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Inventory and Analysis of Salmon (*Oncorhynchus* spp.) Data Collected on Joint Base Elmendorf-Richardson (JBER), with Recommendations for Future Research

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Alaska Fisheries Technical Report Number 112, March 2022
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Inventory and Analysis of Salmon (Oncorhynchus spp.) Data Collected on Joint Base Elmendorf-Richardson (JBER) with Recommendations for Future Research

MaryKate Swenarton

Abstract

The objectives of this study were to inventory existing fisheries and related data collected on Joint Base Elmendorf-Richardson (JBER) and analyze the data to determine if the freshwater life stage is limiting salmon populations on Sixmile Lake, Alaska. This report also provides an opportunity for the U.S. Fish and Wildlife Service to continue exploring factors that may be influencing the freshwater productivity of salmon, and for JBER to identify limits to forage fish production for endangered Cook Inlet Beluga Whales (CIBW). Since 1998, JBER and their partners have enumerated adult Coho Salmon *Oncorhynchus kisutch* and Sockeye Salmon *O. nerka* at a weir located at the outlet of Sixmile Lake. Smolt data has been collected intermittently since 2003 at a smolt trap placed at the same location. Using adults as spawners and smolt as recruits, I fit a density-dependent Ricker model and a density-independent model to the spawn-recruit data for both species. A good fit to the density-dependent model would indicate a limitation to the production of recruits in the freshwater environment. The models were compared using Akaike's Information Criterion (AIC), corrected for small sample sizes. The density-independent model best described the Coho Salmon data, although AIC values for both models were similar ($\Delta AICc = 3.35$). The analysis suggests that the freshwater life stage may not be limiting this population and additional spawners in the system may increase production. The Ricker model best fit the Sockeye Salmon data (although AIC values for both models were similar, $\Delta AICc = 1.62$), suggesting that density-dependent factors could be limiting this population. However, the Ricker model violated several model assumptions, indicating this result should be considered with caution. Future work may improve model results through the addition of environmental covariate data from the Sixmile Lake system. Based on the results of this study, I recommend investigating five factors which could influence salmon productivity 1) a year-round temperature monitoring network; 2) back calculation of temperature, precipitation, and ice out conditions; 3) evaluation of seasonal changes in juvenile size and abundance; 4) consistent spawning surveys; 5) evaluation of population and diet of predators.

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Introduction

Joint Base Elmendorf-Richardson (JBER) in Anchorage, AK, supports five salmon species: Chinook (*Oncorhynchus tshawytscha*), Sockeye (*O. nerka*), Chum (*O. keta*), Pink (*O. gorbuscha)* and Coho (*O. kisutch)* salmon. Data on salmon runs occurring on JBER have been collected continuously as part of a long-term fisheries monitoring program and opportunistically as part of short-term, focused studies since the early 1990s. The Natural Resources Program on JBER partnered with the U.S. Fish and Wildlife Service (USFWS) Fisheries Program to inventory and analyze existing fisheries data, plan future research, and make management recommendations, such as habitat enhancements or changes to the lake stocking plan, to increase salmon productivity, if appropriate.

The JBER Natural Resources Program is responsible for contributing towards the recovery of endangered Cook Inlet Beluga Whales (CIBW), listed in 2008 under the Endangered Species Act. This population is currently decreasing in size at rate of ~1.5% per year (Hobbs et al. 2015), despite discontinuing subsistence harvest. The CIBW utilize habitat in Cook Inlet abutting JBER (Castellote et al. 2015), and have been observed as far as 5 miles upstream in Eagle River (Huntington 2002). The CIBW have been observed feeding on salmon at the mouth of both Eagle River and Sixmile Creek (Castellote et al. 2015), which drain directly into Cook Inlet. The Critical Habitat designation for CIBW determined that persistence of their primary prey species is essential to species conservation. Recent research suggests CIBW are deriving a higher percentage of their diet from freshwater sources, such as salmon smolt, than they have in the past (Quakenbush et al. 2015, Nelson et al. 2018, Norman et al. 2020). Thus, the persistence of outmigrating salmon smolt from lakes and streams on JBER is important to ensuring readily available prey to CIBW feeding in adjacent areas (National Marine Fisheries Service 2016).

The Fish and Wildlife Conservation Office, Fisheries Program, in Anchorage has recently focused on research projects related to freshwater productivity of salmon. Drivers of salmon productivity, or the number of surviving offspring produced per spawning adult, are complex, and variables in both marine (Hare et al. 1999) and freshwater environments affect salmon productivity (Ohlberger et al. 2016; Mauger et al. 2017). One variable found to be important to salmon productivity in both freshwater and marine environments is water temperature. Changes to food availability (Burgmer et al. 2007), optimal growth, emergence, migration (Quinn et al. 1997), and smolting are all affected by water temperature. Alterations to optimal stream and lake temperature regimes can lead to prey mismatch in the onset exogenous feeding, delayed or reversed smoltification, suboptimal growth rates, reduced predator avoidance behavior (Marine and Cech Jr. 2004), heat stress (Mathes et al. 2010), increased disease incidence, delayed migration, or mortality (Keefer et al. 2008). Instream environmental conditions driven by changes in temperature and climate, such as precipitation, date of ice-out, sustained warm temperatures in the summer, fall, and spring (Mauger et al. 2017), can have large effects on productivity. Biological factors with the potential to alter in-stream productivity include predation (Ruggerone and Rogers 1992), and competition for food and space.

Sixmile Creek was dammed in the 1980s to form a floatplane base, and Sockeye Salmon from the Big Lake drainage soon naturally colonized the lake (Barclay and Habicht 2012). Sockeye Salmon are the largest run of salmon into Sixmile Lake, but Coho Salmon and Pink Salmon also use the lake and its tributaries. Both adult salmon entering the Sixmile Lake to spawn and juveniles leaving the lake as smolts are monitored on JBER, thus providing an opportunity to isolate which environmental or biological variables are affecting freshwater productivity of salmon in this watershed. These data were used to accomplish the following objectives:

- •Inventory fisheries and fish-related data from water bodies on JBER,
- •Analyze existing data from the Sixmile Creek drainage to learn (1) which environment (fresh water or marine) is limiting production in these salmon populations and (2) the environmental and biological factor(s) that limit productivity in that environment,
- •Make recommendations for future research and management options, including habitat enhancements to alleviate factors limiting salmon productivity.

Study Area

Data was inventoried from all salmon-bearing water bodies on JBER (Figure 1), which includes 10 creeks, 3 lakes, and Eagle River. The Sixmile drainage, which includes both Sixmile Lake and Sixmile Creek, is the geographic focus of the analysis described in this report. The Sixmile watershed drains approximately 2,033 acres and flows directly into Eagle Bay within the Knik Arm of Cook Inlet (Figure 2). Sixmile Creek was dammed in the 1980s to form Sixmile Lake and a floatplane base.

Methods

Data Inventory

I inventoried fisheries and habitat data from annual reports, external contracted reports, and unpublished spreadsheets. Inventoried data includes fish population data: salmon spawning surveys (2001-present), invasive Northern Pike surveys (2015-2016), Rainbow Trout stocking data (1992-present), and general fish diversity and abundance data (2015), and habitat data: lake bathymetry and water quality (2015), and intermittent temperature data (2004-present). I compiled the data types and sources in Table 1. The analysis in this report was completed using data originating from the Sixmile drainage, which was the most robust fisheries dataset available.

Data Collection

An adult salmon weir has been in operation since 1988 but has been run by different state, private, and federal entities depending on the year. From 1988 to 1998, the weir was located at a meadow in the middle of Sixmile Creek; in 1998, it was moved upstream to the Sixmile Lake outlet underneath the Fairchild Bridge (Figure 2). The weir consists of a custom picket weir with a gate to allow controlled fish passage. JBER deployed a seine net to corral fish daily through the gate and into Sixmile Lake. JBER enumerated and identified adult salmon twice daily. Weir operation occurred from early June to late September. A smolt trap is deployed at the same location as the weir at the Sixmile Lake outlet (Figure 2). A modified fyke net, consisting of panels constructed with small mesh, blocks the entire outlet, and funnels fish into an aluminum trap box, where JBER identified them according to Pollard et al. (1997) and enumerated them daily from early May to late June. In 2018, JBER measured a subset of smolt for fork length (Figure 3). Sockeye Salmon spawning locations were mapped in the lake in 2000 and 2001 (Gotthardt 2003, 2006).

Beginning in 1998, a handheld thermometer measured water temperatures at the weir intermittently during the adult sampling period. From 2012 to 2016, the same method was used to measure temperature, but measurements lasted the duration of the smolt and adult salmon sampling. Since 2017, a HOBO logger recorded water temperatures from the beginning of smolt sampling in May through the duration of adult sampling at the end of October.

Data Organization

I organized all adult weir counts, smolt counts, smolt lengths, and temperature data from the Sixmile drainage according to the standards of Hadley Wickham's tidy data (Wickham et al. 2019) using the tidyr package in R. I used the ggplot2 package in R to generate all plots in this report.

Data Analysis

Recruitment is the addition of fish to the parent stock and can be measured at different life history phases. In this analysis, I designated smolt enumerated at the smolt trap as recruits to the Sixmile Sockeye Salmon and Coho Salmon populations. I designated adults enumerated at the weir entering Sixmile Lake as spawners. I assumed a 2-year rearing period in the lake in both models, as evidenced from smolt length measurements taken in 2018 and compared to length-at-age data from nearby Cook Inlet streams (Figure 3; Koenings et al. 1985); smolt age data in the Sixmile system was not available, but is planned beginning in 2020.

I fit a density-independent model to the Sockeye and Coho salmon spawner-recruit data. The density-independent model assumes smolt recruitment production is a function of the number of spawners and is described by the equation:

$$\frac{R}{S} = a$$

Where, *R* is the number of recruits, *S* is the number of spawners, and *a* is a density-independent constant.

I also fit a density-dependent model, a Ricker model (Ricker 1954, 1975), to the Sockeye and Coho salmon spawner- recruit data. The Ricker model describes a density-dependent relationship between spawners and recruits, where smolt recruitment is highest at intermediate densities of spawners. The Ricker model is described by the equation:

$$E[R][S] = aSe^{-bS}$$

Where, *R* is the number of recruits, *S* is the number of spawners, *a* is still a density-independent constant and *b* is a density-dependent constant. When *b* = 0, the equation reduces to the density-independent function.

I visually evaluated the model assumptions of constant variability and normal distribution of residuals. I checked for constant variability by plotting fitted model values against residuals; any pattern in the plot was indicative of non-constant variance. I checked the second assumption by plotting a histogram of the residuals and looking for normality in their distribution.

I used the corrected Akaike Information Criterion (AICc, Akaike 1973; Suguira 1978) because of the small sample size, to compare the density-independent and density-dependent models and selected the model with the best fit that is not over parameterized.

Results

Data Inventory

Juvenile salmon studies, adult salmon studies, and fish-related environmental data were collected on 10 creeks, 3 lakes, and Eagle River; inventoried data and sources are described in Table 1. Although data from all these waterways were organized and inventoried, the analysis in this report is focused on Sixmile Lake and Creek, in which the most long-term, extensive data has been collected by JBER.

Smolt Salmon Trends

Recruitment trends have been highly variable, with the highest recorded smolt recruitment for Sockeye Salmon (*n* = 23,644) occurring in 2012 and the lowest recorded smolt recruitment (*n* = 1,245) recorded four years later (Figure 4). Sockeye Salmon smolt recruitment has not exceeded 2,456 since 2016. Coho Salmon smolt recruitment was low for many years in the 2000s but has recently exceeded 3,000 recruits in both 2014 and 2017 (Figure 4).

Adult Salmon Trends

Sockeye Salmon spawning trends are variable, with a low of 317 adults entering the lake in 2012, compared to an average spawner count of 2,133 across years (Figure 5). There were less than 100 Coho Salmon adults entering the lake every year from 1998 to 2017, but in 2015, Sixmile Lake experienced an increase in adult returns with 527 individuals (Figure 5).

Temperature

Temperature was one of the only consistently measured, potential environmental covariates that could explain salmon recruitment variability. July was the warmest water temperature month each year, and 2013 and 2016 experienced especially warm temperatures (exceeding 22°C) in that month (Figure 6). Also in 2016, temperatures remained over tolerable recommendations for Pacific salmon through August.

Model

Predicted recruitment in all models was highly variable (Figure 6 and 7). Tests for the assumptions of constant variability and normal distribution of residuals were satisfied for both Sockeye and Coho salmon density-independent models and the Coho Salmon Ricker model (Figure 8, 9, and 10). The same diagnostics ran on the Sockeye Salmon Ricker model indicated that the model violated the assumptions of constant variability and normal distribution of residuals (Figure 11). The AICc test selected the Ricker model as the best model to fit the Sockeye Salmon data (ΔAICc = 1.62, Table 2) and the density-independent model as the best model to fit the Coho Salmon data (ΔAICc = 3.36, Table 3).

Discussion

Recruitment data is notoriously variable and this variability has been extensively studied (Quinn II and Deriso 1999; Hilborn and Walters 2013; Ogle 2016). Pacific salmon specifically show large interannual fluctuations in recruitment (Peterman 1981; Adkison et al. 1996); despite this variability, much of which is unexplained, spawner-recruit models are used extensively in setting annual salmon harvest rates. Sockeye Salmon smolt recruitment data from Sixmile Lake similarly exhibit high variability in annual recruitment and a weak relationship between spawners and recruits (Figure 7). AIC revealed a density-dependent Ricker model was the best model to predict Sockeye Salmon smolt recruitment from Sixmile Lake, but the fit of the Ricker model was poor and violated several model assumptions (Figure 11). In addition, AIC revealed the density-dependent model was only marginally better than the density-independent model (ΔAICc = 1.32). Therefore, the evidence for density dependence in the Sixmile Sockeye Salmon population is weak and a definitive conclusion will require more data.

In general, biological situations that normally contribute to a Ricker relationship between spawners and recruits in salmon are redd superimposition and competition for spawning habitat, size-dependent predation, cannibalism, and the effects of density-dependent slower growth of juveniles due to competition for resources. Sockeye Salmon use select gravel patches in lower and upper Sixmile Lake to spawn (Gotthart 2003), but superimposition has not yet been studied or observed. Predation could be occurring in the form of cannibalism, predation on Sockeye Salmon juveniles by Coho Salmon juveniles, or predation by stocked Rainbow Trout or invasive

Northern Pike*,* but more studies would be necessary to determine if this predation is size dependent. Rainbow Trout congregate below the outlet of Sixmile Lake during outmigration (Colette Brandt, JBER Biologist, pers. comm.), providing some evidence for predation. Juvenile Coho Salmon could be predating on juvenile and fry Sockeye Salmon as evidenced in other systems (Ruggerone and Rogers 1992). Limitations in rearing habitat or food resources could also be leading to density dependence, but no studies have analyzed the quantity of either of those factors in this system.

Attempts to tie smolt recruitment to spawner counts were more successful for Coho Salmon in the Sixmile drainage, as both model assumptions were met and fits to these data were good (Figure 7, 8, and 9). AIC revealed the density-independent model was the best model to predict the Coho Salmon smolt recruitment data, but the model was only marginally better than the density-dependent model ($\Delta AIC = 3.36$). The acceptance of the density-independent model as the best model indicates that smolt recruitment increases linearly with the addition of more spawners to the system and suggests smolt production could increase with the addition of more spawners to the system. Escapement of more Coho Salmon in Cook Inlet could be beneficial to Coho Salmon production in this system. Coho Salmon are not lake spawners, but the increase in Coho Salmon arriving at the weir over time (Figure 5), and subsequent recruitment (Figure 4), indicates they are successfully utilizing Sixmile Lake and its tributaries for spawning and rearing. The results from the model indicate density-dependent competition for space or resources may not be substantially affecting this small Coho Salmon population however with an increase in returning adults, density dependence could occur in the future if carrying capacity is reached. Current Coho Salmon population abundance appears to be consistently below carrying capacity. Recruitment in this population could be limited by density-independent factors, such as environmental conditions.

The recovery plan for CIBW lists several threats and potential recovery actions. Reduction in prey was listed as a threat of medium concern, and the persistence of Chum, Sockeye, Coho and Chinook salmon, as primary prey species of CIBW, was listed as essential to conservation of the species. Ongoing essential base operations, including noise generated from training exercises, military aircrafts, and detonations, and rare explosive projectiles into CIBW habitat, are listed as threats of concern (National Marine Fisheries Service 2016). Biologists on base are interested in mitigating those negative effects and contributing towards conservation of the species. Ensuring maximum salmon production for CIBW prey is one of their goals and understanding salmon production will help them achieve that goal. Our preliminary analysis suggests Sockeye Salmon production could be limited by biological or abiotic factors in the freshwater environment, thus determining the contributing factor(s) may provide opportunity to alleviate them and produce more prey species in an area where belugas are often observed feeding. Our analysis also suggests Coho Salmon production is not limited yet and could be increased with more spawning adults in the system in the future.

Recommendations

To increase our understanding of the freshwater variables affecting Sockeye and Coho salmon production in Sixmile Lake, I suggest employing both field projects (evaluation of predation and habitat availability) and modeling approaches (build upon this model by incorporating additional environmental data from online databases). In addition to illustrating potential productivity limitations for fisheries managers, these studies will also provide insight into prey production for CIBW in the Knik Arm.

Predation

Predation in the Sixmile system could come from four main sources: Rainbow Trout stocked annually into Sixmile Lake, Invasive Northern Pike, Coho Salmon year 1+ juveniles predating upon Sockeye Salmon emerging fry, or cannibalism. Previous studies have shown that predation can vastly decrease production in salmon populations (Beauchamp 1995; Sepulveda et al. 2013). Northern Pike have recently been found in Sixmile Lake, but little is known about their population there besides that they exist in relatively low densities (Colette Brandt, JBER Biologist, pers. comm.). Rainbow Trout ~200 mm in size are annually stocked in the spring into Sixmile Lake (n = 1,611 on average per year). Anecdotal information suggests that Rainbow Trout in Sixmile Lake congregate at and below the lake outlet during outmigration, presumably to feed on outmigrating salmon. To determine the effect to which predation by Rainbow Trout and Northern Pike is decreasing salmon productivity, an assessment of the population in Sixmile Lake would be necessary. Further, diet information and bioenergetics rates would also be necessary. As common sportfish species, literature on Rainbow Trout (Railsback and Rose 1999) and Northern Pike (Muhlfeld et al. 2008) bioenergetics is readily available. Temperature of the lake, coupled with a bioenergetics model, prey composition and population size could determine the number of juvenile salmon consumed by both predators. I propose a strategic gill-netting population assessment with monofilament gillnets of various mesh sizes to target different size classes of Rainbow Trout and Northern Pike; this strategy is in alignment with the assessments on stocked lakes conducted by the Alaska Department of Fish and Game (Pawluck and Berkhahn 2012). The surveys should be completed in different seasons to determine how the population changes throughout the year: once after ice-out, once during the summer but before salmon spawning, and once post-salmon spawning. Diet could be determined with traditional gastric lavage; but I recommend testing if the system is an appropriate candidate for stable isotope studies (Heady and Moore 2013). Several samples of different potential Rainbow Trout prey items should be collected in a pilot year of data collection, and if the carbon to nitrogen ratios are detectably different between different prey sources, stable isotope collection and analysis from various trout tissues, organs, and skeletal structures may be a cost-effective and low-effort method to determine seasonal diet in the Sixmile Lake system.

Temperature and Precipitation

Temperature, precipitation, and timing of ice out are environmental factors that have been found to be significant in Alaska Sockeye Salmon productivity (Schindler et al. 2005; Ohlberger et al. 2016; Mauger et al. 2017). On the Sixmile Lake system, there has only been intermittent temperature data collected in Sixmile Lake. I recommended the creation of a temperature monitoring network of 20 Onset TidbiT data loggers be installed, and in the summer of 2020, they were installed and provide continuous, year-round measurements of water temperature. Depth and temperature profiles in both Sixmile Lake and Otter Lakes can be determined using a buoy of four data loggers: surface, limnetic, transition, and deep. Sockeye Salmon tend to exhibit diel migrations as juveniles and utilize a variety of lake strata (Groot 1991), necessitating the collection of temperature data beyond just surface temperatures. For further analysis of past smolt recruitment data, I advise the inclusion of modeled water temperature from air temperature available from the National Weather Service. Precipitation, and its relationship to streamflow, can be extremely important to freshwater productivity of salmon (Mauger et al. 2017). It is unclear to the extent that precipitation affects annual productivity in this lake environment, but changes in water flow can affect upstream and downstream migrations and data is readily available online through the National Weather Service and will be added as a covariate in future modeling efforts.

Competition during Rearing

Ideal Sockeye Salmon rearing habitat is in the limnetic zone of lakes, from the surface to about 20 m. Juvenile Sockeye Salmon exhibit schooling behavior, which is uncharacteristic of other salmon species during the rearing stage (Groot 1991). Because of this lack of established rearing territories, competition for space in Sixmile Lake is not a likely mechanism influencing productivity. Competition for prey resources would be the more likely driver of density dependence at this stage. Juvenile Sockeye Salmon consume a variety of prey sources but typically move from the consumption of aquatic insects and their larvae post-emergence to pelagic zooplankton in later rearing stages (Groot 1991). Paired seasonal, diurnal and nocturnal juvenile salmon trawls and zooplankton tows (Bollens et al. 2010) in the limnetic zone will elucidate juvenile abundances and the available plankton prey assemblage and any potential deficiencies in available prey items.

Competition during Spawning

Sockeye Salmon utilize lake tributaries, nearshore habitats, and islands, if present, as spawning habitat (Groot 1991). A Sockeye Salmon-specific spawning study was completed in 2000-2001 by Gotthardt (2003) identifying spawning locations in Sixmile Lake. Sockeye Salmon spawn in nearshore habitats of Sixmile Lake and the upper Sixmile Lake was utilized for spawning more than lower Sixmile Lake (Gotthardt 2003). Although redds were identified, no assessments of superimposition occurred. Sockeye Salmon construct oblong redds that in Alaska tend to be about 80 cm by 60 cm (Groot 1991). I propose three years of spawning surveys where “new” redds are marked weekly to understand superimposition and the potential limitation of spawning habitat. I recommend accurate GPS locations, depth, and temperature measurements to be taken at each redd in addition to redd size. Superimposition should be identified by examining the degree of overlap of redds and tail spills as detailed in Hartwell (1996); rates of superimposition and egg mortality can be calculated with this data.

Conclusion

JBER and USFWS biologists have joint objectives to analyze limitations in freshwater productivity of salmon on Sixmile Lake, which is the longest studied watershed on JBER. Modeling indicates that Coho Salmon may not be limited by their freshwater life stage in this population, and increased escapement from Cook Inlet could increase Coho Salmon production in this system. Sockeye Salmon experienced the highest number of recruits at intermediate spawner levels, indicating density-dependence may be affecting Sockeye Salmon production, but because of the poor model fit and violations of model assumptions, directed studies are recommended to verify this conclusion and to tie density dependence to a responsible factor or factors. I am hopeful the inclusion of field projects and extensive temperature and precipitation datasets will reveal the variables responsible for smolt production variability and management objectives that could be applicable to alleviate them.

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Table 1. Compiled fisheries and related data collected on Joint Base Elmendorf-Richardson (JBER), 1998-2018. Data was collected from unpublished spreadsheets, annual Department of Defense (DoD) reports, and external contracted reports.

LOCATION	STUDY	MONTH	YEAR	SPECIES	COMMENTS
LOWER SIXMILE LAKE OUTLET	ESCAPEMENT	JULY-SEPTEMBER	1998-PRESENT	SOCKEYE SALMON	
LOWER SIXMILE LAKE OUTLET	ESCAPEMENT	JULY-SEPTEMBER	2002-PRESENT	COHO SALMON	
LOWER SIXMILE LAKE OUTLET	ESCAPEMENT	JULY-SEPTEMBER	2002-2008, 2011-2014, 2017-PRESENT	PINK SALMON	
LOWER SIXMILE LAKE OUTLET	ESCAPEMENT	JULY-SEPTEMBER	2003-2008, 2011-2014, 2017-PRESENT	CHUM SALMON	
LOWER SIXMILE LAKE OUTLET	SMOLT	MAY-JUNE	2003-2006, 2011-PRESENT	SOCKEYE SALMON	
LOWER SIXMILE LAKE OUTLET	SMOLT	MAY-JUNE	2003-2006, 2011-PRESENT	COHO SALMON	
LOWER SIXMILE LAKE OUTLET	SMOLT LENGTHS	MAY-JUNE	2017-PRESENT	SOCKEYE SALMON	
LOWER SIXMILE LAKE OUTLET	SMOLT LENGTHS	MAY-JUNE	2017-PRESENT	COHO SALMON	
LOWER SIXMILE LAKE OUTLET	TEMPERATURE	MAY-JUNE	2004-2006, 2012-PRESENT	N/A	OUTMIGRATION
LOWER SIXMILE	TEMPERATURE	JULY-SEPTEMBER	2011-PRESENT	N/A	ESCAPEMENT

LOCATION	STUDY	MONTH	YEAR	SPECIES	COMMENTS
LAKE OUTLET					
SIXMILE LAKE	HABITAT ASSESSMENT	MAY-SEPTEMBER	2001	N/A	BATHYMETRY
SIXMILE LAKE	SPAWNING SURVEY	AUGUST-SEPTEMBER	2000-2002	SOCKEYE SALMON	
SIXMILE LAKE	STOCKING HISTORY	MAY	1992-2006, 2012-PRESENT	RAINBOW TROUT	
SIXMILE LAKE	LAKE SURVEY	SEPTEMBER-OCTOBER	2015	N/A	ENVIRONMENTAL DATA COLLECTION
SIXMILE CREEK	SPAWNING SURVEYS	AUGUST-SEPTEMBER	2016-PRESENT	ALL SALMON SPP.	WALKING SURVEYS
SIXMILE CREEK	STREAM SURVEY	JUNE-AUGUST	2015	ALL FISH SPP.	ELECTROFISHING; ENVIRONMENTAL DATA COLLECTION
OTTER LAKE OUTLET	ESCAPEMENT	JULY-SEPTEMBER	2017-PRESENT	COHO SALMON	VIDEO
OTTER LAKE OUTLET	PIKE SURVEYS	OCTOBER	2004-2007, 2015	NORTHERN PIKE	NETTING
OTTER LAKE	STOCKING HISTORY	MAY	1992-1995, 1999-2006, 2012-PRESENT	RAINBOW TROUT	
OTTER LAKE	LAKE REPORT	SEPTEMBER-OCTOBER	2015	N/A	
OTTER CREEK	BATHYMETRY	U	2018	N/A	
OTTER CREEK	SPAWNING SURVEYS	AUGUST-SEPTEMBER	2016-PRESENT	ALL SALMON SPP.	WALKING SURVEYS
OTTER CREEK	STREAM SURVEY	JUNE-AUGUST	2015	ALL FISH SPP.	ELECTROSHOCKING; ENVIRONMENTAL DATA COLLECTION
EAGLE RIVER FLATS	PIKE SURVEYS	JULY	2015-2016	NORTHERN PIKE	EDNA AND NETTING
EAGLE RIVER	DIDSON	MAY-SEPTEMBER	2013-PRESENT	ALL SALMON SPP.	

LOCATION	STUDY	MONTH	YEAR	SPECIES	COMMENTS
JERRY'S CREEK	SPAWNING SURVEYS	AUGUST-SEPTEMBER	2016-PRESENT	ALL SALMON SPP.	WALKING SURVEYS
CHESTER CREEK	SPAWNING SURVEYS	AUGUST-SEPTEMBER	2003-2006, 2016-PRESENT	ALL SALMON SPP.	WALKING SURVEYS
CHESTER CREEK	STREAM SURVEY	JUNE-AUGUST	2015	ALL FISH SPP.	ELECTROSHOCKING; ENVIRONMENTAL DATA COLLECTION
CLUNIE LAKE	LAKE SURVEY	SEPTEMBER-OCTOBER	2015	N/A	ENVIRONMENTAL DATA COLLECTION
EOD CREEK	STREAM SURVEY	JUNE-AUGUST	2015	ALL FISH SPP.	ELECTROSHOCKING; ENVIRONMENTAL DATA COLLECTION
GARNER CREEK	STREAM SURVEY	JUNE-AUGUST	2015	ALL FISH SPP.	ELECTROSHOCKING; ENVIRONMENTAL DATA COLLECTION
SHIP CREEK	STREAM SURVEY	JUNE-AUGUST	2015	ALL FISH SPP.	ELECTROSHOCKING; ENVIRONMENTAL DATA COLLECTION
MOONSHINE CREEK	STREAM SURVEY	JUNE-AUGUST	2015	ALL FISH SPP.	ELECTROSHOCKING; ENVIRONMENTAL DATA COLLECTION
SNOWHAWK CREEK	STREAM SURVEY	JUNE-AUGUST	2015	ALL FISH SPP.	ELECTROSHOCKING; ENVIRONMENTAL DATA COLLECTION
CLUNIE CREEK	STREAM SURVEY	JUNE-AUGUST	2015	ALL FISH SPP.	ELECTROSHOCKING; ENVIRONMENTAL DATA COLLECTION

Table 2. AIC Table that includes the degrees of freedom (df), AIC values, corrected AIC values, and difference in AIC values (ΔAIC) for Sockeye Salmon density independent and density dependent models.

Model	Df	AIC	AICc	ΔAICc
Density independent	2	44.14317	45.47650	1.62341
Ricker	3	40.85309	43.85309	0

Table 3. AIC Table that includes the degrees of freedom (df), AIC values, and difference in AIC values (ΔAIC) for Coho Salmon density independent and density dependent models.

Model	Df	AIC	AICc	ΔAICc
Density independent	2	41.48787	42.98787	0
Ricker	3	42.91626	46.34483	3.35696


Clunie Lake
Garner Creek
Eagle River Flats
Clunie Creek
EOD Creek
Eagle River
Otter Creek
Sixmile Creek
Sixmile Lake
Otter Lake
Moonshine Creek
Ship Creek
Snowhawk Creek
Chester Creek
0 0.75 1.5 3 Miles
N

Figure 2. Map of the Sixmile Lake/ Creek system.

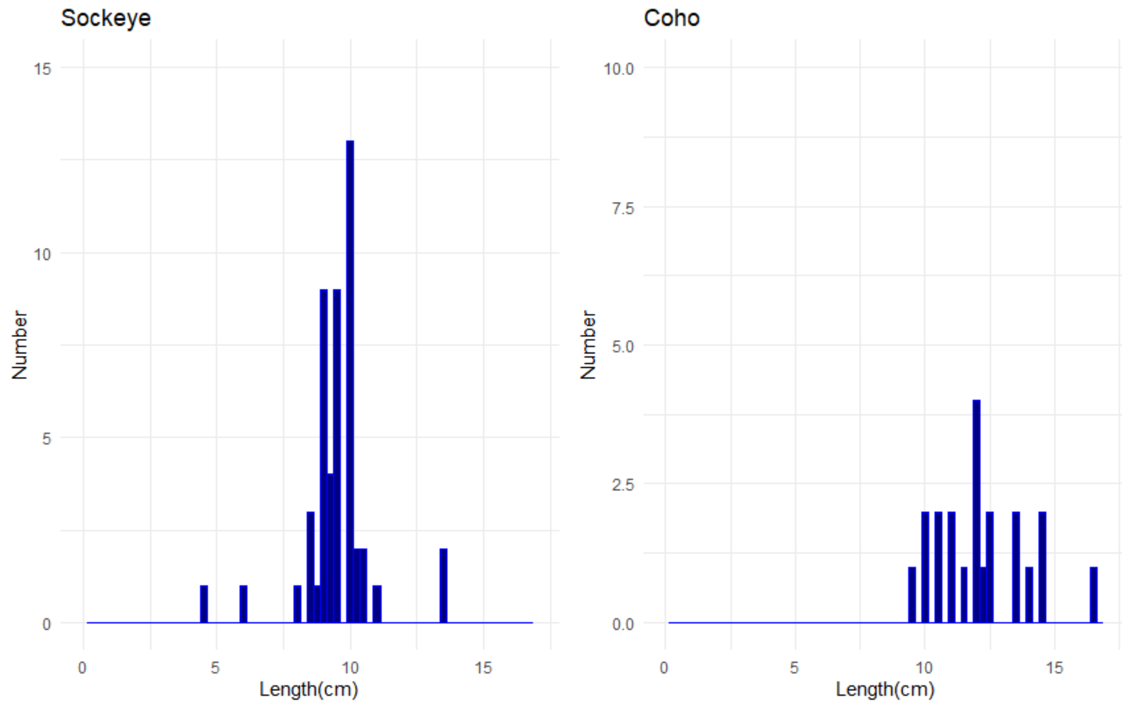


Figure 3. Length-frequency histograms of Sockeye and Coho salmon smolt measured May–June 2018 at the Sixmile Lake outlet.

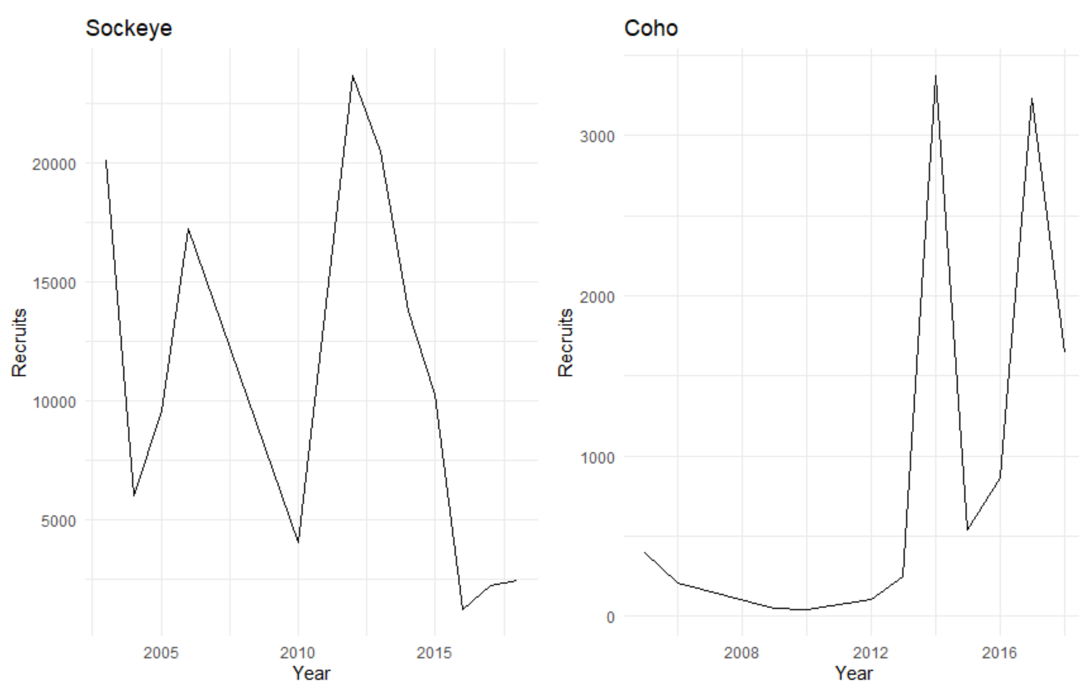


Figure 4. Smolt counts at the Sixmile Creek outlet from early May to late June, 2003-2017 of Sockeye Salmon (left panel) and Coho Salmon (right panel).

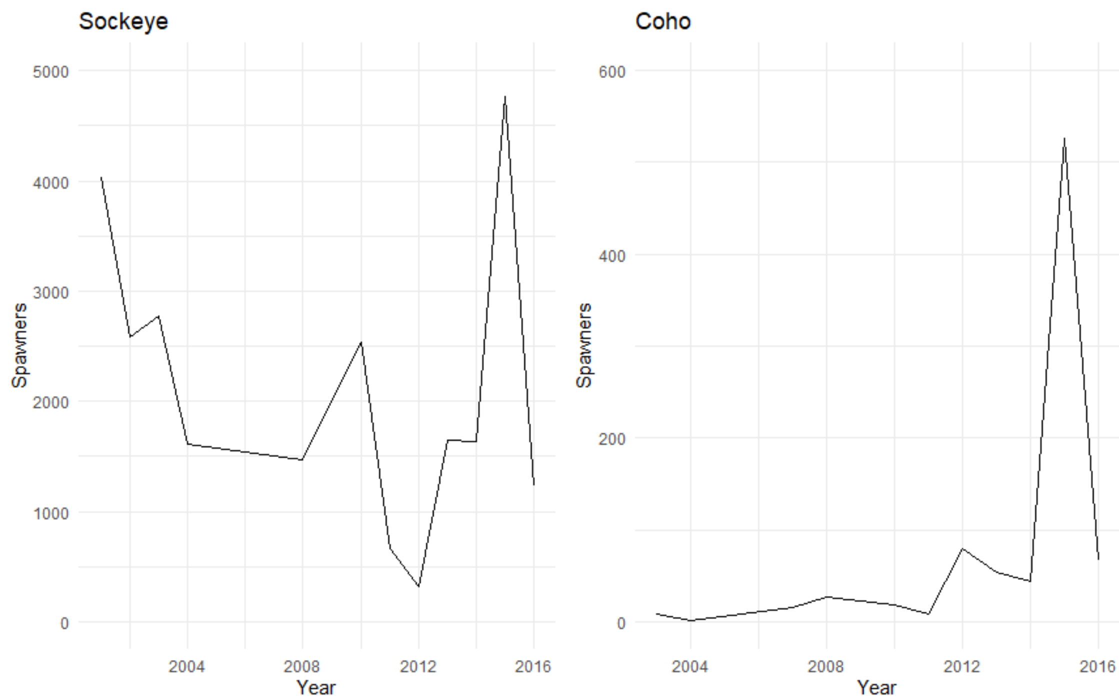


Figure 5. Adult Sockeye (left panel) and Coho (right panel) salmon counted at the weir from mid-July to mid-October, 2002-2018.

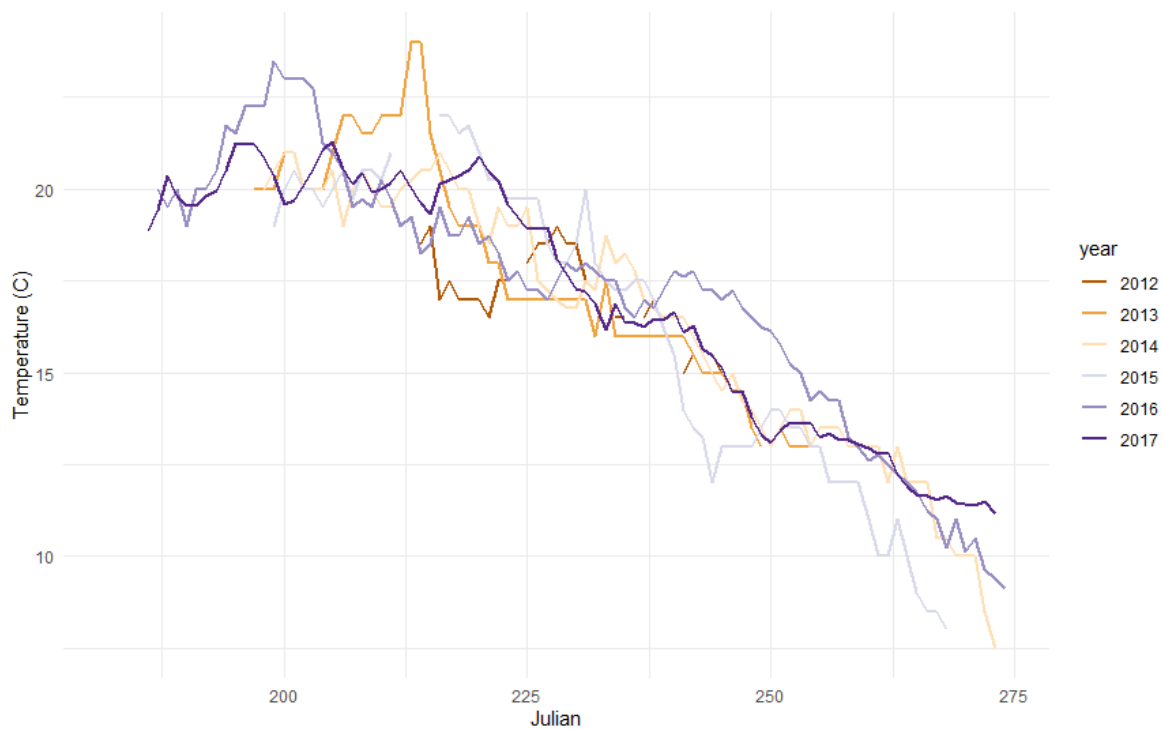


Figure 6. Water temperatures measured at the adult salmon weir under the Fairchild Avenue bridge 2012-2017. Temperatures were measured with a handheld thermometer 2012-2016 and a HOBO data logger in 2017.

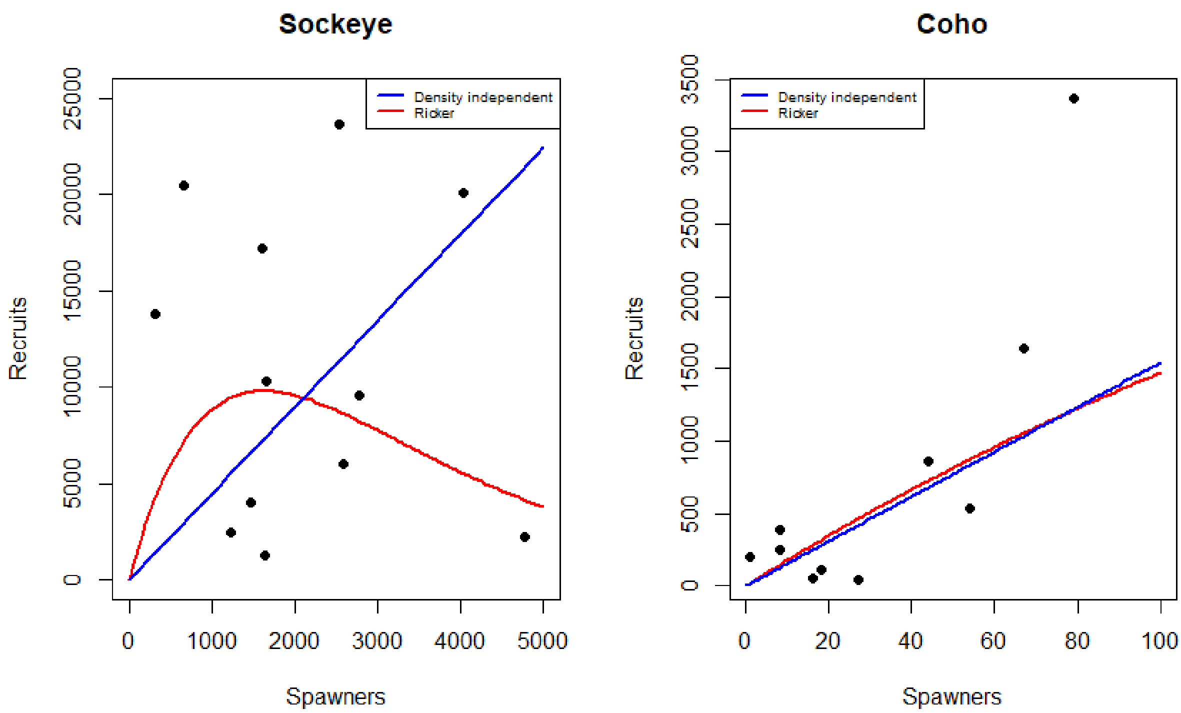
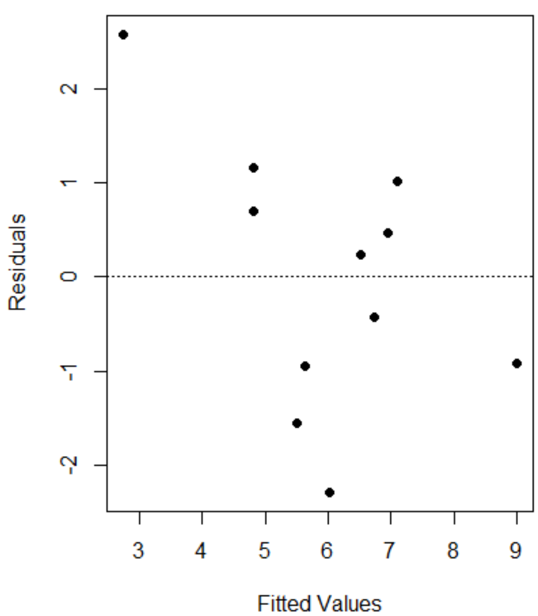
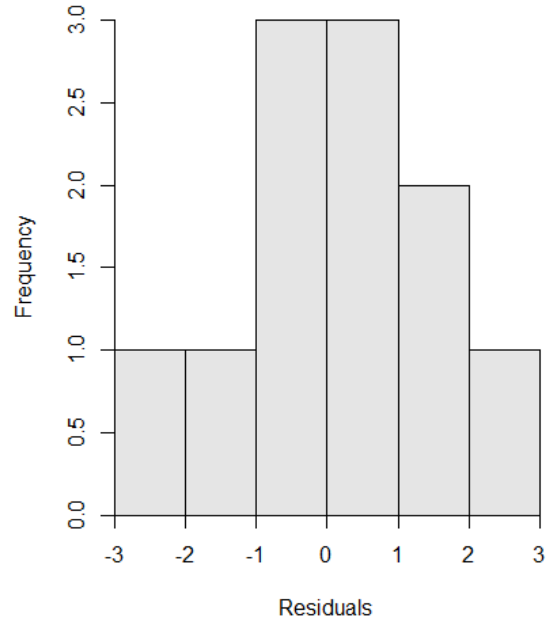


Figure 7. Density-independent (blue) and dependent (red) models fit to Sockeye (left panel) and Coho (right panel) salmon spawner and recruit data. A lag of two years between spawners and recruits was assumed based on length-frequency data taken in 2018. The density-dependent model was a better fit for the Sockeye Salmon data, whereas the density-independent model better was a better fit for the Coho Salmon data, based on Akaike's Information Criterion (AIC).


Residuals
-2
-1
0
1
2
3
4
5
6
7
8
9
Fitted Values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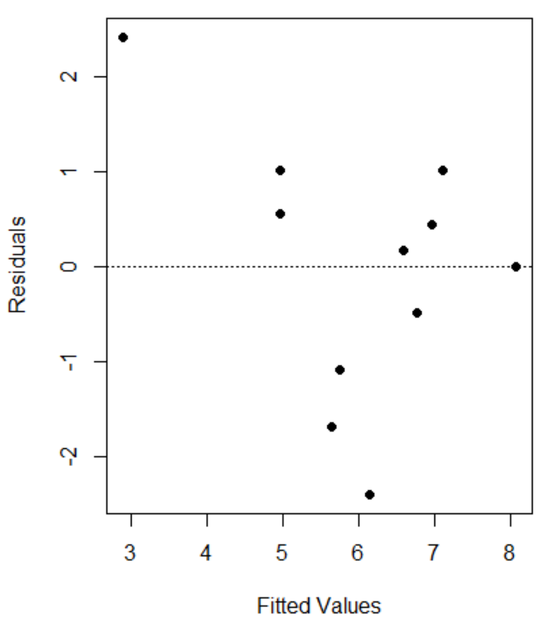
1.0
1.5
2.0
2.5
3.0
-3
-2
-1
0
1
2
3
Residuals


Residuals
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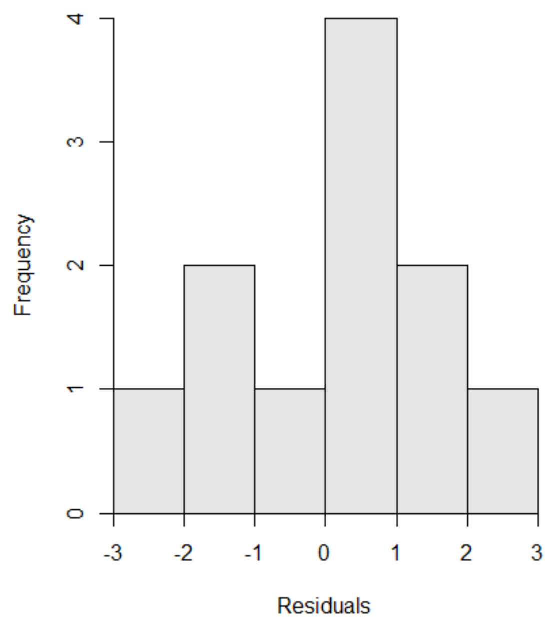
0
1
2
3
4
5
6
7
8
Fitted Values


Frequency
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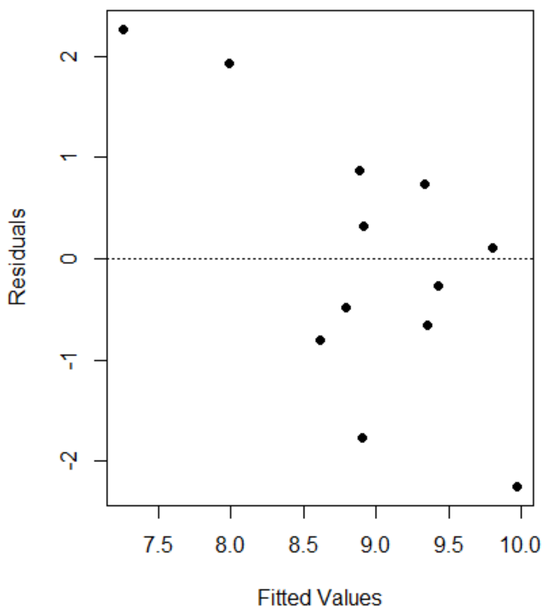
1
2
3
4
-3
-2
-1
0
1
2
3
Residuals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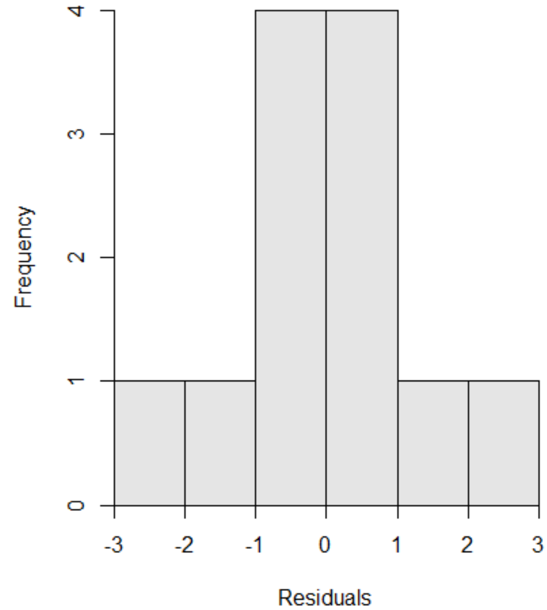
0
-1
-2
7.5
8.0
8.5
9.0
9.5
10.0
Fitted Values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3
2
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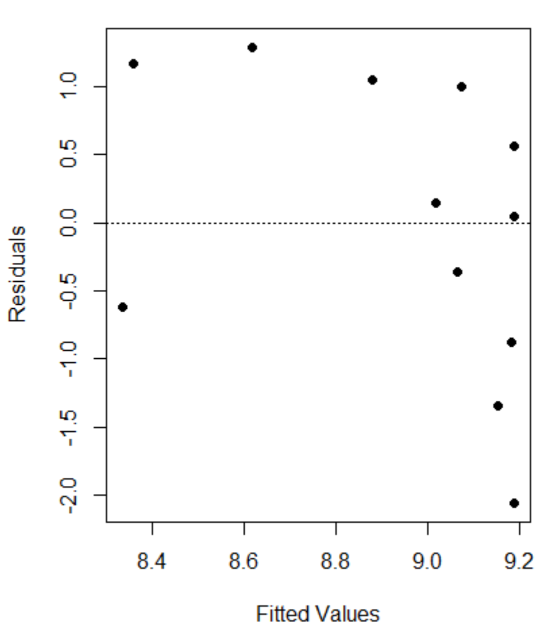
-1
0
1
2
3
Residuals


Residuals
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0.0
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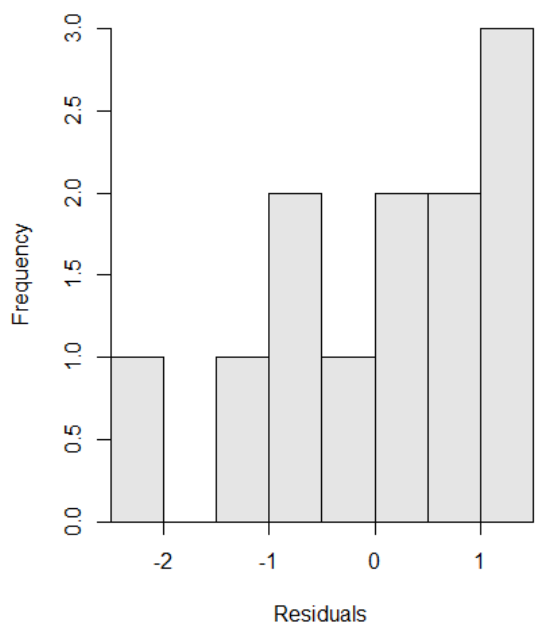
-2.0
8.4
8.6
8.8
9.0
9.2
Fitted Values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1.5
1.0
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-2
-1
0
1
Residuals