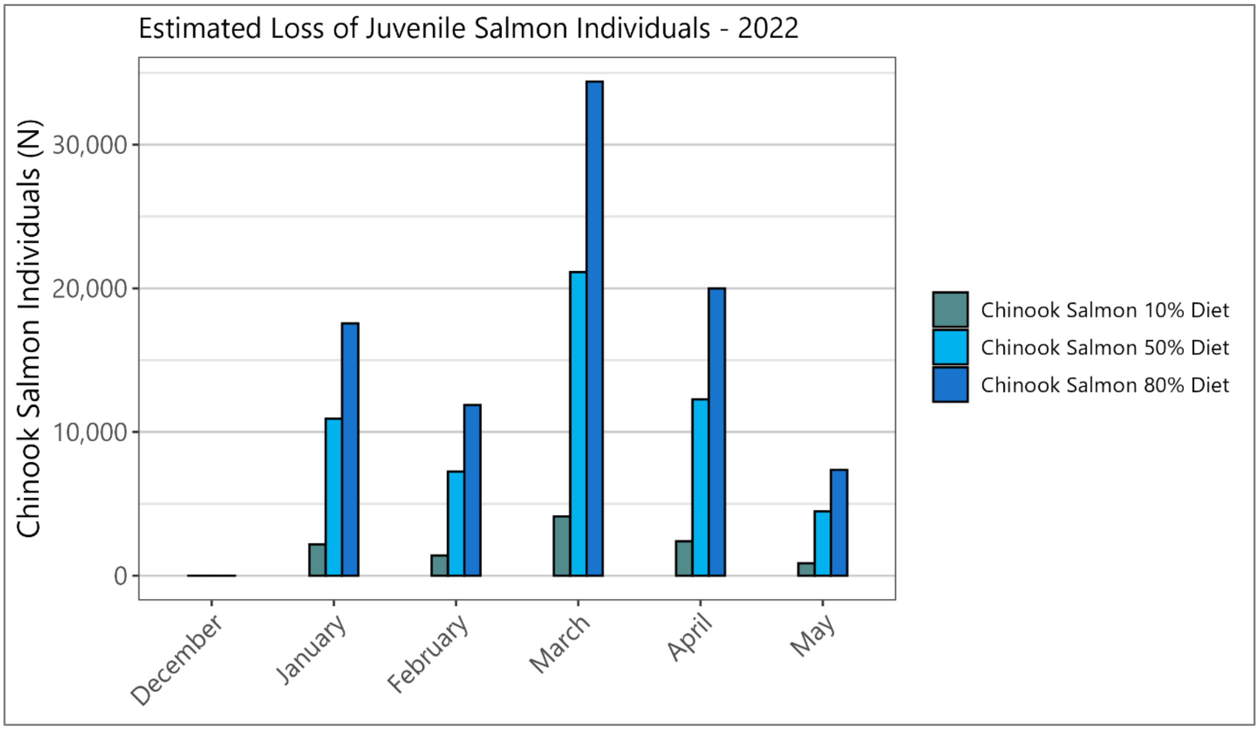

Estimated Loss of Juvenile Salmon Biomass - 2023
Chinook Salmon Consumption (g)
60,000
40,000
20,000
0
December
January
February
March
April
May
Chinook Salmon 10% Diet
Chinook Salmon 50% Diet
Chinook Salmon 80% Diet

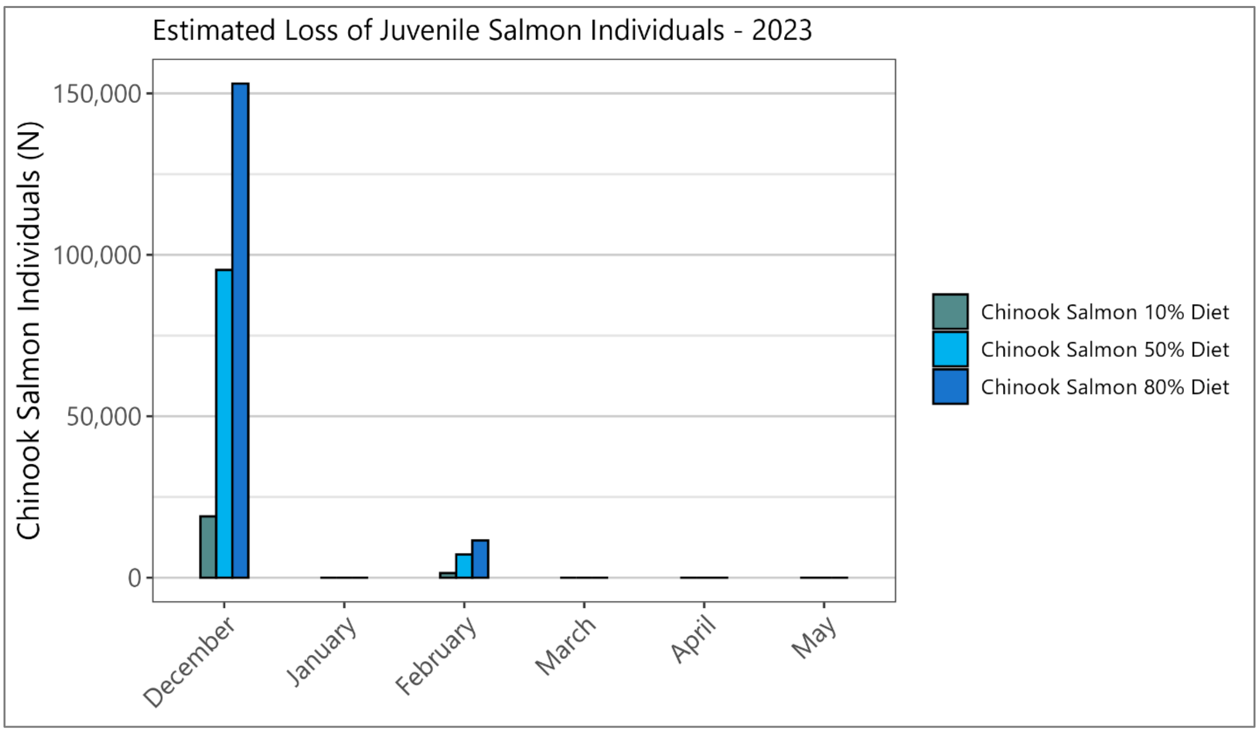

Estimated Loss of Juvenile Salmon Biomass - 2024
Chinook Salmon Consumption (g)
3,000,000
2,000,000
1,000,000
0
December
January
February
March
April
May
Chinook Salmon 10% Diet
Chinook Salmon 50% Diet
Chinook Salmon 80% Diet

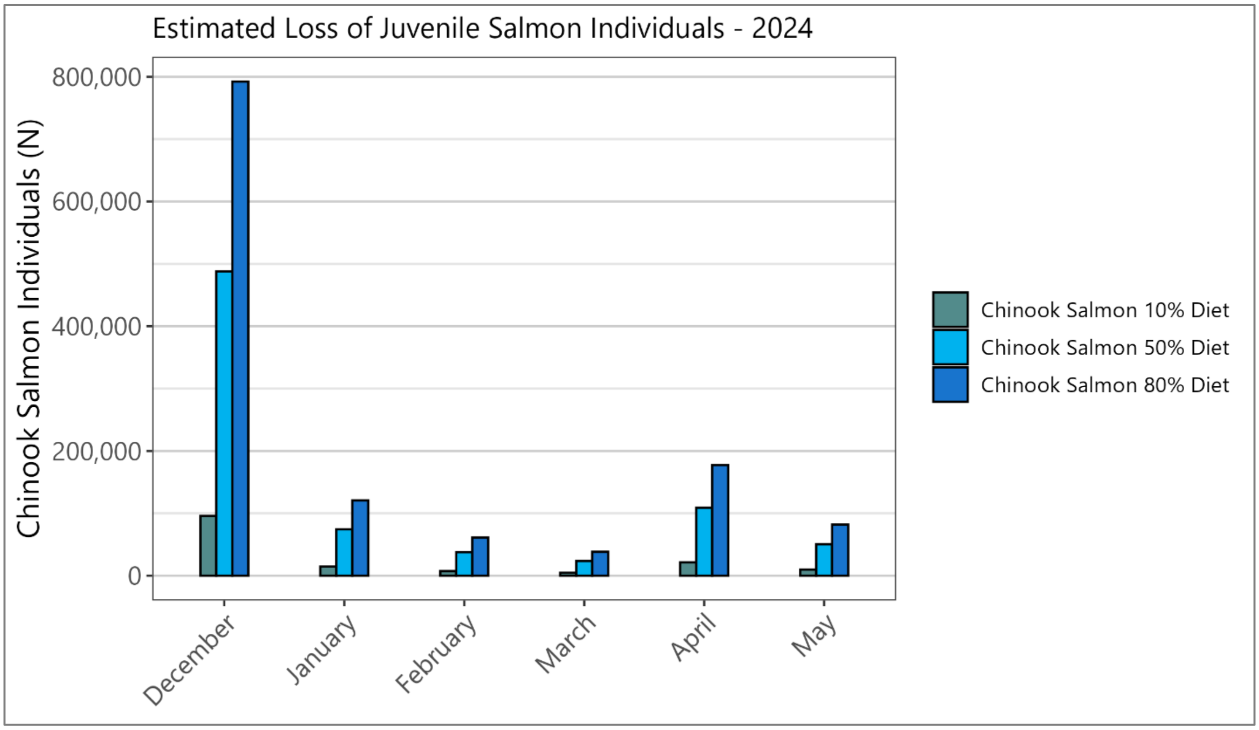
Estimated Consumption of Chinook Salmon Individuals (n) by Diet



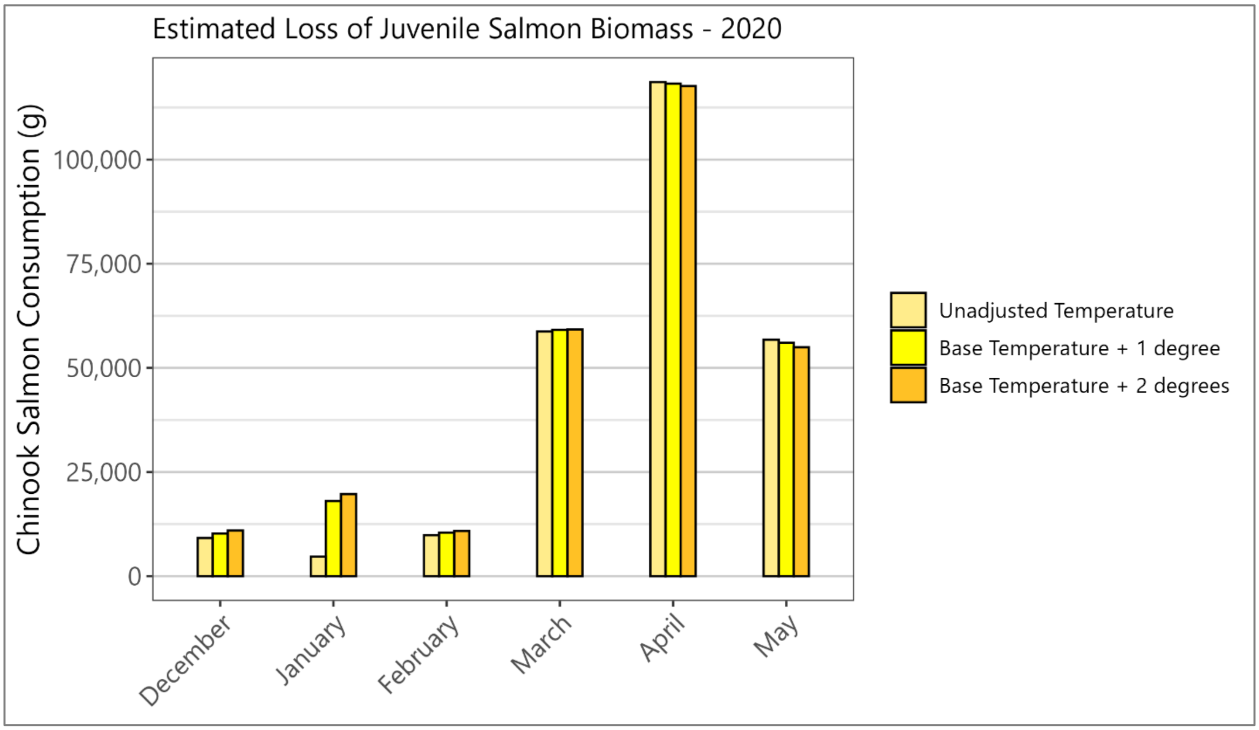


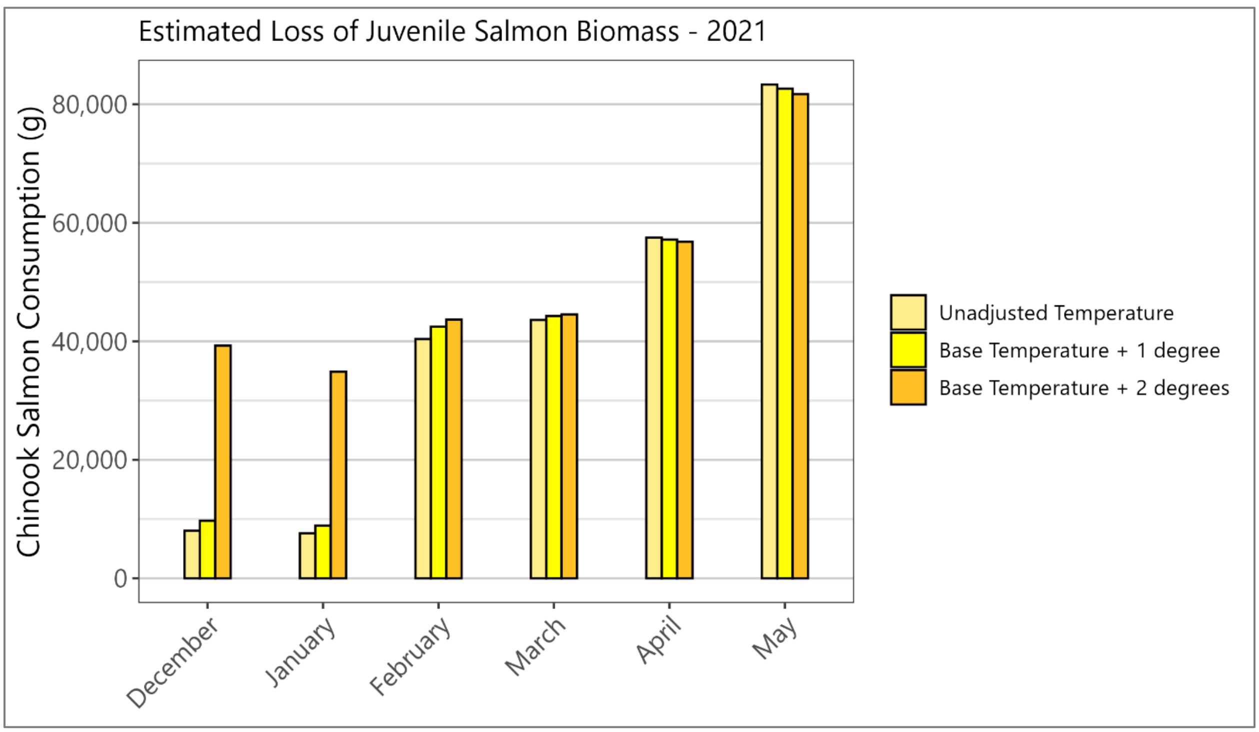

Estimated Loss of Juvenile Salmon Individuals - 2022
Chinook Salmon Individuals (N)
30,000
20,000
10,000
0
December
January
February
March
April
May
Chinook Salmon 10% Diet
Chinook Salmon 50% Diet
Chinook Salmon 80% Diet

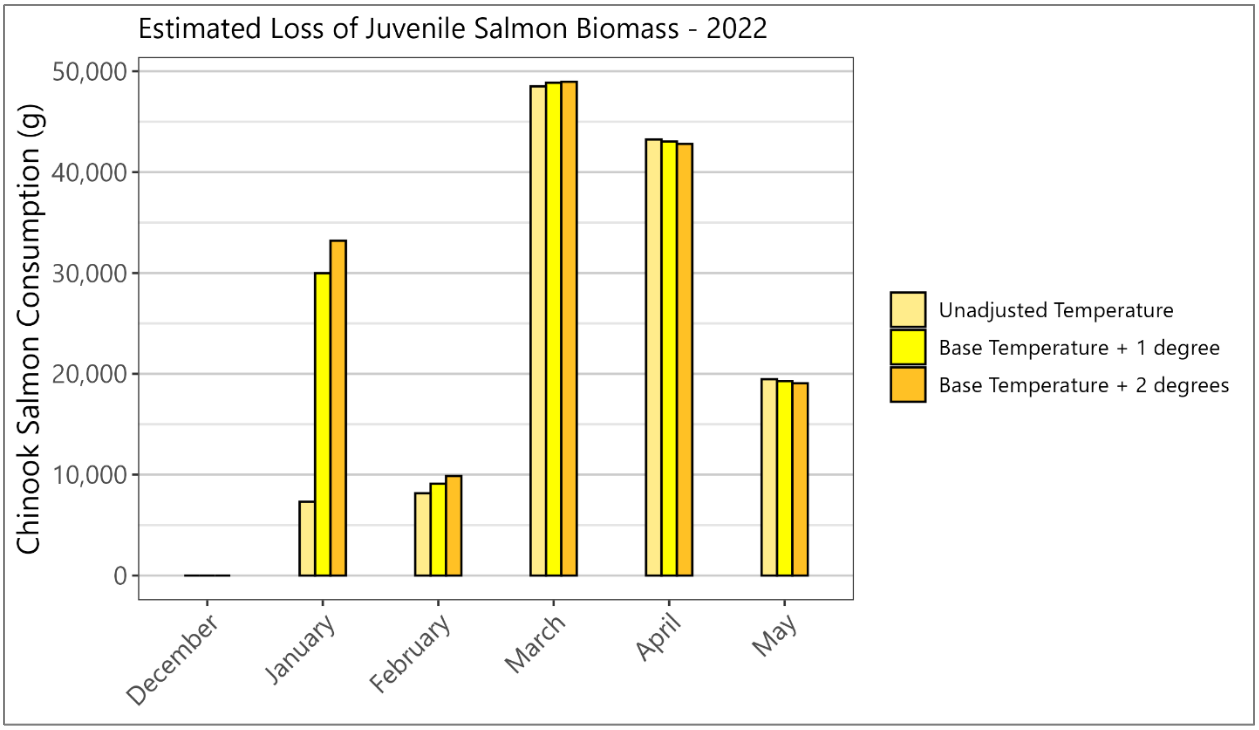

Estimated Loss of Juvenile Salmon Individuals - 2023
Chinook Salmon Individuals (N)
150,000
100,000
50,000
0
December
January
February
March
April
May
Chinook Salmon 10% Diet
Chinook Salmon 50% Diet
Chinook Salmon 80% Diet


Estimated Loss of Juvenile Salmon Individuals - 2024
Chinook Salmon Individuals (N)
800,000
600,000
400,000
200,000
0
December
January
February
March
April
May
Chinook Salmon 10% Diet
Chinook Salmon 50% Diet
Chinook Salmon 80% Diet

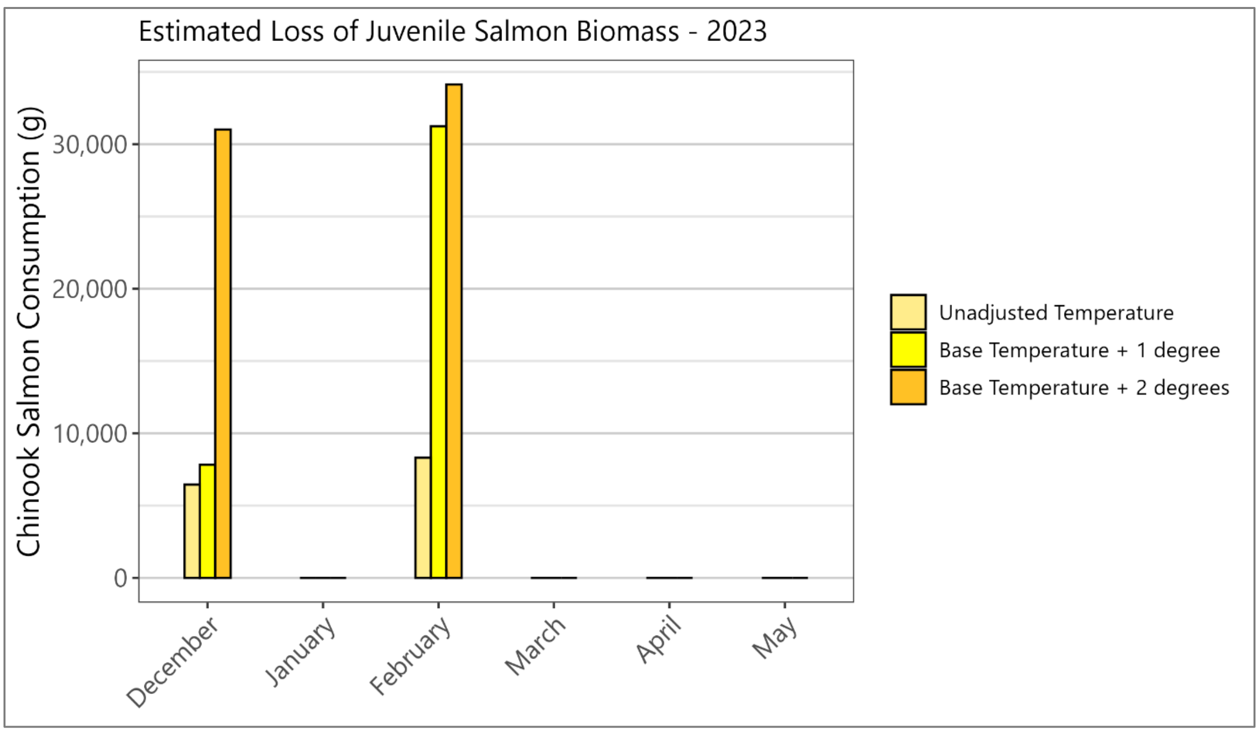
Estimated Consumption of Chinook Salmon Mass (g) by Temperature



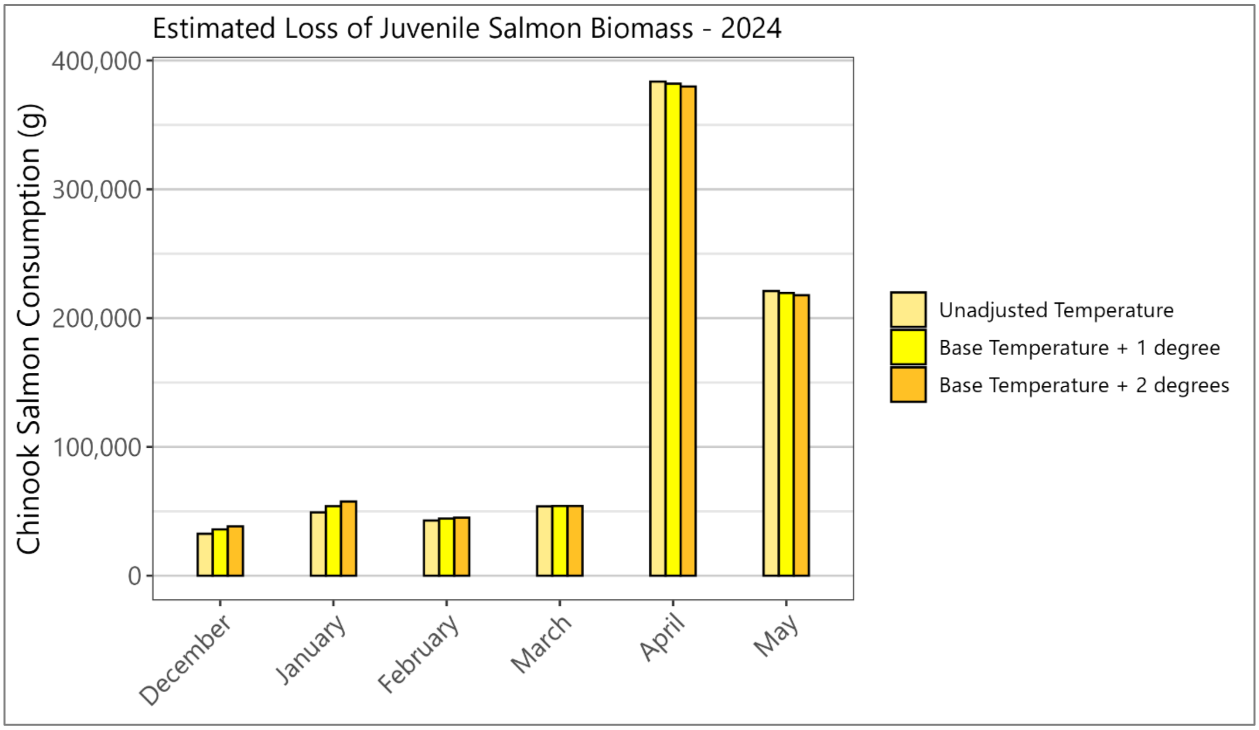




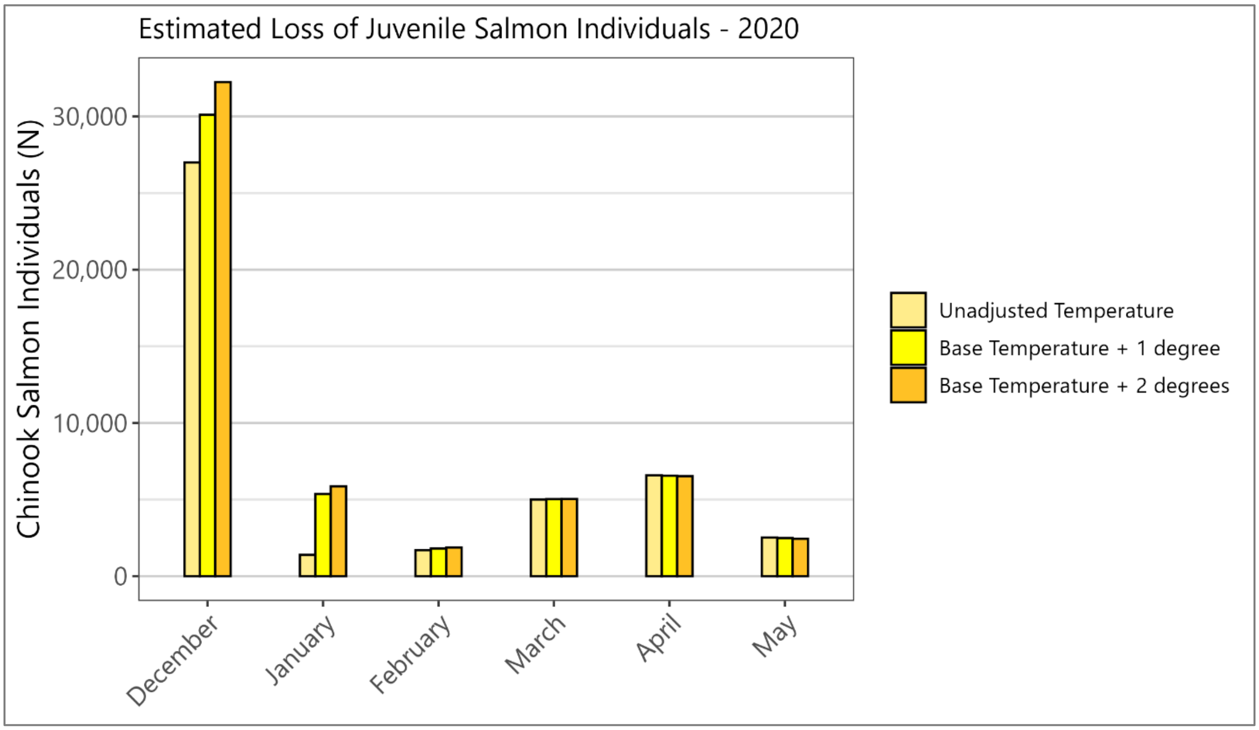
Estimated Loss of Juvenile Salmon Biomass - 2022
Chinook Salmon Consumption (g)
50,000
40,000
30,000
20,000
10,000
0
December
January
February
March
April
May
Unadjusted Temperature
Base Temperature + 1 degree
Base Temperature + 2 degrees

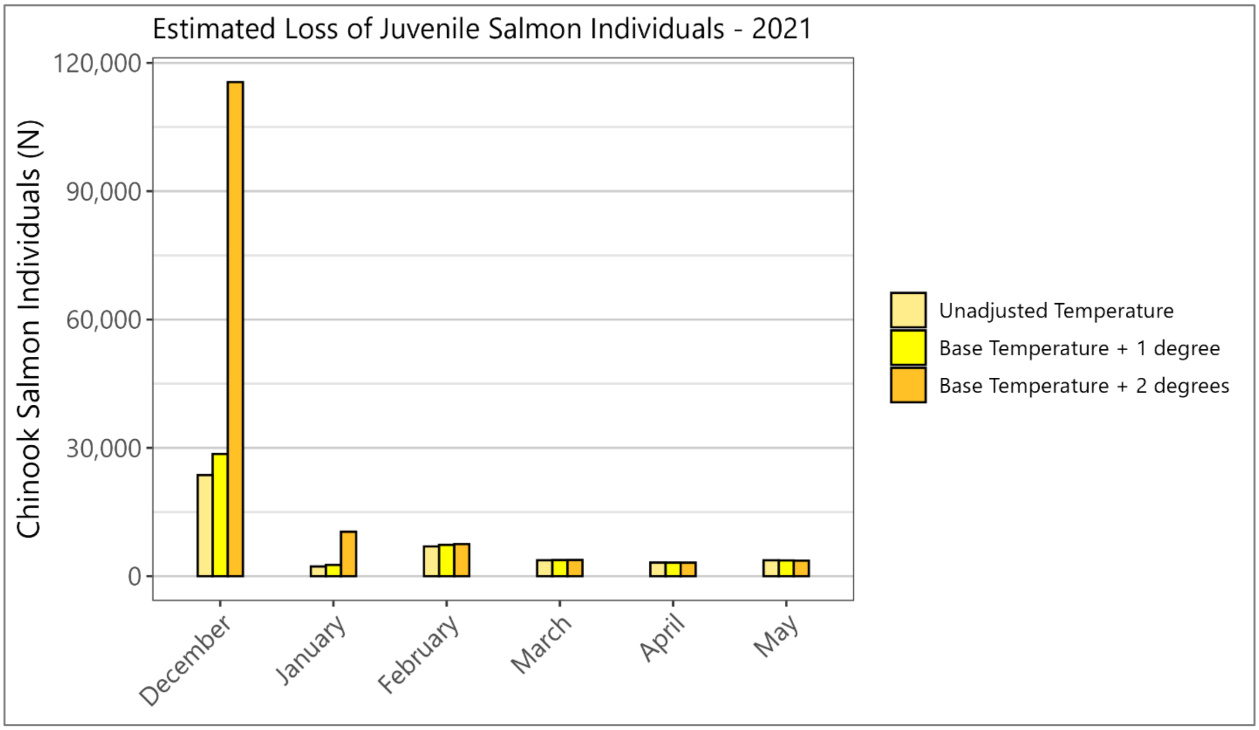


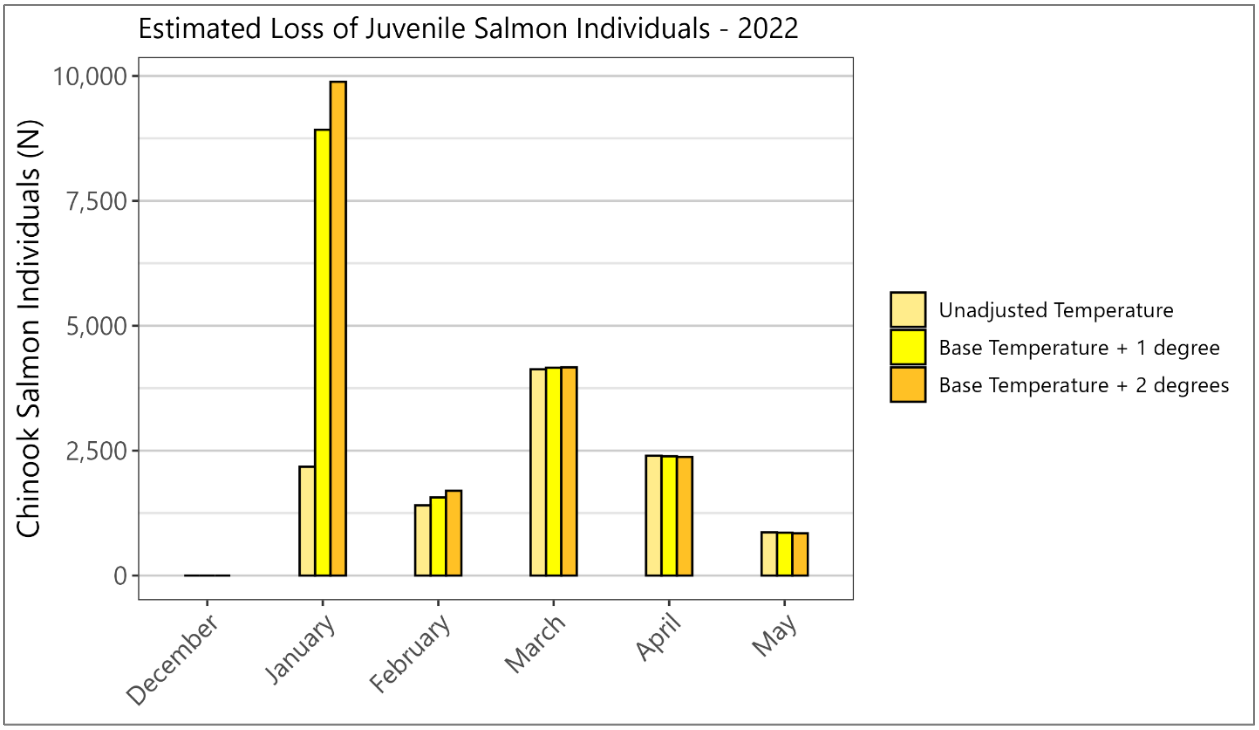
Estimated Loss of Juvenile Salmon Biomass - 2023
Chinook Salmon Consumption (g)
30,000
20,000
10,000
0
December
January
February
March
April
May
Unadjusted Temperature
Base Temperature + 1 degree
Base Temperature + 2 degrees

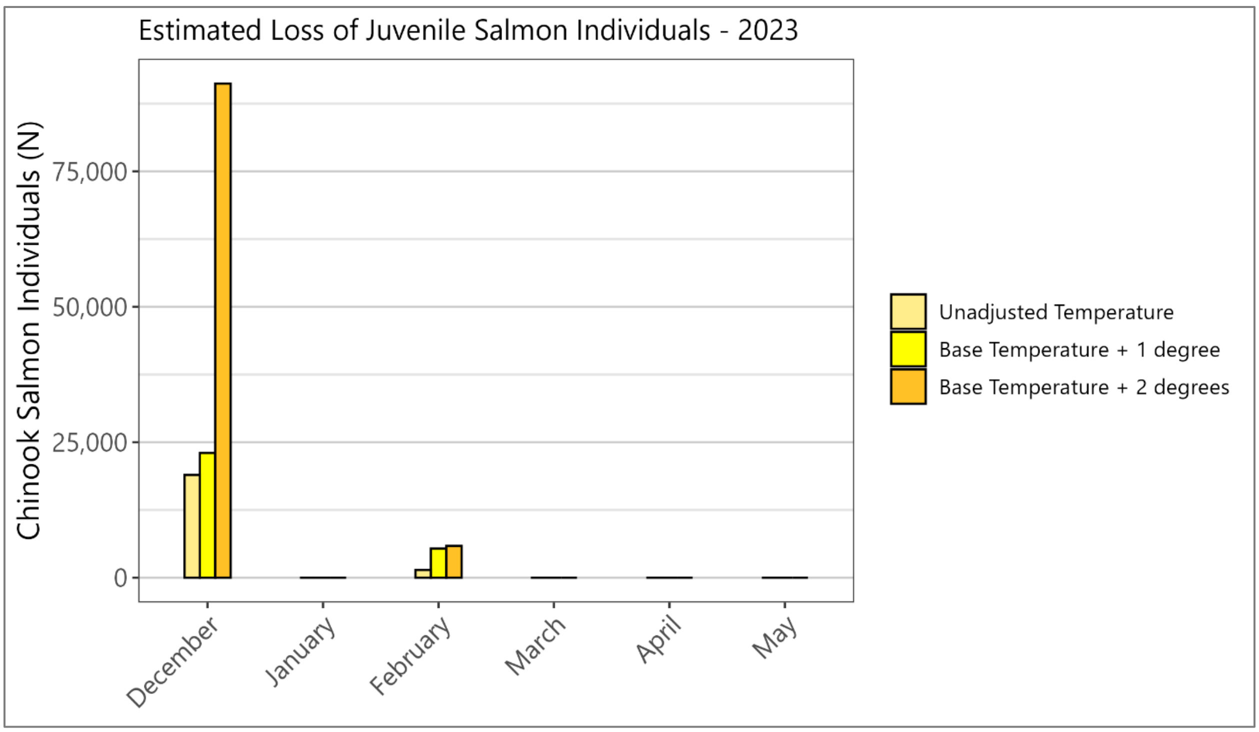

Estimated Loss of Juvenile Salmon Biomass - 2024
Chinook Salmon Consumption (g)
400,000
300,000
200,000
100,000
0
December
January
February
March
April
May
Unadjusted Temperature
Base Temperature + 1 degree
Base Temperature + 2 degrees

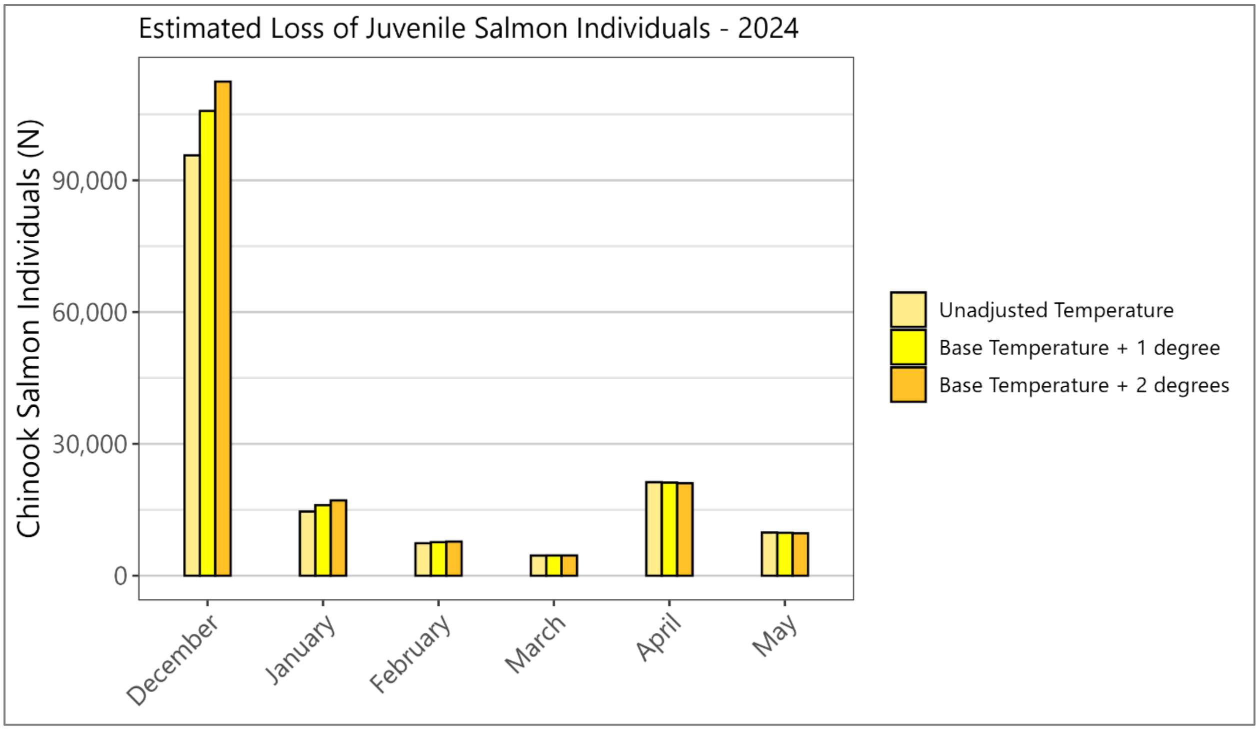
Estimated Consumption of Chinook Salmon Individuals (n) by Temperature






Estimated Loss of Juvenile Salmon Individuals - 2022
Chinook Salmon Individuals (N)
10,000
7,500
5,000
2,500
0
December
January
February
March
April
May
Unadjusted Temperature
Base Temperature + 1 degree
Base Temperature + 2 degrees


Estimated Loss of Juvenile Salmon Individuals - 2023
Chinook Salmon Individuals (N)
75,000
50,000
25,000
0
December
January
February
March
April
May
Unadjusted Temperature
Base Temperature + 1 degree
Base Temperature + 2 degrees


Estimated Loss of Juvenile Salmon Individuals - 2024
Chinook Salmon Individuals (N)
90,000
60,000
30,000
0
December
January
February
March
April
May
Unadjusted Temperature
Base Temperature + 1 degree
Base Temperature + 2 degrees