Response of Juvenile Steelhead and Chinook to Drought in the Nicola Watershed

Prepared for BC Conservation Foundation

And

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Executive Summary

There is a long history of water-related conflicts in the Nicola River watershed. The demand for surface water withdrawals – primarily for irrigation – intensifies during summer periods with low precipitation and high temperatures, which can coincide with the lowest stream flows. Maintaining adequate flows for fish while allowing surface water withdrawals has at times not been possible. During the summer of 2015, the Nicola Basin experienced severe drought conditions following a winter with record low snowpack and low precipitation and high temperatures in spring and summer. Discharge in the Coldwater River fell below the Theoretical Critical Level (TCL) for juvenile salmonids triggering a Fish Protection Order which limited or banned surface water withdrawals for irrigation starting July 31st and continued until September 18th, 2015.

The objective of this study is to look at a longer time series of juvenile abundance data for the Nicola system and examine to what extent variation in annual summer drought intensity, measured by discharge and/or temperature, explains the annual trend in juvenile Steelhead and Chinook abundance given the influence of stock size (brood spawners).

We compared predicted abundance of juvenile Steelhead Trout and Chinook Salmon based on stock-recruitment models with and without including a single covariate representing either summer drought or winter flow conditions. We then used the Akaike information criterion adjusted for small sample (AIC_c) to compare the relative effectiveness of covariates to explain the observed data. Additionally, we used linear regression to compare the ability of covariates to explain the variance in residuals from stock-recruitment models based on brood spawner abundance only (abundance not explained by stock-recruitment model), as well as the direction of the relationship.

Based on $AIC_{c,}$ no one index of summer drought or winter flow explained any more of the variation in juvenile abundance than any other. Also, they did not explain any additional variation than that explained by adult brood abundance alone. It was evident from the outset that with the limited number of years in the stock-recruitment time series that adding any more than one covariate would lead to overfitting. However, even with one covariate, the penalty added to AIC_c values was far greater than the improvement in model fit with such a low sample size (n =

6-11). On this basis, there is no more support for indices related to summer drought than any other, nor is there support to exclude summer drought as a factor at this time.

Based on correlation coefficients ($r^2_{spawner}$ values), there was only very weak support for the hypothesis that drought negatively impacts juvenile production in terms of the strength or consistence of indices across species / age-classes or stream areas. For the Nicola, Spius or Coldwater, there was only one comparison group where a summer drought index explained the largest amount of variation in abundance and predicted lower than expected abundance under increased drought conditions. The most consistent support for any covariate was for the index of minimum September discharge, which explained the most variance in productivity for every Chinook fry comparison group and for Steelhead parr using the Spius comparison group. However, this covariate predicts increased productivity with decreasing discharge, contrary to the drought hypothesis of improved productivity with increasing discharge. We should view correlations sceptically and likely to change with additional data.

These results do not provide support for the drought hypothesis based on these indices. This is primarily due to the low power to detect differences in model support as a result of insufficient sample size and low explanatory ability of environmental covariates. The effectiveness of covariates should be examined primarily by way of model fit (AIC_c values) and not only on the strength of correlations (r^2 values) since the former better incorporates uncertainty and penalizes for additional parameters whereas the latter does not. On this basis, there is no more support for indices related to summer drought than any other, including the spawner-only model. There is also no support to exclude summer drought as a factor at this time.

This study was designed to make use of an existing dataset collected for a different purpose. This required an analytical approach with several weaknesses but also introduce considerable uncertainty since we were limited to once per year abundance estimates. Indices may not have been specific enough to accurately represent biologically significant drought conditions. For instance, Chinook fry abundance was both much higher and lower than that predicted by adult brood abundance under conditions of severe drought based on a number of indices. Though unavailable, using water temperature instead of air temperature would provide a more effective measure of the combined effect of flow and air temperature. For the Nicola, minimum summer flows typically occur August to September whereas during 2015, near minimum flows were reached in early July coinciding with longer day length and higher air temperatures that resulted in water temperatures that exceeded BC Water Quality Guidelines. Water temperature monitoring at the reach or river level would provide key information for a wide range of inquires as to the response of fish to drought conditions. Alternative study designs that focus on directly measuring survival, movement and other measure of fish health during summer low flow period would provide a more rapid means to learn about drought impacts than the long duration necessary to accumulate sufficient years for a robust analysis using this method.

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Acknowledgements

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1.0 Introduction

The Nicola Basin supports populations of Steelhead (*Oncorhynchus mykiss*), Bull Trout (*Salvelinus confluentus*), Chinook (*Oncorhynchus tshawytscha*), Coho (*Oncorhynchus kisutch*) and Pink (*Oncorhynchus gorbuscha*) salmon and other species. This included several stocks of high conservation concern including Interior Coho stocks, designated as endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC); Bull Trout, listed as a Species of Concern by British Columbia Conservation Data Centre; and Thompson River Steelhead, which have had decreasing adult stock productivity since 1990 (Johnston 2013).

The Nicola Basin has widespread industrial and agricultural uses. Agriculture is the primary land use within the valley bottom of the Nicola River from its confluence with the Fraser River upstream to Nicola Lake and is common along the lower half of the Coldwater River and lowest 10km of Spius Creek. Agriculture operations draw surface water primarily for irrigation during the typically dry summer months. Upland areas of these watersheds are commonly used for forestry and cattle grazing.

There is a long history of water-related conflicts in the Nicola River watershed. The demand for surface water withdrawals – primarily for irrigation – intensifies during summer periods with low precipitation and high temperatures, which can coincide with the lowest stream flows. At low flow periods, allocations for surface water licences can reduce of stream flows to the point of impacting the quantity and quality fish habitat. Efforts to maintain adequate fish flows in a system with extensive surface water withdrawals – primarily for irrigation – began in 1983 with the drafting of the Nicola Basin Strategic Plan and continued with several more management and action plans, most recently the Nicola Water Use Management Plan (2010). The high fisheries values of the Nicola watershed are well recognized in these documents. More recently, the Coldwater River and Spius Creek were identified as candidates for Fisheries Sensitive Watershed designation. The entire Nicola River watershed was identified as a candidate for designation as a Temperature Sensitive Stream. These designations afford additional protective measures under the Province of BC Forest and Range Practices Act.

During the summer of 2015, the Nicola Basin experienced severe drought conditions following a winter with record low snowpack followed by low precipitation and high temperatures in spring and summer. A Drought Level 4 (extremely dry) was declared to the Nicola Region on July 21, 2015. Mean daily discharge in the Coldwater at Merritt fell below Theoretical Critical Level (TCL) for juvenile salmonids (5% of Mean Annual Discharge or 0.48m^3/sec at Water Survey of Canada gauge station 08LG010) July 10 – Aug 15. A Fish Protection Act Order was issued July 31, 2015 for the Coldwater River, which limited water withdrawals to between 6pm -6am and then transitioned to a complete ban on surface water withdrawals August 11th. Due to precipitation and an increase in streamflow, on August 19th, the order reverted back to partial restrictions. Restrictions were modified according to flow conditions until September 18th, 2015, when the order was rescinded for the season. Flows in the Nicola River below Merritt remained near of above the TCL but relied on increased releases from the Nicola Lake Dam to do so (McCleary, personal communication) though water temperatures during July and August frequently exceeded BC Water Quality Guidelines for steams with rearing juvenile salmonids (daily maximum 19ºC). What is most unique about 2015 is the very early onset of low flows where discharge decreased to its minimum flow and had the lowest discharge on record (1958-present) during the mid-June to late July period (Figure 2). Though concern and interest about the impact of low summer discharge on salmonids in the Nicola watershed has been ongoing for decades, there has been little research directed at measuring the actual impact of discharge levels or temperature on juvenile fish abundance or physiology e.g., size, growth, condition..

There is interest by resource managers to evaluate if the single-threshold approach and levels of such a threshold (e.g. 5% of MAD, Coldwater River) to trigger increased conservation measures are suitable to protect juvenile salmonids population and maintain surface water diversion opportunities. This project was initiated to evaluate the impact of drought conditions on juvenile salmonids rearing in the Nicola River basin. For salmonids, low summer flows have been associated with reduced survival (Grantham et al. 2012), elevated, yet sub-lethal temperatures associated with reduced foraging (Nielson et al. 1994, Sloat and Osterback. 2012), increased predation and decreased growth rates (Marine and Cech 2004).

We restricted the evaluation to stream sections, species and age-classes for which long term population estimates were available for both juveniles and brood spawners and that also have relatively long freshwater residence times. This limited the study to two Steelhead age-groups: fry (0+) and age-1+ parr; and Chinook fry. Steelhead in the Nicola River watershed emerge from redds in early summer, then spend two to three winters in freshwater before smolting (migrate from freshwater to the ocean). Chinook stocks in the Nicola Basin are primarily 'stream-type' meaning they spend at least one year in freshwater before smolting. The time series comprise up to 11-years of juvenile standing stock estimates based on surveys using both night snorkeling and electrofishing (Decker et al. 2015) and the corresponding brood stock abundance for each species and age-class. We also include the Deadman River / Criss Creek system and Bonaparte River, two other tributaries of the Thompson River, to evaluate the consistency findings beyond the Nicola system.

The objective of this study is to examine to what extent annual variation in summer drought intensity, measured by discharge and/or temperature, explains annual variation in juvenile Steelhead and Chinook abundance beyond the influence of parent spawner abundance. We also consider the influence of winter flow conditions due to the potential association between winter flood events and reduced overwinter survival (Cunjak et al. 1998, Doyle *et al.* 1994) and, for Chinook fry only, discharge conditions during spawning (Decker et al. 2009). These were included since the once-annual juvenile standing stock estimates represent the sum of all factors influencing abundance from egg-deposition to the time of fall sampling.

2.0 Methods

2.1 Study Area

The primary study area (Figure 1) includes the Nicola River between Merritt and the confluence with the Thompson River (75km), the Thompson River between confluence with the Fraser and Nicola Rivers (26km) and the entire anadromous sections of Spius Creek (40km) and the Coldwater River (79km) described by Decker et al. (2015). The Thompson River between the Nicola and Fraser Rivers was included in the study because: (1) based on studies of anadromous maternal origin, juvenile Steelhead rearing in this reach likely originate from the Nicola River watershed (Hagen et al. 2012); and (2) there is a sharp increase in age 1+ parr density below the confluence with Nicola River (Decker et al. 2015). The Bonaparte (108km) and Deadman (49km including Criss Creek) were also included as a means of comparison to other Lower Thompson River tributaries however they are not the primary focus of this study.

The hydrograph for the Nicola, Coldwater, Bonaparte and Deadman rivers and Spius Creek are driven by snowmelt. Peak flows occur in May and June followed by a sharp decrease to base summer flows that continue to decrease until fall storms increase flows before temperatures cool and precipitation accumulates as snow. Winter flows are characteristically low but are occasionally punctuated by short duration high flow events as the consequence of rain-on-snow events and have been associated with stream ice breakup and ice jams. Flows in the Nicola mainstem during summer and fall are moderated by Nicola Lake and regulated to some degree by the Nicola Lake Dam. The Thompson River drains extensive high elevation watersheds that include both snow and glacier melt. This, in combination with the moderating effect of many large lakes prolongs relatively high flows from May through to September.

2.2 Stock Recruitment Data

For Steelhead fry, we used juvenile standing stock estimates from Decker et al. (2015), for riffle habitats sampled by backpack electroshocking 2001-2006, 2008, 2010-2012. Note that since no electroshocking occurred in 2015, fry abundance was not available for this low flow year. For Steelhead age-1+ parr and Chinook, standing stock estimates represented abundance in all habitat types sampled 2001-2006, 2008, 2010-2012 using a combination of night snorkeling and backpack electroshocking reported in Decker et al. 2015. Though population estimates for age-1+ parr can be unbiased with electroshocking and snorkeling, precision is much greater with snorkeling whereas for Steelhead fry, abundance estimates are only unbiased using electrofishing (Korman et al. 2010). 2015 Chinook fry and Steelhead parr abundance in the Nicola watershed was based on night snorkel surveys only, with abundance in unsampled riffle habitat approximated using the correlation between abundance in the sampled and unsampled habitats (see Schick 2016 for further information).

Chinook escapement estimates were obtained from the DFO's Salmon Escapement Database System (SEDS). Steelhead escapement estimates were obtained from British Columbia Ministry of Natural Resource Operations Fish and Wildlife Branch. We only included escapement estimates for years when adult sampling occurred and did not utilize any reconstructed estimates based on historic trends.

To develop adult-to-fry and adult-to-parr stock-recruitment models, we paired juvenile standing stock estimates with its corresponding brood spawner escapements estimates for available streams and the aggregate of all study streams in the Nicola watershed (Table 1). Extensive scale analysis from return spawners suggests the vast majority of Bonaparte, Deadman and Nicola watershed Chinook are stream-type, rearing in freshwater for at least one year and occasionally two (as opposed to ocean-type Chinook that migrate to the ocean within 90 days of emergence). Thus, we assumed that juvenile Chinook standing stocks present in the study reaches in the fall represented the sum total of recruitment for a single brood year escapement. Thompson River Steelhead spend two or three years in freshwater before migrating seaward. We use the fall standing-stock estimate of age-1+ parr in the stock-recruitment analysis since this is the oldest age group prior to smolting. For Steelhead, age-specific juvenile standing stock estimates are available for 2001-2012 and 2015.

2.3 Study Design

We used stock-recruitment models of Chinook fry, and Steelhead fry and age-1 parr as the basis for comparing observed and predicted abundance with and without including a single covariate representing either summer drought and winter flood conditions. For these purposes, 'stock' refers to brood spawner abundance while 'recruits' refers to the juvenile abundance produced by the spawners. For each species and age-class, we assembled stock and recruitment information for the aggregates of streams in the Nicola watershed (Nicola Aggregate) and for individual streams if there was sufficient stock and recruitment information. We refer to each permutation of these as comparison groups. Then for each comparison group, we evaluated the effectiveness of each model using the Akaike information criterion adjusted for small sample size (AIC_c), to compare the relative effectiveness of covariates to explain the observed data (see section 2.7 for details). For stock-recruitment models including a covariate, both brood spawner and covariate information was included in when models were fit to observed abundance. We then used r^2 values from linear regression of log predicted versus log observed recruits to quantify the amount variation of juvenile abundance explained by each model. Unlike AIC values, r^2 values are able to be compared with different stock-recruitment data sets. This allows us to evaluate the strength of environmental covariates across species, age-classes and areas. With AIC values we can only compare ranking of covariates across comparison groups. We also used linear regression to compare the ability of covariates to explain the variance in residuals from stock-recruitment models based on brood spawner abundance only (abundance not explained by stock-recruitment model). These are referred to as $r^2_{\text{spawner-only}}$ values. This differs from the model fitting used in the AIC comparisons in that this has two steps: 1) fit stock-recruitment model using only brood spawner abundance and then 2) regress residuals (abundance not explained by stock-recruit model) by each of the drought indices. This approach evaluates how the covariate alone explains what is not accounted for by the stock-recruitment model and most importantly, whether a covariate is positively or negatively related to abundance. Regression statistics are also useful to compare the effectiveness of covariates using different datasets i.e., comparison between streams.

We used the Ricker model (1975) for Chinook for consistency with past studies within this watershed (Decker et al. 2009) and since it has been found to be useful for describing Chinook population dynamics (CTC 1999). We used the Beverton-Holt (Ricker 1975) model for Steelhead fry and parr as it had improved model fit compared with the Ricker model (Schick 2016) and since we were not estimating maximum productivity (R/S_{max}), which it is prone to overestimating.

Covariates for either Ricker or Beverton-Holt models can be incorporated into the equation either as part of α, reflecting productivity at low stock size or β, reflecting how productivity decrease as stock size increases. We included the indices as part of the β component following the approach used by Neuswanger et al. (2015).

Though the study design does not include formal hypothesis testing, we use the following hypotheses as the basis for choosing covariates to incorporate into models and to define the predicted relationship between abundance and covariates (note that not all hypotheses apply to all species and age-classes):

Chinook fry, Steelhead parr and Steelhead fry

H_0 – No covariate improves model support compared to the model without any covariates (spawner-only model).

H_{1a} – Models including summer discharge would have high support. The model would predict a positive relationship between discharge and residuals of the spawner-only model.

H_{1b} – Models including summer temperature would have high support. The model would predict a negative relationship between temperature and residuals of the spawner-only model.

H_{1c} – Models including a single covariate that represent summer temperature and discharge would have high support. Based on residuals from the spawner-only model, residuals would be less than expected under low discharge and high temperature conditions and higher than expected at high discharge and low temperature.

Chinook fry and Steelhead parr

H_2 – Models including winter discharge would have high support. Residuals from the spawner only model would be negatively correlated with winter discharge. This hypothesis does not apply to Steelhead fry since they are the progeny of spring spawning (March-May) so neither eggs or age-0 fry were exposed to winter conditions whereas Chinook fry and Steelhead age-1+ parr enumerated during the fall were either eggs (Chinook) or fry (Steelhead parr) during the previous winter.

Chinook fry only

H_3 – Models including summer discharge the year prior to fry enumeration, during spawning, would have high support. Residuals from the spawner only model would be positively correlated with summer discharge.

2.4 Environmental Covariates

Indices of environmental covariates fall into three general categories based on the four hypotheses under investigation: a) discharge during summer rearing, b) temperature during summer rearing, c) discharge during winter rearing and incubation and d) discharge during spawning (Chinook only; Steelhead spawn in the early spring when low discharge/high water temperatures are not an issue). We calculated discharge related indices based on data from nine Water Survey of Canada (WSC) stations (Table 1), and utilized daily or 15-minute interval data. Temperature related indices were based on air temperature measured at the Merritt STP Environment Canada weather station (Stn. 1125079).

Each water year spanned the period from October 1 of the prior year to September 30 of the current year (e.g. the 2015 water year included the period from October 1, 2014, to September 30, 2015). A list of all indices, including calculation methods are included in Appendix 1. For methods specific to the summer, the period of interest was July 1 to September 30. For methods involving a rolling 30-day mean discharge or temperature, the 30-day mean for a particular date spanned the period from 14 days prior to 15 days following the date of interest. Discharge values were standardized by their long term mean annual discharge (LT MAD) to allow for comparisons between streams of different sizes. We only used periods of interest with complete records (e.g. no missing days during the summer) were utilized (Table 2). If data were missing during the period, no index was reported for that year.

Due to the large number of summer flow related indices considered, and the fact that that many of the indices were highly correlated with one another ($r^2 > 0.95$), we selected a single index that we judged to be the most biologically relevant in cases where there were multiple, correlated indices overlapping the same time period. Table 3 lists the indices used for each species / age-class, covariate category and life-stage of the fish during this period. The index of winter flow was not included for Steelhead fry since this age-class was not exposed to winter flows (November – March) and the index of summer discharge during spawning was only included for Chinook fry.

2.5 Stock-Recruitment Model and Environmental Predictors

The following form of the Ricker model was used to predict juvenile abundance as a function of escapement for chinook fry,

1) $$R_t = \alpha \cdot S_{t-1} \cdot e^{\beta \cdot S_{t-1}} \cdot e^{\lambda \cdot (\bar{X}_t - X_t)} \cdot e^{\varpi_t}$$

where, *t* denotes the year juveniles were sampled, R is recruitment (abundance of juveniles), S is the escapement one calendar year earlier (t-1), α is the initial slope of the stock-recruitment curve (recruitment in the absence of density effects, often termed stock productivity), β is the rate at which recruitment declines with increasing escapement (often called the density-dependent term), λ is the slope of the covariate effect, X is the covariate value for each year, and ω is a randomly distributed error term with mean 0 and standard deviation σ (Hilborn and Walters 1992). Under this form of the Ricker relationship, $\frac{\alpha}{\beta} \cdot e^{-1}$ is the spawning size which maximizes recruitment. Note that covariate values are expressed as deviates relative to the mean $\bar{X}$. To evaluate effects of hydrology covariates on spawning and incubation, covariate values were lagged by one year (e.g. X_{t-1} in eqn. 1).

The following form of the Beverton Holt model was used to predict juvenile abundance as a function of escapement for steelhead fry and age-1+ parr,

2) $$R_t = \frac{\alpha \cdot S_{t-1}}{\beta + S_{t-1}} \cdot e^{\lambda \cdot (\bar{X}_t - X_t)} \cdot e^{\varpi_t}$$

Note the lag between recruitment and escapement is t-1 for fry and t-2 for parr. Under this form of the Beverton-Holt model, $\frac{\alpha}{\beta}$ defines the initial slope of the stock-recruitment curve and α is the maximum recruitment.

2.6 Model Fitting

Models were fit to the data by nonlinear search using the 'optim' function in the R statistical package (R Development Core Team). We fit the model by maximizing a log-likelihood that was calculated assuming that log-transformed predictions and observations were normally distributed (consistent with the lognormal error assumption in the stock-recruit models). Variance estimates for parameters were calculated from the Hessian matrix produced by 'optim'. The 2-parameter stock-recruitment model was fit by fixing λ at 0 and estimating α and β only. This model was compared to a variety of covariate models where α, β, and λ were estimated based on one of the hydrology and temperature statistics.

2.7 Model Selection

We evaluate the relative support for models using Akaike information criterion corrected for small sample size (AIC_c), defined as,

$$AIC_c = 2 \cdot K - 2 \cdot LL + \frac{2 \cdot K \cdot (K+1)}{n - K - 1} \qquad 3)$$

where K is the number of parameters, LL is the log likelihood, and n is the number of stock-recruit data points (sample size). AIC_c is used to compare a range of models applied to the same data (Burnham and Anderson 2002). Models with more parameters may fit the data better but parameter estimates will be less precise. The most parsimonious model from a group of models is the one which exhibits the best trade-off between fit and precision, and will have the lowest AIC_c value. The first term (2·K) is a penalty based on the number of parameters, which will go up with model complexity. The second term (2·LL) is the fit component, which may go up with more parameters, but cannot decline with more parameters. The last term is the small sample size correction, which increases AIC_c with decreases in sample size. Models within 0-2 AIC_c units of the most parsimonious model (the one with the lowest AICc) are considered to have strong support; models within 2-7 units are considered to have moderate support, and models that had AIC_c values > 7 units relative to the best model are considered to have weak support. The log-likelihoods for models that had AICc values close to the lowest AICc model were compared to evaluate the importance of covariate effects. In the absence of a small sample size correction effects, adding a covariate model which had no explanatory power (i.e., did not increase the log likelihood) would increase the AIC by 2 units relative to the base stock-recruit model. By standard AIC definitions, this covariate model would be considered to have strong support, which is an incorrect conclusion as the fit of the model was not improved at all. This logic can be extended to include small sample size effects. For example, the correction for a 3 parameter model with a sample size of 8 would be 6, compared to 2.4 for a 2 parameter model, leading to a difference between models of 3.6. This difference can be added to the difference between models based solely on the $2 \cdot K$ component of the AIC_c equation ($2 \cdot 3 - 2 \cdot 2 = 2$) which would equal 5.6. Thus, a covariate model within 5.6 units of the lowest AIC_c model should not be considered to have moderate support since there was no improvement in fit by adding the covariate effect.

3.0 Results

3.1 Drought Frequency and Severity

During 2000-2015, the Nicola, Coldwater and Spius had approximately twice as many years with below average minimum summer discharge (8 – 10 years with Doyle index[1] <4.5, Figure 3) compared with the Deadman or Bonaparte (4 - 5 years). As well, they had a high number of years under more acute low summer discharge (2-4 years with Doyle index < 2.5) than the Bonaparte or Deadman (1 and 0, respectively). For the Nicola, Coldwater and Spius, the central date of the 30-day minimum flow period occurred considerably earlier in 2015 (July 31 – Aug 15, Appendix 6a-d) than years with comparable or lower minimum summer flows (Aug 20 – Sept 14). This was not the case for the Deadman or Bonaparte where minimum summer discharge occurred well within the range of other below average years (Appendix 6e-f). Averaged across years with available data 2000-2015, the 30-day minimum discharge as a proportion of LT MAD was lowest for the Coldwater and Spius followed by the Nicola, and then Bonaparte and Deadman (Figure 4).

3.2 Model Comparisons

Table 4a-c lists model output statistics for each age-class and stock-recruitment comparison group. It is important to note AIC only allows for a comparison of support for models that are measured against the same set of observed outcomes i.e. juvenile abundance. Similarly, high model support only indicates that it is better than those with less support but gives no indication about amount of variation in productivity that the model explains. To do that, we look to the r^2 values, which can be compared both within comparison groups and across them. All models use brood spawner abundance as the primary component for prediction juvenile abundance. Models that use only brood spawner abundance are referred to as spawner-only models while those including a covariate are referred to by the name of the covariate.

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[1] The Doyle index is a method to standardize flow by the percentile in relation to historic flows. However, instead of a percentile range or 0-100, for simplicity, they are converted to a scale of 1-8. A Doyle value of 1 would reflect the lowest discharge on record and 8 the highest (Doyle 2004). The index value of 4.5 corresponds to the median value.

Several aspects of the results were consistent across all comparison groups. First, for each comparison group, ΔAIC_c values were lowest (highest model support) for the spawner-only stock-recruitment models, however, log likelihood values (*LL*) differed only at the first decimal place indicating that while ignoring the number of model parameters, support was similar for all models. Part of the reason for this is that at the low sample size (n = 8 – 12 years) the penalty for the additional parameter added to the AIC_c value of the spawner-plus-covariate models was greater than the improved model fit from the added parameters. Second, within each comparison group, ΔAIC_c values for models that include covariates differed by less than 2, typically varying at the first decimal place. This indicates a similar level of support for all covariate models for each comparison group, a product of the high uncertainty resulting from low sample size. Third, in all but two cases, the model with the most support (lowest ΔAIC_c) also explained the largest amount of the variance in productivity (r^2 values). Though the similarity of ΔAIC_c within comparison groups is informative about the need for a larger sample size, it is not useful in distinguishing the relative usefulness of covariates with the existing sample size. For this reason, we report primarily on the amount of variance explained (r^2 values) by each model and covariate throughout the remainder of the results section. For reference, consider that r^2 values as high as 0.4 can result from randomly distributed data.

3.2.1 Chinook Fry

For all Chinook fry comparison groups, models that included September.Daily.Min.st had the highest r^2 value (0.24 – 0.77, Table 4a). In all cases, September.Daily.Min.st was negatively correlated with the residuals of the spawner-only model (Appendix 2a-d). That is, residuals of the spawner-only model increased as September daily discharge decreased. In other words, there were more fry than expected in lower flow years with less fry than expected in higher flow years.

The spawner-only Ricker model explained the majority of variation in productivity for the Nicola Aggregate area ($r^2 = 0.66$,). The residuals from this model were poorly explained by any of the covariates ($r^2_{spawner} = 0.00 – 0.20$) but of them, September.Daily.Min.st. had the highest $r^2_{spawner}$ value. The September.Daily.Min.st. model had the highest r^2 and, along with Summer.Days.below.15MAD.

For the Coldwater, the spawner only Ricker model explained almost none of the variation in productivity ($r^2 =0.01$). The residuals of this model were best explained by the

September.Daily.Min.st covariate ($r^2_{spawner}$ = 0.29) and similar to the Nicola Aggregate, was negatively correlated. The September.Daily.Min.st model also had the highest r^2 yet accounted for only a small portion of the variance in abundance ($r^{2 =}$ 0.24).

For the upper Coldwater (CW2), the spawner-only Ricker model explained a moderate amount of the variation in productivity (r^2 =0.41) with only minor increases when including a covariate in the model (r^2 =0.42 – 0.54, Table 4a). The covariate Spawning.summer.30Day.min.st, which reflected summer discharge during the spawning period that produced the fry, had the highest correlation with the residuals from the spawner-only model ($r^2_{spawner}$ = 0.29). Residuals were negatively correlated with discharge i.e. residuals decreased with increasing minimum flows during spawning (Appendix 2c). The model using September.Daily.Min.st explained the largest amount of variance in productivity (r^2 = 0.54) yet all covariates produced relatively similar improvements (r^2 = 0.42 – 0.54, Table 4a). However, this covariate was less than half as effective at explaining the residuals of the spawner-only model as Spawning.Summer.30Day.Min.st ($r^2_{spawner}$ = 0.11 and 0.27, respectively). The September.Daily.Min.st covariate accounts for the negative residual for 2015 by the higher than average discharge during September. This is because the residuals are negatively correlated with minimum September discharge.

For Spius, the spawner-only model explained approximately one third of the variation in productivity (r^2 = 0.35, Table 4a). The September.Daily.Min.st model explained the largest amount of productivity (r^2 = 0.61). This covariate also explained the largest amount variance in the residuals from the spawner-only model and, along with Inv.TMax.30Day.norm, were the only informative covariates in this comparison group ($r^2_{spawner}$ = 0.31 and 0.20, respectively). These models correctly predicted the direction of the residuals for several years with large residuals but accounted for only a portion of the magnitude of the difference between observed and expected abundance (Appendix 3, RunID 37 and 46).

3.2.2 Steelhead Fry

Across the three comparison groups (Nicola Aggregate, Spius and Deadman) there was similar support for all covariate models (ΔAIC_c differing by less than 4, Table 4b). Evaluating model fit based on log likelihood (LL), within each comparison group these values differed only at the first or second decimal place indicating similar support for all models. Only when comparing r^2 and $r^2_{spawner}$ values was there a clear difference in the relative contribution of each covariate for explaining observed productivity. The model with the highest r^2 differed for each comparison group as did the relative contribution of spawner abundance versus each covariate for explaining the variance in productivity.

For the Nicola Aggregate, the spawner-only model explained over one-third of the variance in productivity while the July.Daily.Min.st model accounted for substantially more than any other ($r^2 = 0.69$, Table 4b). This was also the only covariate to explain a substantial amount of the variation of residuals from the spawner-only model ($r^2_{spawner} = 0.46$) and was positively correlated with residuals, i.e. increased fish abundance at higher discharge (Appendix 2e).

For Spius, the spawner-only model accounted for the majority of variance in productivity ($r^2 = 0.74$) with only a slight improvement when including the top performing covariates Summer.30.Day.min.Doyle and Summer.30.Day.min.s ($r^2 = 0.89$, Table 4b). These covariates as well as Summer.Days.10%MAD also explained the most variance of the residuals from the spawner-only model ($r^2_{spawner} = 0.46$ and 0.47). The correlations of all three covariates predict higher abundance at lower discharge (Appendix 2f).

For the Deadman, the spawner-only model explained almost none of the variance in productivity ($r^2 = 0.02$, Table 4b). The Invers.TMax.30Day.norm had the highest r^2 value ($r^2 = 0.46$). This was also the only covariate to account for a moderate amount of the variance in the spawner-only model residuals ($r^2_{spawner} = 0.34$) and was positively correlated, Appendix 2f). Since the values in this index increase as temperature decreases, a positive correlation reflects a higher abundance at lower temperatures. All other models were relatively ineffective at explaining the variance in productivity ($r^2 = 0.03 – 0.20$, Table 4b).

3.2.3 Steelhead Age 1+ parr

For Steelhead age 1+ parr, there was similar support for all models based on log likelihood (LL), which varied by less than 1 for each comparison group except for the Bonaparte where the Summer.30Day.Min.Doyle model had a uniquely low value (Table 4c). Similar to Steelhead and Chinook fry, the small sample size penalty for adding a covariate to the spawner-only model was far greater than the improvement it provided to model support. In terms of r^2 values, the Invers.TMax.30Day.norm model had the highest r^2 values for two of the four comparison groups (Nicola aggregate $r^2 = 0.34$, Deadman $r^2 = 0.57$) but for only the Deadman was it substantially different from the majority of other models.

For the Nicola Aggregate, the spawner-only model accounted for close to one-third of the variation in productivity ($r^2 = 0.30$, Table 4c). Improvements were minimal from including any covariates in the model ($r^2 = 0.30 – 0.34$) and none of them explained a meaningful amount of the variation in the residuals of the spawner-only model ($r^2_{spawner} = 0.00 – 0.06$). Productivity for the 2015 parr cohort was particularly low (Appendix 5, Run75). To evaluate the significance of 2015 on effectiveness of covariates, we compared models while excluding this data point. Without 2015, amount of the variance in productivity explained for the spawner-only model increased from $r^2 = 0.30$ to $r^2 = 0.52$. Most other covariate models did not substantially improve on this and accounted for very little of the variance in residuals of the spawner-only model (Appendix 7a). The Winter.Daily.Max.st was the exception to this, which was positively correlated with productivity and accounted for a large amount of the variance in productivity ($r^2 = 0.85$, Figure 4a).

For Spius, the spawner-only model accounted for a relatively small portion of the variance in productivity ($r^2 = 0.13$, Table 4c). The September.Daily.Min.st model accounted for over half of the variance in productivity ($r^2 = 0.59$), which was close to double the amount of the next closest model. It was also the only covariate to explain a substantial portion of the variance in residuals of the spawner-only model ($r^2_{spawner} = 0.47$) and was negatively correlated (Appendix 2i). As with the Nicola Aggregate, omitting 2015 increased the amount of variance in productivity explained by the spawner-only model, increasing r^2 from 0.13 to 0.43. With 2015 excluded, all covariates related to summer discharge explained a large amount of the variance in the residuals of the spawner-only model ($r^2_{spawner} = 0.66 – 0.85$, Appendix 7b) and model Summer.Days.below.10MAD accounted for almost all of the variance in productivity ($r^2 = 0.95$, Figure 5b). All summer flow related covariates were negatively related to productivity such that abundance decreased with discharge (Appendix 7b).

The spawner-only model explained only a small amount of the variance in productivity for the Bonaparte ($r^2_{spawner} = 0.19$). Summer.30Day.Min.st and Summer.30Day.Min.Doyle models explained the greatest amount of variance in productivity ($r^2 = 0.50$ and 0.57, respectively). Both were positively correlated with the residuals from the spawner-only model ($r^2_{spawner}$ = 0.50 and 0.57, respectively, Appendix 2j).

For the Deadman, model fit, in terms of log likelihood, was again similar for all models (Table 4c). The Spawner only model accounted for a minor amount of the variance in productivity (r^2 = 0.09) with only slightly higher explanatory ability with the best performing covariate model, Invers.TMax.30Day.norm (r^2 = 0.24). This covariate was the only one to explain any of the variance of the residuals from the spawner-only model ($r^2_{spawner}$ = 0.24), which was positively correlated (Appendix 2k)

3.3 Support for Drought Effects

Based on the model support within each comparison group, there is no support that any of the indices tested provided meaningful improvements to the stock-recruitment models for Chinook fry, Steelhead fry or Steelhead age 1+ parr. For all species / age-classes and comparison areas, model fit (LL) and model support (AIC_c) values did not vary enough to support one model over any other. Both the low variation in LL and AIC_c values and large penalty assigned for the additional parameter of the covariate models are largely a product of the low sample size. The largest sample size was for the Steelhead parr-Nicola Aggregate comparison group (n = 11) to and lowest for the Steelhead fry-Deadman comparison group (n = 7).

Based on our second analytical approach where we focused on the effectiveness of environmental covariates for explaining only the residuals of spawner-only stock-recruitment models and the direction of these relationships, correlation coefficients ($r^2_{spawner}$) only provided very weak support for the hypothesis that drought negatively impacts juvenile production in terms of the strength or consistence of indices across species / age-classes or stream areas. For the Nicola, Spius or Coldwater, there was only one comparison group where a summer drought index had the highest $r^2_{spawner}$ value and predicted lower than expected abundance under drought conditions (Steelhead fry – July.Daily.Min.st, $r^2_{spawner}$ = 0.46, Table 4b). The most consistent support for any covariate was for September.Daily.Min.st, which explained the most variance in productivity for every Chinook fry comparison group and for Steelhead parr using the Spius comparison group. However, this covariate predicts increased productivity with decreasing discharge, contrary to the drought hypothesis of improved productivity with increasing discharge. So while it is the most supported covariate of those examined, it does not support the summer drought hypothesis. The only other indication of consistent support for the drought hypothesis was for Steelhead fry and parr in the Deadman. Here, the index representing maximum daily summer air temperature (Invers.TMax.30Day.norm) were the only to produce more than minimal $r^2_{spawner}$ values, however this index was a very poor predictor for all other comparison groups.

Support for drought effects was weakened in part by the large variance in abundance particularly at the most acute drought levels (low flow or high temperature) for all species/age-groups and streams. Examples of this were Chinook fry in the Coldwater and Steelhead parr in Spius, the lowest and highest stock-recruitment residuals were during years with similarly low summer flows (Summer.30Day.Min.st, Appendix 2b and 2i). For Chinook fry, where there were more low abundance years, drought severity varied widely for years where abundance was much lower than predicted by stock-recruitment models. Again using the Coldwater as an example, residuals were lowest for years with relatively low and high minimum summer flow (Summer.30Day.Min.st, Appendix 2b). For Steelhead parr in the Nicola Aggregate and Spius where 2015 abundance was far less than predicted by brood abundance, its large negative residual was typically an outlier to trends based on all other years (Appendix 2h-k).

4.0 Discussion

4.1 Effectiveness of Study Approach

Our decision to use stock-recruitment models with an environmental covariate as the basis to make inferences about the role of drought on juvenile production was based on 1) the importance of spawner brood stock on juvenile abundance and 2) that the reliance on once-annual juvenile abundance estimates necessitate considering the importance of summer and winter condition abundance. However, this repurposing of data collected for a different purpose required an analytic approach with several weaknesses. Hilborn and Walters (1992) describe two dangers of adding environmental variables to stock-recruitment models. First, that it is almost impossible to confirm that a correlation is not spurious, particularly when lacking a well supported a priori hypothesis. This is especially problematic when seeking a variable to explain a small number of outliers since the strength of the correlation can depend on very few data points. A consequence of this is that correlations are rarely replicated when tested against new time series (Myers 1998). The second danger is overfitting parameters to the model: model fit generally improves as more parameters are added. Methods employed for this study address these concerns to varying degrees.

4.1.1 Spurious Correlations

Our strategy to reduce the possibility of spurious correlations was to restrict covariates to those related to one of the four primary hypotheses, or to one of the sub-hypotheses for summer drought. However, given the lack of prior studies conducted over comparable spatial scales, there was little evidence to choose among the several indices of summer drought. This included two different metrics of minimum summer discharge in addition to minimum discharge by month from July to September. In this aspect, this study would be considered exploratory according to the criteria outlined in Myers (1998) and increases the possibility of spurious correlations. In this situation Myers proposed any correlations of interest be tested with a different time series. We were somewhat able to do this comparing across species and streams but this approach has the weakness that a lack of consistency could also be explained by a lack of comparability between streams as much as to the weakness of the covariate. Furthermore, correlations that do persist over time or space do not provide any evidence about the causality of a relationship.

4.1.2 Overfitting

It was evident from the outset that the limited number of years in the stock-recruitment time series that adding any more than one covariate would lead to overfitting. Using AIC for small sample size safeguards against ignoring overfitting by adding a penalty for every additional parameter in the model. The size of the penalty increases as sample size decreases. For this study, where the maximum sample size was 12, the penalty for the additional covariate parameter was far larger than any improvement in model fit. This meant that the spawner-only model was always the most supported over any of the covariate models even though all models had similar fit. A similar analysis using a 24-year time series was able to compare models with up to two covariates without the small sample size penalty overly influencing model support values (Neuswanger et al. 2015). Correlation coefficients do not incorporate a penalty for additional parameters. However, they are useful for comparing the effectiveness of models with different datasets that have the same number of parameters and similar sample size, or of the relative improvement of adding one parameter versus others to a model.

4.1.3 Persistence of Findings

Both model fit and correlations between covariates and stock-recruitment residuals are likely to change with additional years in the time series. With reduced uncertainty from a longer time series, model support would become more informative for making inferences about the role of drought on abundance. Correlations between covariates and stock-recruitment residuals should be expected to change both in terms of the direction and magnitude as the influence of single data points diminishes. This was particularly evident when comparing the strength of Steelhead parr correlations with and without including the 2015 year-class. In this case, eliminating 2015 in the Spius time series increased the r^2 from 0.10 to 0.95. A larger data set would reduce the overall uncertainty added by this data point.

Another consideration for persistence of findings is whether observer efficiency during snorkelling could change across the range of flows that were sampled. The question of whether relative discharge affects observer efficiency was not thoroughly examined for the studies that provided the data used here (Hagen et al. 2010) or for other studies relying on similar snorkel survey methods. Results from mark-recapture experiments used to estimates snorkelers' observer efficiency provide only weak inferences due to small sample size and low variability of discharge within each river. For Chinook fry and Steelhead parr 100-140mm forklength, which encompasses the majority of age-1+ parr, correlations between relative discharge and observer efficiency were either weak or non-informative at the river level (Appendix 10) or when pooled by river width-class[2] (Appendix 11). Discharge did explain a moderate amount of the variance in observer efficiency in the case of Chinook fry in the Coldwater (negative, $R^2 = 0.31$) and Steelhead parr in the Thompson (positive, $R^2 = 0.50$), however these values had high uncertainty due to the low number of marked and recaptured fish related to each data point. It is also questionable how applicable estimates of observer efficiency were to the complete range of flows during snorkel surveys. By river, discharge conditions during mark-recapture experiments were representative of only a narrow range of flows during surveys (Appendix 12). Only when observer efficiency was pooled by river width-class did conditions during mark-recapture experiments span the majority of relative discharge levels during surveys. However, grouping

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[2] River width-class was an informative predictor of observer efficiency (Hagen et al. 2010) with wide rivers (Thompson and Nicola) having a lower observer efficiency than narrow rivers (all others).

rivers by width hinges on the assumption that discharge / observer efficiency relationships were similar within each stream-width category, which the present data cannot confirm. Learning more about this relationship requires additional mark-recapture experiments across a more complete range of survey discharge levels for individual rivers. Efforts to maintain similar observer efficiency across years were primarily through 1) meeting minimum underwater visibility criteria (≥3m, Hagen et al. 2010); 2) conducting surveys largely during the same month, for consistency of water temperature and seasonal habitat use; and 3) limiting surveys to a 4-hour period starting 30-minutes after dusk when Steelhead parr concealment is lowest (Bradford and Higgins 2001).

4.2 Relationship between Indices and Hypotheses

Indices of minimum summer discharge represent the discharge component of drought severity at the river level moderately well for all but at extreme low discharge. At very low discharge, the accuracy and precision of discharge measurements are unclear but considered lower than throughout the majority of the discharge range. Aside from potential measurement error, minimum summer discharge is likely a too general indicator of drought severity. The negative relationship between September discharge and Chinook fry abundance suggests that low flows during late summer are not indicative of low abundance. Furthermore, residuals for spawner-only stock recruit models varied widely for relatively low discharge years based on July and August or summer wide time intervals indicates that discharge alone is a poor predictor of lower than expected abundance.

The hypothesis that high temperatures during drought events negatively impacts juvenile salmonids is poorly represented by the temperature index used, which was air temperature measure at the Merritt Environment Canada weather station. Water temperature measured at each WSC gauge station would have been preferable but was unavailable at sufficient locations or was incomplete for all years in the stock-recruitment time series. While air temperature may be effective to distinguish general temperature trends between years at the watershed level, it is unable to incorporate water temperature changes in relation to air temperature, day length and discharge. Incorporating these relationships into a water temperature model would have been preferable but was beyond the scope of this study and may not have improved model fit. For example, even with much larger time series, the penalty to AIC_c values from the additional parameters from such models outweighed the benefits compared to using air temperature for a similar analysis of Chinook salmon for two Alaska watersheds (Neuswanger et al. 2015). Our variable that combined the index of maximum daily temperature and minimum discharge during summer – low values represented high temperatures and low discharge – poorly approximates water temperature since the two measures can occur at different times during the summer. Maximum air temperatures tend to occur mid-July to mid-august whereas minimum discharge for the Nicola, Spius and Coldwater occurs mid-August to mid-September.

The index of winter discharge only reflects one component of the hypothesis that low metabolic rates and the mobilization of the riverbed substrate and or ice scour during winter flood events leads to increased mortality of juvenile steelhead and destruction of Chinook redds. This hypothesis would be better represented by separating discharge from ice considering increased mortality of juvenile Atlantic Salmon during winter was only associated with the occurrence of ice break-up and without this, survival increased with winter discharge (Cunjak et al. 1998). While high discharge is one of several components necessary for an ice scour event, it also depends on several factors related to ice formation (Prowse et al. 1990) which are not represented in the index used in the model.

4.3 Alternative Indices and Monitoring

There are several reasons that a direct measure of water temperature or one based on a separate model would be a more effective measure of drought severity than those examined in this study. Juvenile salmonids’ response to above optimal temperature in terms of behaviour and habitat use is well described using both lab and field experiments (reviewed in USEPA 2001). Movement from riffle or run habitat to pools (thermal refuge) as mainstem temperatures approach or exceed listed lethal temperatures has been reported for individual fish using radio telemetry at temperatures between 22 – 25ºC (Brewitt and Danner 2014). As well, fish presence was maintained in pools at a constant rate between 22-31 ºC but rapidly dropped to complete absence by 33.4 ºC (Sloat and Osterback 2012). Both indicate a reduction in the availability of thermally suitable habitat.

Air temperature is likely a poor surrogate for water temperature (see section 4.2) and does not represent one of the main distinctions of discharge during 2015: the early end of freshet and short duration until reaching base summer flow (Figure 2). This increased the period of low discharge that coincides with maximum summer temperatures which could have resulted in higher stream temperatures than for years with similar or lower discharge but that occurred later in the summer when average daily temperatures are lower.

Monitoring water temperature would also allow for the evaluation conservation thresholds used in other jurisdictions. The US Environmental Protection Agency developed recommended temperature thresholds by species, life-stage and habitat importance as well as standardized approach to temperature averaging: Maximum 7 Day Average of the Daily Maximums (USEPA 2003). Incorporating this metric into future examinations of juvenile survival in response to drought would also be useful for evaluating of their conservation thresholds (16ºC core juvenile rearing, 18ºC non-core juvenile rearing) as an alternative or addition to the current discharge based mechanism for initiating conservation actions.

5.0 Conclusion

These results do not provide support for the drought hypothesis measured by intensity (temperature or discharge) or duration. This is primarily due to the low power to detect differences in model support as a result of insufficient sample size and low explanatory ability of environmental covariates. The effectiveness of covariates should be examined primarily by way of model fit (AIC_c values) and not by way of the strength of correlations (r^2 values) since the former better incorporates uncertainty and penalizes for additional parameters whereas the latter does not. On this basis, there is no more support for indices related to summer drought than any other, including the spawner-only model. There is also no support to exclude summer drought as a factor at this time.

We should view correlations sceptically and likely to change with additional data. This relates to outcomes consistent with our hypotheses as well as unexpected results. The strength of correlations was often dependant on which of a small number of outliers was better explained by one covariate than another.

This study design was used with the hope of gaining insights from the only long-term time series of juvenile Steelhead and Chinook abundance for the Nicola watershed. One of the most apparent findings is that a much larger time series is required to make meaningful inferences about the association between juvenile abundance and environmental covariates. Alternative study designs that focus on directly measuring survival, movement and other measures of fish health during summer low flow period should be actively developed. Such studies have the potential to improve our understand of drought impacts in a far shorter time than the 10 or more years necessary to accumulate sufficient years for a robust analysis using this method.

6.0 Recommendations

6.1 Conduct a thorough literature review of the effects of drought conditions on salmonids including ongoing studies. Establish a working group comprised of experts in this field. This is the most effective way to improve decision making around improving triggers for conservation measures in the near term (1-3 years).

6.2 Test drought hypotheses with dedicated studies. Studies designed to evaluate the impact of drought on survival, immigration, emigration and growth during the summer drought period would accelerate learning compared with the current stock-recruitment based approach relying on once-a-year fall standing stock-estimates for juvenile abundance. This would provide information for decision making in the medium to long term (5-10 years).

6.3 Continue to use the stock-assessment focused sampling programs for monitoring at the river and watershed level. New studies focused on measuring over summer survival would likely focus on small areas within the Nicola watershed. Continuing this monitoring would allow linkages between drought effects at the reach level and watershed level abundance. Monitoring would include both parr and fry sampling in all habitat types. Including low summer discharge as criteria for initiating fall juvenile surveys would reduce the uncertainty of the response at the watershed level to low flow conditions.

6.4 Initiate water temperature monitoring at the reach level to better understand the frequency and duration of periods that exceed optimal or approach lethal temperatures and how they differ throughout the Nicola basin. A robust temperature monitoring program would also allow water temperature to be better used for triggering conservation actions. The advantage of this is the deleterious impacts of high temperature are better documented than the effects of low discharge allowing for improved justification for management decisions given the uncertainty about the significance of discharge on abundance in the Nicola watershed.

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Tables

Table 1. Juvenile and adult survey areas relating to each stock-recruitment area for Steelhead and Chinook.

Species	Stock-recruitment areas	Juvenile survey area	Adult survey area
Steelhead	Nicola Aggregate	Nicola to Merritt, Spius, Coldwater, Thompson below Spences Bridge	Nicola to Nicola Lake, Spius, Maka, Guichon, Coldwater
Steelhead	Spius	Spius	Spius, Maka
Steelhead	Bonaparte	Bonaparte	Bonaparte
Steelhead	Deadman	Deadman, Criss	Deadman, Criss
Chinook	Nicola Aggregate	Nicola to Merritt, Spius, Coldwater	Nicola to Nicola Lake, Spius, Maka, Guichon, Coldwater
Chinook	Spius	Spius	Spius, Maka
Chinook	Coldwater	Coldwater	Coldwater

Table 2. Summary of the Water Survey of Canada stations used to generate indices.

Station Name	Station Number	Period of Record	Years with missing data between 2000 & 2015
Nicola River near Spences Br.	08LG006	1911-2015	
Coldwater River near Brookmere	08LG048	1965-2015	
Spius Creek near Canford	08LG008	1911-2015	2008 - 2011
Deadman River above Criss Cr.	08LF027	1913-2015	2002
Bonaparte River below Cache Cr.	08LF002	1911-2015	

Table 3. Covariates included for each stock-recruitment model by species / age-class, environmental attribute represented in the covariate and life-stage it relates to.

Species / Age-class	Covariate	Index category	Life-stage
Chinook fry	Invers.TMax.30Day.norm	summer temperature	summer fry rearing
	Summer.30Day.Min.st	summer discharge	summer fry rearing
	Summer.30Day.Min.Doyle	summer discharge	summer fry rearing
	minflow.plus.tempmax.30day	discharge + temperature	summer fry rearing
	Winter.Daily.Max.st	winter discharge	egg incubation
	Summer.Days.below.10MAD	summer discharge	summer fry rearing
	Summer.Days.below.15MAD	summer discharge	summer fry rearing
	July.Daily.Min.st	summer discharge	summer fry rearing
	August.Daily.Min.st	summer discharge	summer fry rearing
	September.Daily.Min.st	summer discharge	summer fry rearing
	Spawning.Summer.30Day.Min.st	summer discharge	spawning
Steelhead fry	Invers.TMax.30Day.norm	summer temperature	summer fry rearing
	Summer.30Day.Min.st	summer discharge	summer fry rearing
	Summer.30Day.Min.Doyle	summer discharge	summer fry rearing
	minflow.plus.tempmax.30day	discharge + temperature	summer fry rearing
	Summer.Days.below.10MAD	summer discharge	summer fry rearing
	Summer.Days.below.15MAD	summer discharge	summer fry rearing
	July.Daily.Min.st	summer discharge	summer fry rearing
	August.Daily.Min.st	summer discharge	summer fry rearing
	September.Daily.Min.st	summer discharge	summer fry rearing
Steelhead age 1+ parr	Invers.TMax.30Day.norm	summer temperature	summer parr rearing
	Summer.30Day.Min.st	summer discharge	summer parr rearing
	Summer.30Day.Min.Doyle	summer discharge	summer parr rearing
	minflow.plus.tempmax.30day	discharge + temperature	summer parr rearing
	Winter.Daily.Max.st	winter discharge	winter fry rearing
	Summer.Days.below.10MAD	summer discharge	summer parr rearing
	Summer.Days.below.15MAD	summer discharge	summer parr rearing
	July.Daily.Min.st	summer discharge	summer parr rearing
	August.Daily.Min.st	summer discharge	summer parr rearing
	September.Daily.Min.st	summer discharge	summer parr rearing

Table 4a-c. Model performance by study area of the spawner-only and spawner-plus-covariate stock-recruitment models evaluated using log likelihood (LL), Akaike information criterion (AIC_c), linear regression of log predicted x log observed (r^2) and the distance from the lowest AIC_c value (ΔAIC). K is the number of model parameters and cf is the penalty for the number of parameters at each sample size (n). $R^2_{spawner}$ reflects the amount an environmental covariate explained the residuals of the spawner-only model. Shaded area represents the covariate with the highest r^2 and $r^2_{spawner}$ values and lowest ΔAIC value.

Table 4a - Chinook fry

Area / River	RunID	LL	K	cf	AICc	r^2	ΔAIC	$r^2_{spawner}$	Covariate
Nicola Aggregate	1	-10.58	2	1.50	26.66	0.66	0.00	-	NA
n = 11	2	-10.50	3	3.43	30.43	0.71	3.78	0.12	Invers.TMax.30Day.norm
	3	-10.54	3	3.43	30.51	0.69	3.86	0.04	Summer.30Day.Min.st
	4	-10.49	3	3.43	30.41	0.73	3.76	0.10	Summer.30Day.Min.Doyle
	5	-10.57	3	3.43	30.57	0.66	3.92	0.01	minflow.plus.tempmax.30day
	6	-10.58	3	3.43	30.58	0.66	3.93	0.00	Winter.Daily.Max.st
	7	-10.45	3	3.43	30.33	0.75	3.67	0.17	Summer.Days.below.15MAD
	8	-10.57	3	3.43	30.57	0.66	3.91	0.01	July.Daily.Min.st
	9	-10.58	3	3.43	30.58	0.66	3.93	0.00	August.Daily.Min.st
	10	-10.45	3	3.43	30.32	0.77	3.67	0.20	September.Daily.Min.st
	11	-10.58	3	3.43	30.58	0.66	3.92	0.00	Spawning.Summer.30Day.Min.st
Coldwater	12	-12.31	2	1.50	30.12	0.01	0.00	-	NA
n = 11	13	-12.00	3	3.43	33.43	0.09	3.31	0.13	Invers.TMax.30Day.norm
	14	-12.19	3	3.43	33.80	0.06	3.68	0.05	Summer.30Day.Min.st
	15	-12.14	3	3.43	33.71	0.07	3.59	0.06	Summer.30Day.Min.Doyle
	16	-12.31	3	3.43	34.05	0.01	3.93	0.00	minflow.plus.tempmax.30day
	17	-12.16	3	3.43	33.75	0.02	3.63	0.06	Winter.Daily.Max.st
	18	-12.21	3	3.43	33.85	0.05	3.73	0.03	Summer.Days.below.10MAD
	19	-12.28	3	3.43	33.99	0.02	3.87	0.01	Summer.Days.below.15MAD
	20	-12.30	3	3.43	34.02	0.01	3.90	0.01	July.Daily.Min.st
	21	-12.30	3	3.43	34.04	0.02	3.92	0.00	August.Daily.Min.st
	22	-11.64	3	3.43	32.71	0.24	2.59	0.29	September.Daily.Min.st
	23	-12.25	3	3.43	33.93	0.03	3.81	0.02	Spawning.Summer.30Day.Min.st
CW2	24	-11.94	2	1.50	29.38	0.41	0.00	-	NA
n = 11	25	-11.93	3	3.43	33.29	0.42	3.91	0.00	Invers.TMax.30Day.norm
	26	-11.81	3	3.43	33.06	0.49	3.67	0.05	Summer.30Day.Min.st
	27	-11.73	3	3.43	32.88	0.52	3.50	0.10	Summer.30Day.Min.Doyle
	28	-11.88	3	3.43	33.19	0.44	3.81	0.02	minflow.plus.tempmax.30day
	29	-11.92	3	3.43	33.26	0.43	3.88	0.01	Winter.Daily.Max.st
	30	-11.76	3	3.43	32.96	0.50	3.58	0.07	Summer.Days.below.10MAD
	31	-11.78	3	3.43	33.00	0.49	3.62	0.05	Summer.Days.below.15MAD
	32	-11.53	3	3.43	32.48	0.50	3.10	0.18	July.Daily.Min.st
	33	-11.50	3	3.43	32.44	0.53	3.06	0.15	August.Daily.Min.st
	34	-11.74	3	3.43	32.90	0.54	3.52	0.11	September.Daily.Min.st
	35	-11.39	3	3.43	32.21	0.50	2.83	0.27	Spawning.Summer.30Day.Min.st

Table 4a cont'd - Chinook fry

Area / River	RunID	LL	K	cf	AICc	r^2	ΔAIC	$r^2_{spawner}$	Covariate
Spius	36	-8.65	2	2.40	23.70	0.35	0.00	-	NA
n = 8	37	-8.36	3	6.00	28.72	0.48	5.03	0.20	Invers.TMax.30Day.norm
	38	-8.59	3	6.00	29.18	0.41	5.48	0.03	Summer.30Day.Min.st
	39	-8.54	3	6.00	29.09	0.44	5.39	0.07	Summer.30Day.Min.Doyle
	40	-8.62	3	6.00	29.25	0.35	5.55	0.01	minflow.plus.tempmax.30day
	41	-8.64	3	6.00	29.27	0.36	5.58	0.00	Winter.Daily.Max.st
	42	-8.65	3	6.00	29.29	0.36	5.60	0.00	Summer.Days.below.10MAD
	43	-8.65	3	6.00	29.30	0.35	5.60	0.00	Summer.Days.below.15MAD
	44	-8.61	3	6.00	29.22	0.34	5.53	0.02	July.Daily.Min.st
	45	-8.65	3	6.00	29.29	0.35	5.60	0.00	August.Daily.Min.st
	46	-8.19	3	6.00	28.39	0.61	4.69	0.31	September.Daily.Min.st
	47	-8.53	3	6.00	29.05	0.38	5.36	0.08	Spawning.Summer.30Day.Min.st

Table 4b - Steelhead fry

Area / River	RunID	LL	K	cf	AICc	r^2	ΔAIC	$r^2_{spawner}$	Covariate
Nicola Aggregate	48	-8.39	2	2.00	22.77	0.36	0.00	-	NA
n = 9	49	-8.37	3	4.80	27.54	0.44	4.77	0.15	Invers.TMax.30Day.norm
	50	-8.38	3	4.80	27.56	0.39	4.79	0.03	Summer.30Day.Min.st
	51	-8.38	3	4.80	27.56	0.38	4.79	0.04	Summer.30Day.Min.Doyle
	52	-8.37	3	4.80	27.55	0.42	4.78	0.10	minflow.plus.tempmax.30day
	53	-8.38	3	4.80	27.57	0.37	4.80	0.07	Summer.Days.below.15MAD
	54	-8.33	3	4.80	27.45	0.69	4.68	0.16	July.Daily.Min.st
	55	-8.37	3	4.80	27.55	0.42	4.78	0.11	August.Daily.Min.st
	56	-8.38	3	4.80	27.57	0.36	4.80	0.02	September.Daily.Min.st
Spius	57	-6.49	2	3.00	19.98	0.74	0.00	-	NA
n = 7	58	-6.49	3	8.00	26.98	0.74	7.00	0.00	Invers.TMax.30Day.norm
	59	-6.46	3	8.00	26.92	0.89	6.94	0.46	Summer.30Day.Min.st
	60	-6.46	3	8.00	26.91	0.89	6.93	0.47	Summer.30Day.Min.Doyle
	61	-6.47	3	8.00	26.94	0.82	6.96	0.31	minflow.plus.tempmax.30day
	62	-6.46	3	8.00	26.92	0.87	6.94	0.45	Summer.Days.below.10MAD
	63	-6.47	3	8.00	26.94	0.83	6.96	0.28	Summer.Days.below.15MAD
	64	-6.47	3	8.00	26.94	0.83	6.96	0.31	July.Daily.Min.st
	65	-6.47	3	8.00	26.94	0.83	6.96	0.30	August.Daily.Min.st
	66	-6.47	3	8.00	26.93	0.84	6.95	0.30	September.Daily.Min.st
Deadman	67	-7.72	2	2.40	21.83	0.02	0.00	-	NA
n = 8	68	-7.55	3	6.00	27.09	0.48	5.26	0.34	Invers.TMax.30Day.norm
	69	-7.71	3	6.00	27.42	0.03	5.59	0.01	Summer.30Day.Min.st
	70	-7.71	3	6.00	27.41	0.04	5.58	0.02	Summer.30Day.Min.Doyle
	71	-7.65	3	6.00	27.30	0.20	5.47	0.11	minflow.plus.tempmax.30day
	72	-7.71	3	6.00	27.42	0.03	5.59	0.01	July.Daily.Min.st
	73	-7.71	3	6.00	27.41	0.04	5.58	0.02	August.Daily.Min.st
	74	-7.70	3	6.00	27.40	0.06	5.56	0.04	September.Daily.Min.st

Table 4c - Steelhead 1+ parr

Area / River	RunID	LL	K	cf	AICc	r^2	ΔAIC	$r^2_{spawner}$	Covariate
Nicola Aggregate	75	-10.31	2	1.50	26.13	0.30	0.00	-	NA
n = 11	76	-10.30	3	3.43	30.03	0.34	3.90	0.06	Invers.TMax.30Day.norm
	77	-10.31	3	3.43	30.06	0.30	3.93	0.00	Summer.30Day.Min.st
	78	-10.31	3	3.43	30.05	0.30	3.93	0.00	Summer.30Day.Min.Doyle
	79	-10.31	3	3.43	30.04	0.32	3.92	0.03	minflow.plus.tempmax.30day
	80	-10.31	3	3.43	30.04	0.32	3.92	0.03	Winter.Daily.Max.st
	81	-10.31	3	3.43	30.05	0.31	3.92	0.02	Summer.Days.below.15MAD
	82	-10.31	3	3.43	30.04	0.32	3.91	0.02	July.Daily.Min.st
	83	-10.31	3	3.43	30.06	0.30	3.93	0.00	August.Daily.Min.st
	84	-10.30	3	3.43	30.03	0.33	3.91	0.04	September.Daily.Min.st
Spius	85	-7.70	2	2.40	21.79	0.13	0.00	-	NA
n = 8	86	-7.70	3	6.00	27.39	0.14	5.60	0.00	Invers.TMax.30Day.norm
	87	-8.11	3	6.00	28.23	0.25	6.44	0.06	Summer.30Day.Min.st
	88	-7.62	3	6.00	27.25	0.31	5.46	0.18	Summer.30Day.Min.Doyle
	89	-7.66	3	6.00	27.33	0.22	5.53	0.07	minflow.plus.tempmax.30day
	90	-7.69	3	6.00	27.37	0.16	5.58	0.02	Winter.Daily.Max.st
	91	-8.30	3	6.00	28.60	0.10	6.81	0.06	Summer.Days.below.10MAD
	92	-7.68	3	6.00	27.36	0.17	5.57	0.04	Summer.Days.below.15MAD
	93	-7.67	3	6.00	27.35	0.19	5.55	0.05	July.Daily.Min.st
	94	-8.22	3	6.00	28.44	0.22	6.65	0.12	August.Daily.Min.st
	95	-7.52	3	6.00	27.03	0.59	5.24	0.47	September.Daily.Min.st
Bonaparte	96	-8.89	2	2.00	23.78	0.19	0.00	-	NA
n = 9	97	-8.80	3	4.80	28.41	0.14	4.63	0.14	Invers.TMax.30Day.norm
	98	-8.58	3	4.80	27.96	0.50	4.18	0.50	Summer.30Day.Min.st
	99	-12.83	3	4.80	36.46	0.57	12.68	0.57	Summer.30Day.Min.Doyle
	100	-8.67	3	4.80	28.13	0.36	4.36	0.36	minflow.plus.tempmax.30day
	101	-8.89	3	4.80	28.58	0.00	4.80	0.00	Winter.Daily.Max.st
	104	-8.86	3	4.80	28.52	0.05	4.74	0.05	July.Daily.Min.st
	105	-8.67	3	4.80	28.13	0.36	4.36	0.36	August.Daily.Min.st
	106	-8.87	3	4.80	28.54	0.03	4.76	0.03	September.Daily.Min.st
Deadman	107	-8.58	2.00	2.00	23.16	0.09	0.00	-	NA
n = 9	108	-8.51	3.00	4.80	27.81	0.24	4.65	0.24	Invers.TMax.30Day.norm
	109	-8.58	3.00	4.80	27.96	0.00	4.80	0.00	Summer.30Day.Min.st
	110	-8.58	3.00	4.80	27.96	0.00	4.80	0.00	Summer.30Day.Min.Doyle
	111	-8.55	3.00	4.80	27.90	0.10	4.74	0.01	minflow.plus.tempmax.30day
	112	-8.58	3.00	4.80	27.96	0.01	4.79	0.01	Winter.Daily.Max.st
	115	-8.58	3.00	4.80	27.95	0.01	4.79	0.01	July.Daily.Min.st
	116	-8.58	3.00	4.80	27.96	0.00	4.80	0.00	August.Daily.Min.st
	117	-8.58	3.00	4.80	27.95	0.01	4.79	0.01	September.Daily.Min.st

Figures

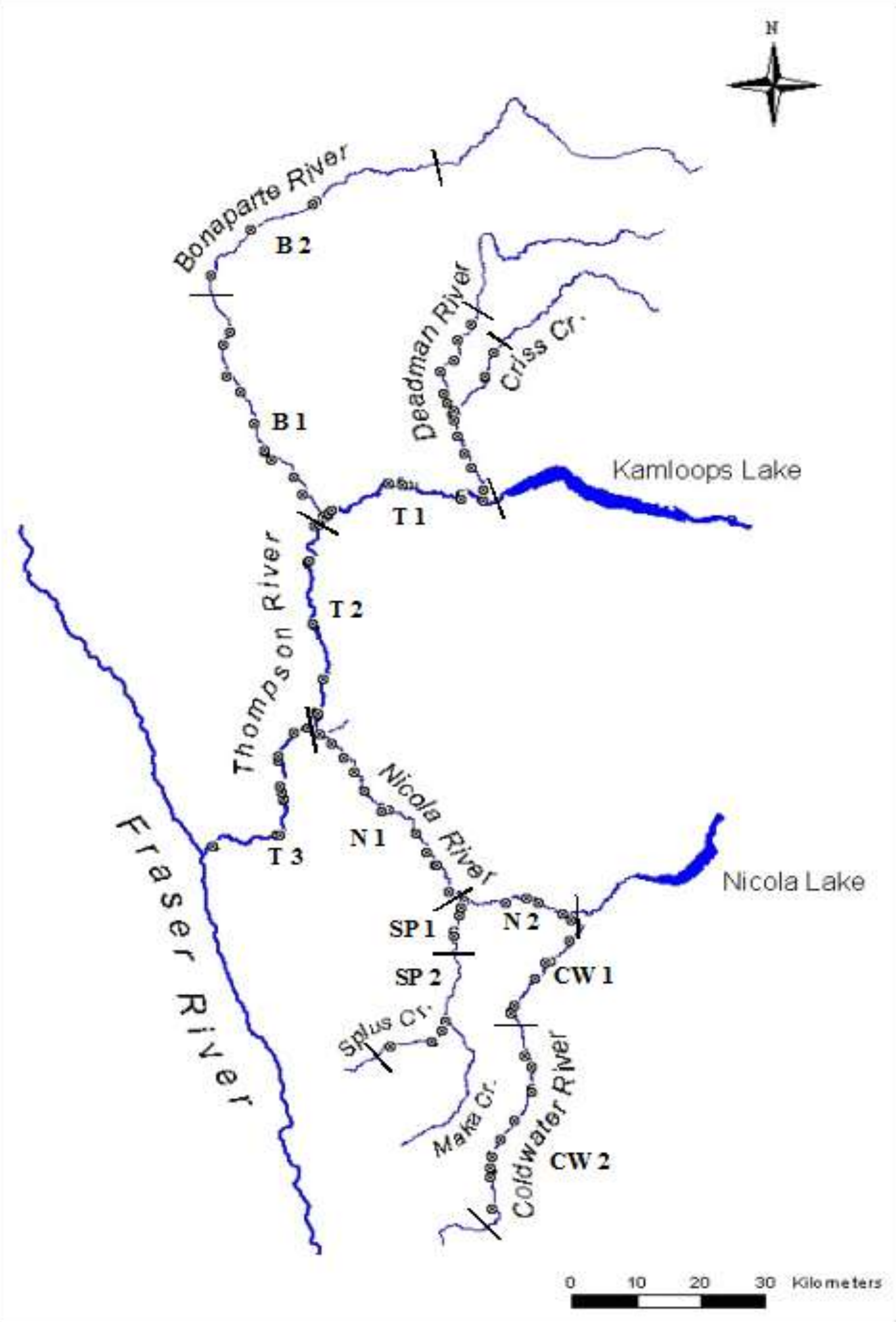


Figure 1. Map of the lower Thompson River basin showing all mainstem and tributary reaches included in the study area. Reach names are given for streams with more than one reach. Reach breaks are indicated by solid slashes and juvenile sampling sites are indicated by dotted circles (Decker et al. 2015)

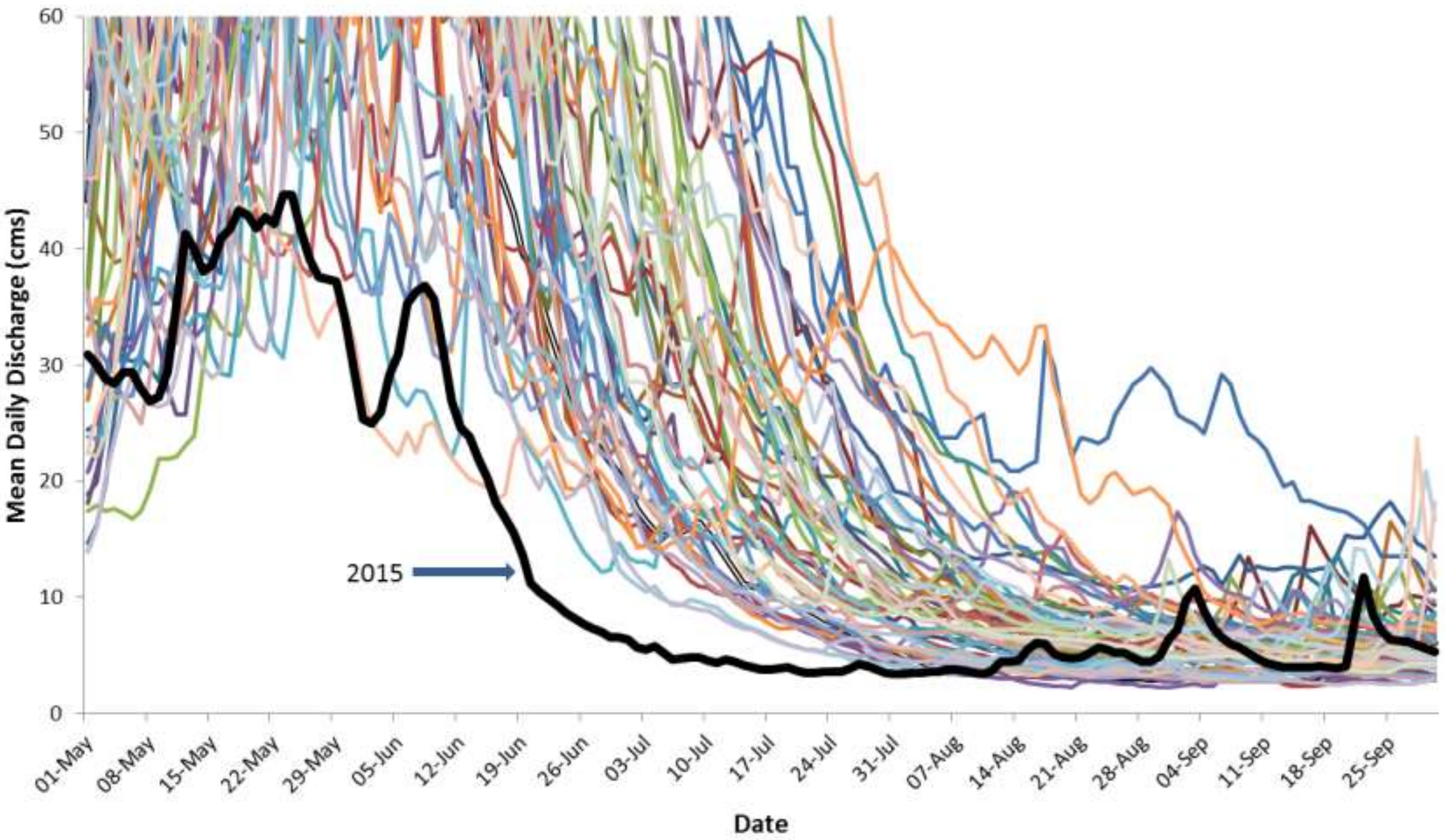


Figure 2. Daily average discharge rates during late spring and summer for the Nicola River near Spences Bridge (WSC Station 08LG006). Thin lines represent years 1958-2014 and the thick line represents 2015.

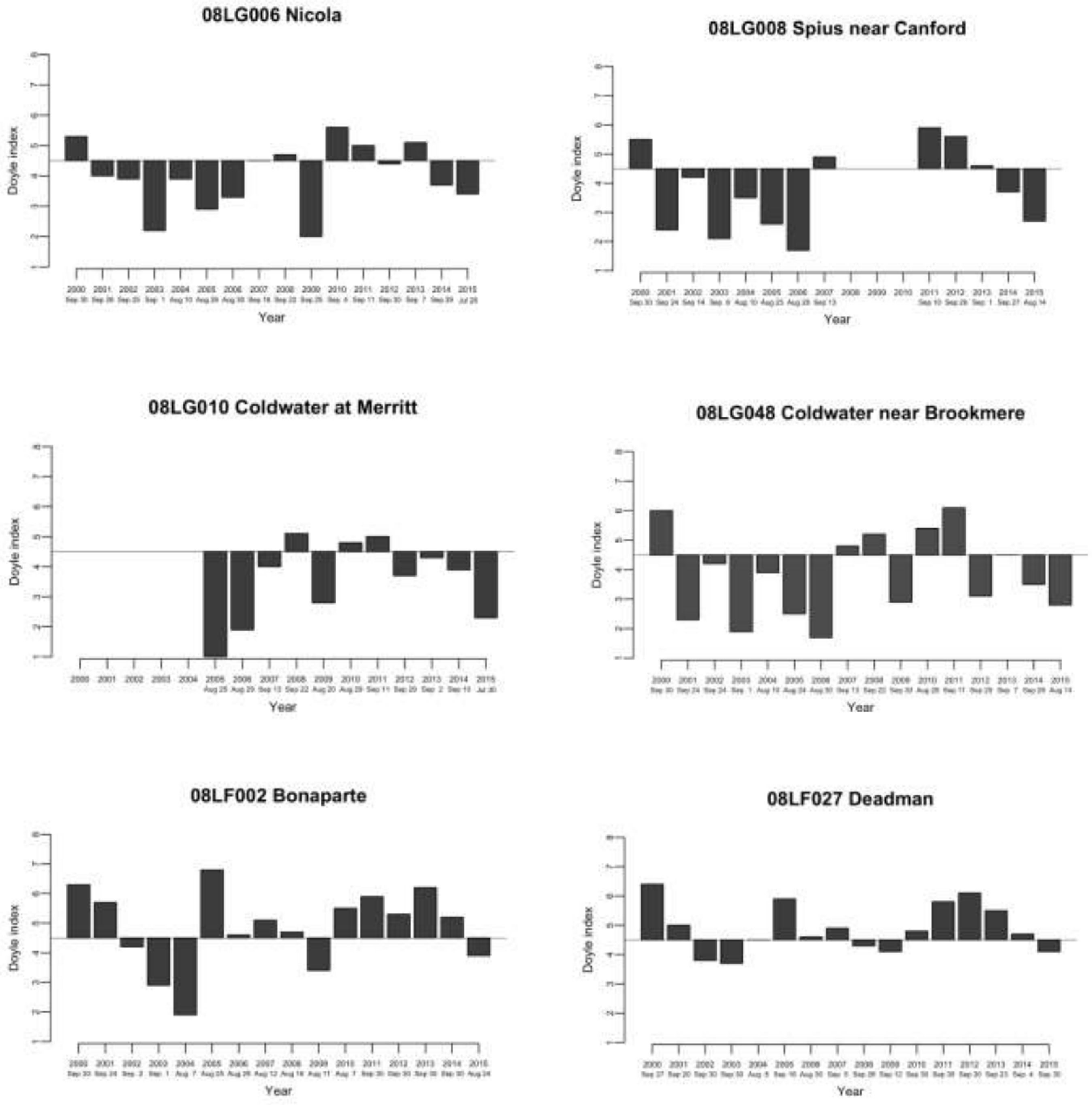


Figure 3. Minimum 30-day summer discharge using the Doyle Index (see Appendix 1) and date of the center of the 30-day period for WSC stations used as covariates in stock-recruitment models.

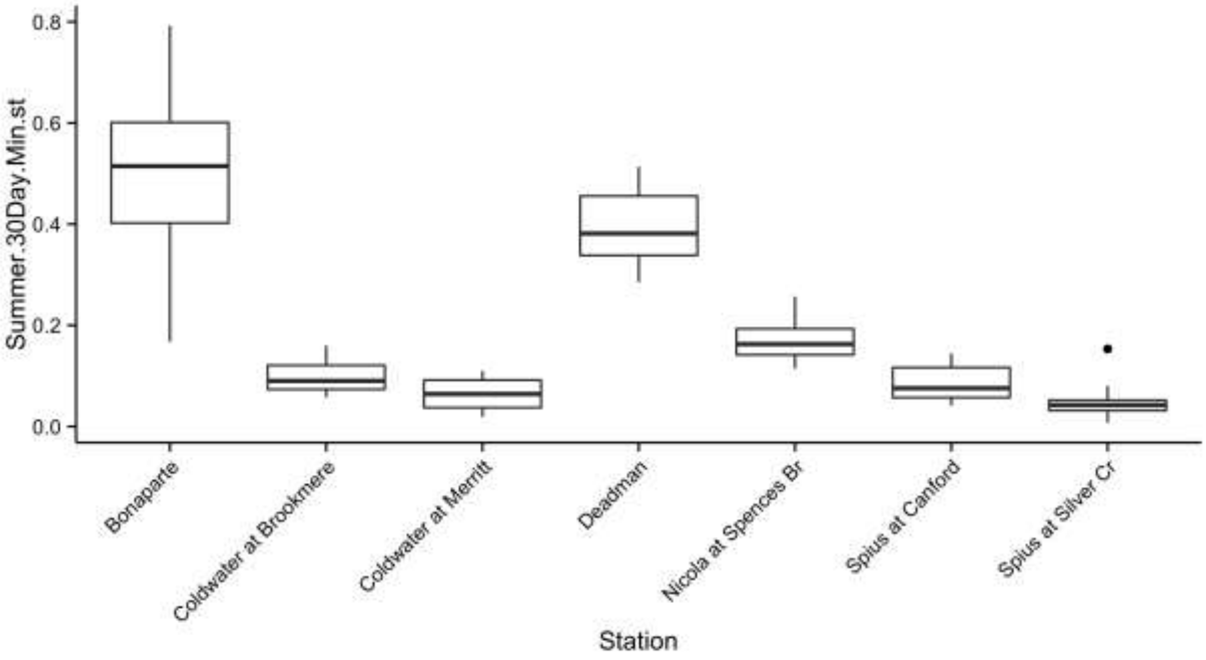
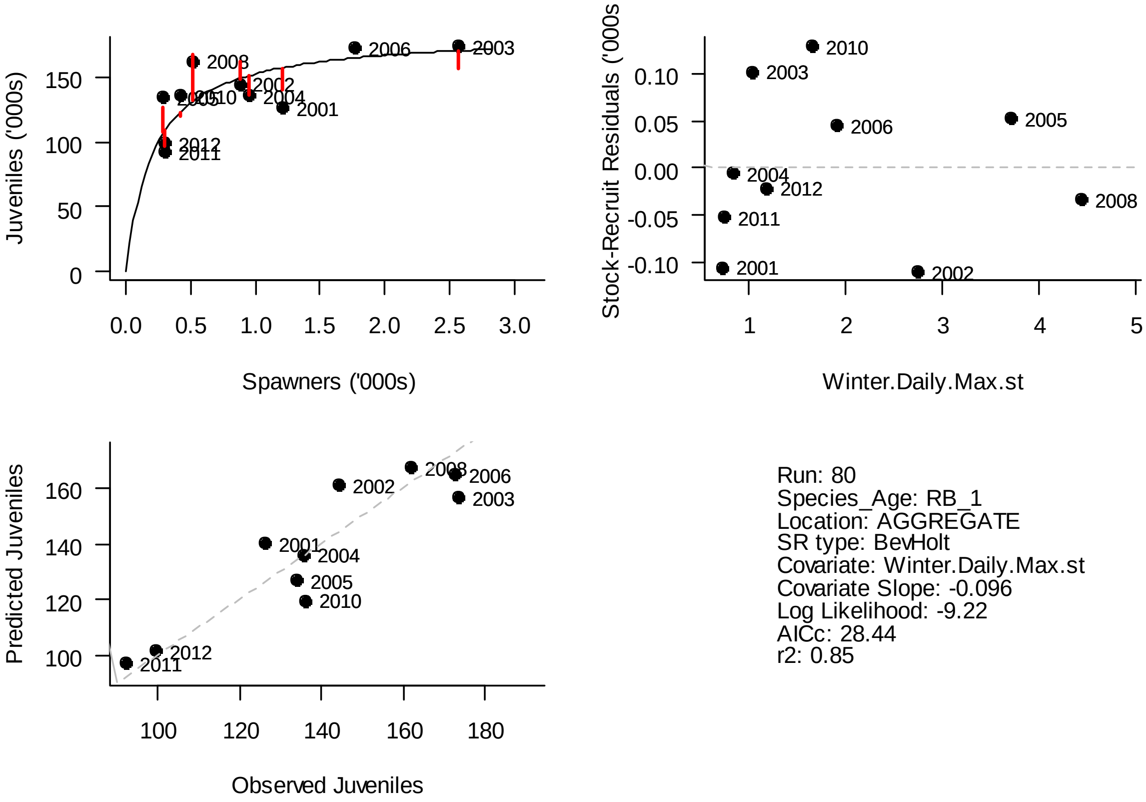


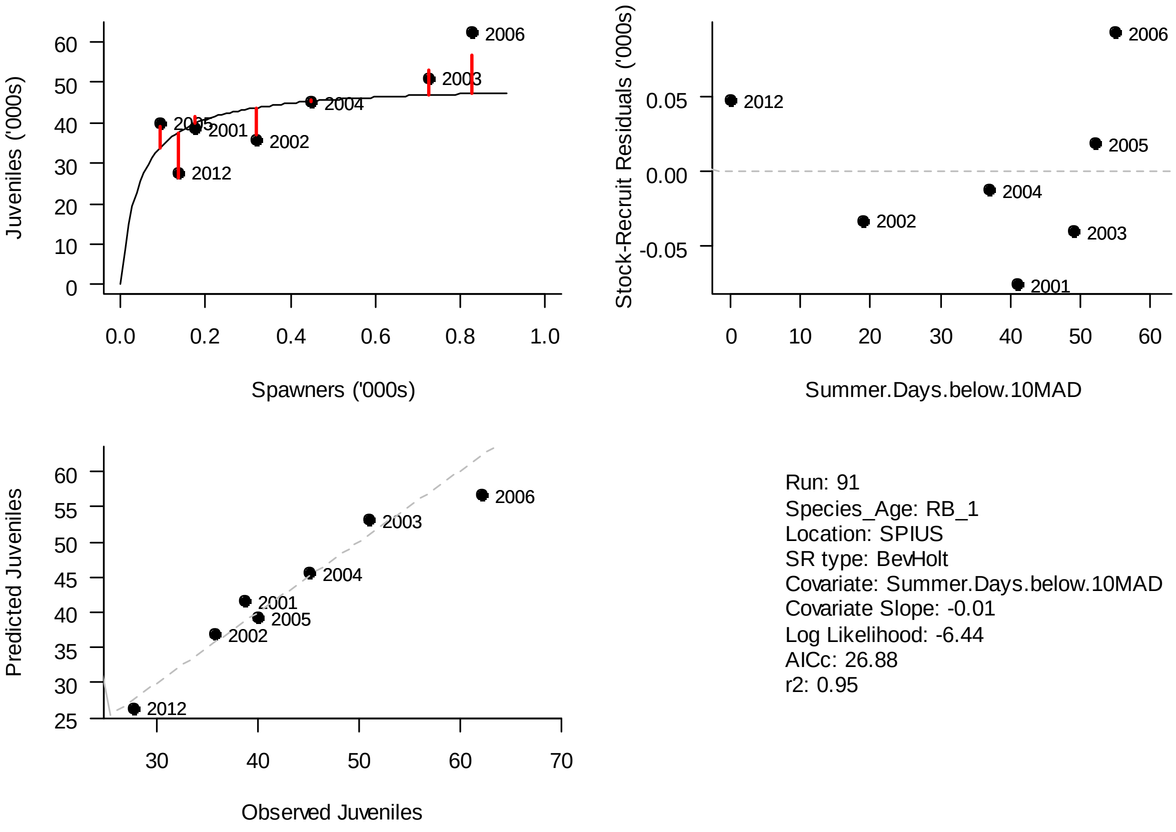
Figure 4. Average Summer 30-day minimum discharge standardized by long term Mean Annual Discharge for years with available data 2000-2015 at select WSC stations on tributaries of the lower Thompson and Nicola Rivers.

Figure 5a-b. The Beverton-Holt stock-recruitment models of Steelhead age 1+ parr for a)Nicola Aggregate and b) Spius comparison groups omitting the 2015 year class using the environmental covariates that explained the most variance in productivity. Dots represent observed abundance, curves represent prediction based on spawner abundance and the vertical lines extending above and below the curve represent the prediction of the full model. AIC$_c$ and r^2 values of predected versus observed are also listed for each model.

a) Nicola Aggregate (excluding 2015)



b) Spius (excluding 2015)



Run: 91
Species_Age: RB_1
Location: SPIUS
SR type: BevHolt
Covariate: Summer.Days.below.10MAD
Covariate Slope: -0.01
Log Likelihood: -6.44
AICc: 26.88
r2: 0.95

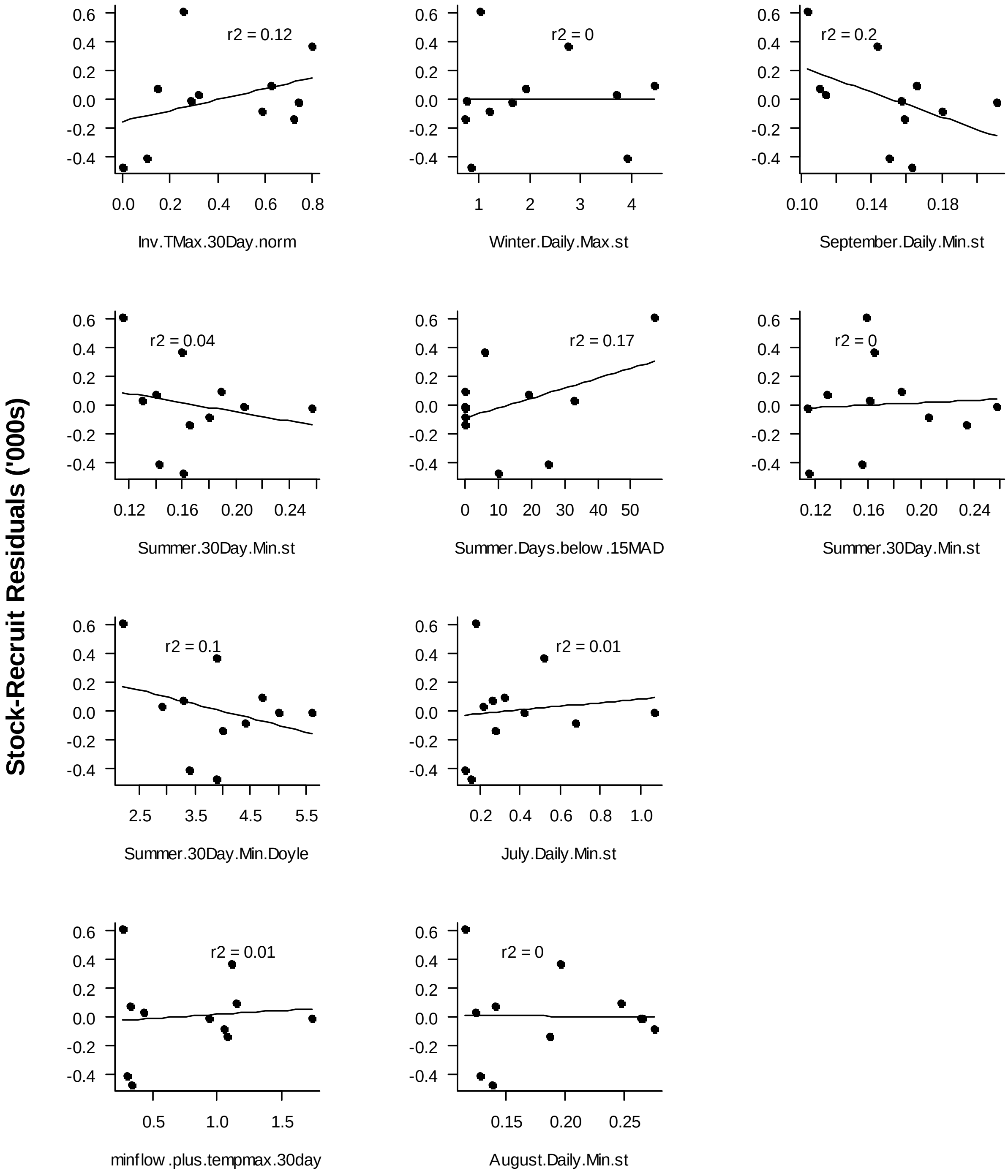
Appendices

Appendix 1. Complete list of indices to represent summer drought severity or duration, and intensity of winter high flow events to be used as covariates in stock-recruitment models.

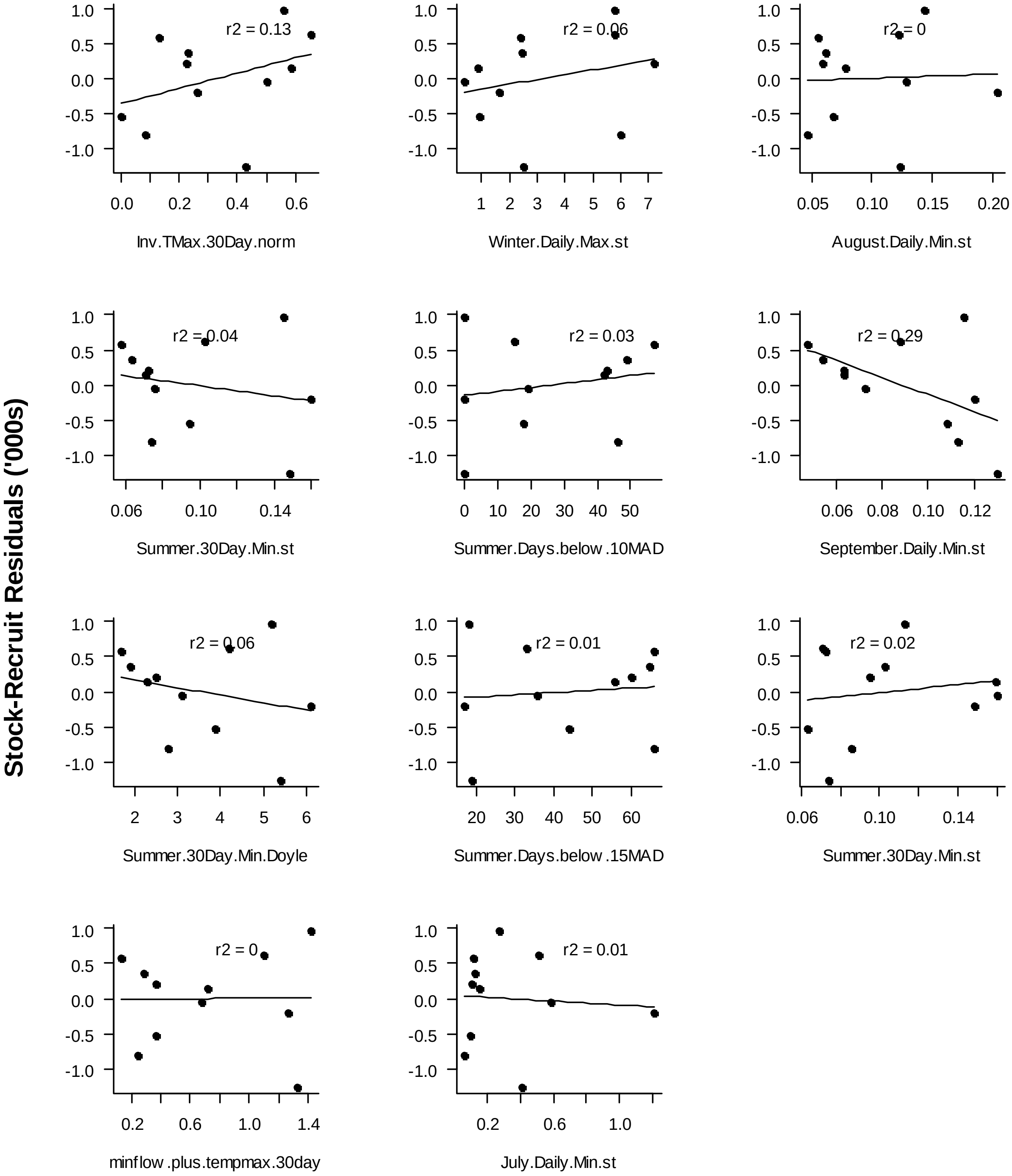
<table>
<tr><th>Index</th><th>Description</th></tr>
<tr><td>Annual.Discharge.st</td><td>Mean of daily discharge over the water year. (Standardized by dividing by long term MAD)</td></tr>
<tr><td>Summer.30Day.Min.st</td><td>Minimum of the 30-day average discharge during the Jul-Sep period. (Standardized by dividing by long term MAD)</td></tr>
<tr><td>Summer.30Day.Min.Doyle</td><td>Minimum of the 30-day average discharge during the Jul-Sep period. (Indexed using the approach of Doyle 2004 (1-8 scale where 1 is the minimum and 8 is the maximum over the full period of record) (See page 9 of Doyle, 2004)
<table>
<tr><td>Discharge percentile range</td><td>minimum</td><td>1 - 9</td><td>10 - 24</td><td>25 - 49</td><td>50 - 74</td><td>75 - 89</td><td>90 - 99</td><td>maximum</td></tr>
<tr><td>Index</td><td>1</td><td>1.5 - 2.4</td><td>2.5 - 3.4</td><td>3.5 - 4.4</td><td>4.5 - 5.4</td><td>5.5 - 6.4</td><td>6.5 - 7.4</td><td>8</td></tr>
</table>
</td></tr>
<tr><td>Tavg.30Day.norm</td><td>The inverse of the 30-day average of daily average temperature at Merritt during the 30-day period of minimum flow during that year (i.e. corresponding period to minimum 30-day average discharge). The inverse was used so that high temperatures will be assigned a low index value. (Normalized (0-1 scale) by subtracting 99.9% of the minimum value during the 2000-2015 period and dividing by the maximum of the resulting set of values.)</td></tr>
<tr><td>TMax.30Day.norm</td><td>The inverse of the 30-day average of daily maximum temperature at Merritt during the 30-day period of minimum flow during that year (i.e. corresponding period to minimum 30-day average discharge). The inverse was used so that high temperatures will be assigned a low index value. (Normalized (0-1 scale) by subtracting 99.9% of the minimum value during the 2000-2015 period and dividing by the maximum of the resulting set of values.)</td></tr>
<tr><td>Winter.Daily.Max.st</td><td>Maximum of daily discharge during the Nov-March period. (Standardized by dividing by long term MAD)</td></tr>
<tr><td>Summer.Daily.Min.st</td><td>Minimum of daily discharge during the Jul-Sep period. (Standardized by dividing by long term MAD)</td></tr>
<tr><td>July.Daily.Min.st</td><td>Minimum of daily discharge during July. (Standardized by dividing by long term MAD)</td></tr>
<tr><td>August.Daily.Min.st</td><td>Minimum of daily discharge during August. (Standardized by dividing by long term MAD)</td></tr>
<tr><td>September.Daily.Min.st</td><td>Minimum of daily discharge during September. (Standardized by dividing by long term MAD)</td></tr>
<tr><td>Summer.Days.below.5MAD</td><td>Number of days during the July-September period when daily discharge was below 5% of long term MAD.</td></tr>
<tr><td>Summer.Days.below.10MAD</td><td>Number of days during the July-September period when daily discharge was below 10% of long term MAD.</td></tr>
<tr><td>Summer.Days.below.15MAD</td><td>Number of days during the July-September period when daily discharge was below 15% of long term MAD.</td></tr>
<tr><td>Spawning.Summer.30Day.Min.st</td><td>Minimum of the 30-day average discharge during the Jul-Sep period in the year prior to juvenile sampling. This is used for Chinook only (Standardized by dividing by long term MAD)</td></tr>
</table>

Appendix 2a-k Residuals of the spawner-only stock-recruitment model plotted against environmental covariates by species / age-class and comparison group.

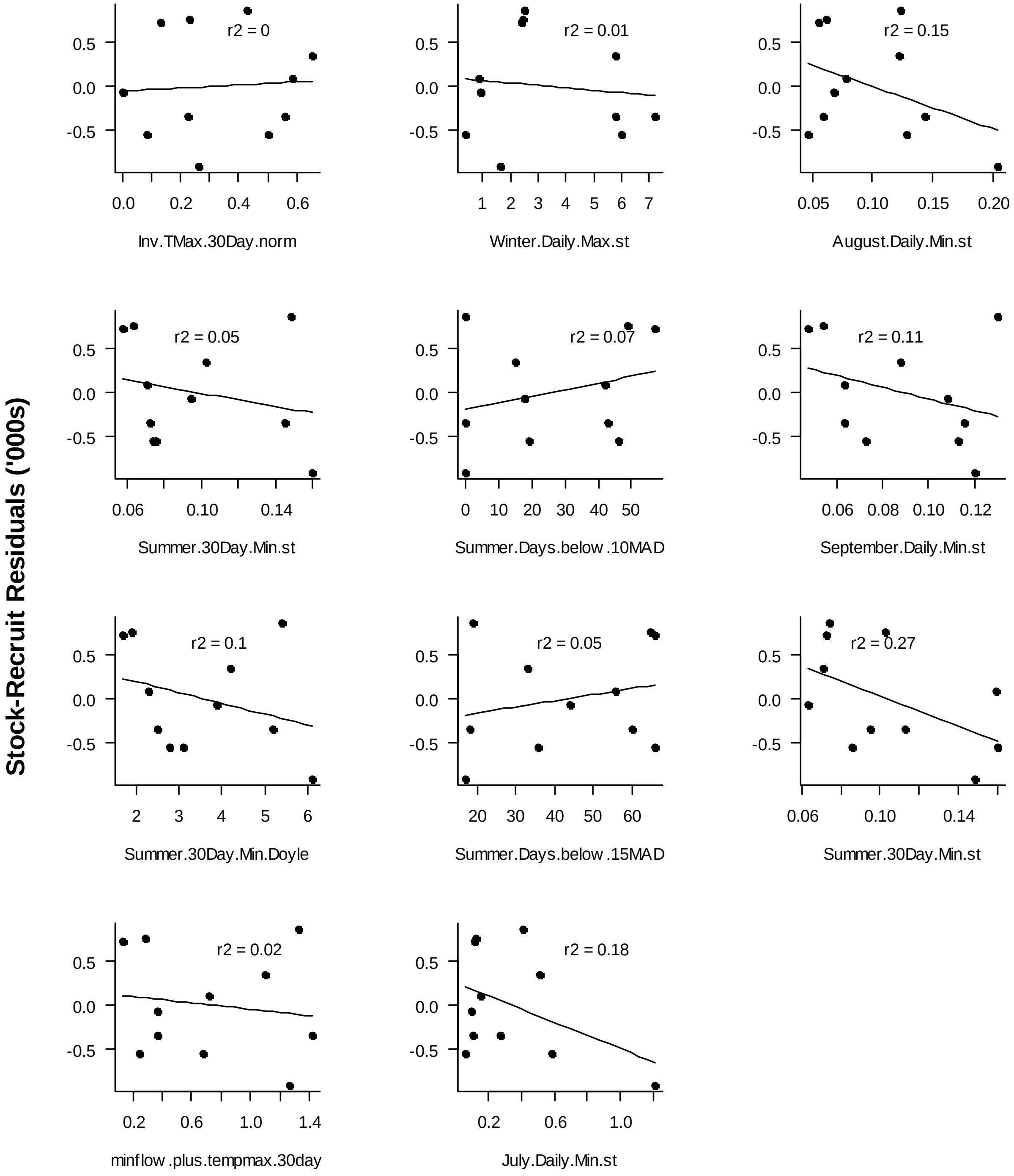
A. Chinook Fry - Nicola Aggregate



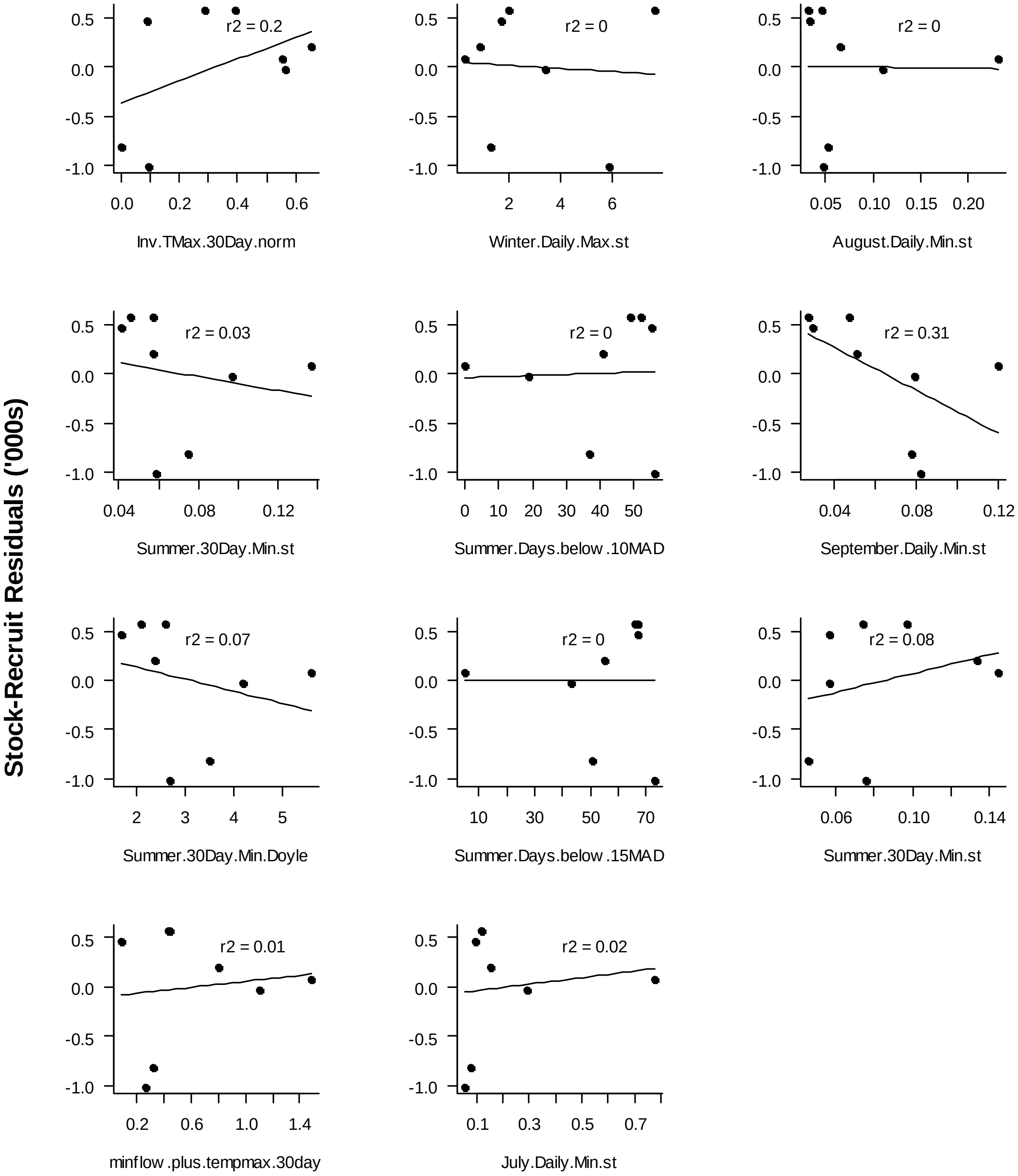
B. Chinook Fry - Coldwater



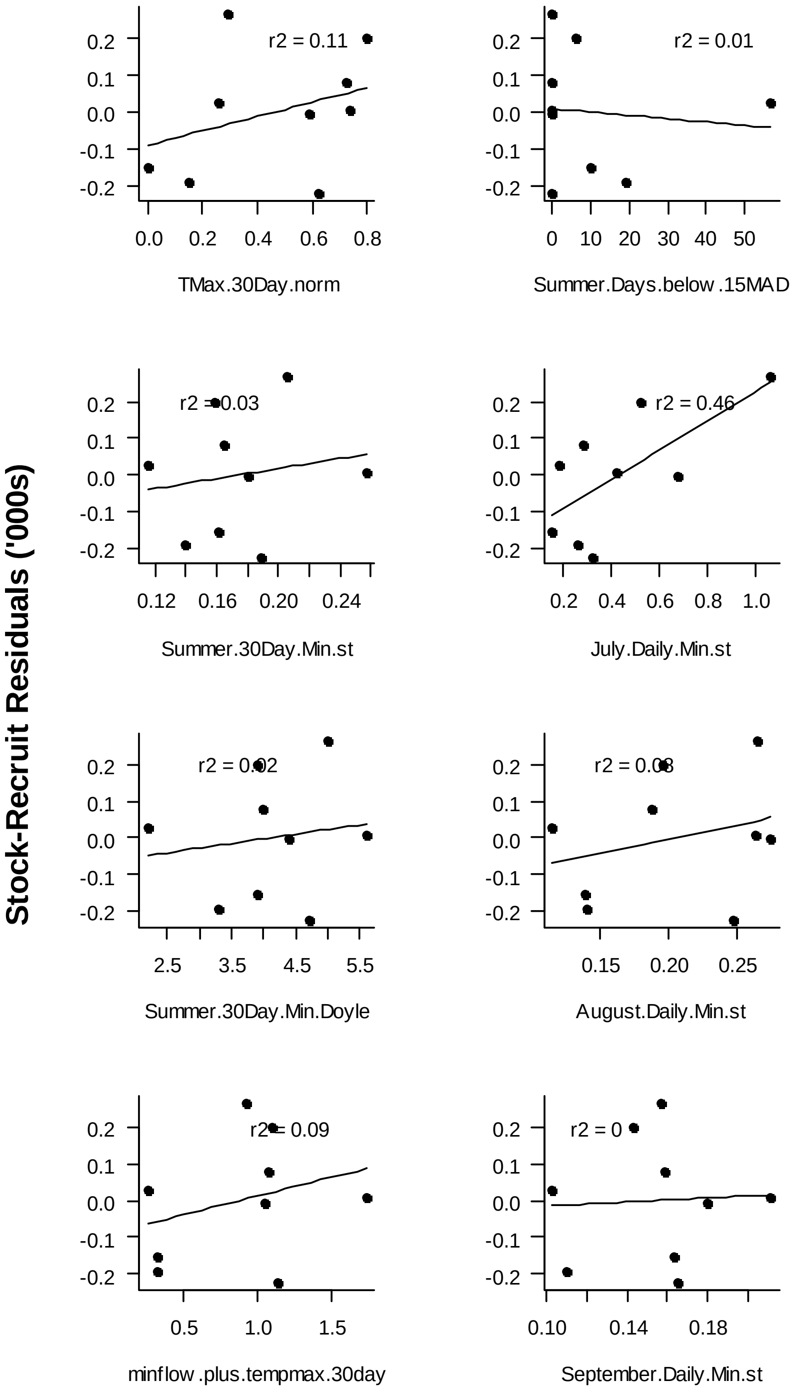
C. Chinook Fry - CW2



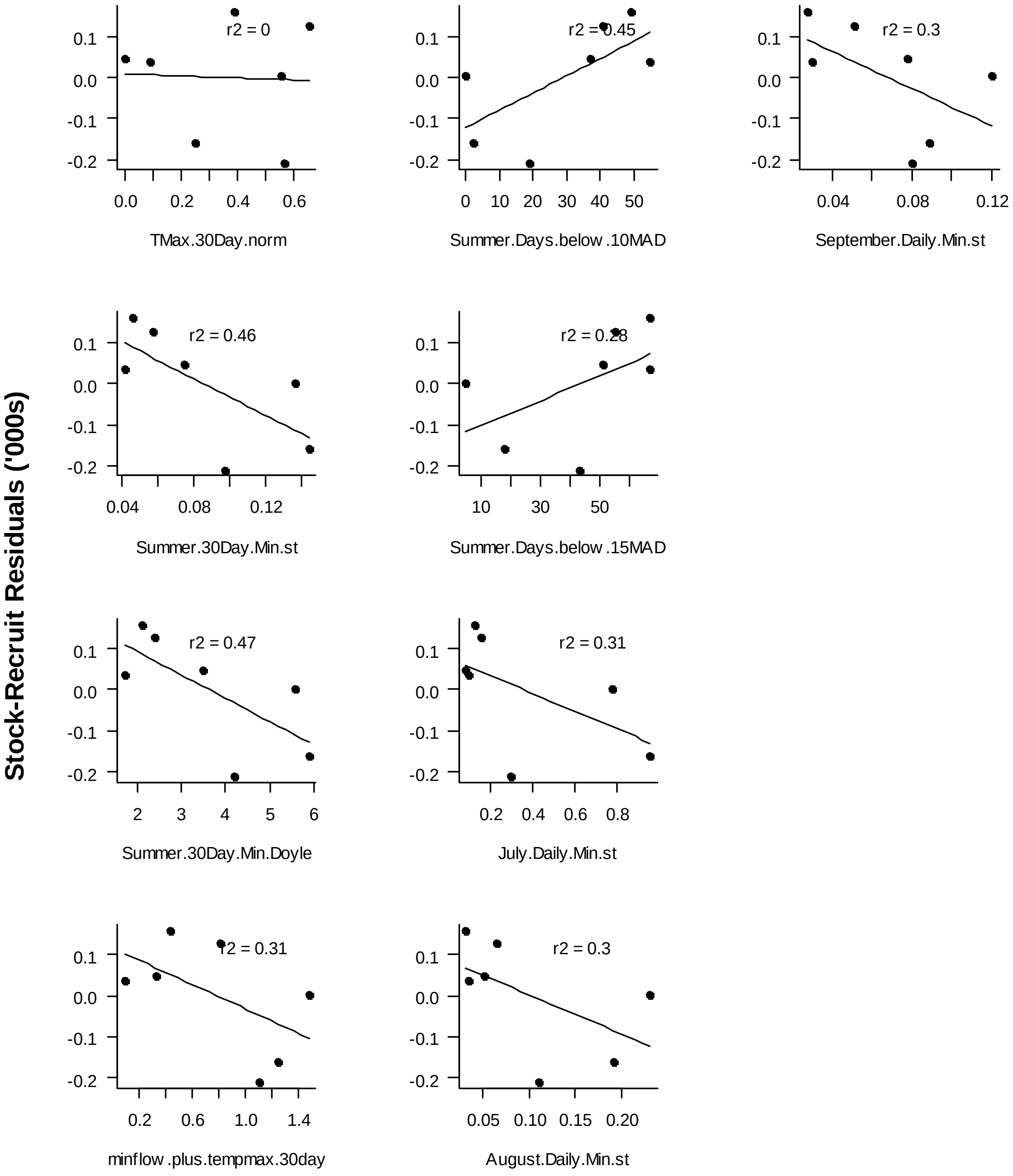
D. Chinook Fry - Spius



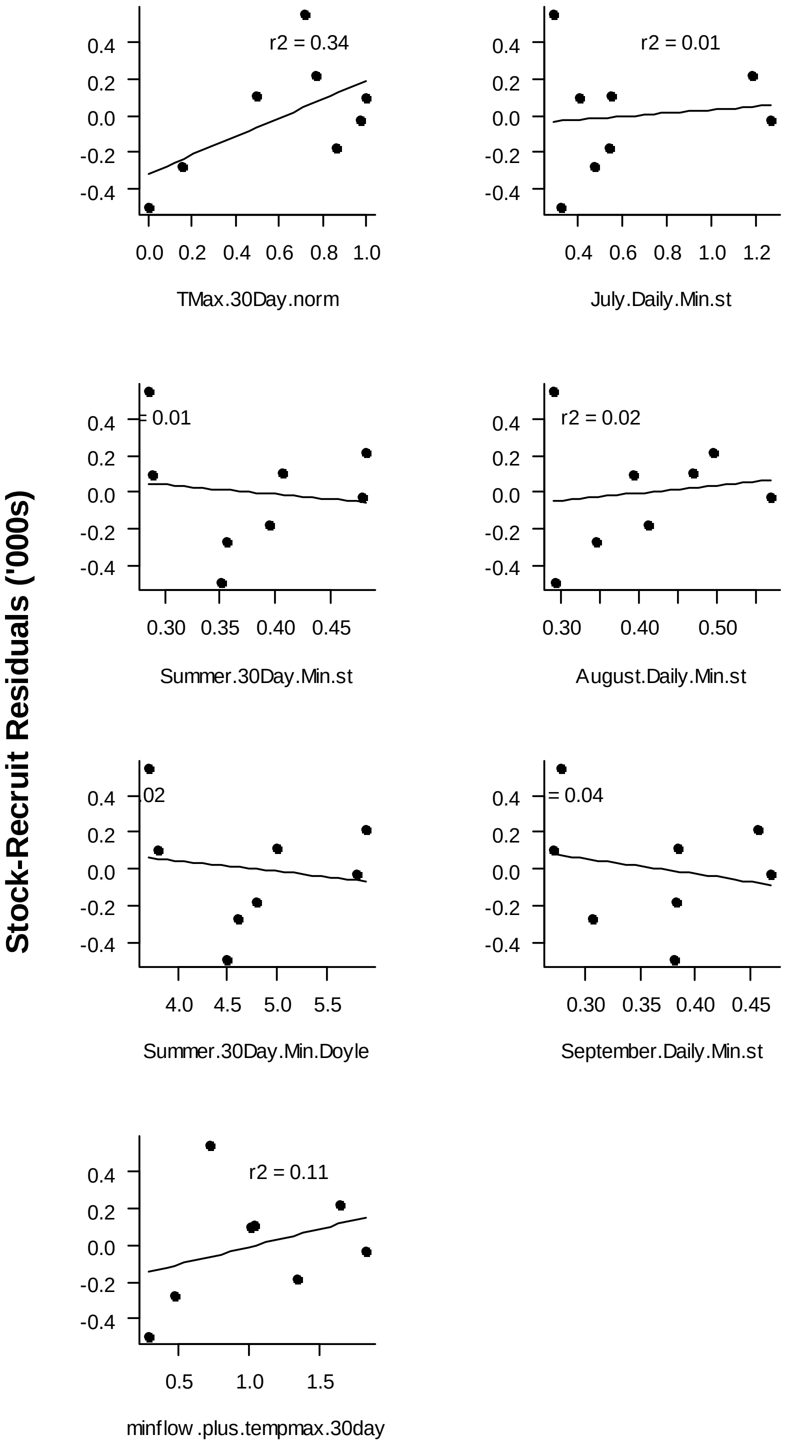
E. Steelhead Fry – Nicola Aggregate



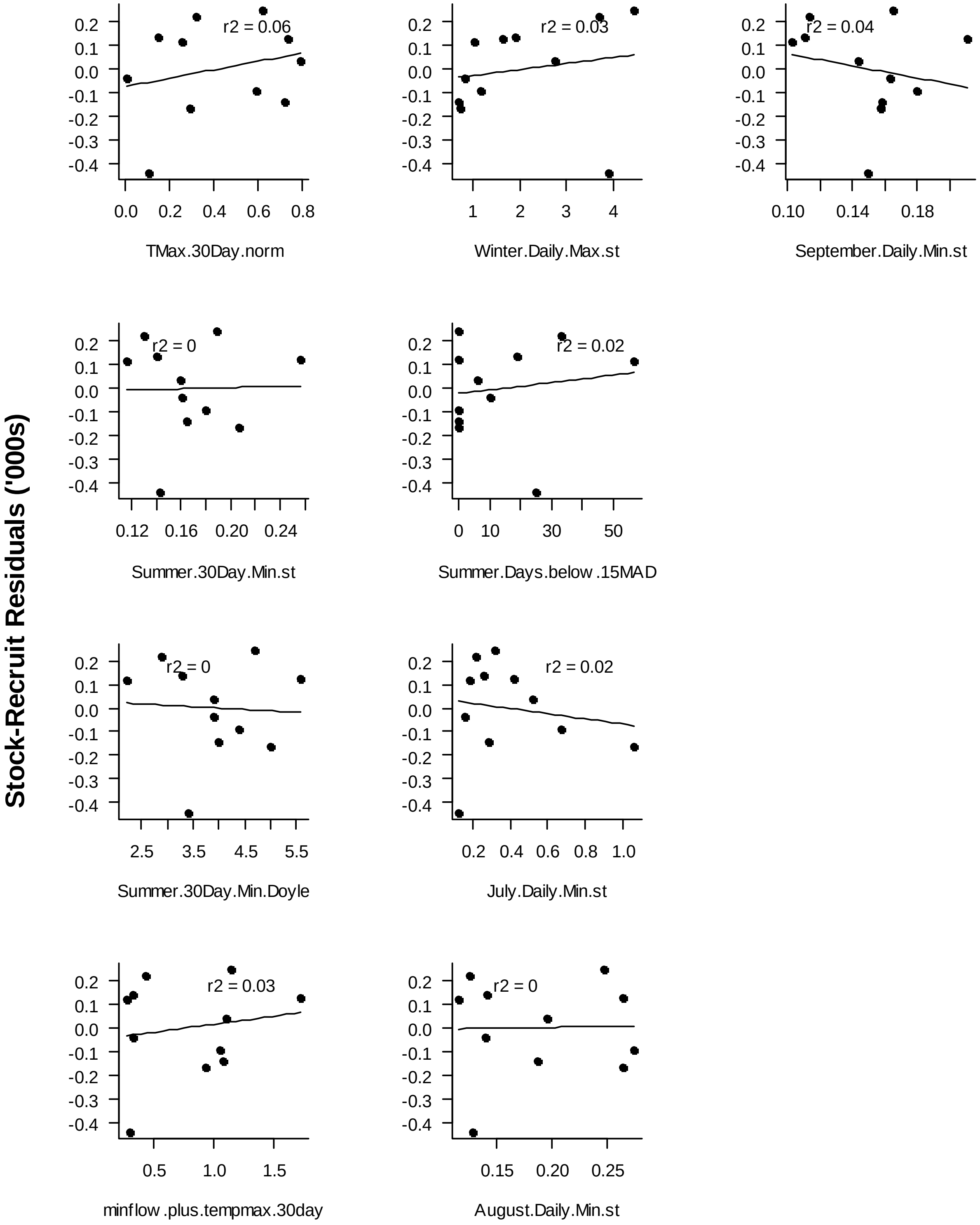
F. Steelhead Fry - Spius



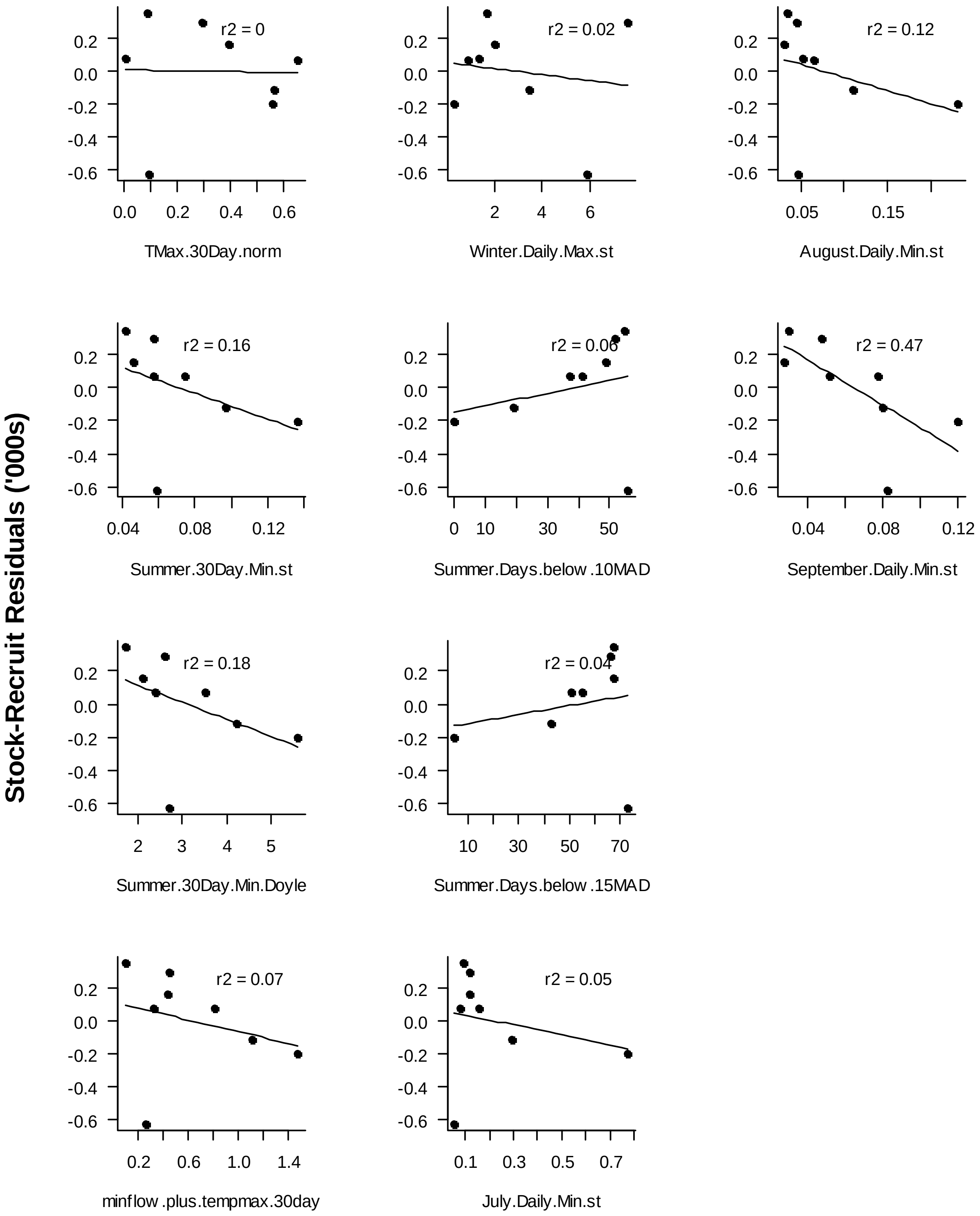
G. Steelhead Fry – Deadman



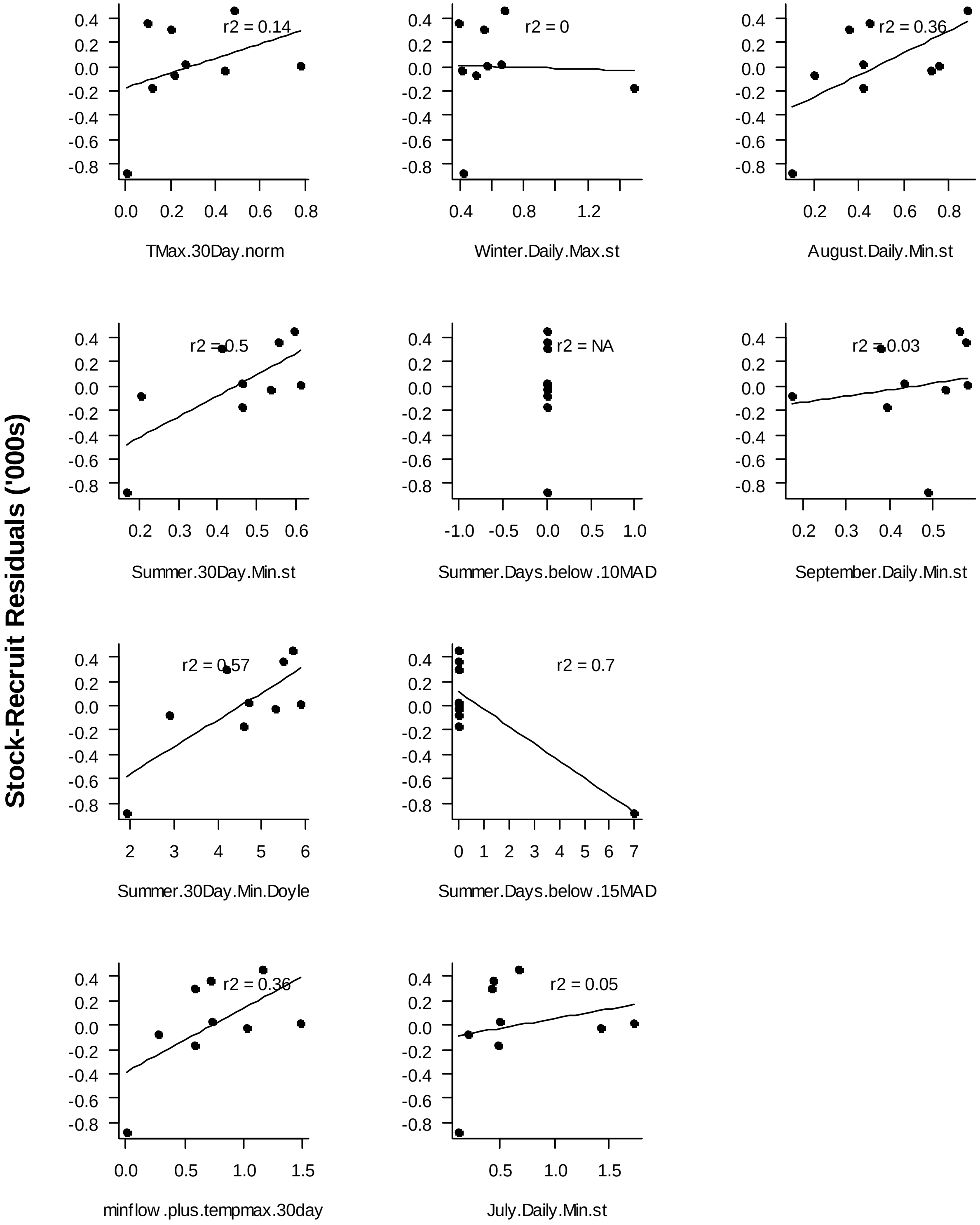
H. Steelhead parr – Nicola Aggregate



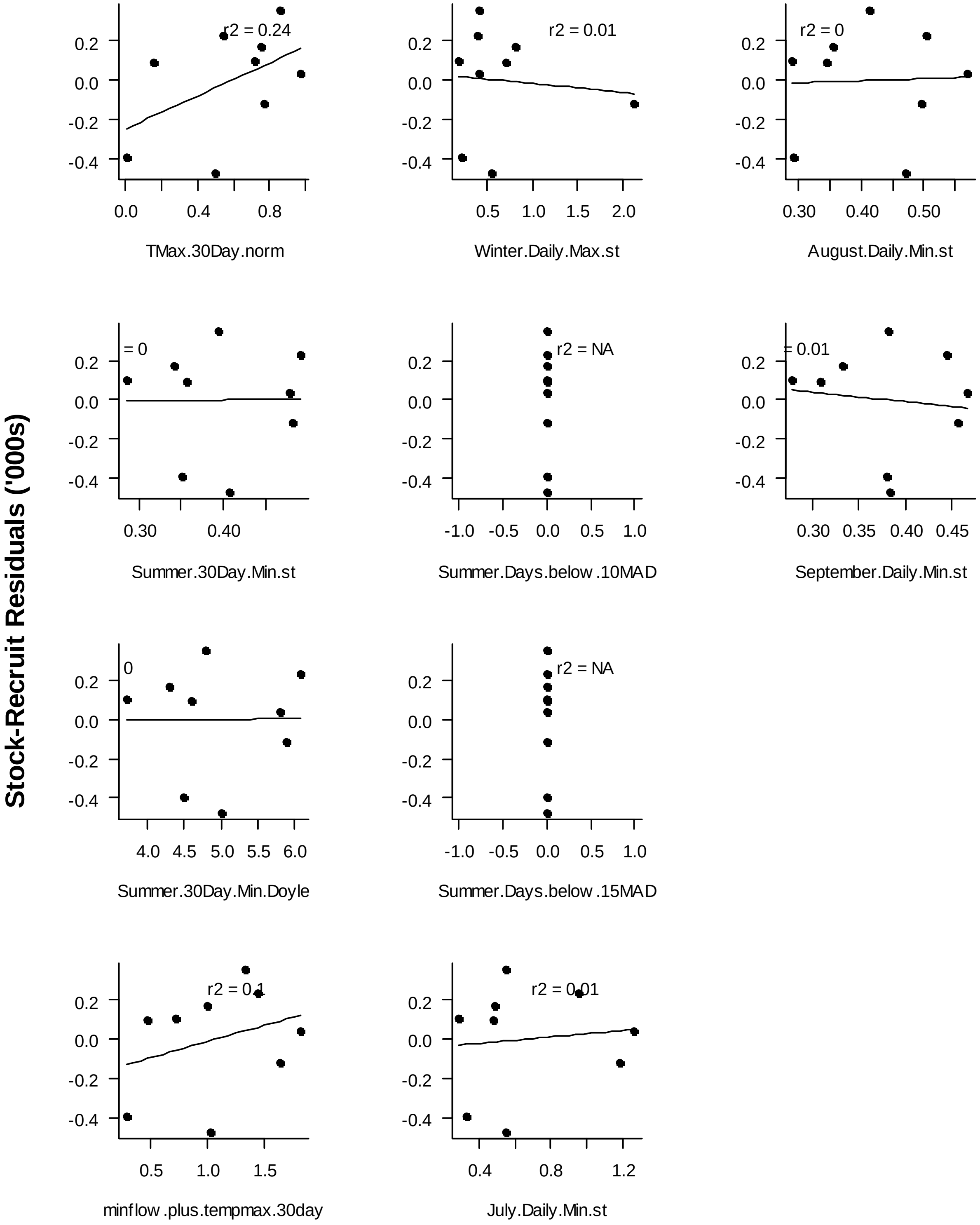
I. Steelhead parr – Spius



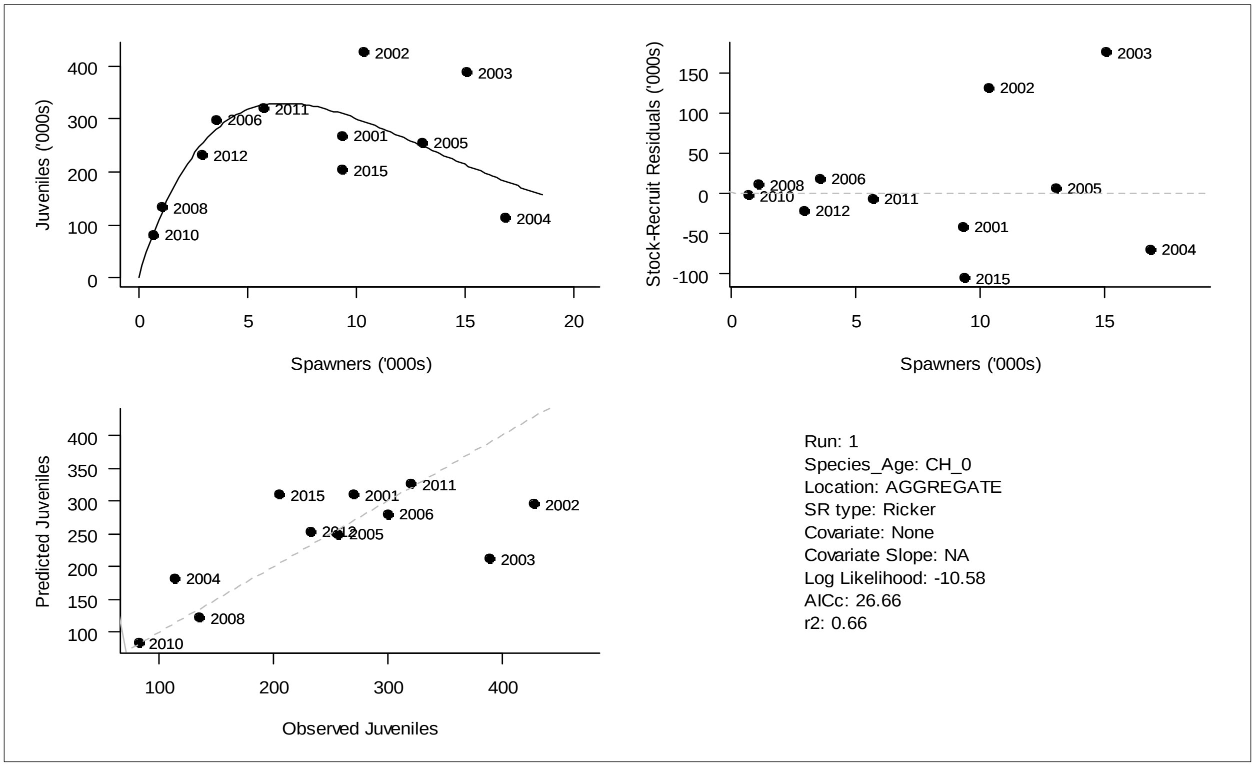
J. Steelhead parr – Bonaparte



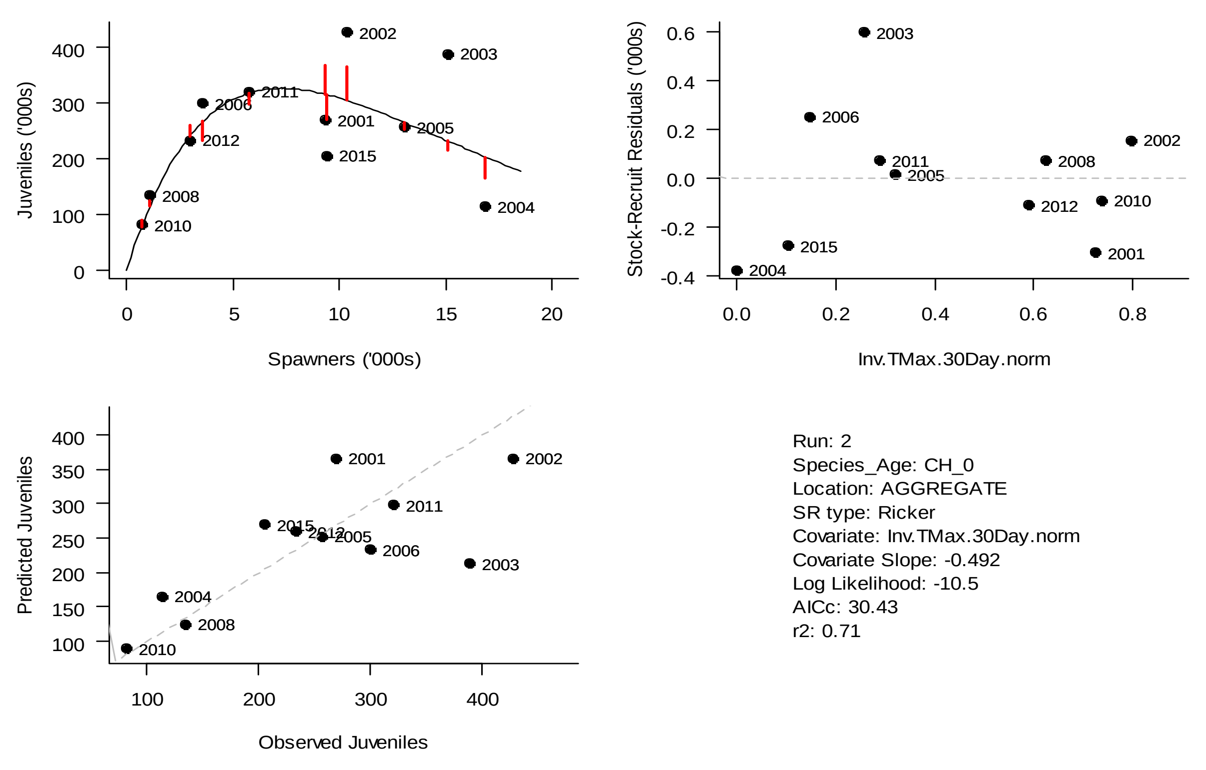
K. Steelhead parr – Deadman



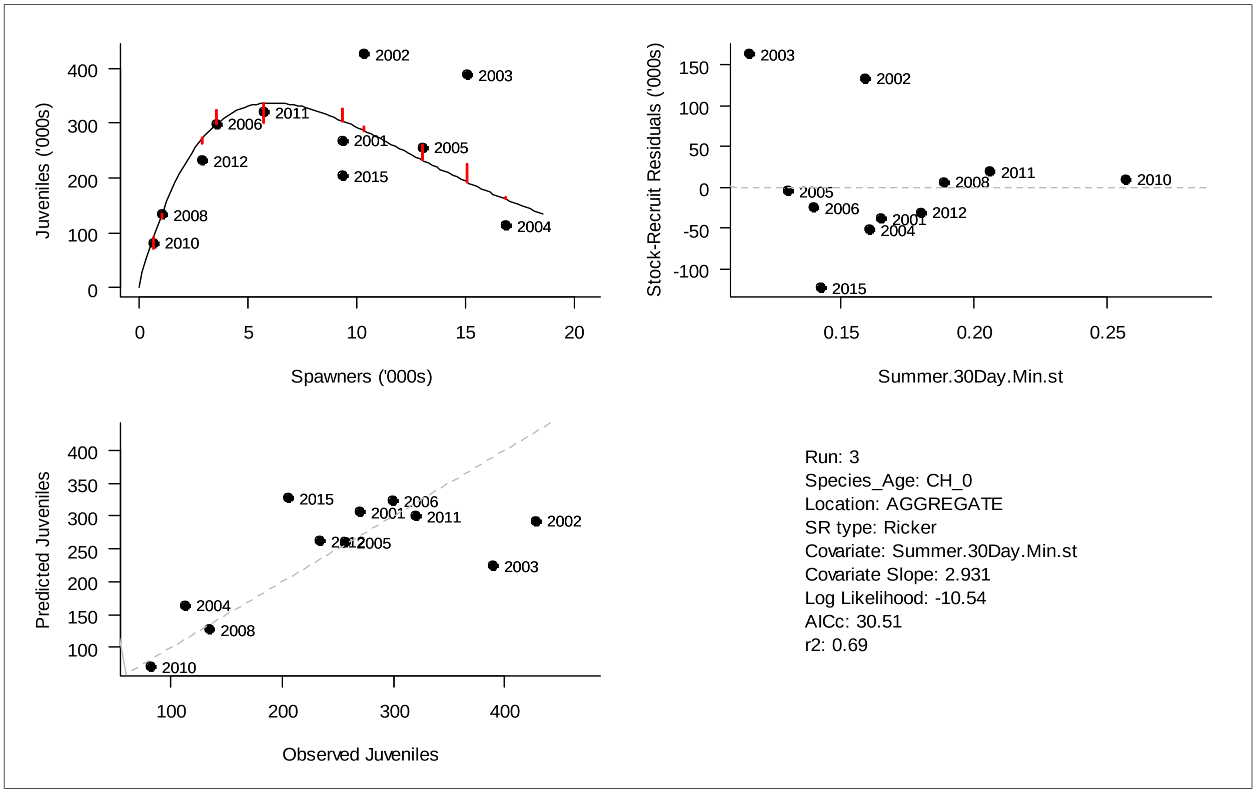
Appendix 3. Outputs from Ricker stock-recruitment models of Chinook fry for each stream section and fitted using only brood spawner abundance or in combination with one environmental covariate. Dots represent observed abundance, curves represent prediction based on spawner abundance and, when includeing a covariate, the vertical lines represent the prediction of the full model. AIC$_c$ and R^2 values of predected versus observed are also listed for each model.



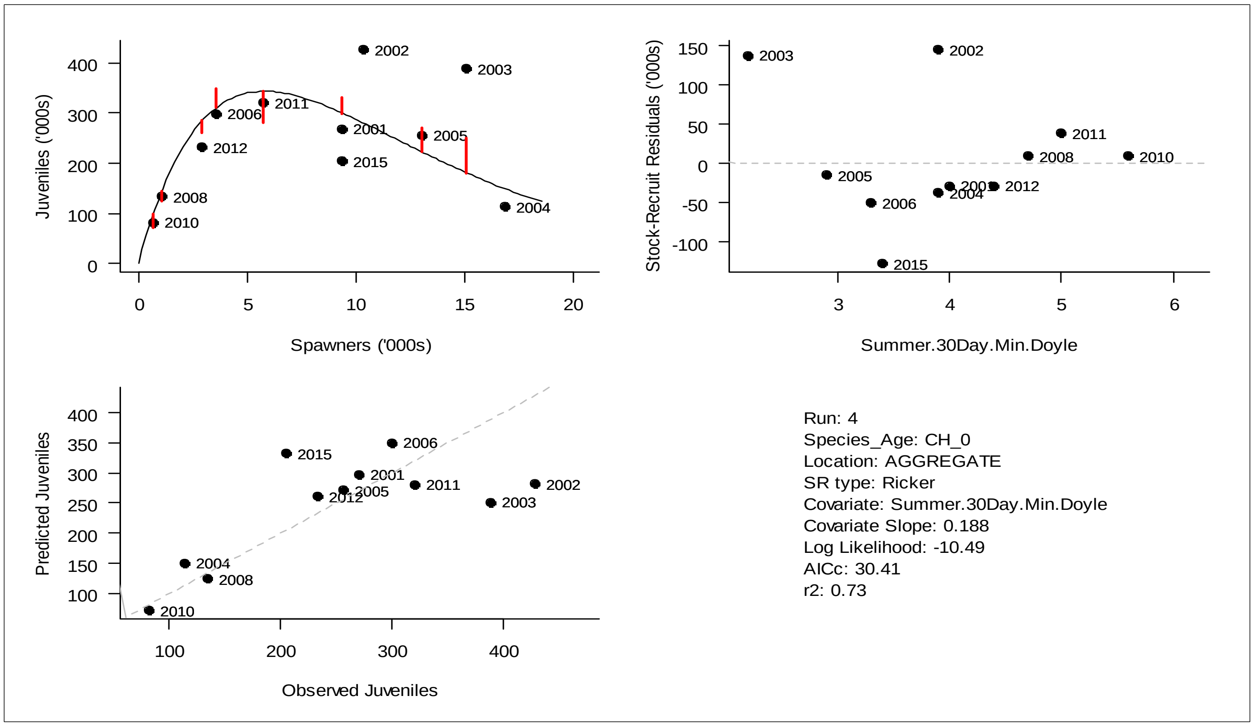
Run: 1
Species_Age: CH_0
Location: AGGREGATE
SR type: Ricker
Covariate: None
Covariate Slope: NA
Log Likelihood: -10.58
AICc: 26.66
r2: 0.66



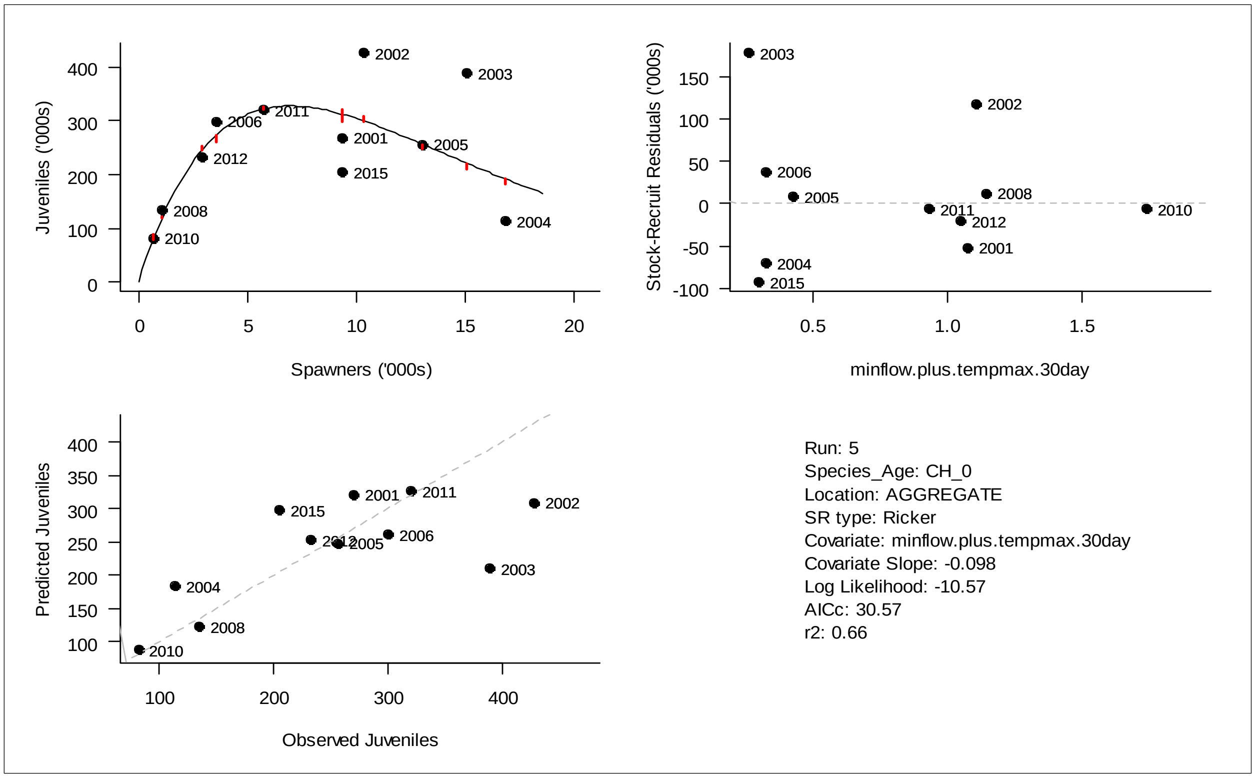
Run: 2
Species_Age: CH_0
Location: AGGREGATE
SR type: Ricker
Covariate: Inv.TMax.30Day.norm
Covariate Slope: -0.492
Log Likelihood: -10.5
AICc: 30.43
r2: 0.71



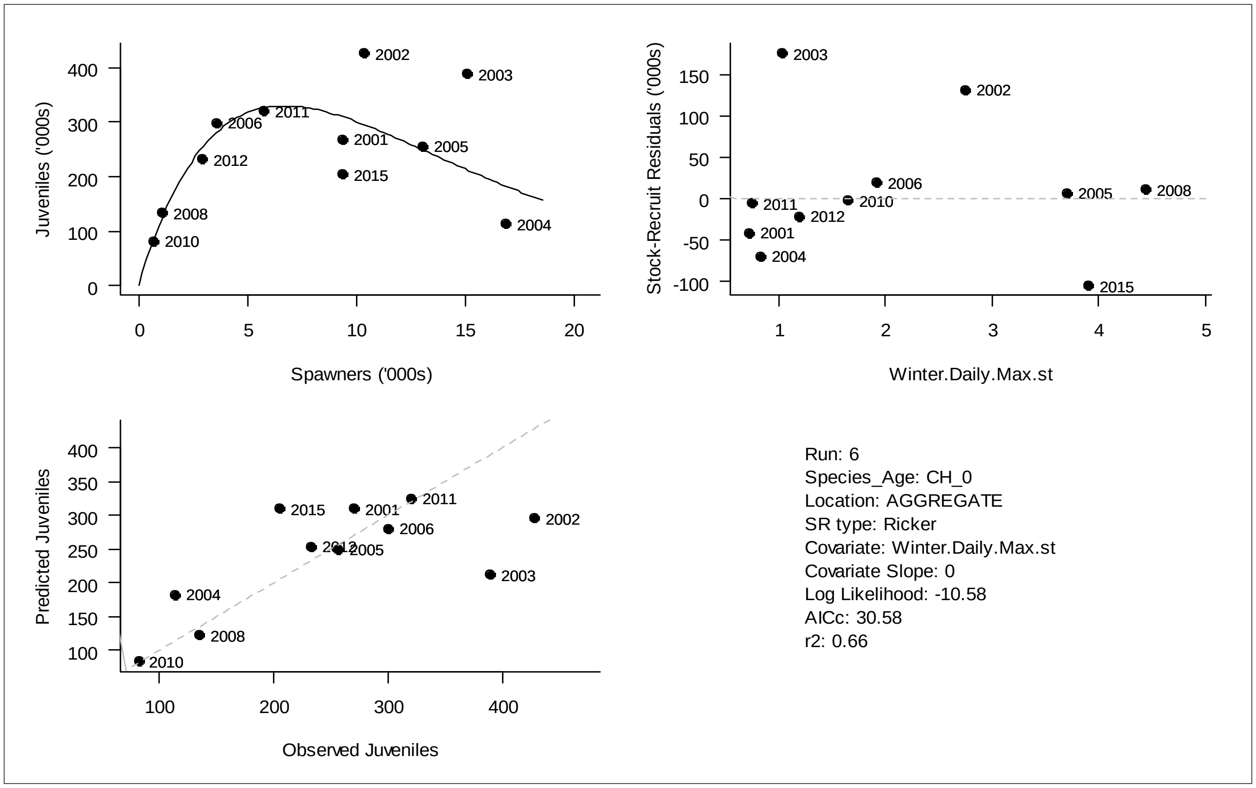
Run: 3
Species_Age: CH_0
Location: AGGREGATE
SR type: Ricker
Covariate: Summer.30Day.Min.st
Covariate Slope: 2.931
Log Likelihood: -10.54
AICc: 30.51
r2: 0.69



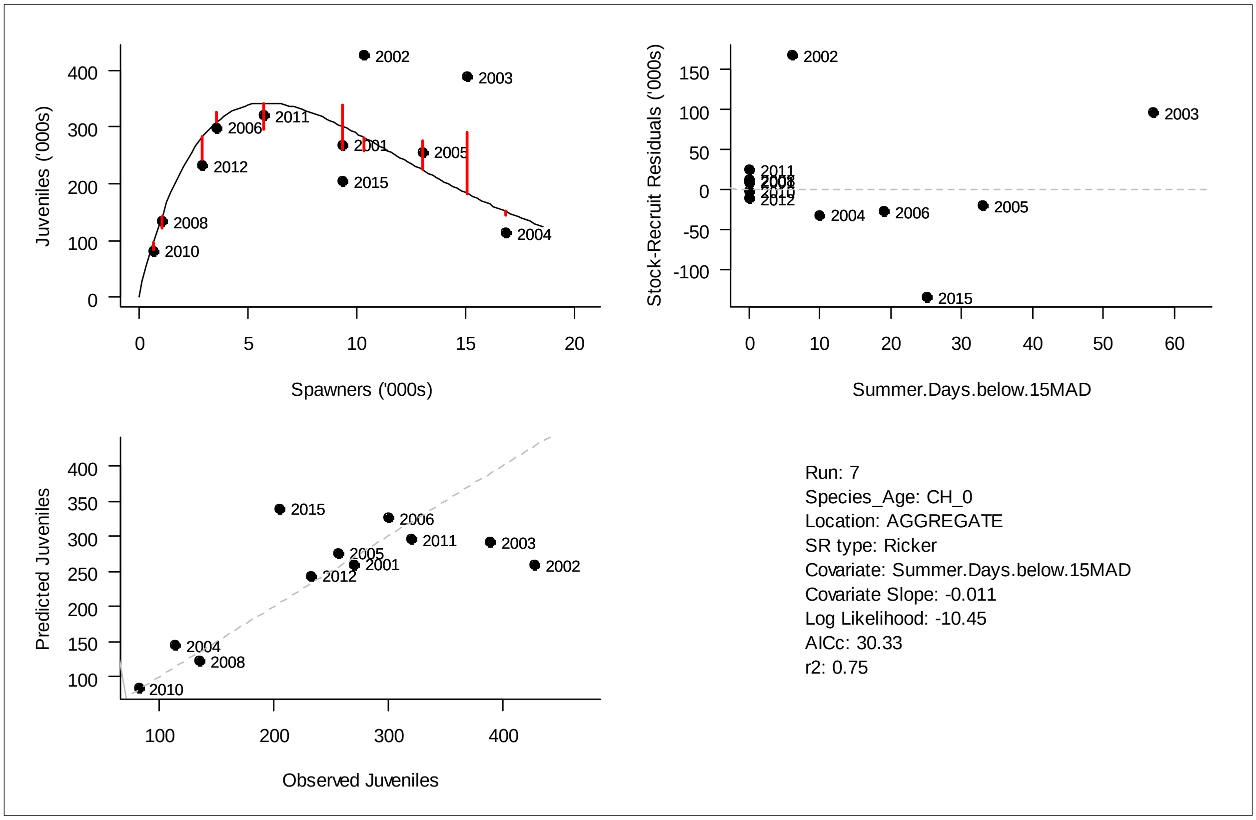
Run: 4
Species_Age: CH_0
Location: AGGREGATE
SR type: Ricker
Covariate: Summer.30Day.Min.Doyle
Covariate Slope: 0.188
Log Likelihood: -10.49
AICc: 30.41
r2: 0.73



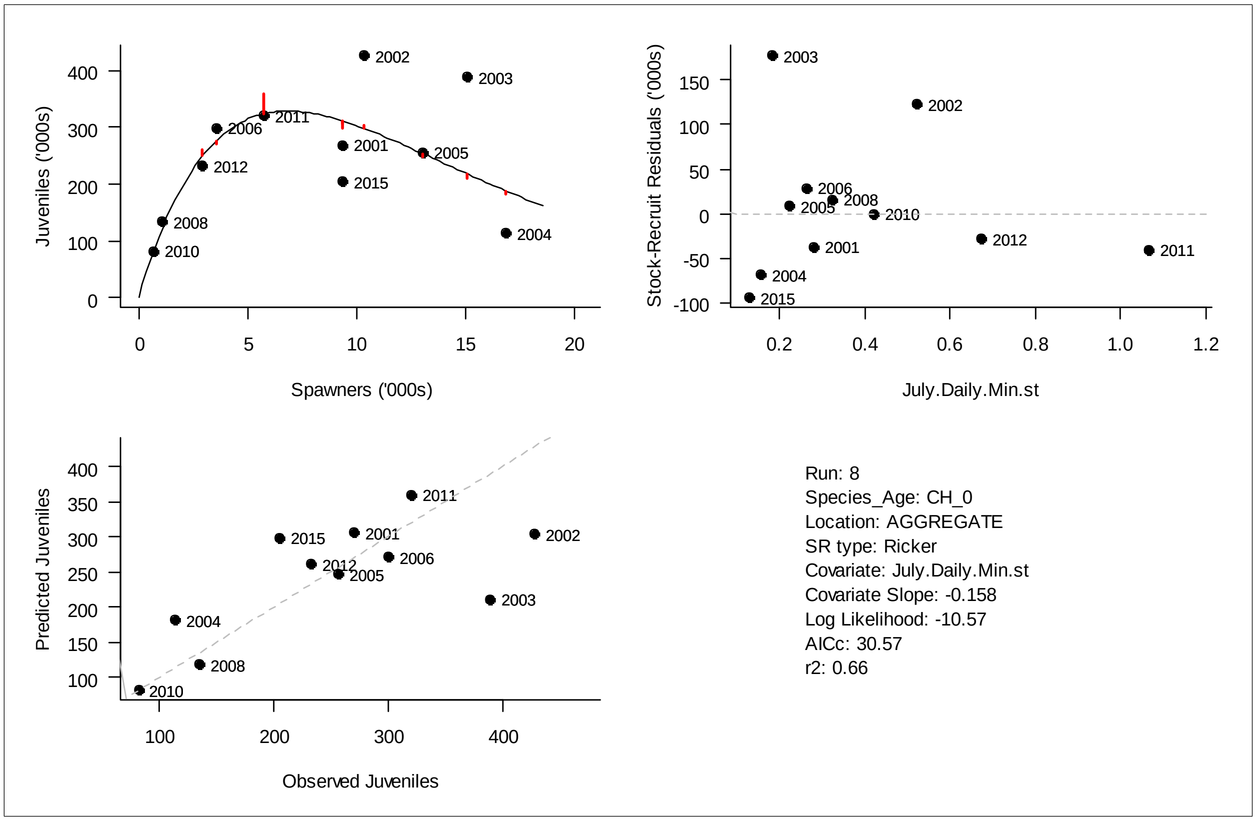
Run: 5
Species_Age: CH_0
Location: AGGREGATE
SR type: Ricker
Covariate: minflow.plus.tempmax.30day
Covariate Slope: -0.098
Log Likelihood: -10.57
AICc: 30.57
r2: 0.66



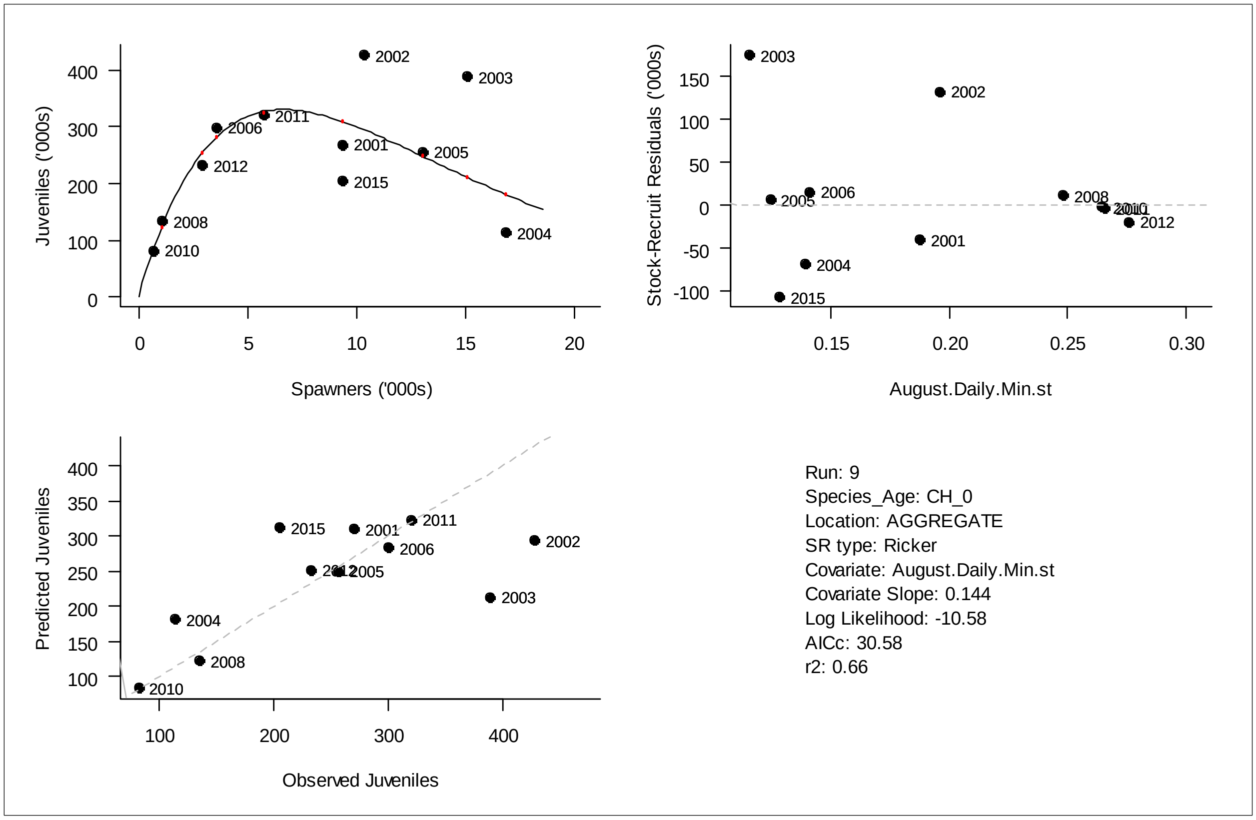
Run: 6
Species_Age: CH_0
Location: AGGREGATE
SR type: Ricker
Covariate: Winter.Daily.Max.st
Covariate Slope: 0
Log Likelihood: -10.58
AICc: 30.58
r2: 0.66



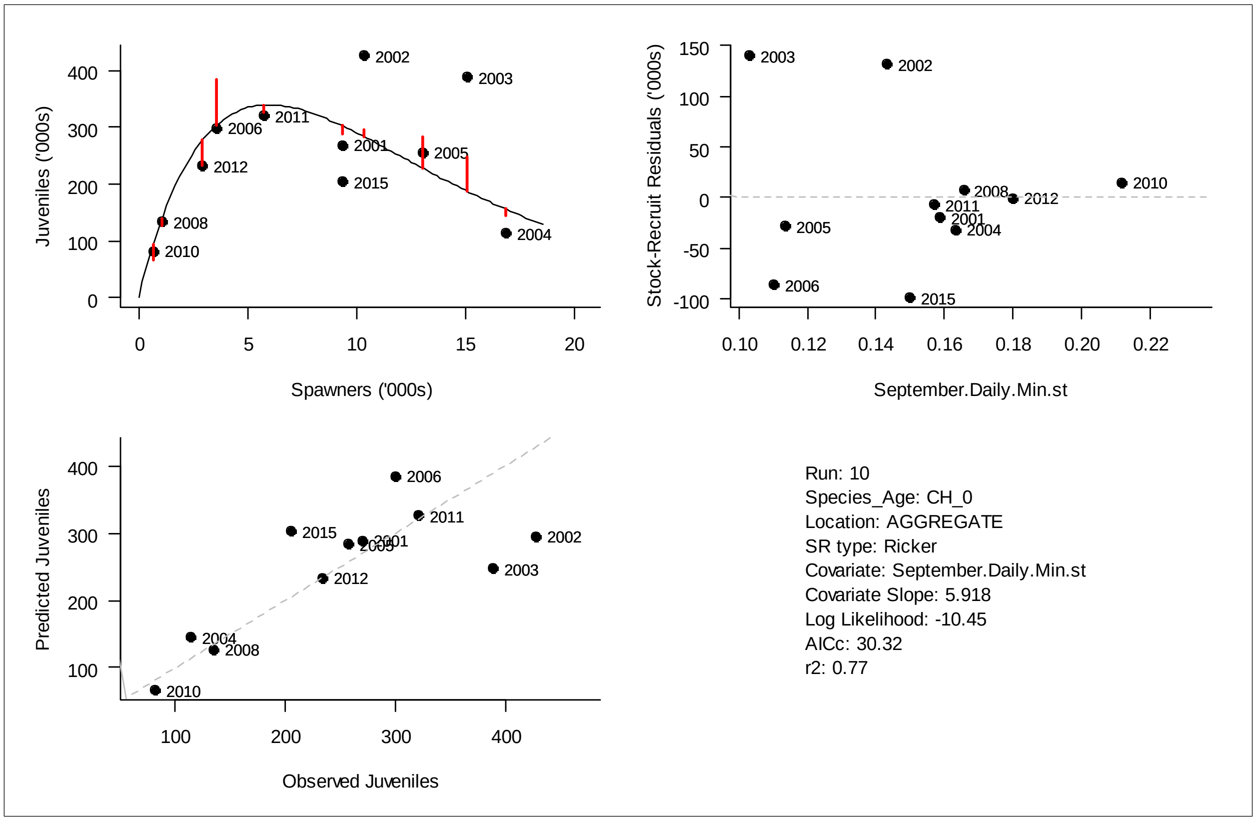
Run: 7
Species_Age: CH_0
Location: AGGREGATE
SR type: Ricker
Covariate: Summer.Days.below.15MAD
Covariate Slope: -0.011
Log Likelihood: -10.45
AICc: 30.33
r2: 0.75



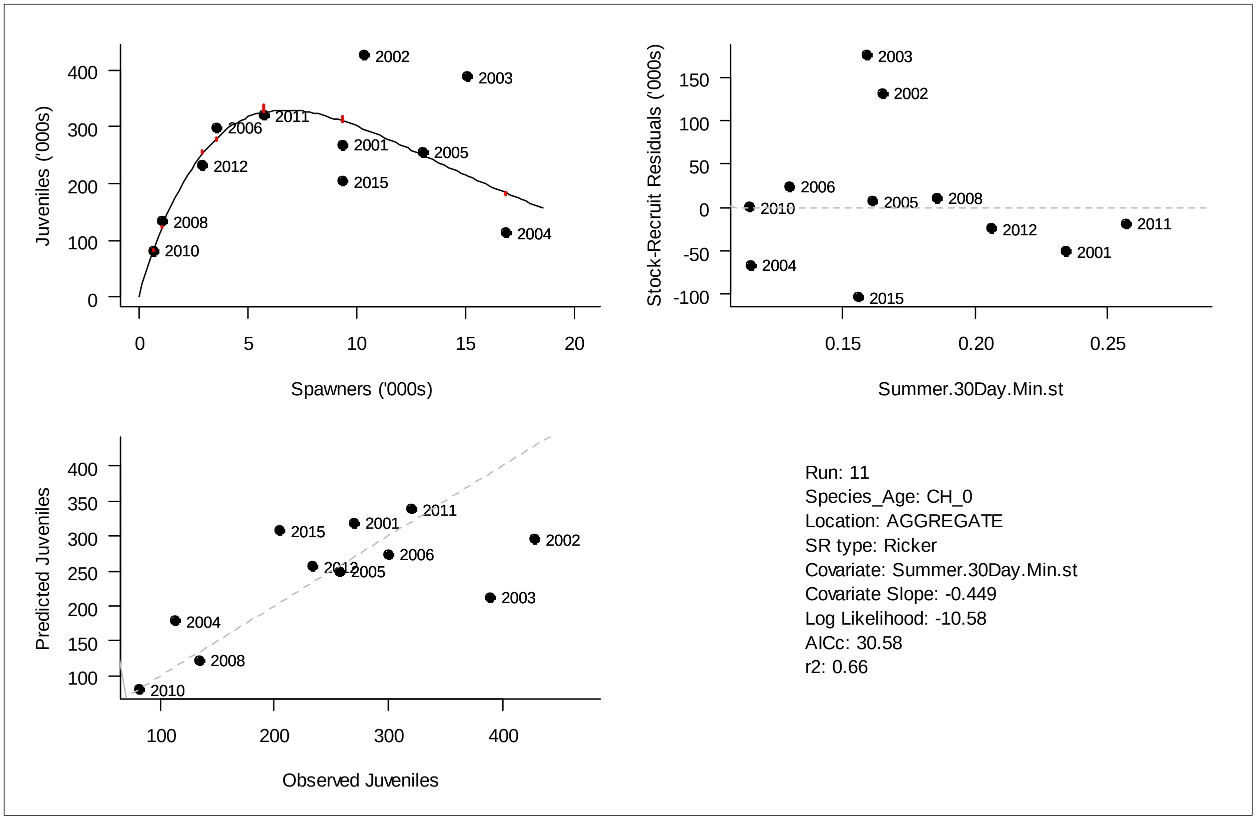
Run: 8
Species_Age: CH_0
Location: AGGREGATE
SR type: Ricker
Covariate: July.Daily.Min.st
Covariate Slope: -0.158
Log Likelihood: -10.57
AICc: 30.57
r2: 0.66



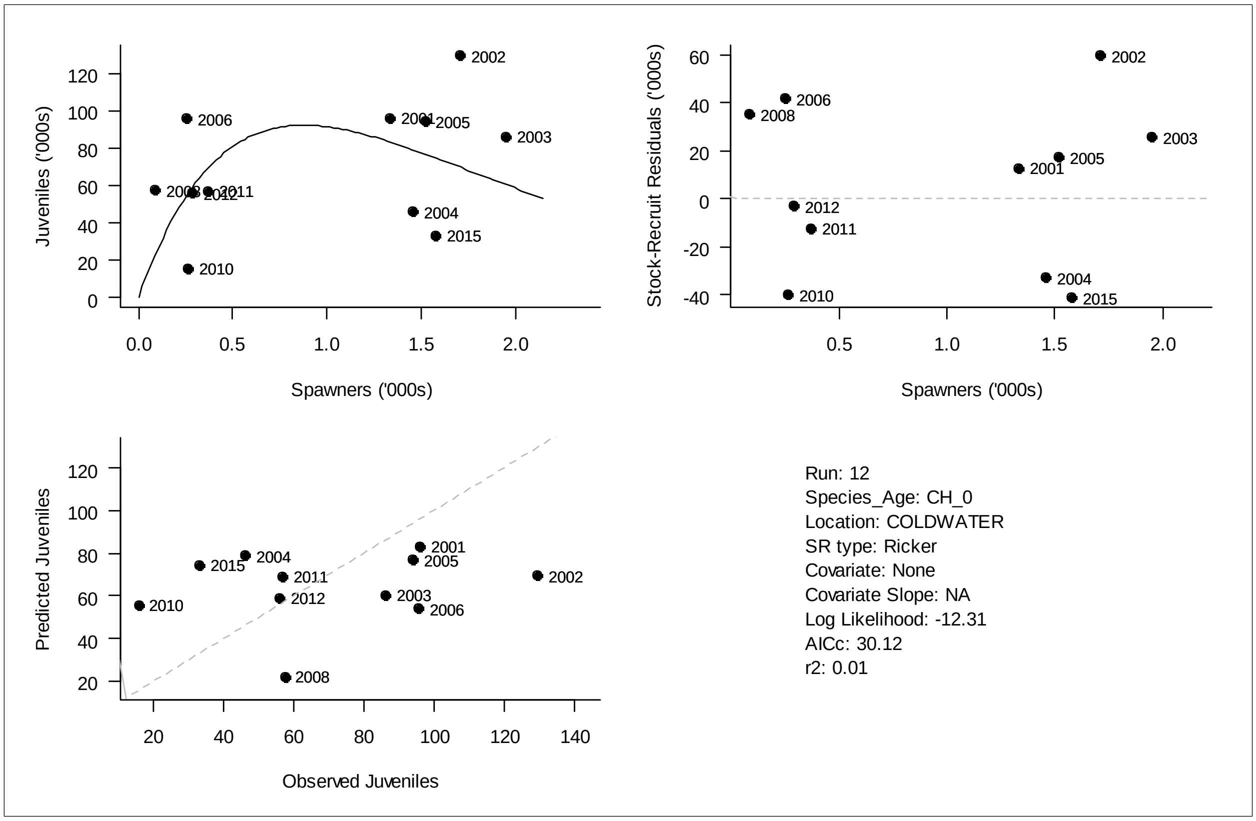
Run: 9
Species_Age: CH_0
Location: AGGREGATE
SR type: Ricker
Covariate: August.Daily.Min.st
Covariate Slope: 0.144
Log Likelihood: -10.58
AICc: 30.58
r2: 0.66



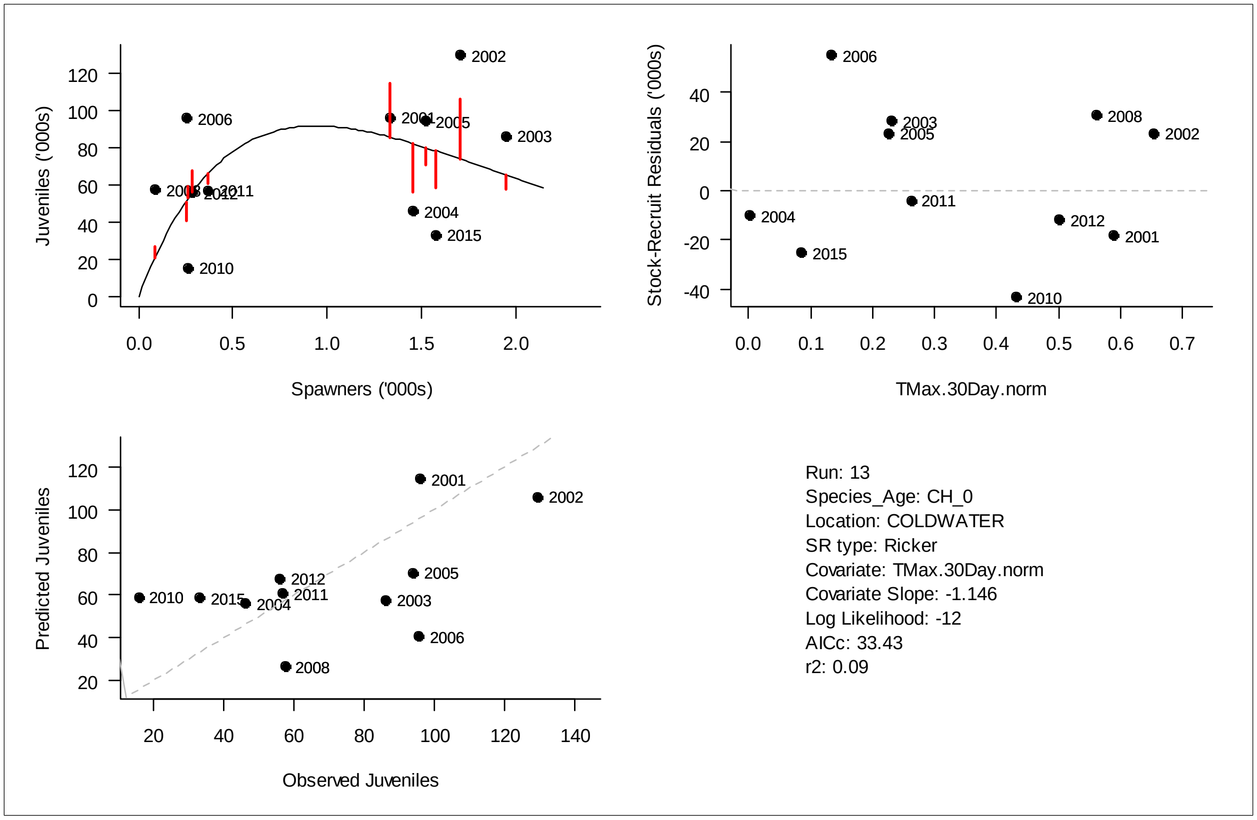
Run: 10
Species_Age: CH_0
Location: AGGREGATE
SR type: Ricker
Covariate: September.Daily.Min.st
Covariate Slope: 5.918
Log Likelihood: -10.45
AICc: 30.32
r2: 0.77



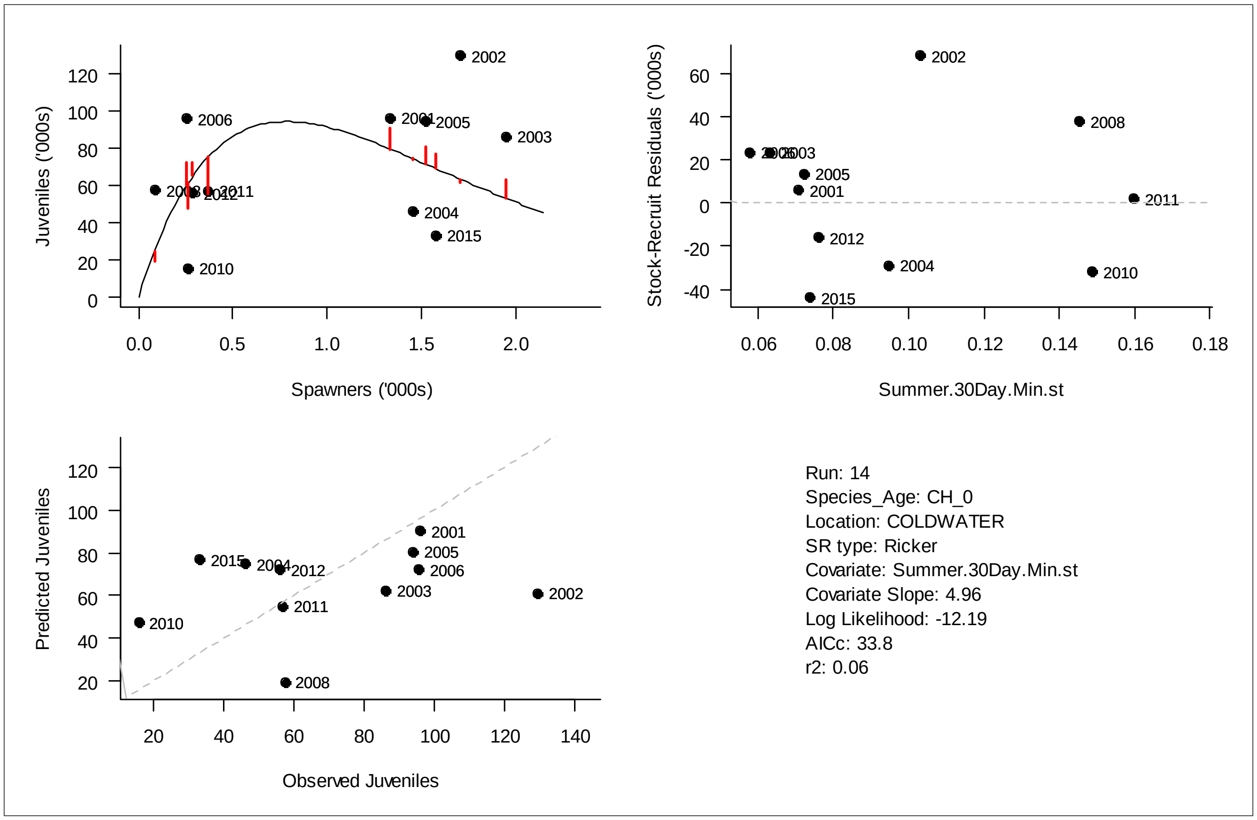
Run: 11
Species_Age: CH_0
Location: AGGREGATE
SR type: Ricker
Covariate: Summer.30Day.Min.st
Covariate Slope: -0.449
Log Likelihood: -10.58
AICc: 30.58
r2: 0.66



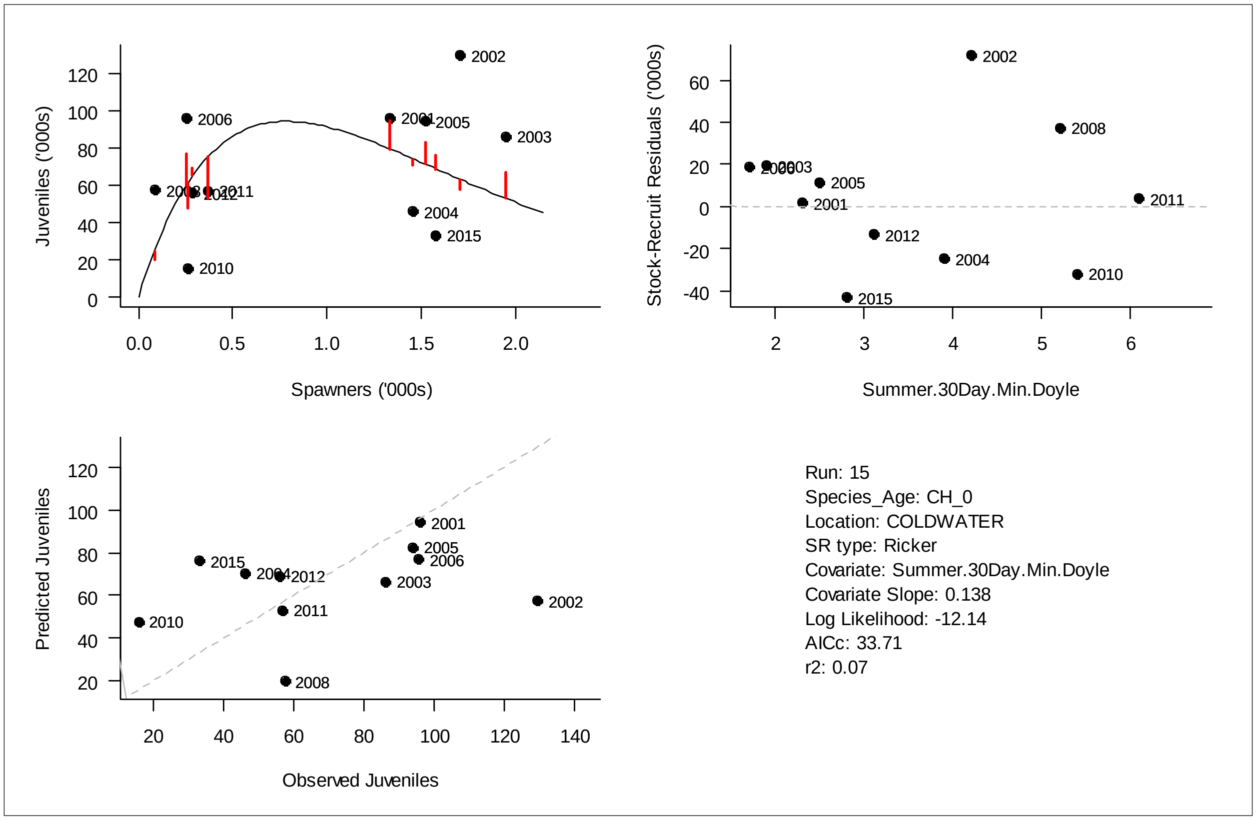
Run: 12
Species_Age: CH_0
Location: COLDWATER
SR type: Ricker
Covariate: None
Covariate Slope: NA
Log Likelihood: -12.31
AICc: 30.12
r2: 0.01



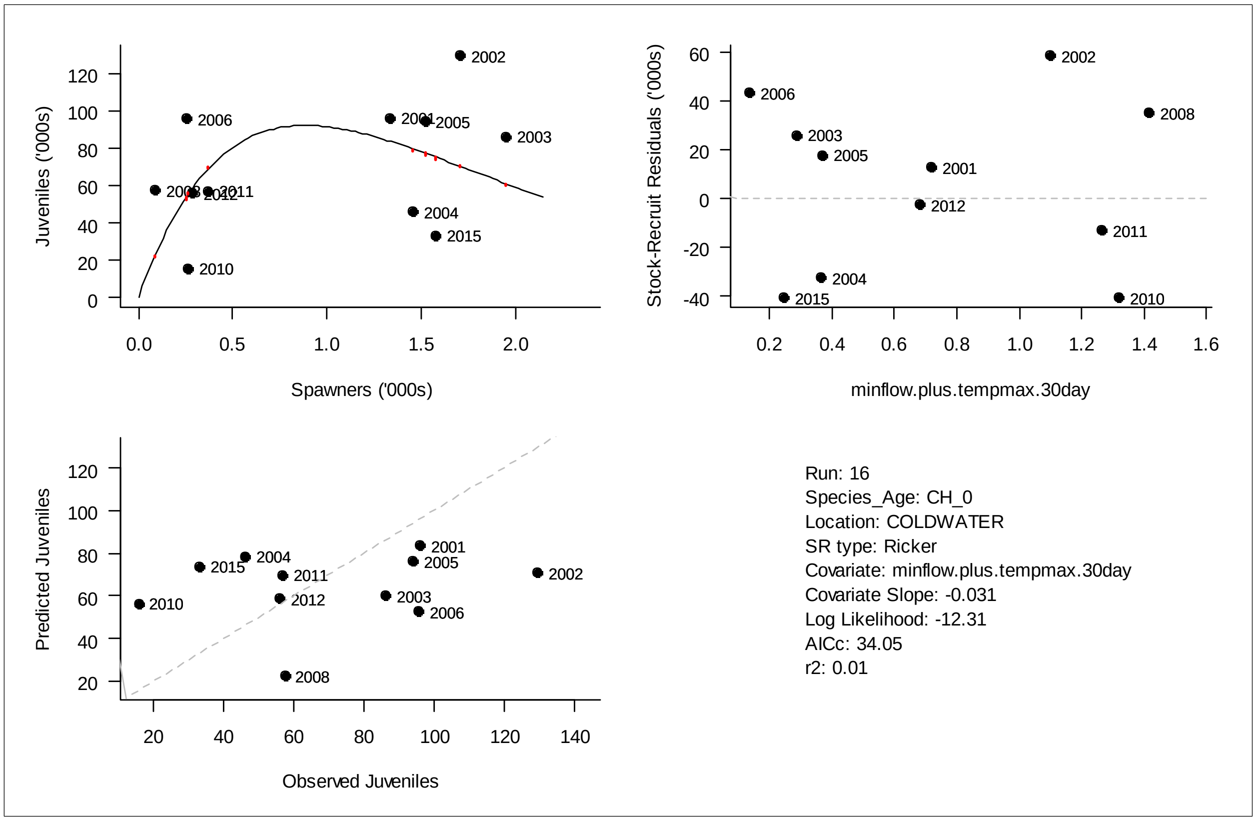
Run: 13
Species_Age: CH_0
Location: COLDWATER
SR type: Ricker
Covariate: TMax.30Day.norm
Covariate Slope: -1.146
Log Likelihood: -12
AICc: 33.43
r2: 0.09



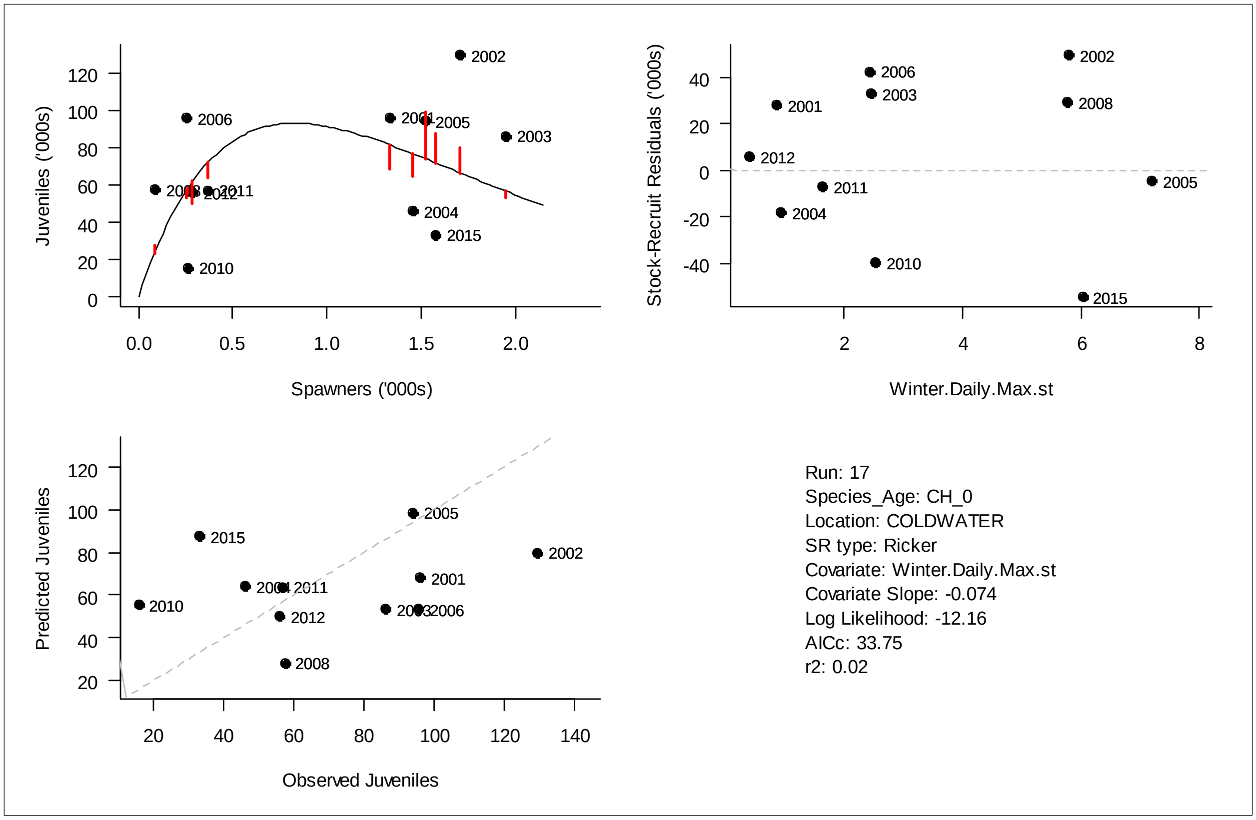
Run: 14
Species_Age: CH_0
Location: COLDWATER
SR type: Ricker
Covariate: Summer.30Day.Min.st
Covariate Slope: 4.96
Log Likelihood: -12.19
AICc: 33.8
r2: 0.06



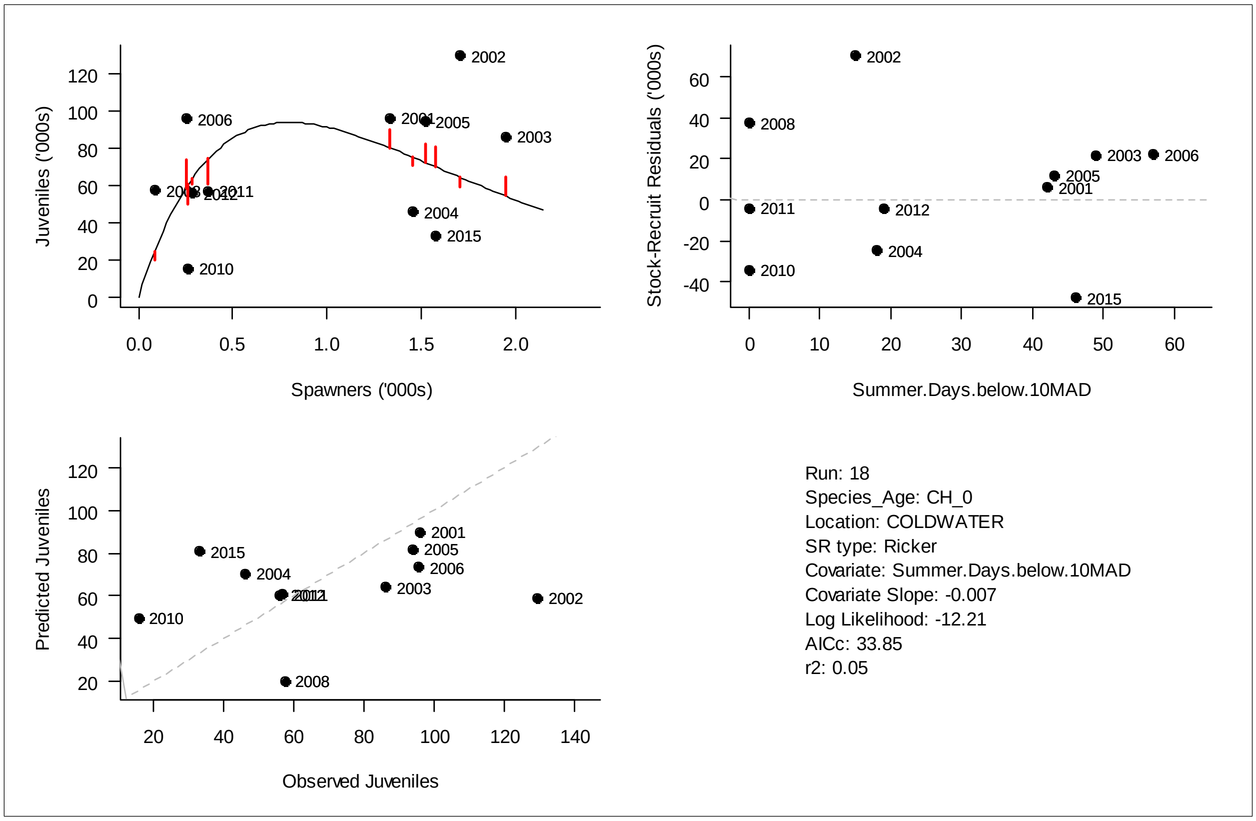
Run: 15
Species_Age: CH_0
Location: COLDWATER
SR type: Ricker
Covariate: Summer.30Day.Min.Doyle
Covariate Slope: 0.138
Log Likelihood: -12.14
AICc: 33.71
r2: 0.07



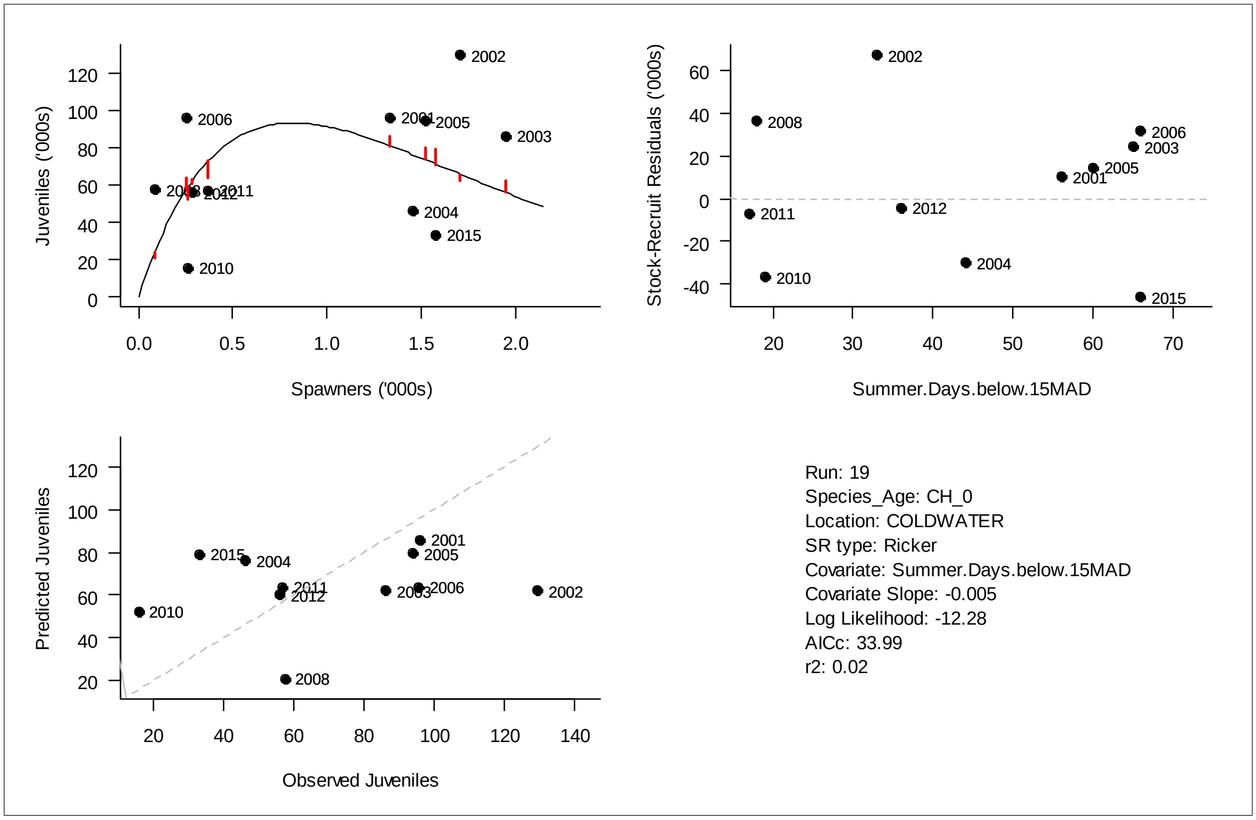
Run: 16
Species_Age: CH_0
Location: COLDWATER
SR type: Ricker
Covariate: minflow.plus.tempmax.30day
Covariate Slope: -0.031
Log Likelihood: -12.31
AICc: 34.05
r2: 0.01



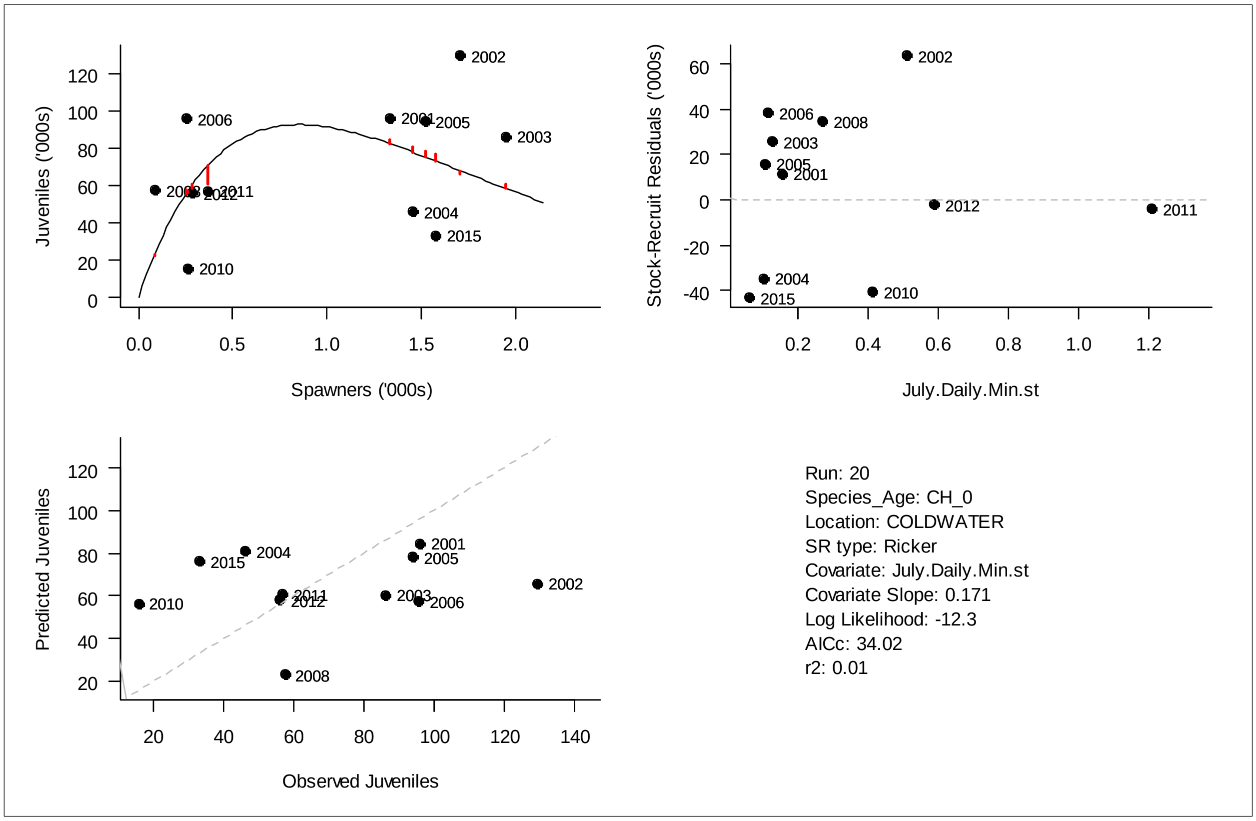
Run: 17
Species_Age: CH_0
Location: COLDWATER
SR type: Ricker
Covariate: Winter.Daily.Max.st
Covariate Slope: -0.074
Log Likelihood: -12.16
AICc: 33.75
r2: 0.02



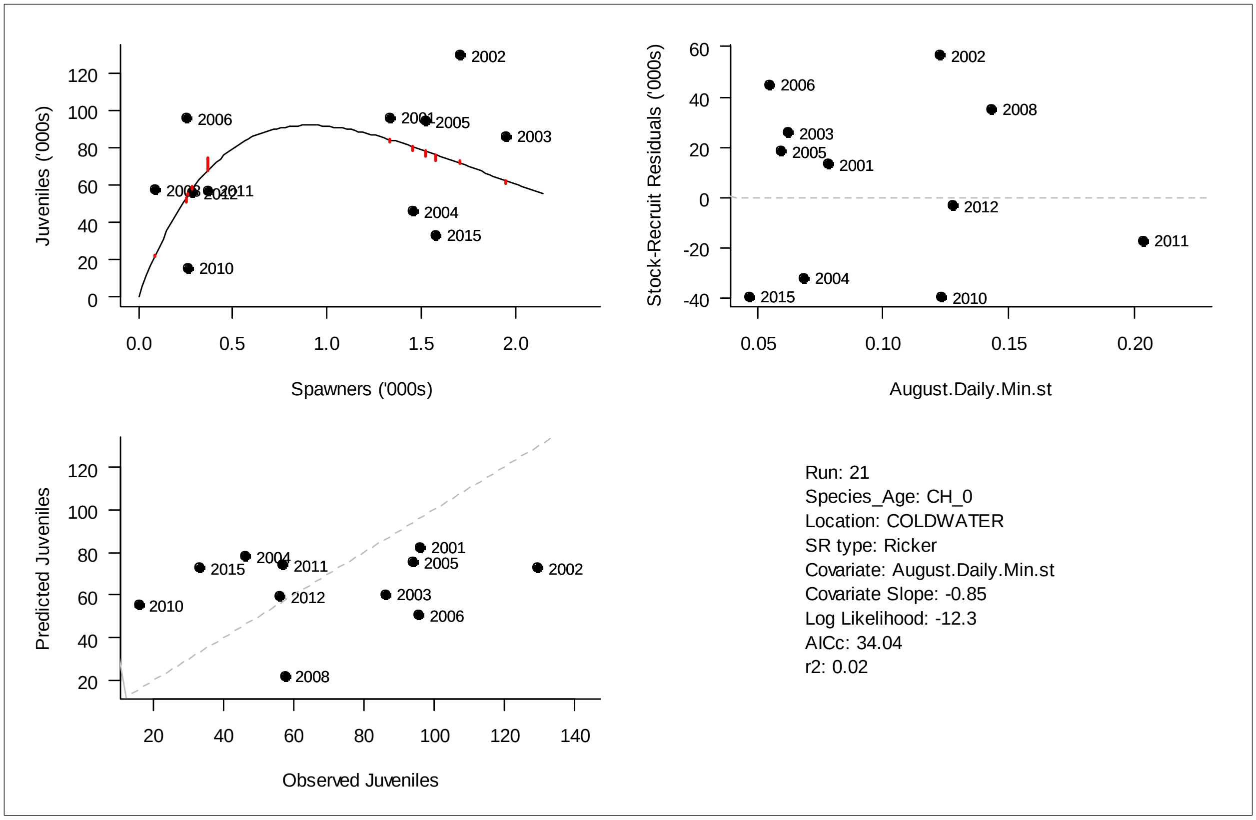
Run: 18
Species_Age: CH_0
Location: COLDWATER
SR type: Ricker
Covariate: Summer.Days.below.10MAD
Covariate Slope: -0.007
Log Likelihood: -12.21
AICc: 33.85
r2: 0.05



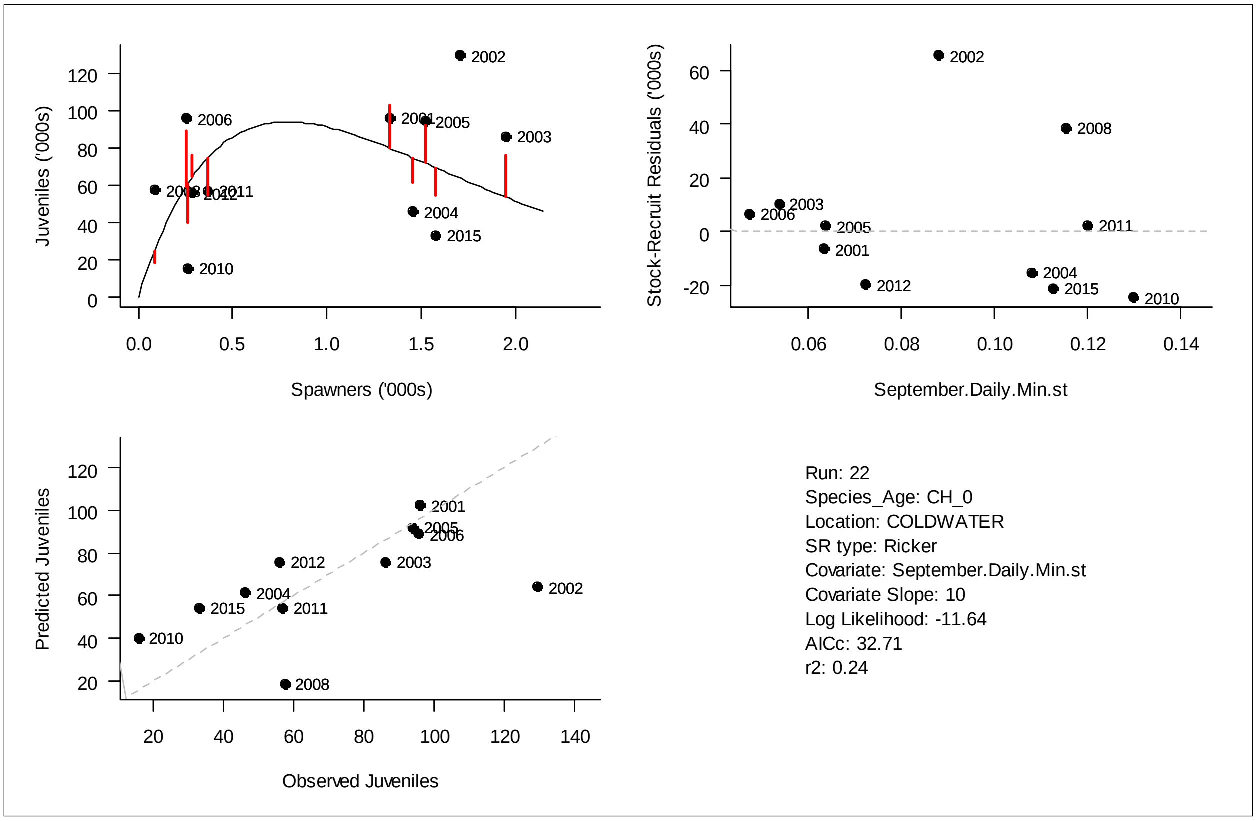
Run: 19
Species_Age: CH_0
Location: COLDWATER
SR type: Ricker
Covariate: Summer.Days.below.15MAD
Covariate Slope: -0.005
Log Likelihood: -12.28
AICc: 33.99
r2: 0.02



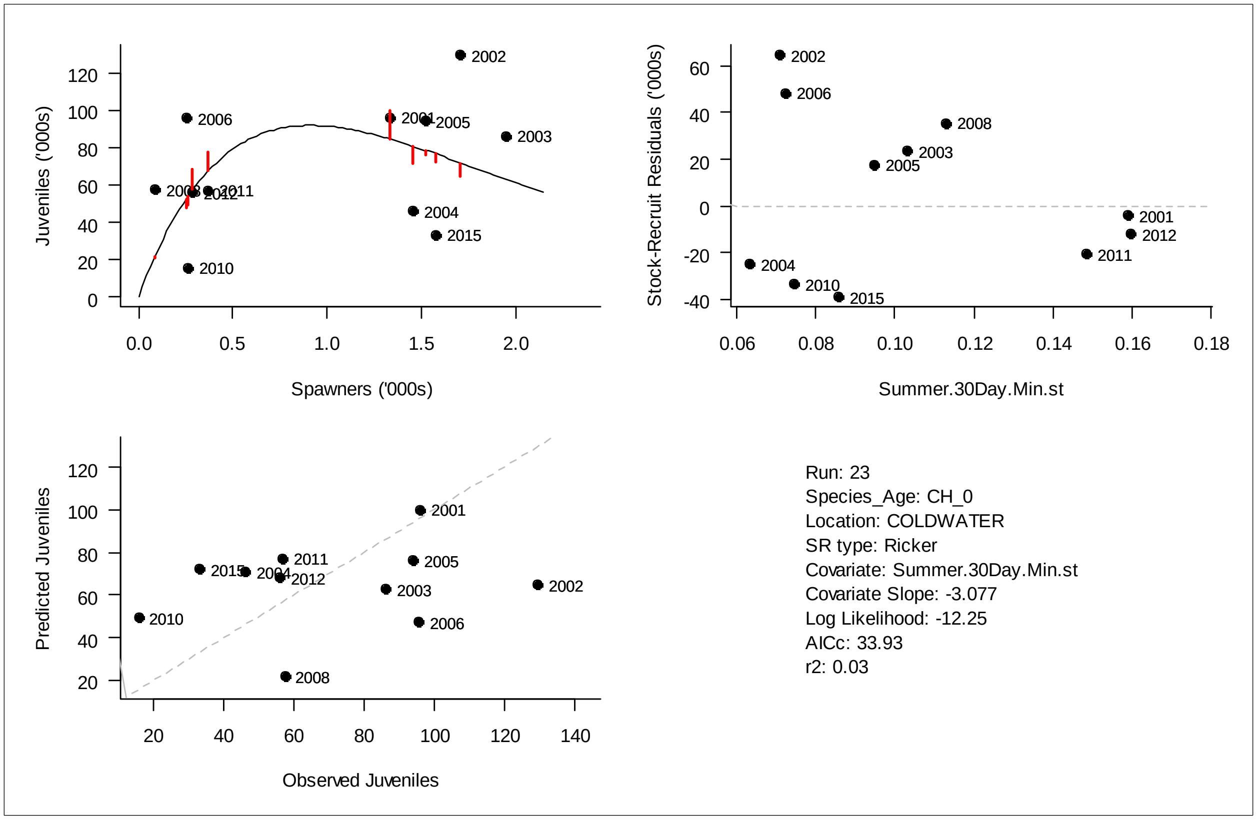
Run: 20
Species_Age: CH_0
Location: COLDWATER
SR type: Ricker
Covariate: July.Daily.Min.st
Covariate Slope: 0.171
Log Likelihood: -12.3
AICc: 34.02
r2: 0.01



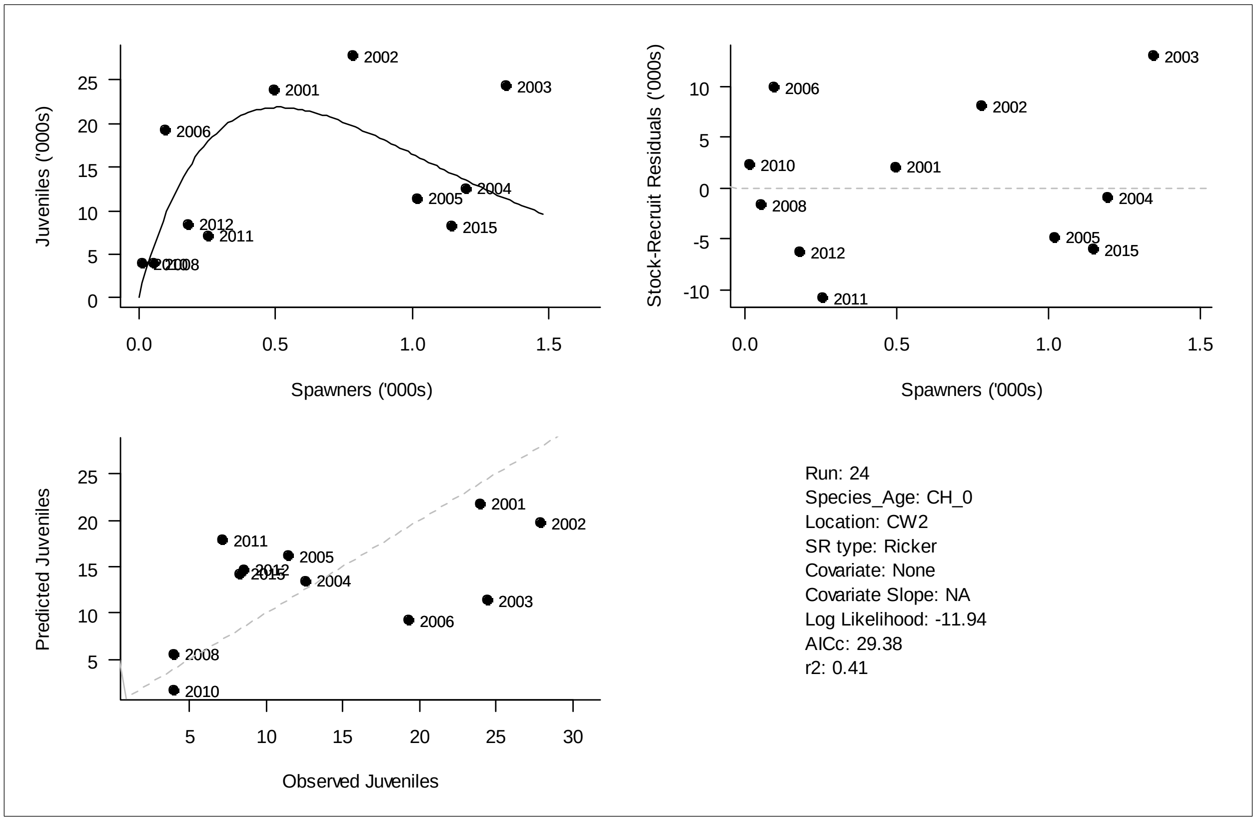
Run: 21
Species_Age: CH_0
Location: COLDWATER
SR type: Ricker
Covariate: August.Daily.Min.st
Covariate Slope: -0.85
Log Likelihood: -12.3
AICc: 34.04
r2: 0.02



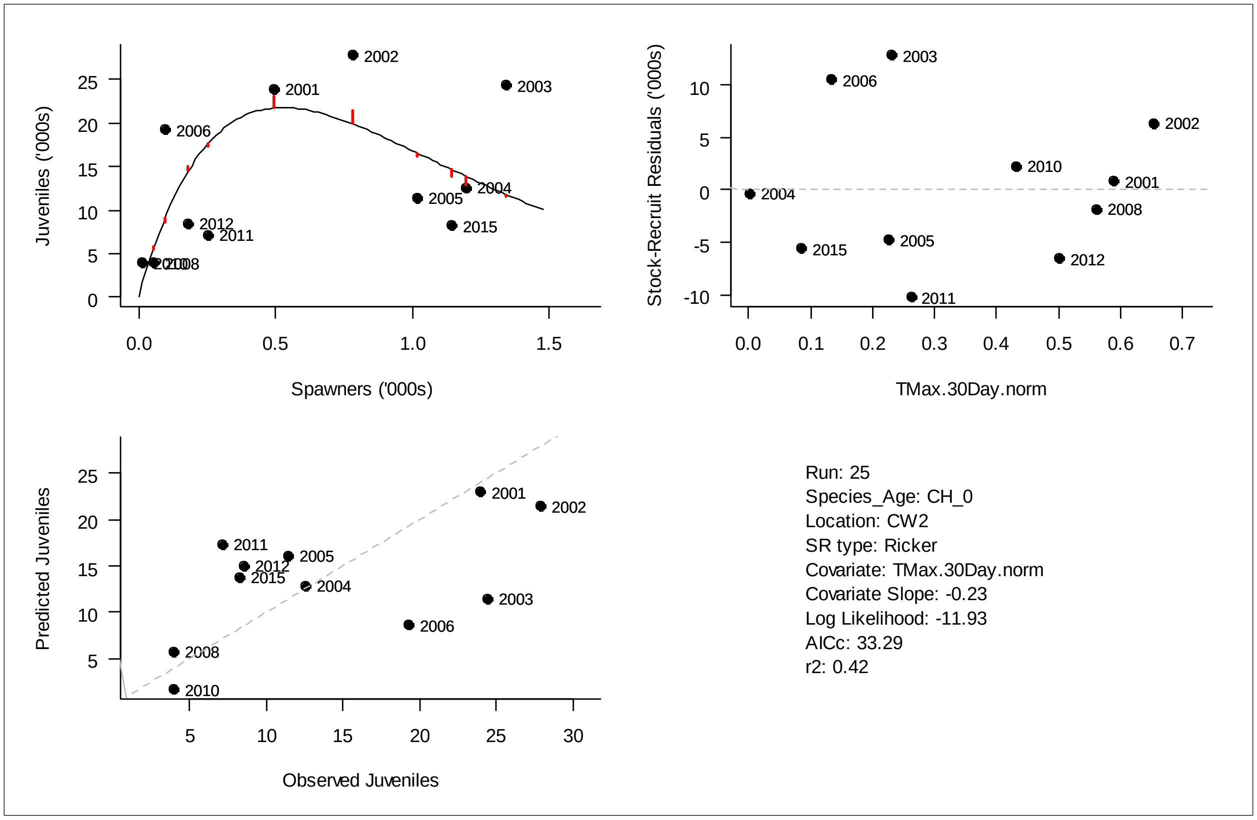
Run: 22
Species_Age: CH_0
Location: COLDWATER
SR type: Ricker
Covariate: September.Daily.Min.st
Covariate Slope: 10
Log Likelihood: -11.64
AICc: 32.71
r2: 0.24



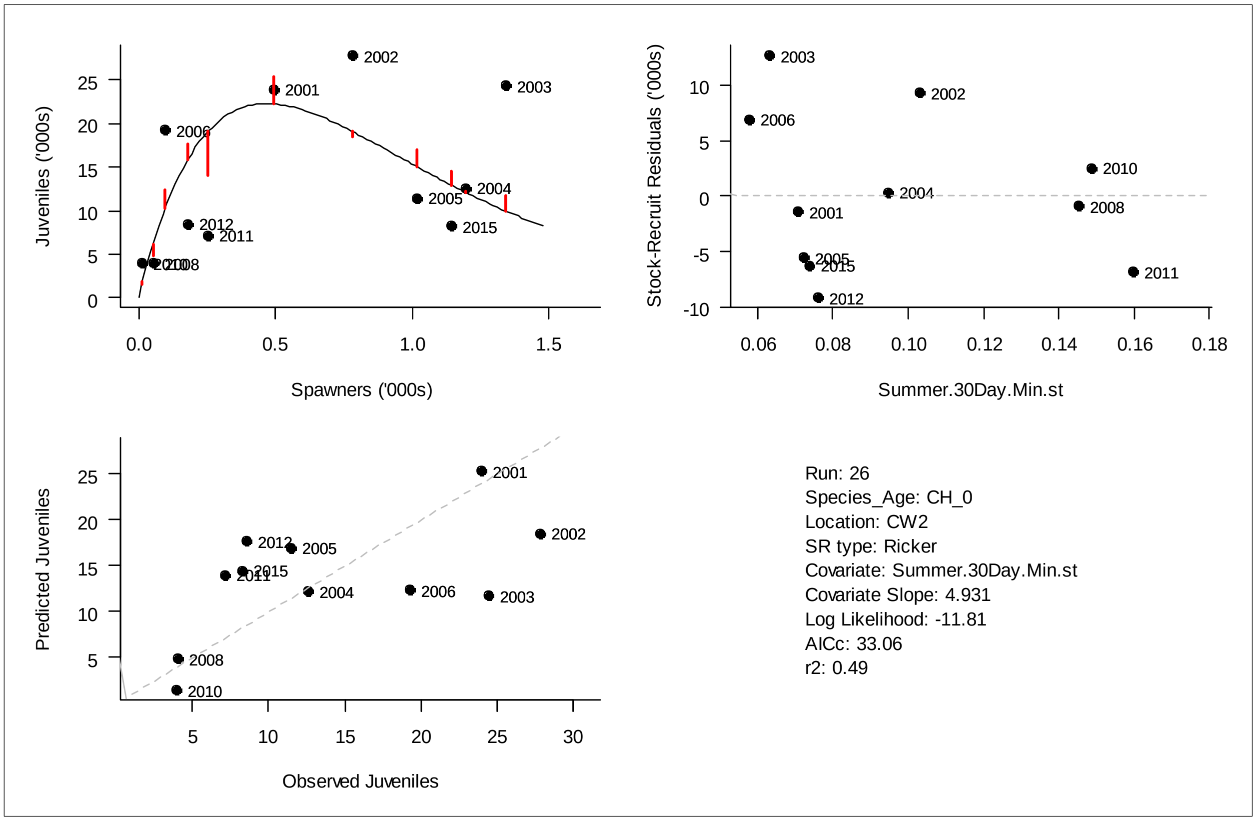
Run: 23
Species_Age: CH_0
Location: COLDWATER
SR type: Ricker
Covariate: Summer.30Day.Min.st
Covariate Slope: -3.077
Log Likelihood: -12.25
AICc: 33.93
r2: 0.03



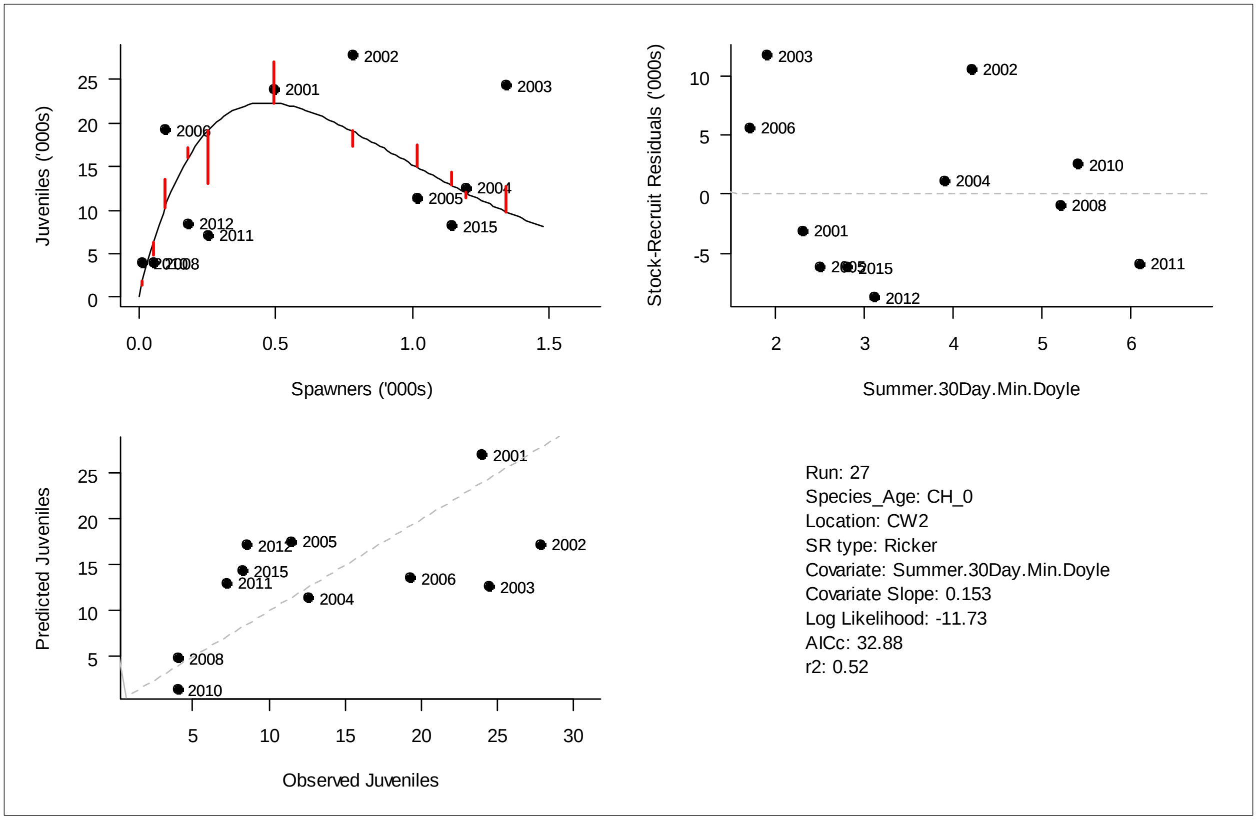
Run: 24
Species_Age: CH_0
Location: CW2
SR type: Ricker
Covariate: None
Covariate Slope: NA
Log Likelihood: -11.94
AICc: 29.38
r2: 0.41



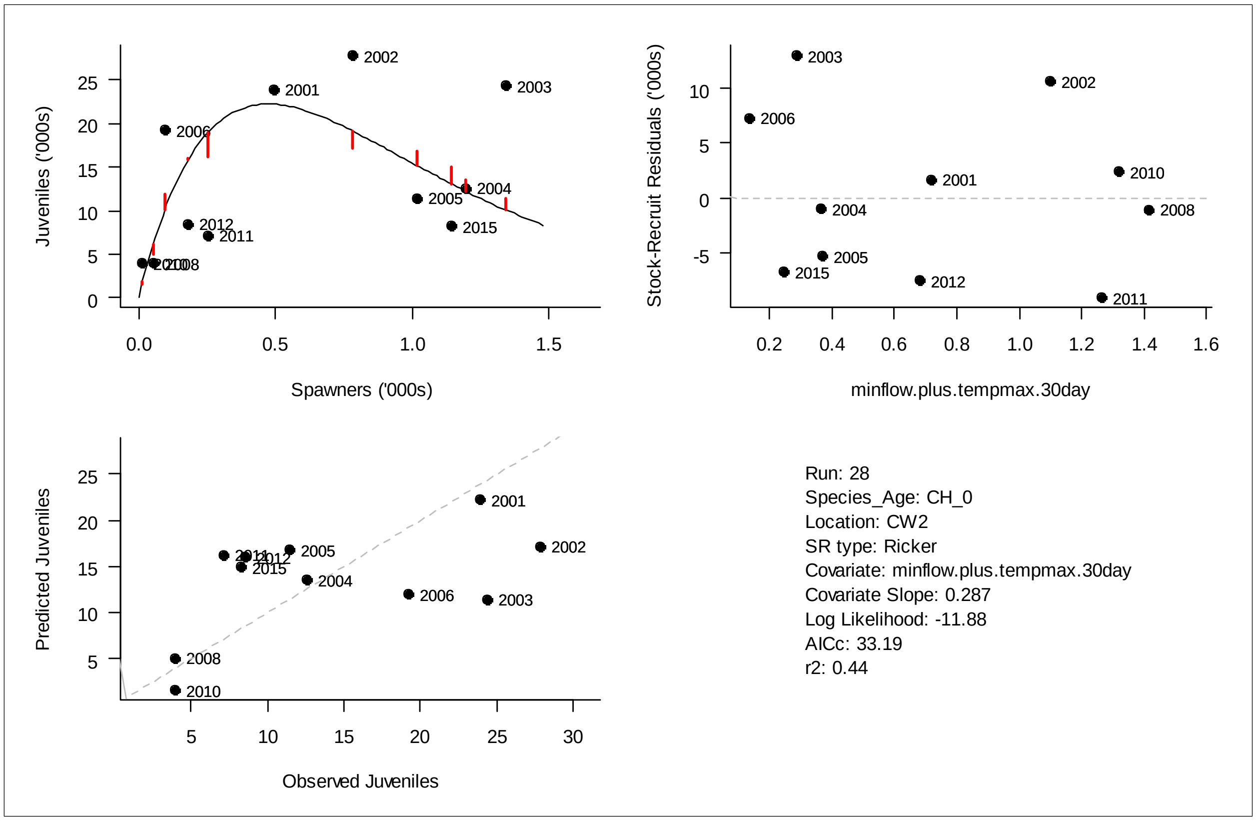
Run: 25
Species_Age: CH_0
Location: CW2
SR type: Ricker
Covariate: TMax.30Day.norm
Covariate Slope: -0.23
Log Likelihood: -11.93
AICc: 33.29
r2: 0.42



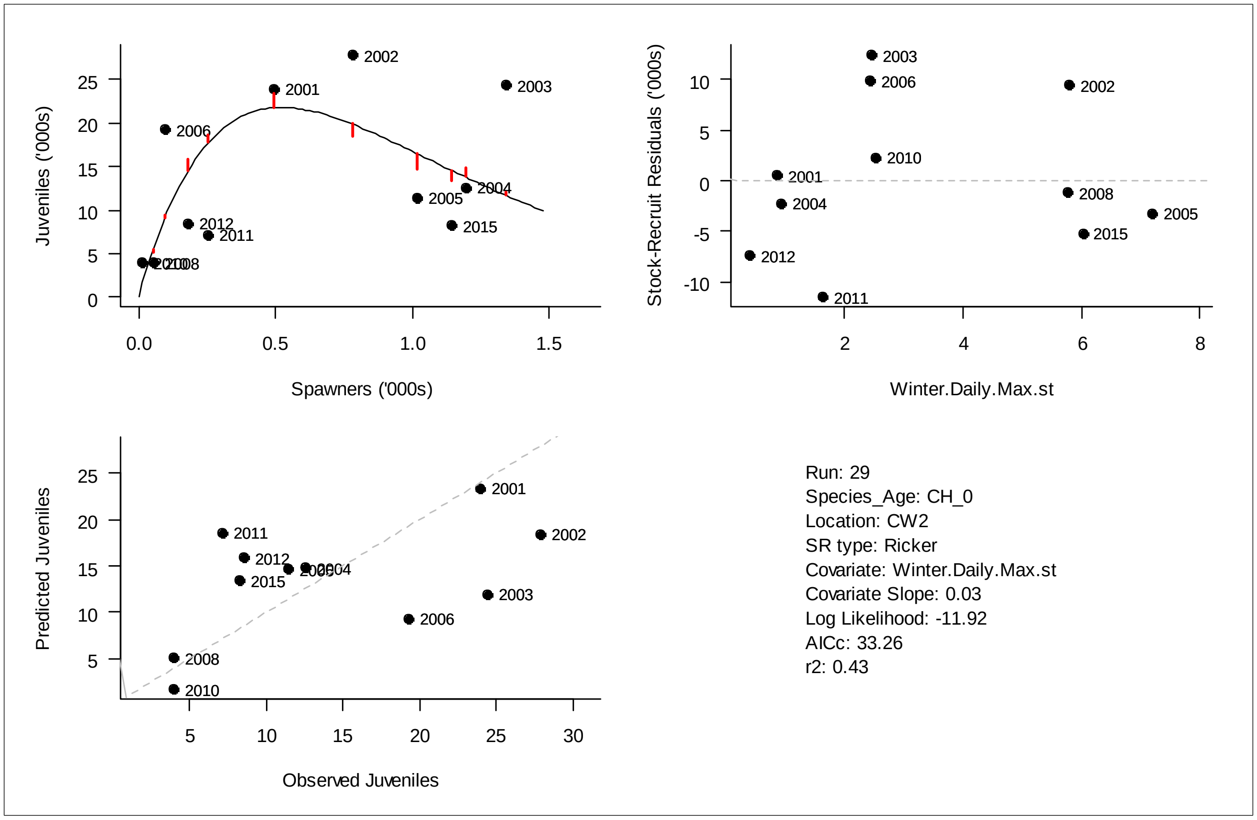
Run: 26
Species_Age: CH_0
Location: CW2
SR type: Ricker
Covariate: Summer.30Day.Min.st
Covariate Slope: 4.931
Log Likelihood: -11.81
AICc: 33.06
r2: 0.49



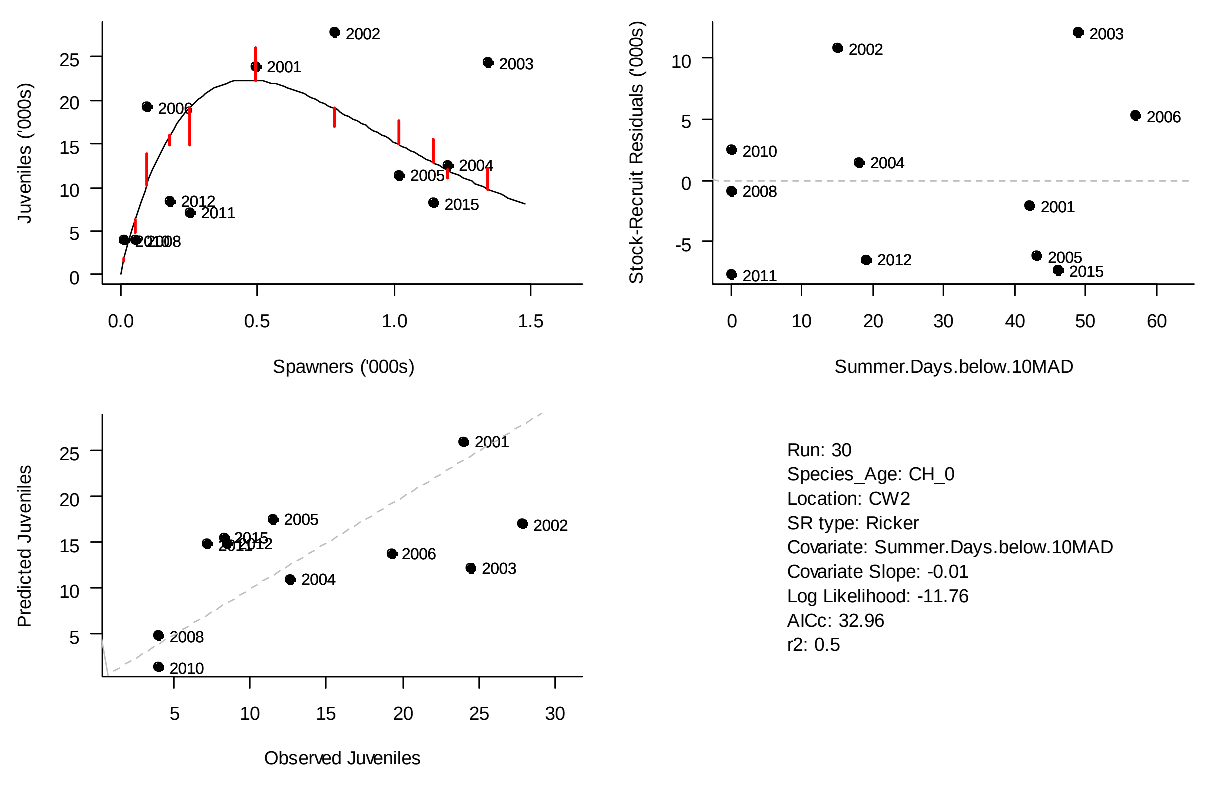
Run: 27
Species_Age: CH_0
Location: CW2
SR type: Ricker
Covariate: Summer.30Day.Min.Doyle
Covariate Slope: 0.153
Log Likelihood: -11.73
AICc: 32.88
r2: 0.52



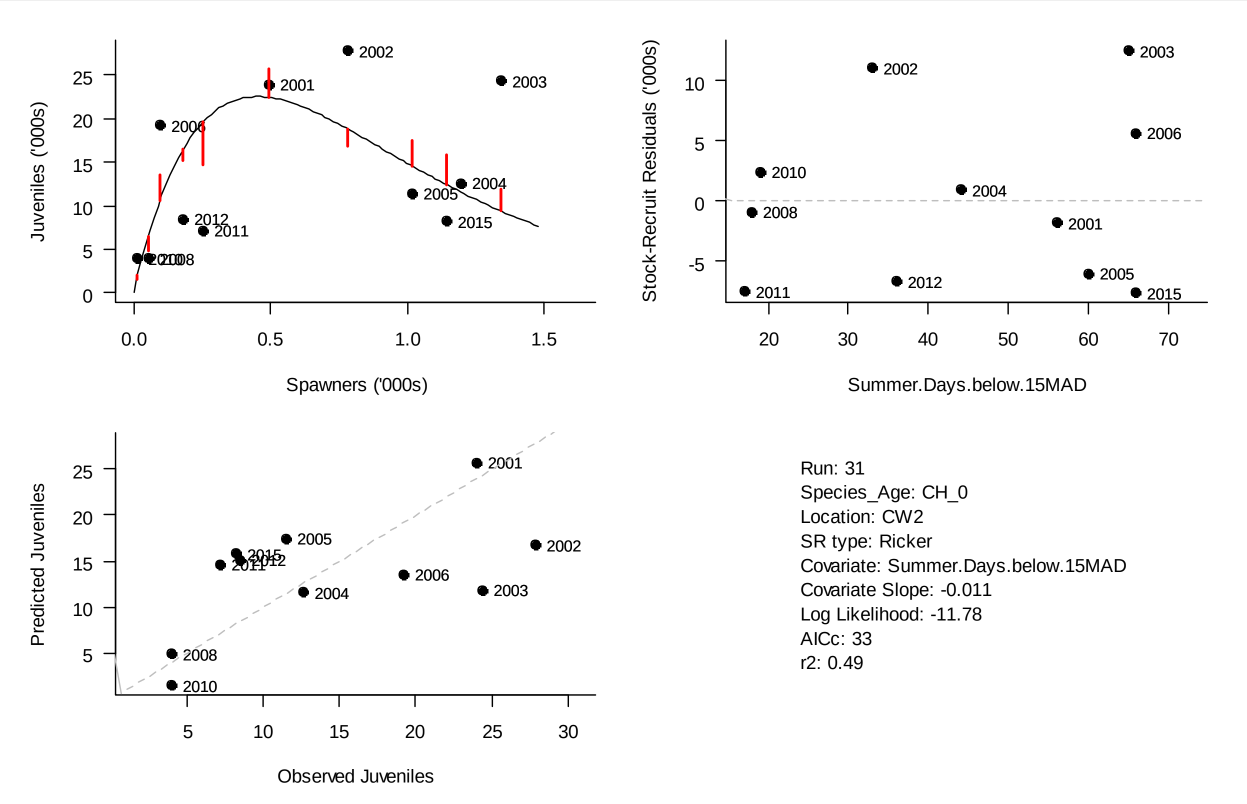
Run: 28
Species_Age: CH_0
Location: CW2
SR type: Ricker
Covariate: minflow.plus.tempmax.30day
Covariate Slope: 0.287
Log Likelihood: -11.88
AICc: 33.19
r2: 0.44



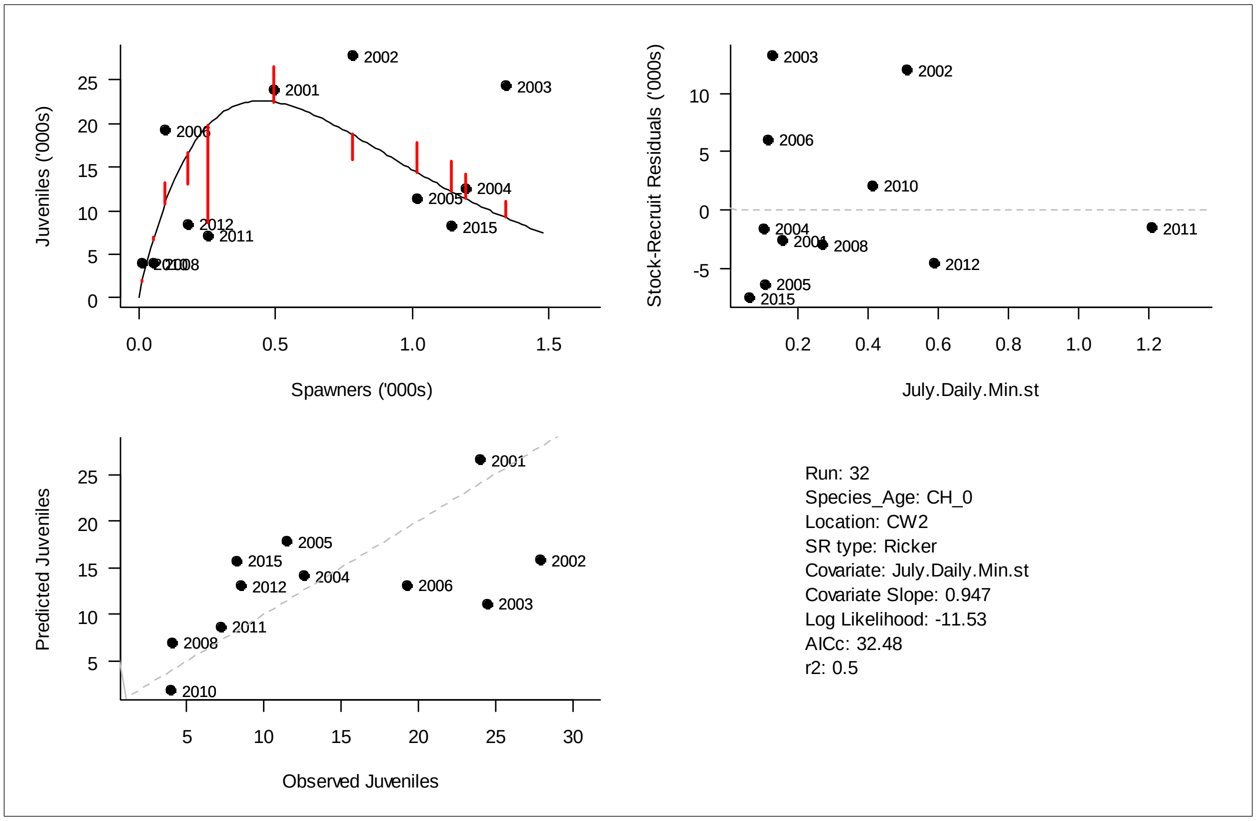
Run: 29
Species_Age: CH_0
Location: CW2
SR type: Ricker
Covariate: Winter.Daily.Max.st
Covariate Slope: 0.03
Log Likelihood: -11.92
AICc: 33.26
r2: 0.43



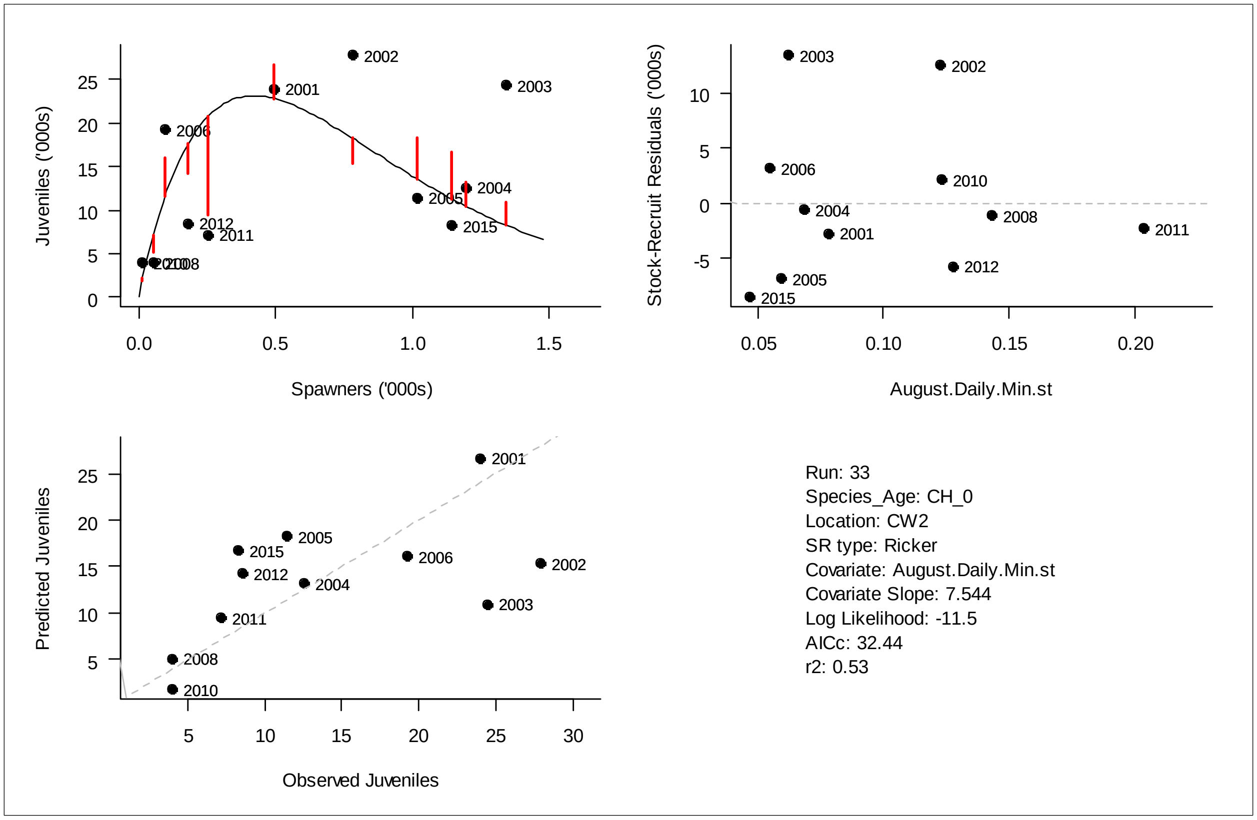
Run: 30
Species_Age: CH_0
Location: CW2
SR type: Ricker
Covariate: Summer.Days.below.10MAD
Covariate Slope: -0.01
Log Likelihood: -11.76
AICc: 32.96
r2: 0.5



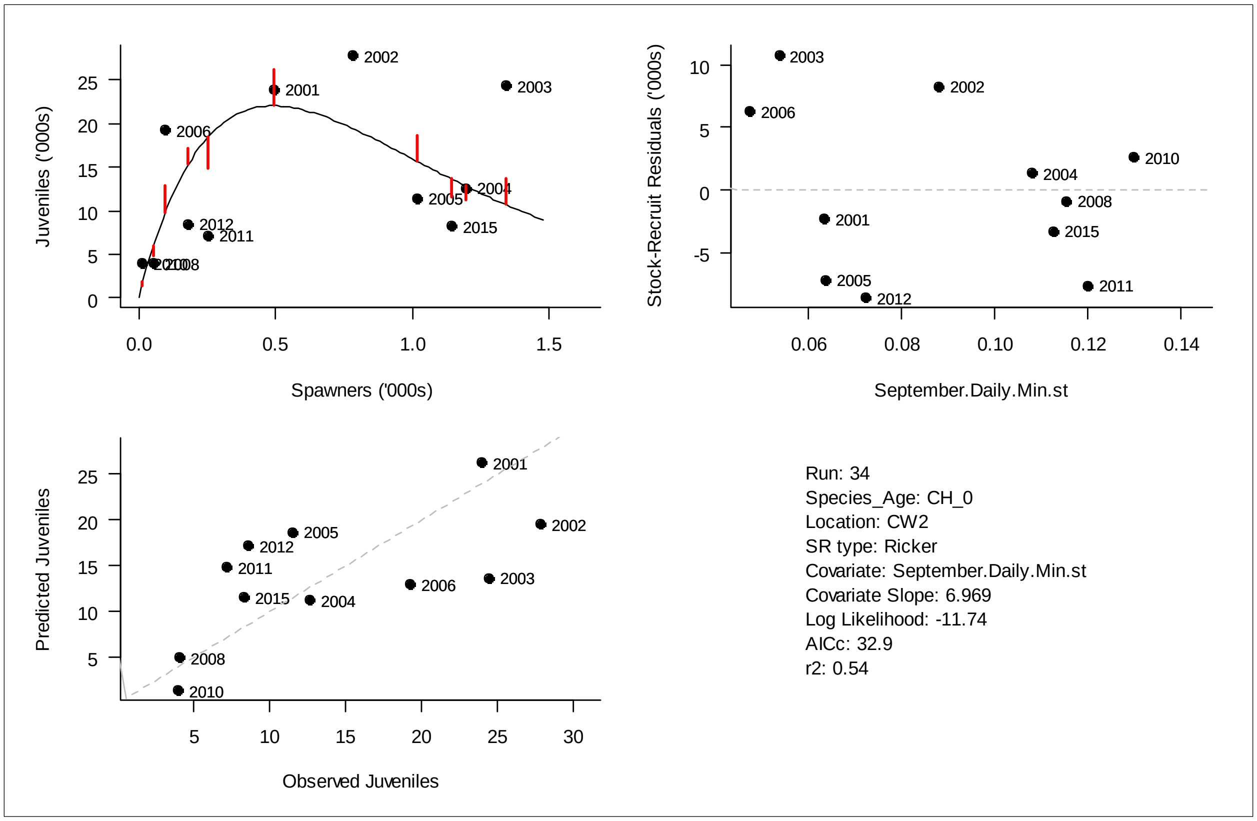
Run: 31
Species_Age: CH_0
Location: CW2
SR type: Ricker
Covariate: Summer.Days.below.15MAD
Covariate Slope: -0.011
Log Likelihood: -11.78
AICc: 33
r2: 0.49



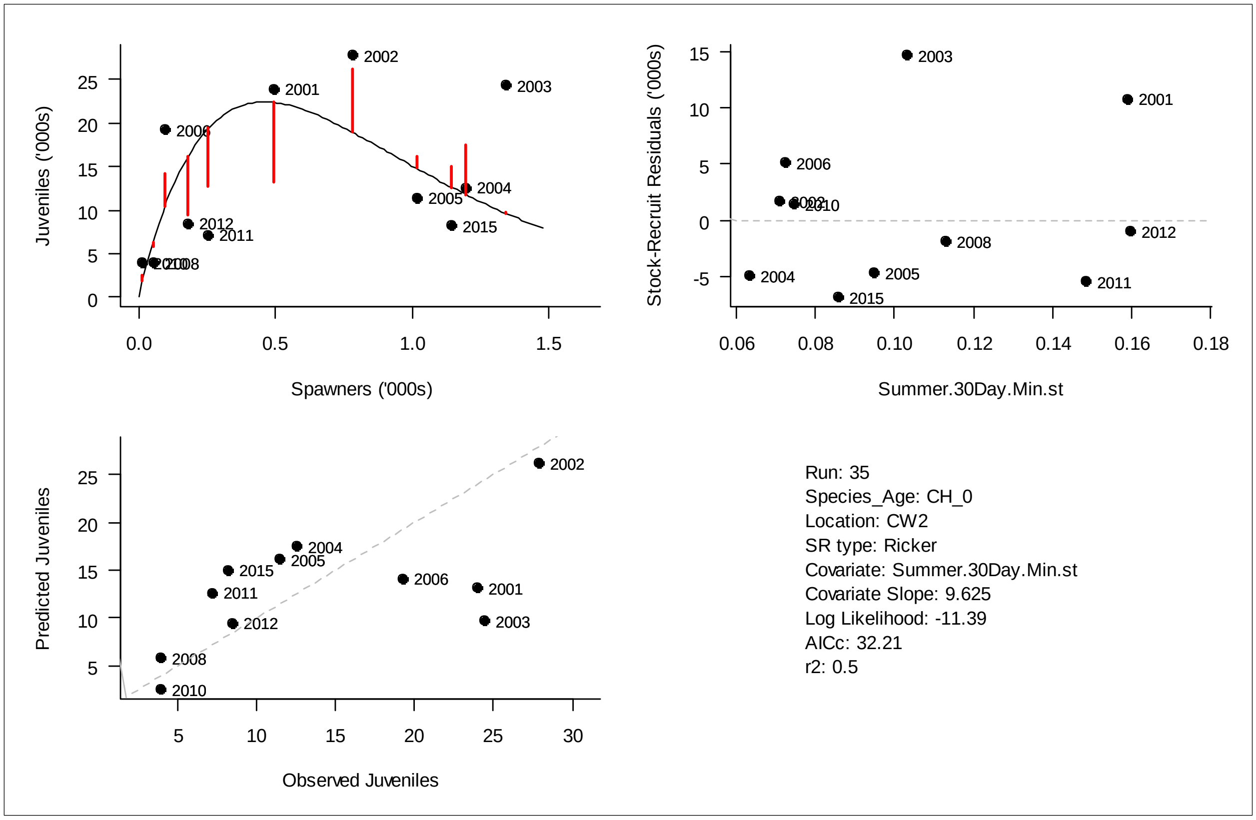
Run: 32
Species_Age: CH_0
Location: CW2
SR type: Ricker
Covariate: July.Daily.Min.st
Covariate Slope: 0.947
Log Likelihood: -11.53
AICc: 32.48
r2: 0.5



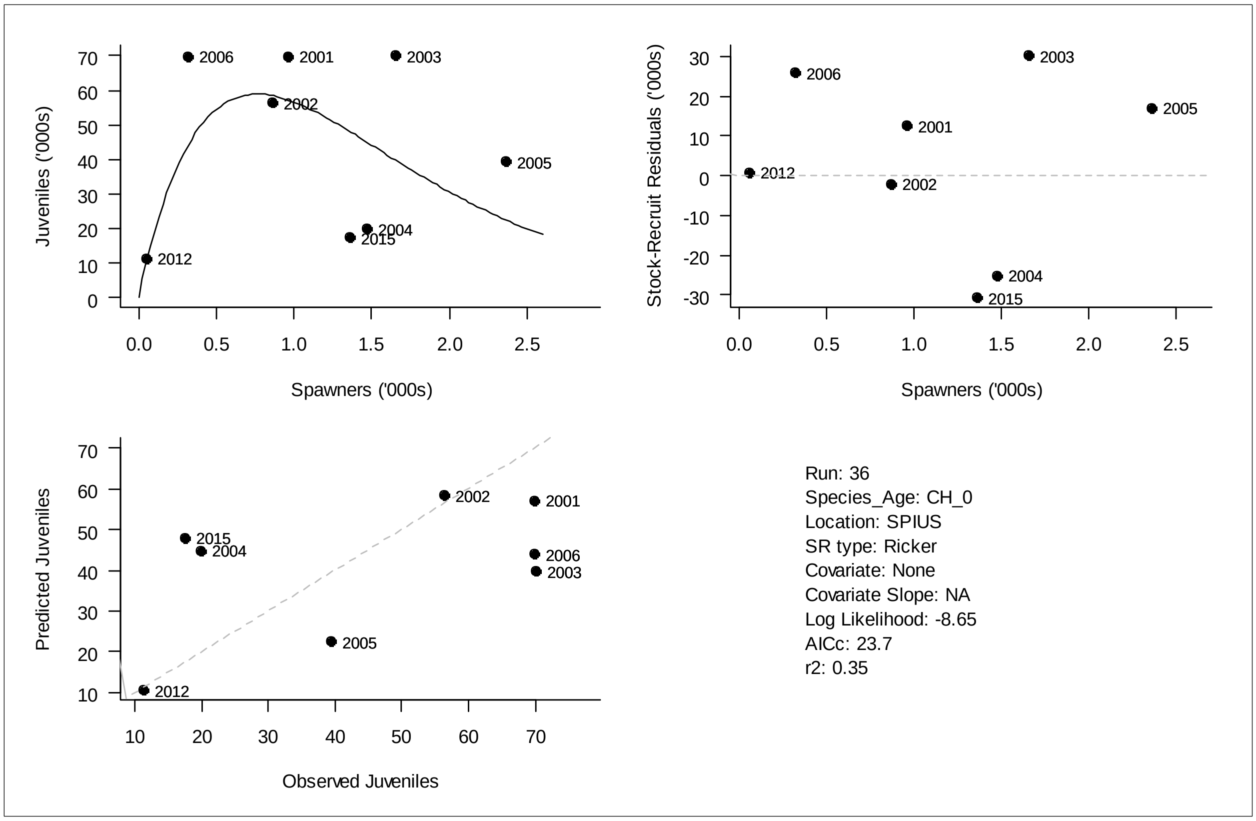
Run: 33
Species_Age: CH_0
Location: CW2
SR type: Ricker
Covariate: August.Daily.Min.st
Covariate Slope: 7.544
Log Likelihood: -11.5
AICc: 32.44
r2: 0.53



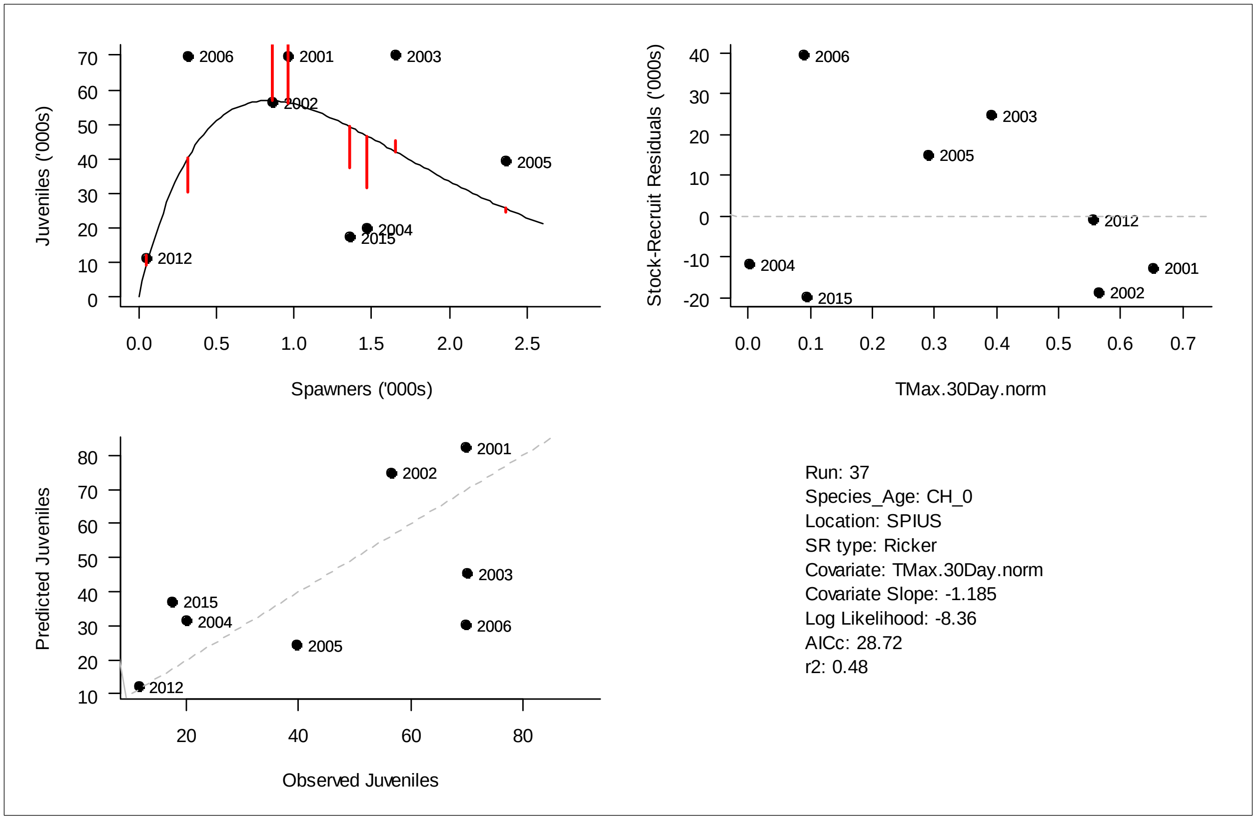
Run: 34
Species_Age: CH_0
Location: CW2
SR type: Ricker
Covariate: September.Daily.Min.st
Covariate Slope: 6.969
Log Likelihood: -11.74
AICc: 32.9
r2: 0.54



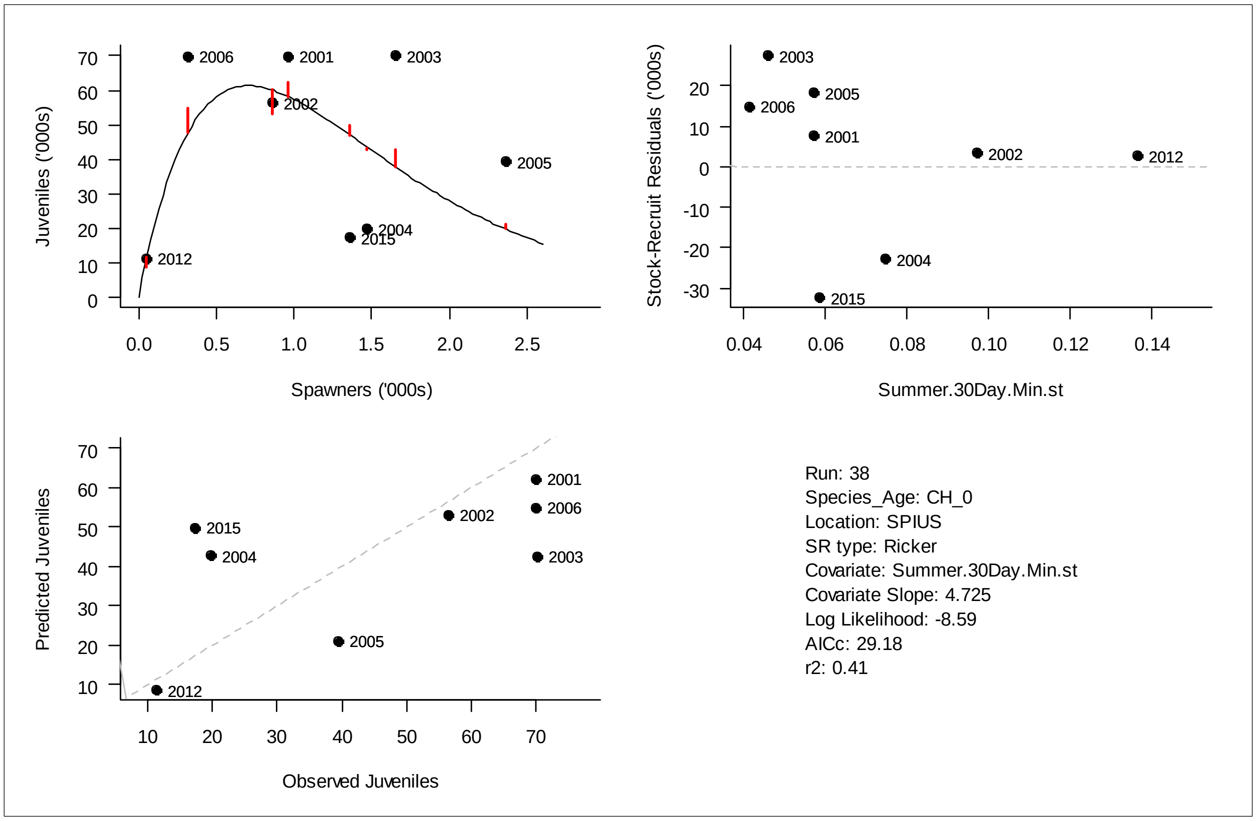
Run: 35
Species_Age: CH_0
Location: CW2
SR type: Ricker
Covariate: Summer.30Day.Min.st
Covariate Slope: 9.625
Log Likelihood: -11.39
AICc: 32.21
r2: 0.5



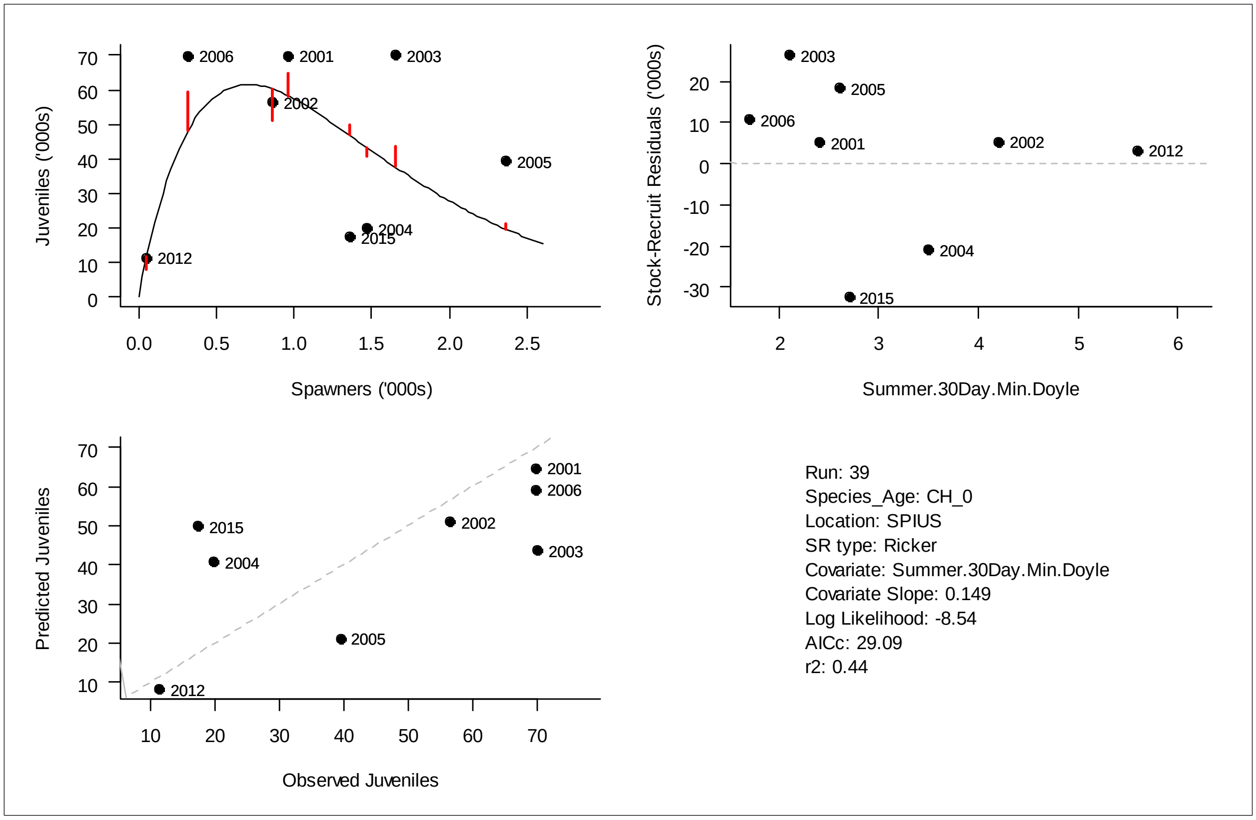
Run: 36
Species_Age: CH_0
Location: SPIUS
SR type: Ricker
Covariate: None
Covariate Slope: NA
Log Likelihood: -8.65
AICc: 23.7
r2: 0.35



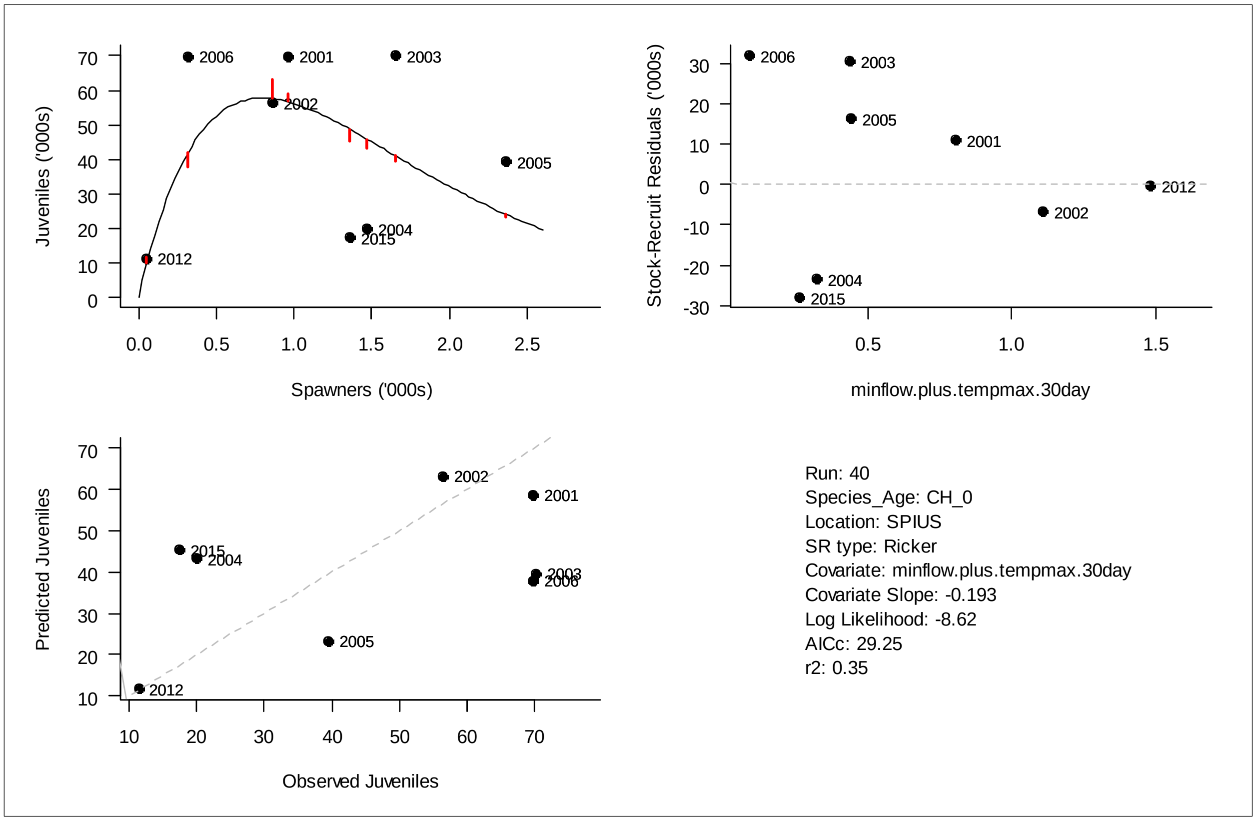
Run: 37
Species_Age: CH_0
Location: SPIUS
SR type: Ricker
Covariate: TMax.30Day.norm
Covariate Slope: -1.185
Log Likelihood: -8.36
AICc: 28.72
r2: 0.48



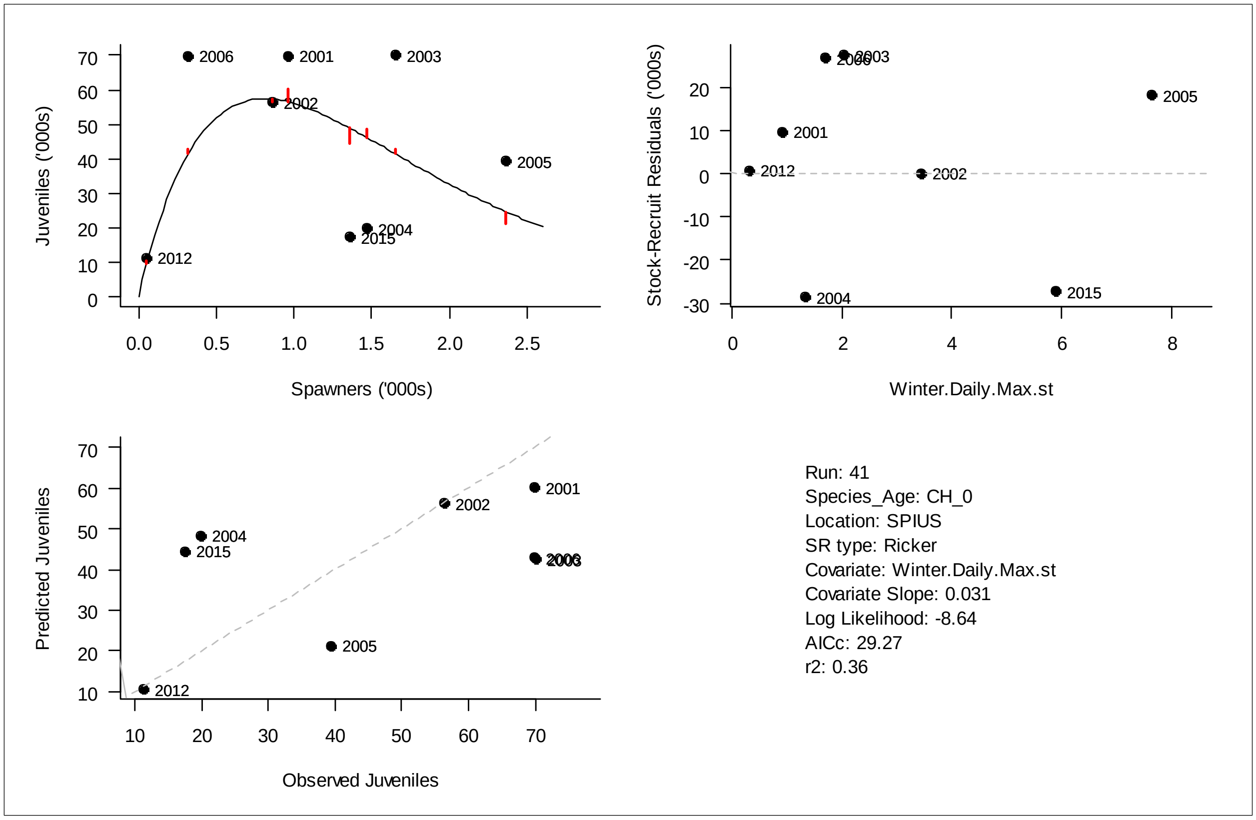
Run: 38
Species_Age: CH_0
Location: SPIUS
SR type: Ricker
Covariate: Summer.30Day.Min.st
Covariate Slope: 4.725
Log Likelihood: -8.59
AICc: 29.18
r2: 0.41



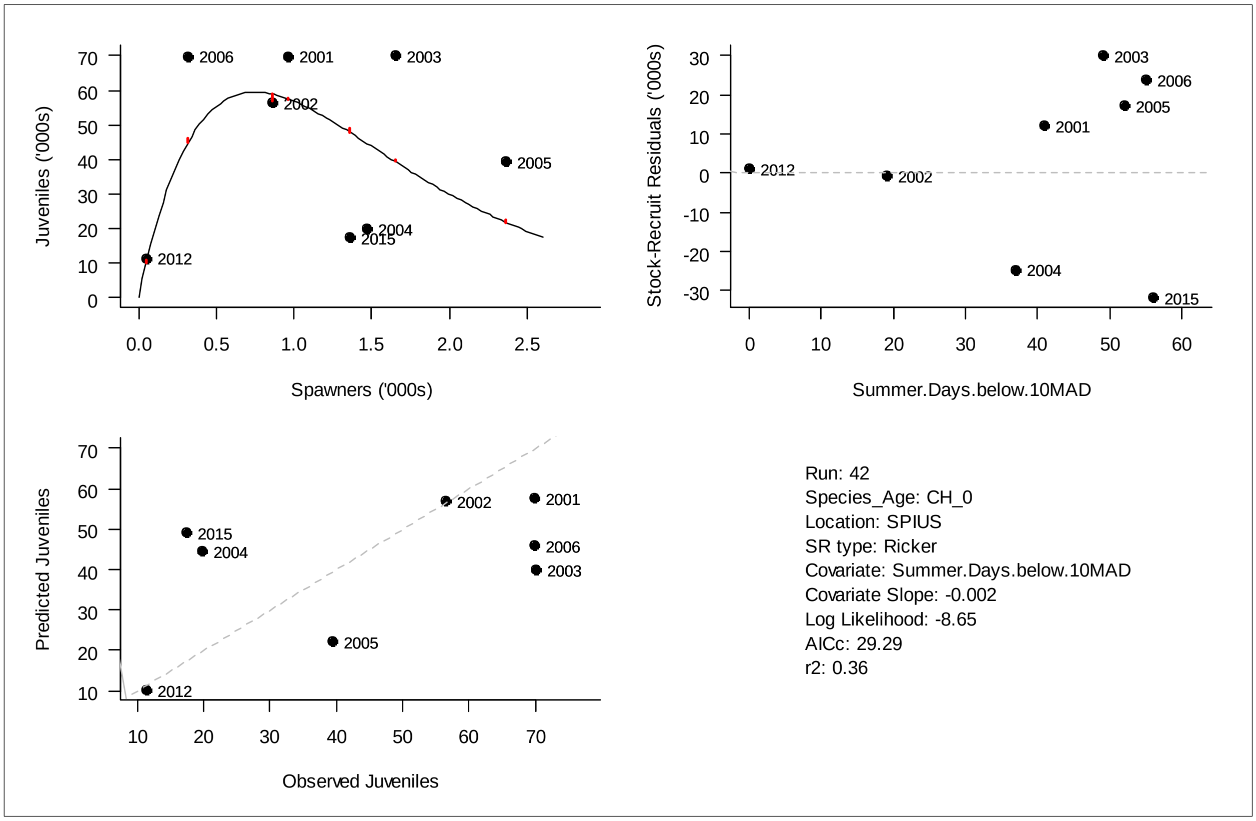
Run: 39
Species_Age: CH_0
Location: SPIUS
SR type: Ricker
Covariate: Summer.30Day.Min.Doyle
Covariate Slope: 0.149
Log Likelihood: -8.54
AICc: 29.09
r2: 0.44



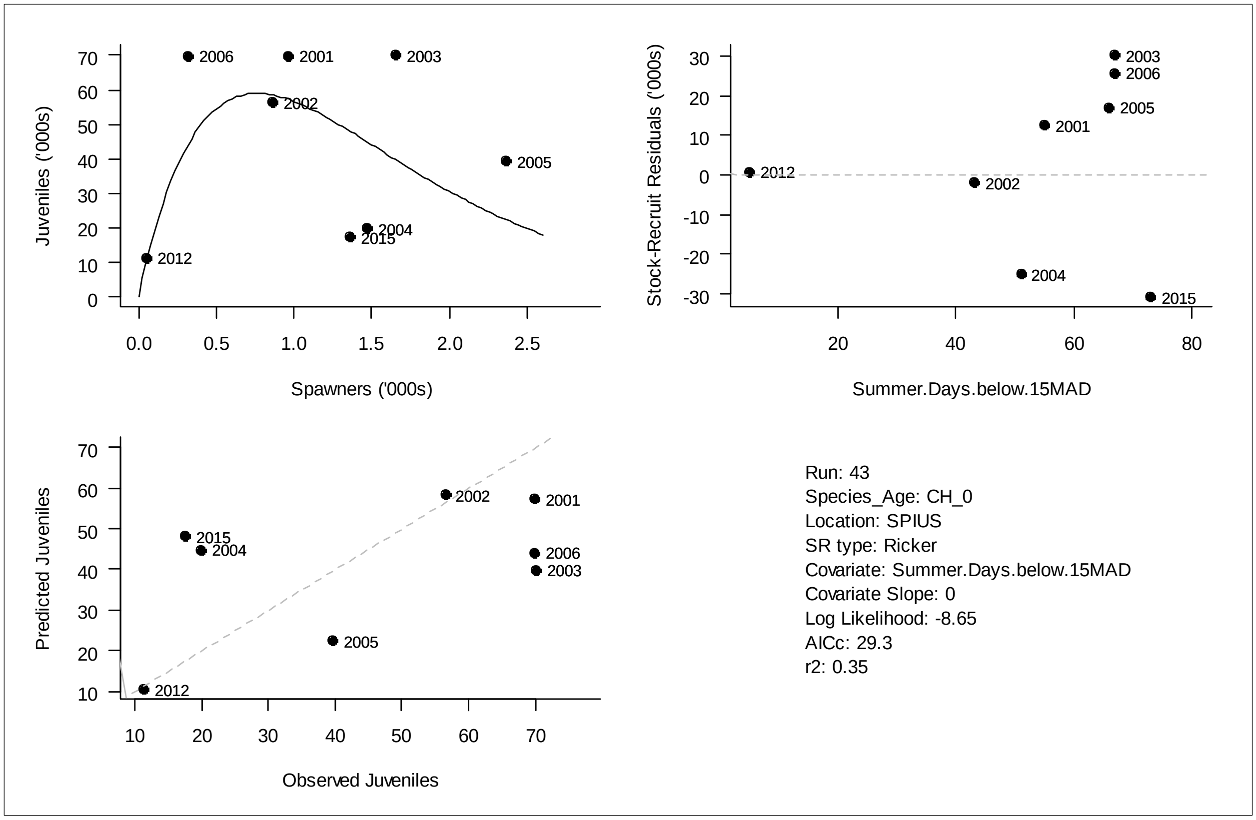
Run: 40
Species_Age: CH_0
Location: SPIUS
SR type: Ricker
Covariate: minflow.plus.tempmax.30day
Covariate Slope: -0.193
Log Likelihood: -8.62
AICc: 29.25
r2: 0.35



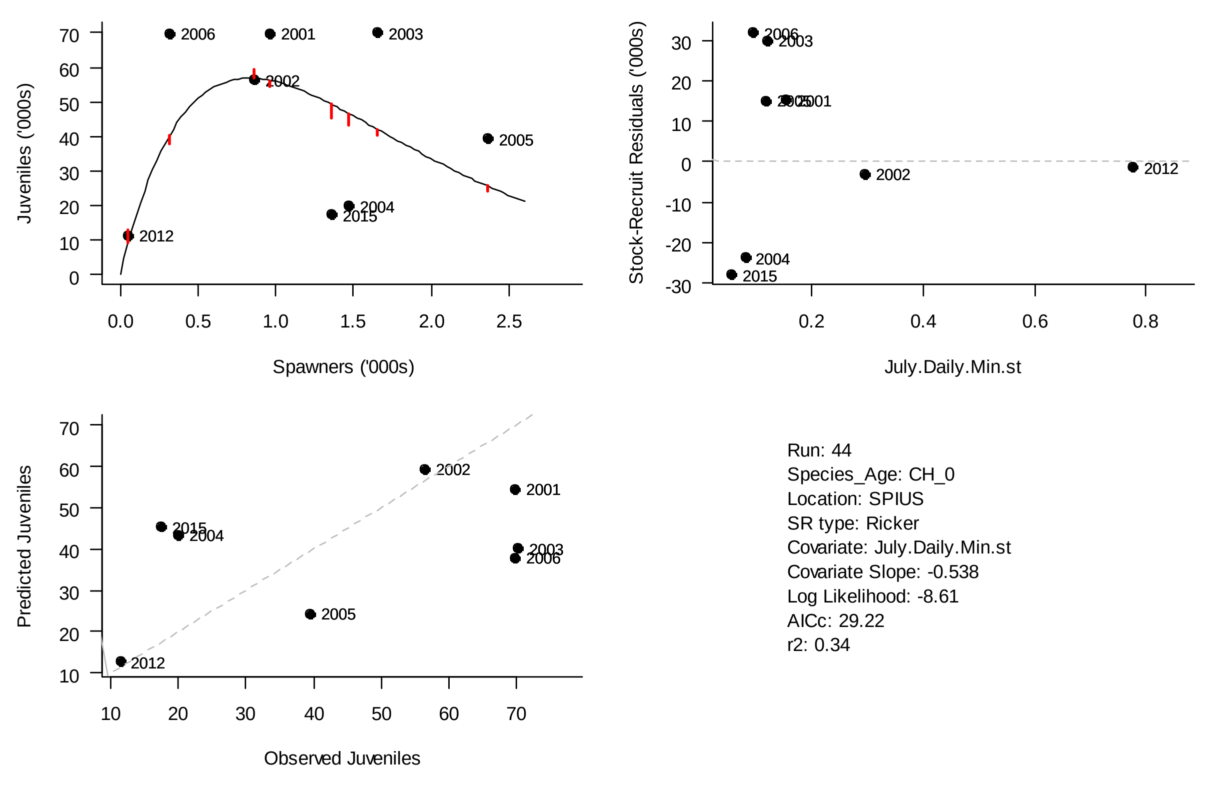
Run: 41
Species_Age: CH_0
Location: SPIUS
SR type: Ricker
Covariate: Winter.Daily.Max.st
Covariate Slope: 0.031
Log Likelihood: -8.64
AICc: 29.27
r2: 0.36



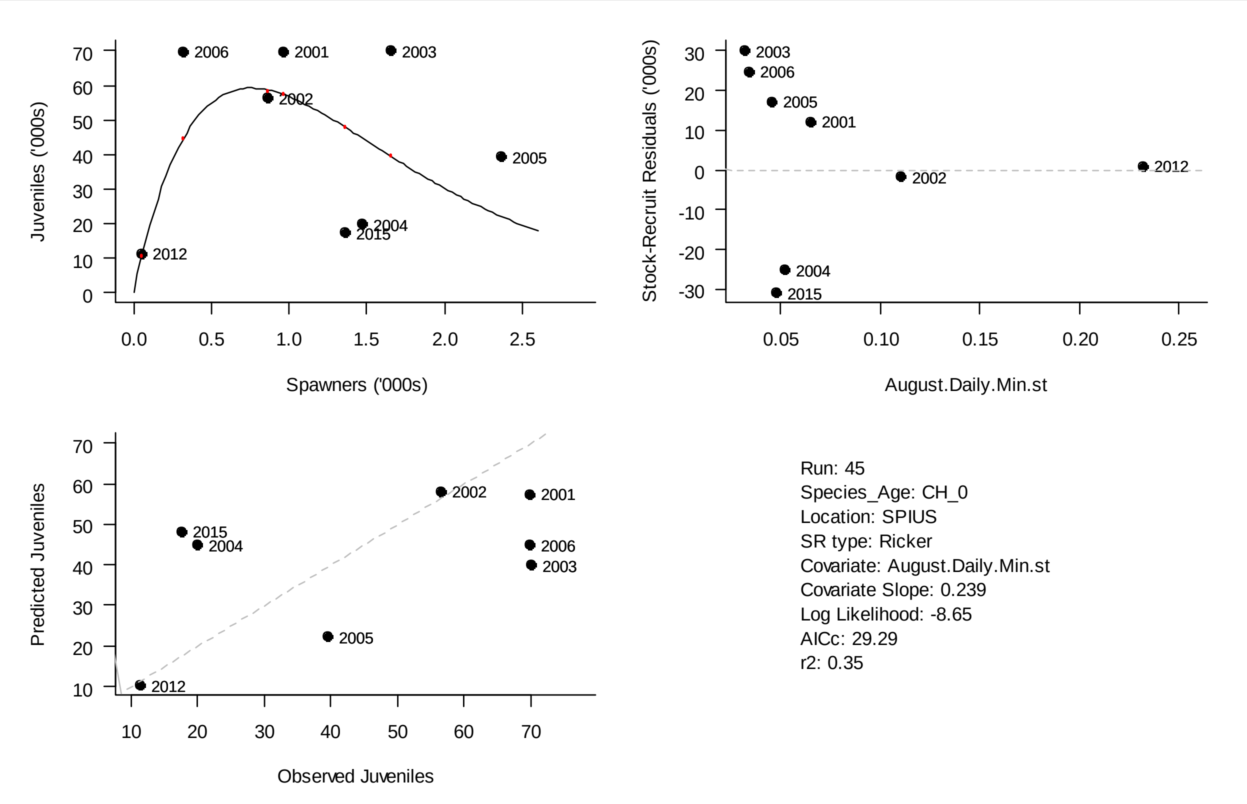
Run: 42
Species_Age: CH_0
Location: SPIUS
SR type: Ricker
Covariate: Summer.Days.below.10MAD
Covariate Slope: -0.002
Log Likelihood: -8.65
AICc: 29.29
r2: 0.36



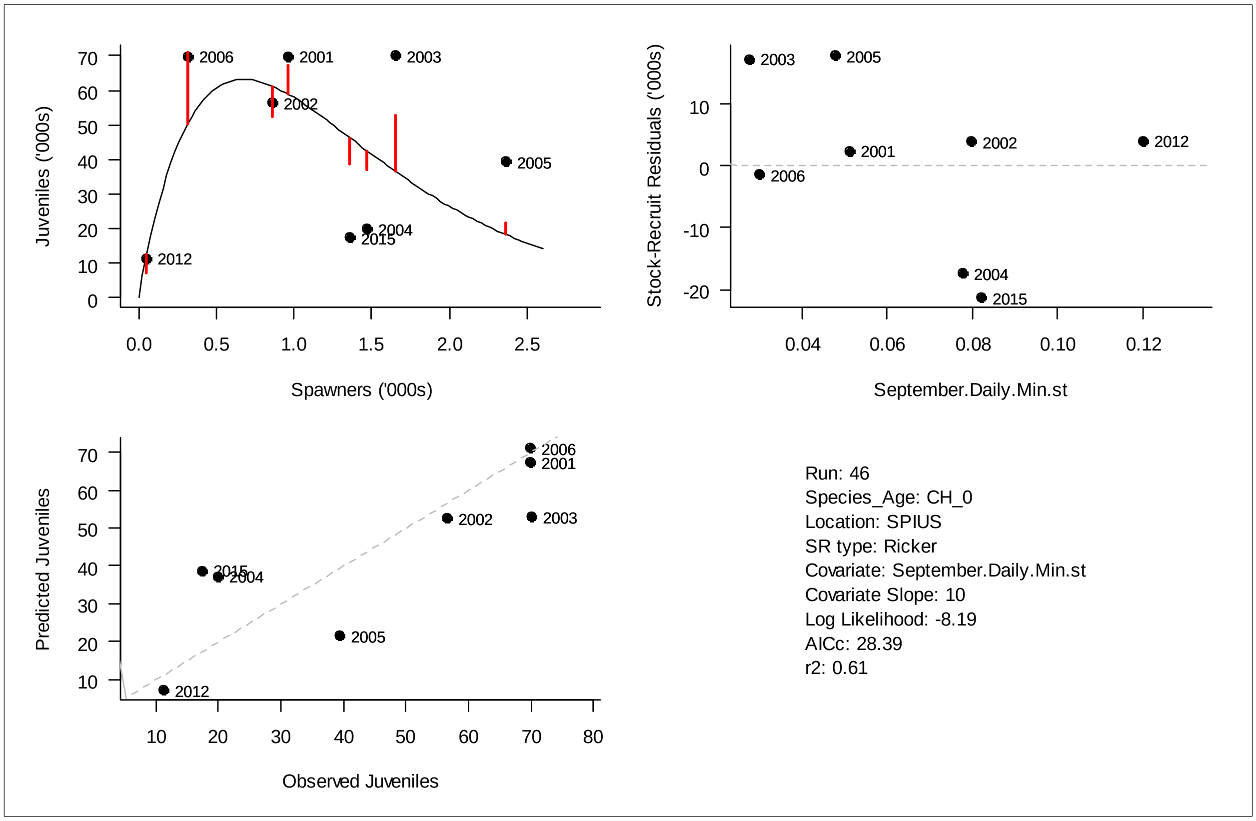
Run: 43
Species_Age: CH_0
Location: SPIUS
SR type: Ricker
Covariate: Summer.Days.below.15MAD
Covariate Slope: 0
Log Likelihood: -8.65
AICc: 29.3
r2: 0.35



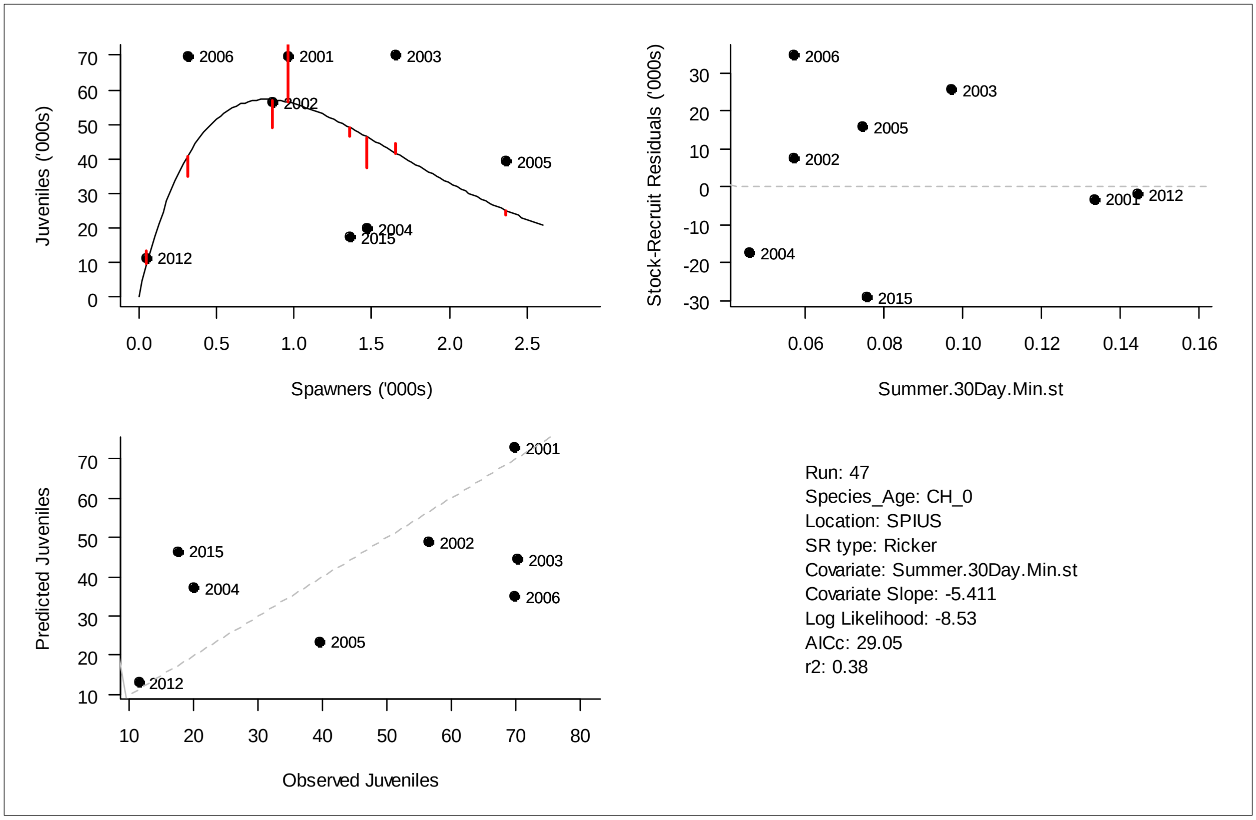
Run: 44
Species_Age: CH_0
Location: SPIUS
SR type: Ricker
Covariate: July.Daily.Min.st
Covariate Slope: -0.538
Log Likelihood: -8.61
AICc: 29.22
r2: 0.34



Run: 45
Species_Age: CH_0
Location: SPIUS
SR type: Ricker
Covariate: August.Daily.Min.st
Covariate Slope: 0.239
Log Likelihood: -8.65
AICc: 29.29
r2: 0.35

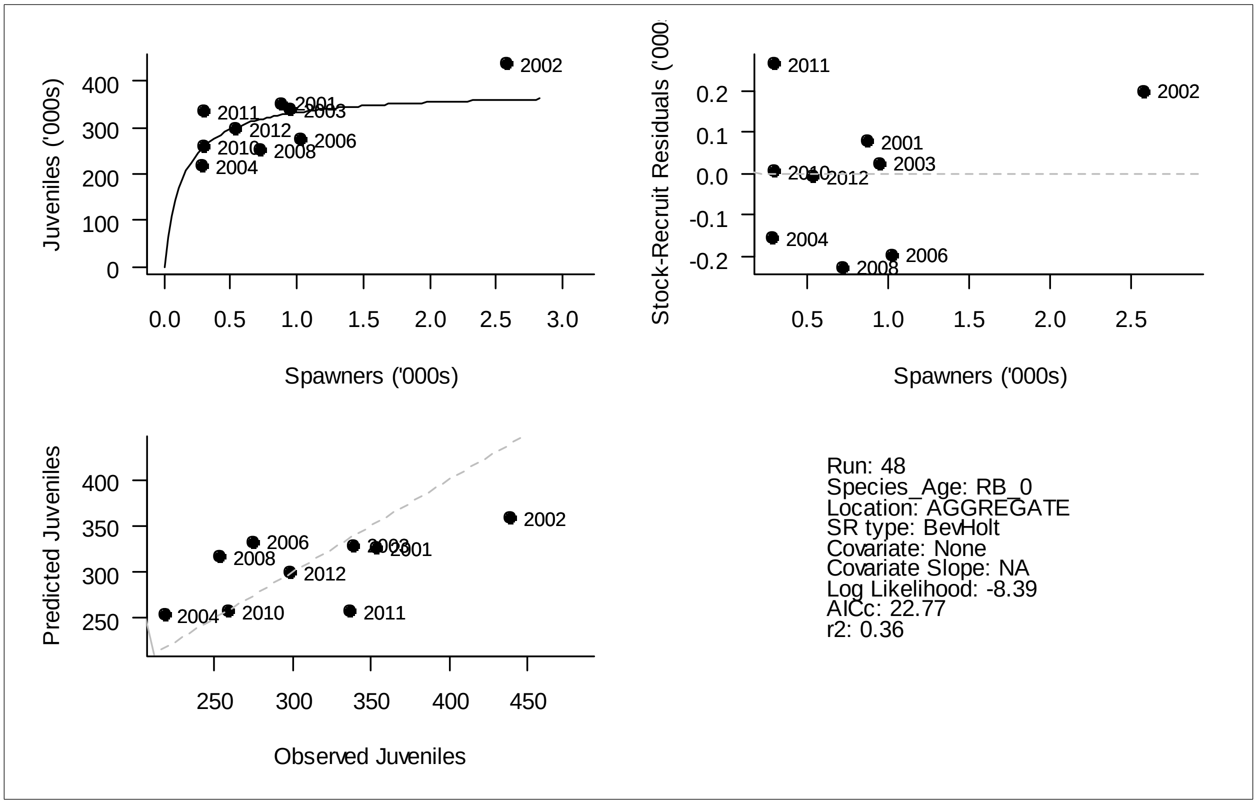


Run: 46
Species_Age: CH_0
Location: SPIUS
SR type: Ricker
Covariate: September.Daily.Min.st
Covariate Slope: 10
Log Likelihood: -8.19
AICc: 28.39
r2: 0.61

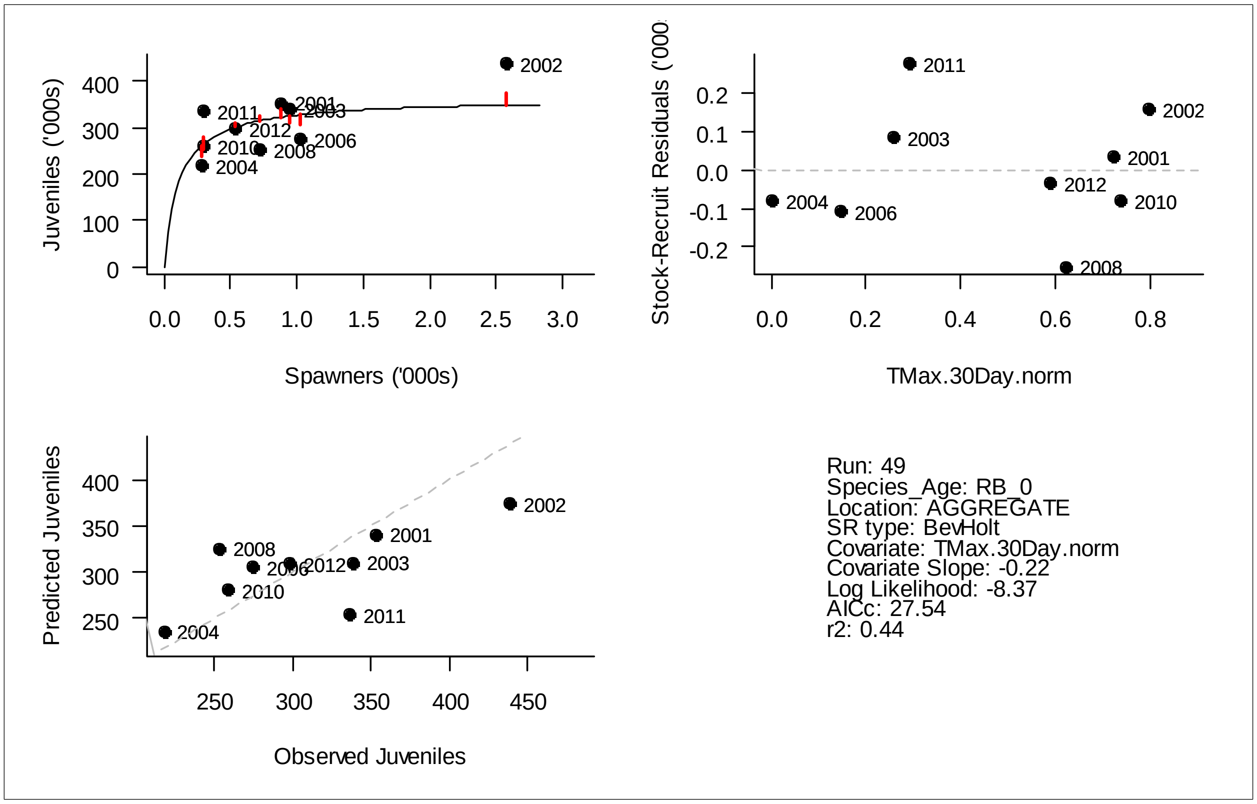


Run: 47
Species_Age: CH_0
Location: SPIUS
SR type: Ricker
Covariate: Summer.30Day.Min.st
Covariate Slope: -5.411
Log Likelihood: -8.53
AICc: 29.05
r2: 0.38

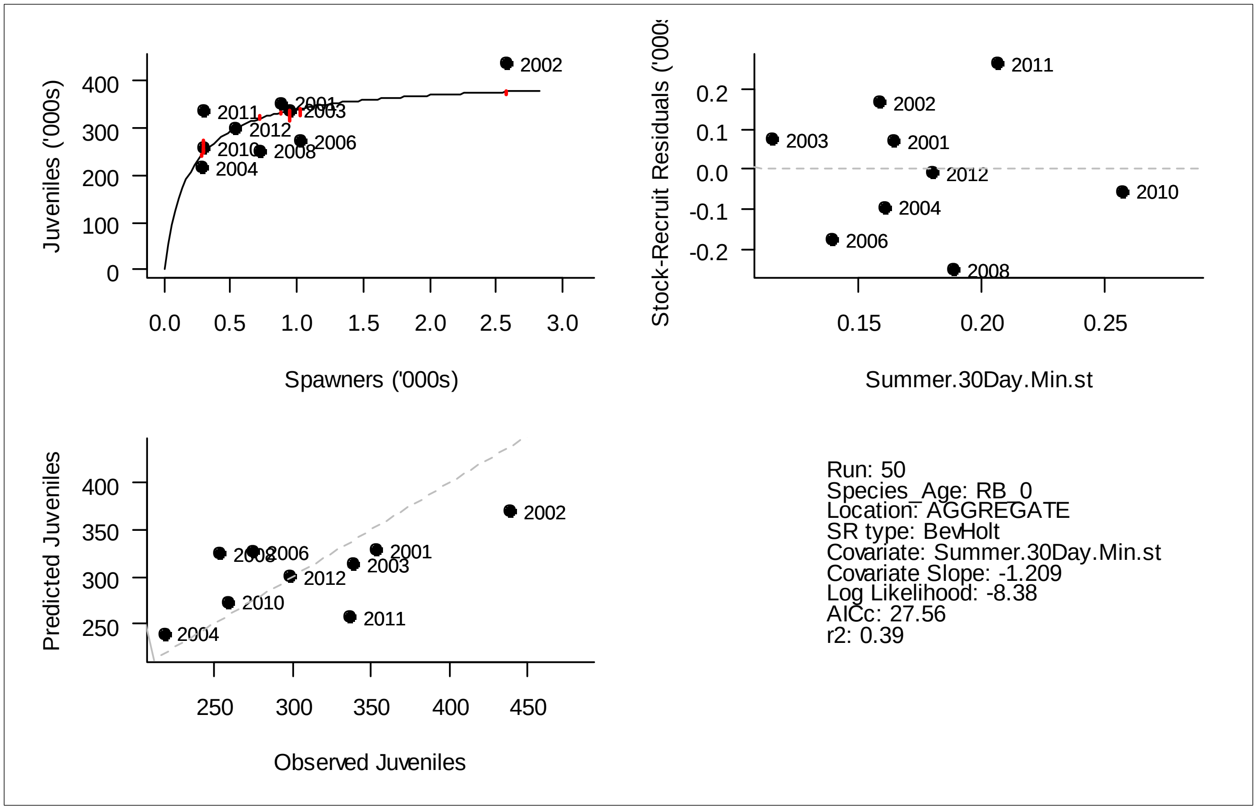
Appendix 4. Outputs from Beverton-Holt stock-recruitment models of Steelhead fry for each stream section and fitted using only brood spawner abundance or in combination with one environmental covariate. Dots represent observed abundance, curves represent prediction based on spawner abundance and, when includeing a covariate, the vertical lines represent the prediction of the full model. AIC_c and R^2 values of predected versus observed are also listed for each model.



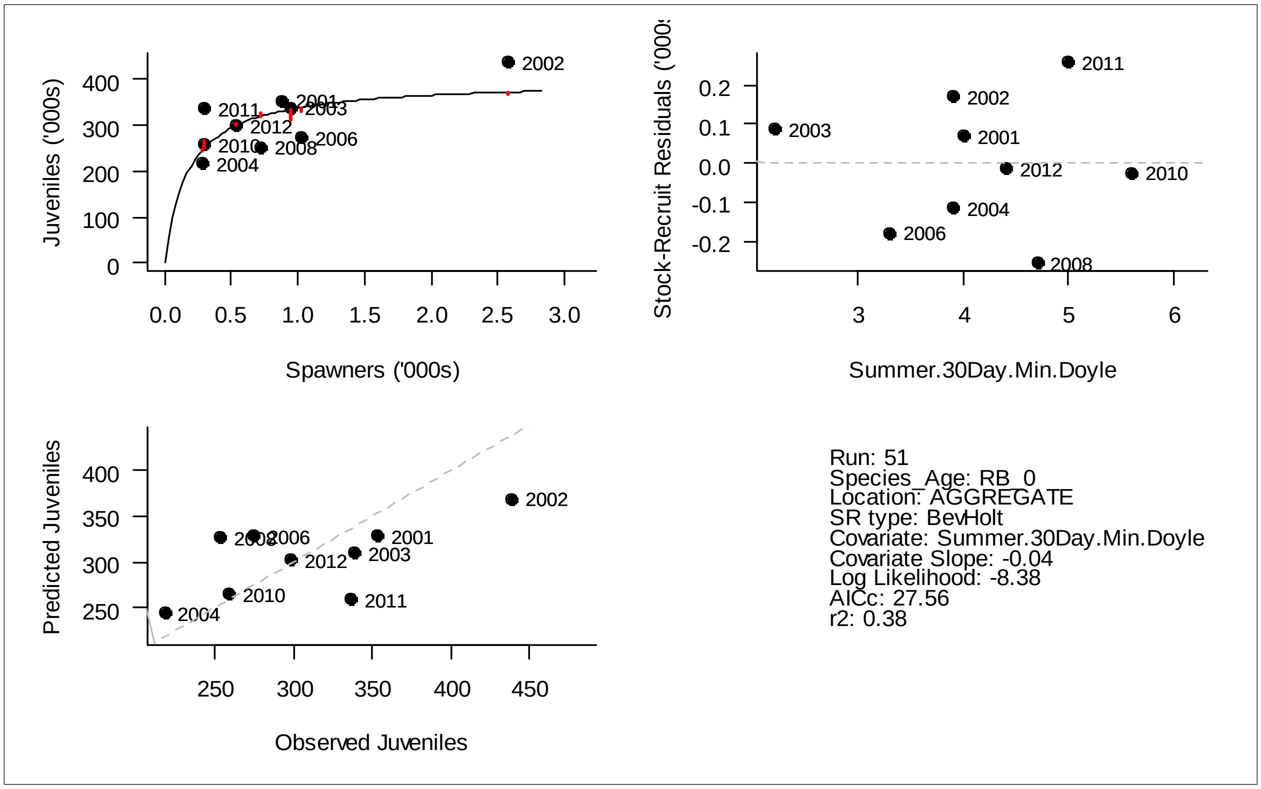
Run: 48
Species_Age: RB_0
Location: AGGREGATE
SR type: BevHolt
Covariate: None
Covariate Slope: NA
Log Likelihood: -8.39
AICc: 22.77
r2: 0.36



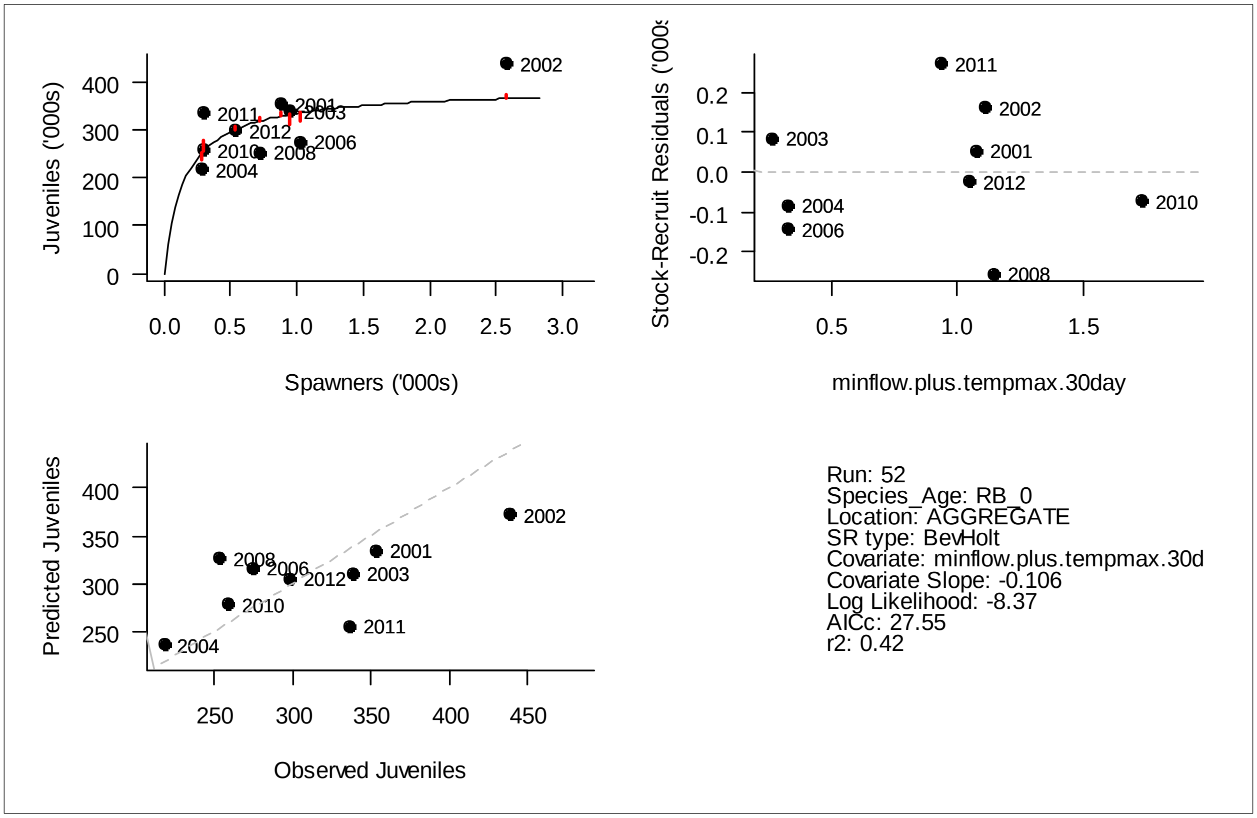
Run: 49
Species_Age: RB_0
Location: AGGREGATE
SR type: BevHolt
Covariate: TMax.30Day.norm
Covariate Slope: -0.22
Log Likelihood: -8.37
AICc: 27.54
r2: 0.44



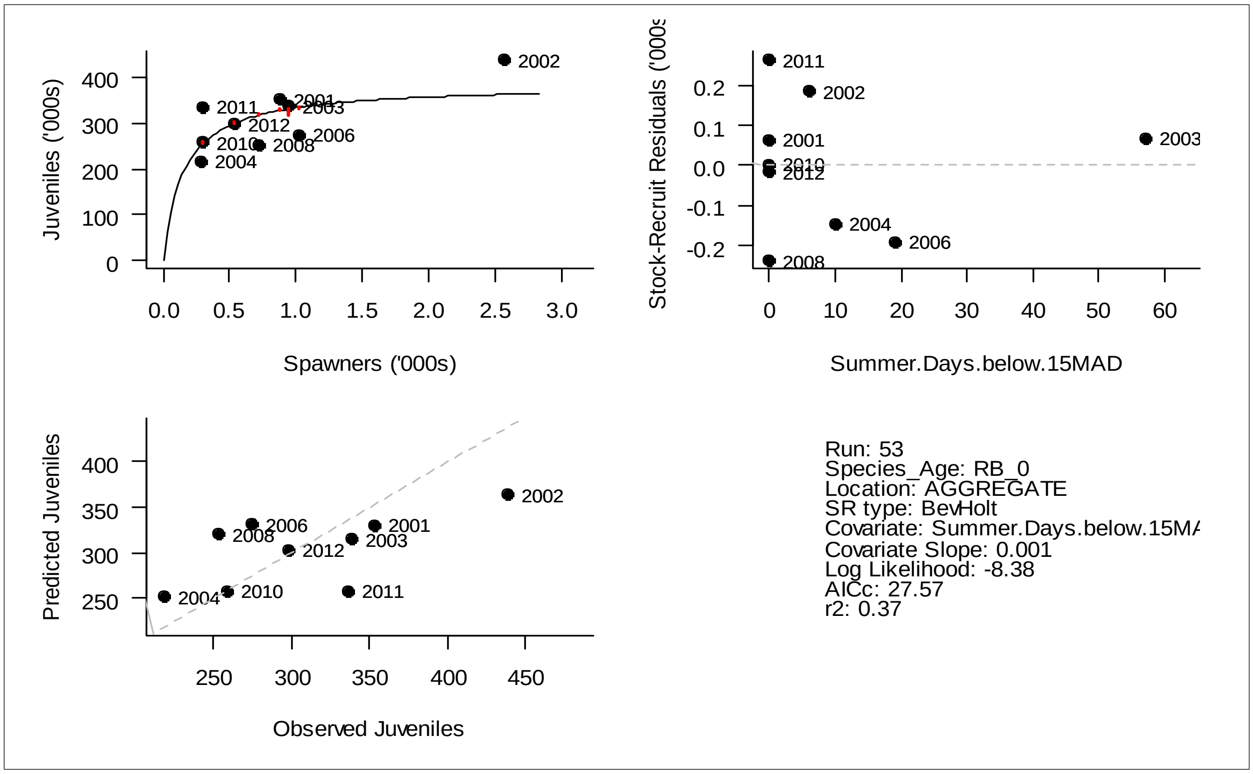
Run: 50
Species_Age: RB_0
Location: AGGREGATE
SR type: BevHolt
Covariate: Summer.30Day.Min.st
Covariate Slope: -1.209
Log Likelihood: -8.38
AICc: 27.56
r2: 0.39



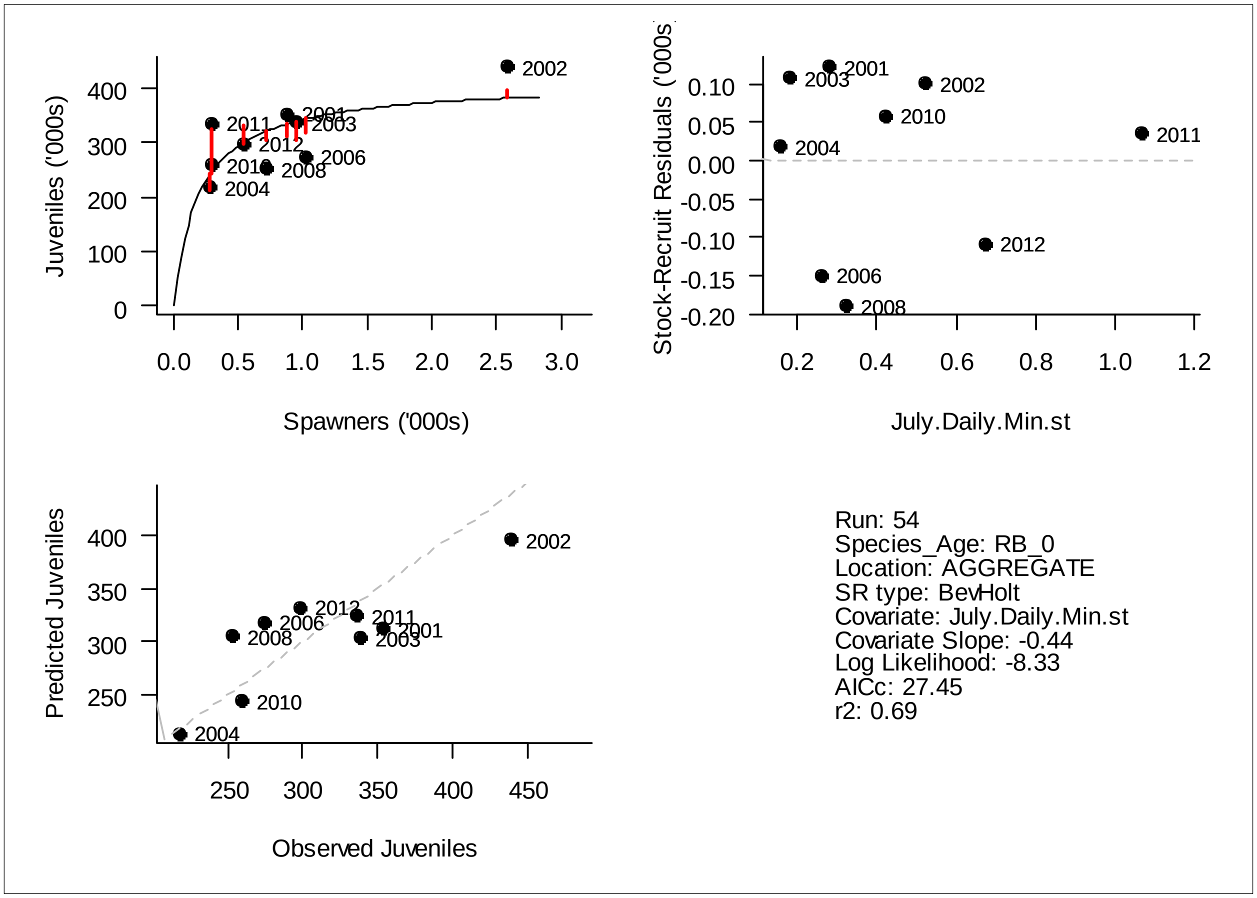
Run: 51
Species_Age: RB_0
Location: AGGREGATE
SR type: BevHolt
Covariate: Summer.30Day.Min.Doyle
Covariate Slope: -0.04
Log Likelihood: -8.38
AICc: 27.56
r2: 0.38



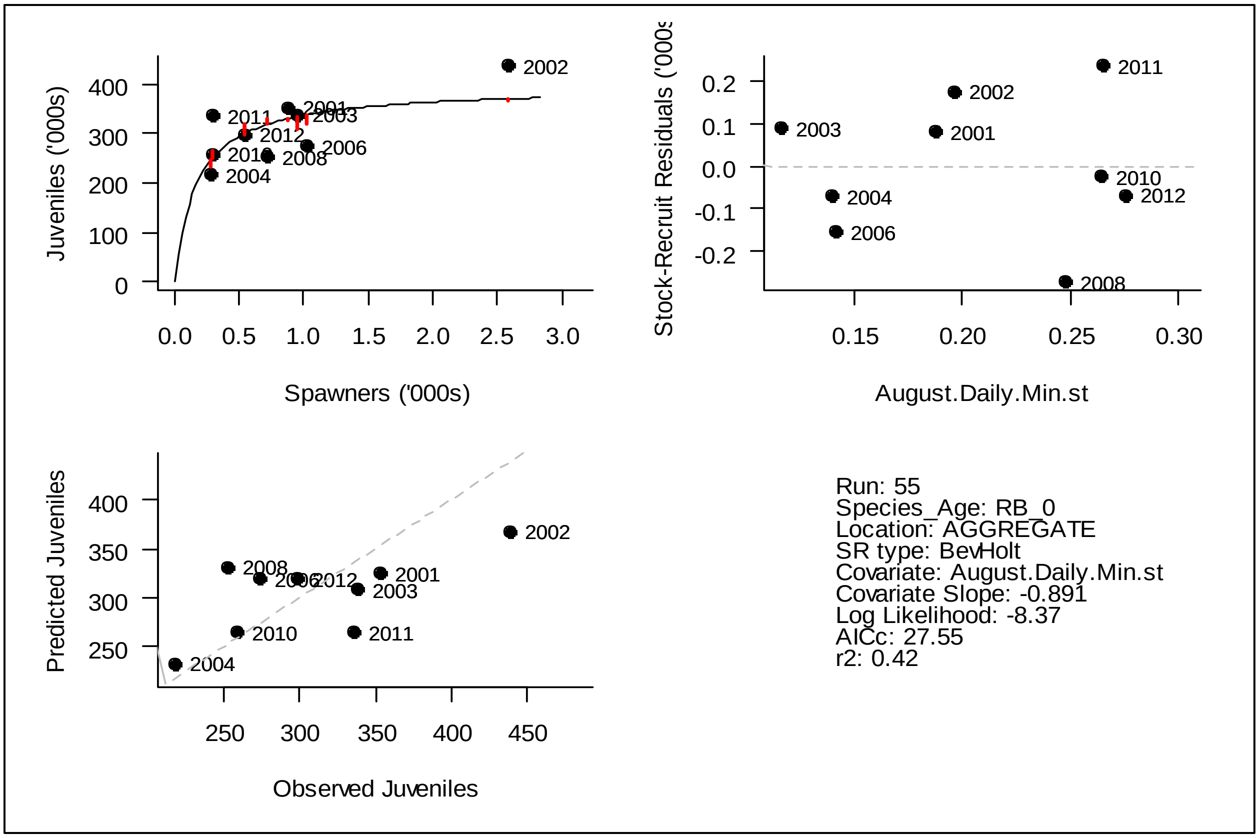
Run: 52
Species_Age: RB_0
Location: AGGREGATE
SR type: BevHolt
Covariate: minflow.plus.tempmax.30d
Covariate Slope: -0.106
Log Likelihood: -8.37
AICc: 27.55
r2: 0.42



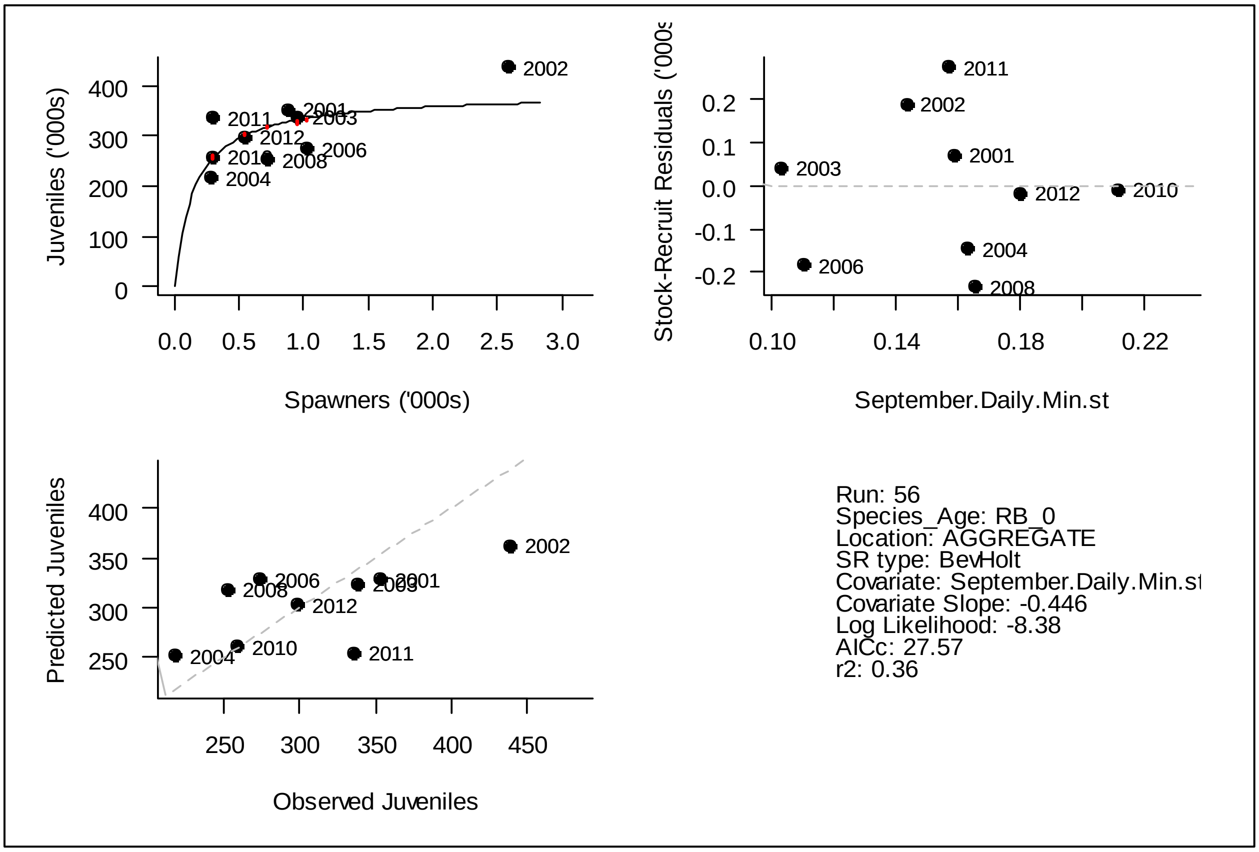
Run: 53
Species_Age: RB_0
Location: AGGREGATE
SR type: BevHolt
Covariate: Summer.Days.below.15M
Covariate Slope: 0.001
Log Likelihood: -8.38
AICc: 27.57
r2: 0.37



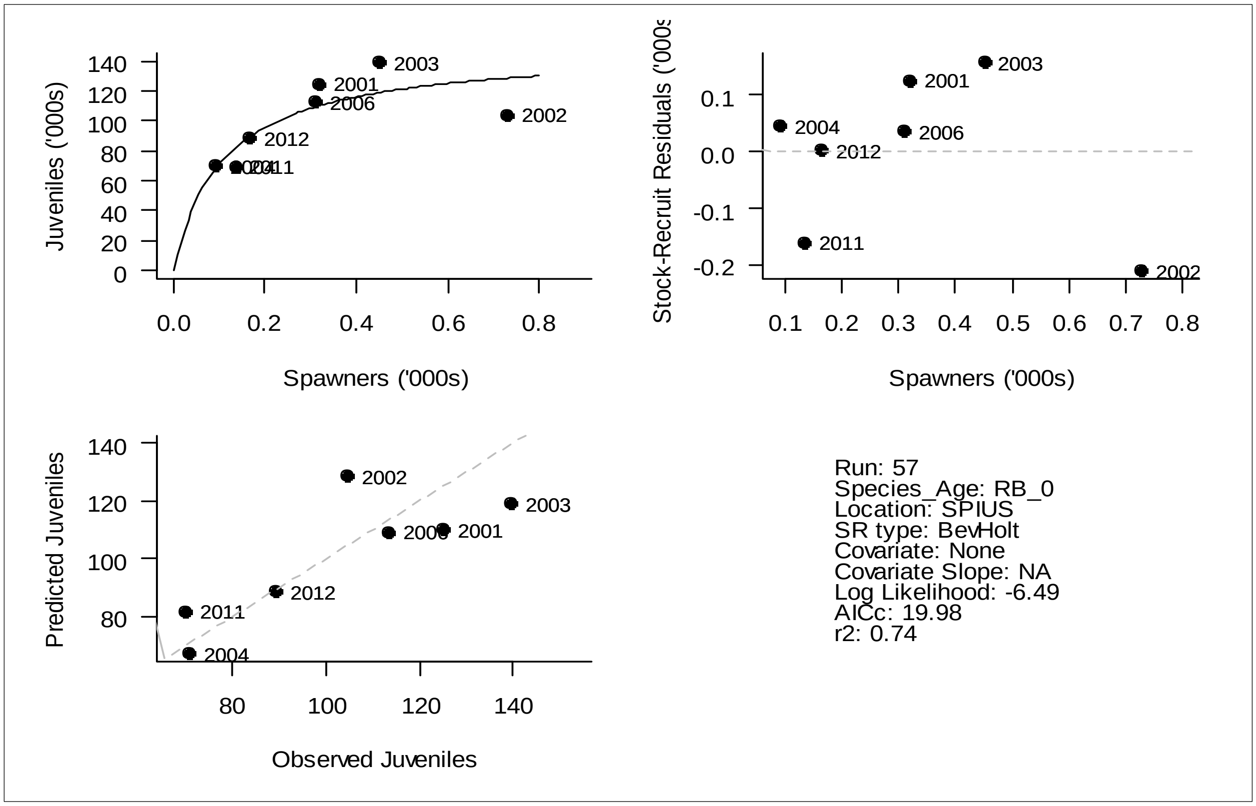
Run: 54
Species_Age: RB_0
Location: AGGREGATE
SR type: BevHolt
Covariate: July.Daily.Min.st
Covariate Slope: -0.44
Log Likelihood: -8.33
AICc: 27.45
r2: 0.69



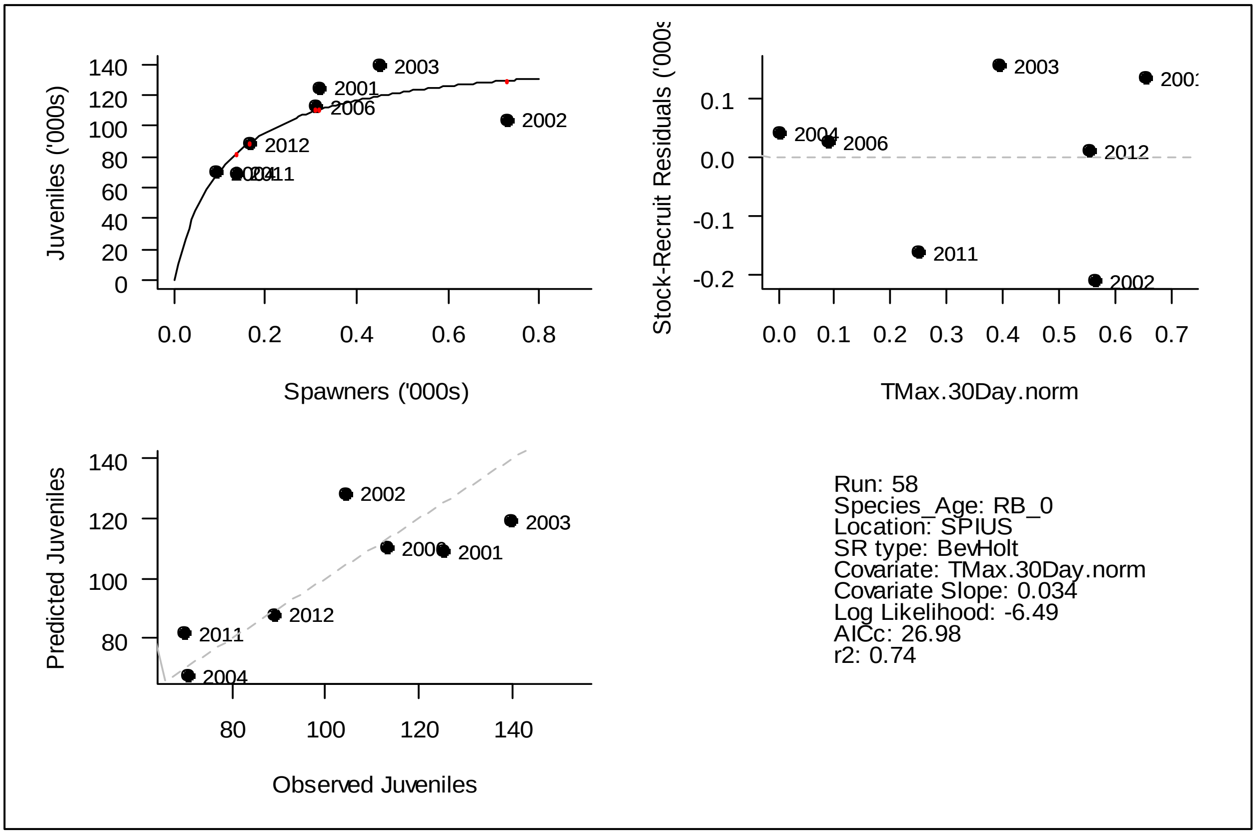
Run: 55
Species_Age: RB_0
Location: AGGREGATE
SR type: BevHolt
Covariate: August.Daily.Min.st
Covariate Slope: -0.891
Log Likelihood: -8.37
AICc: 27.55
r2: 0.42



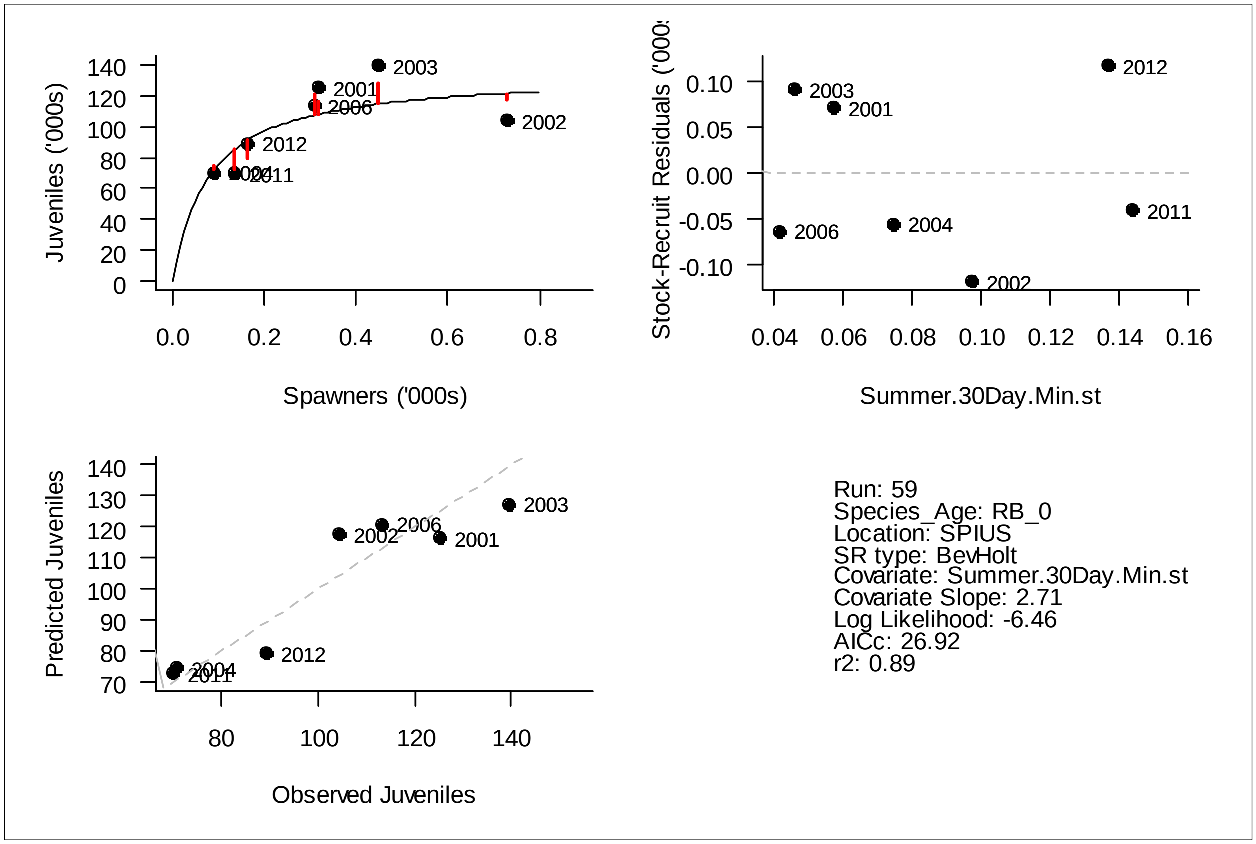
Run: 56
Species_Age: RB_0
Location: AGGREGATE
SR type: BevHolt
Covariate: September.Daily.Min.st
Covariate Slope: -0.446
Log Likelihood: -8.38
AICc: 27.57
r2: 0.36



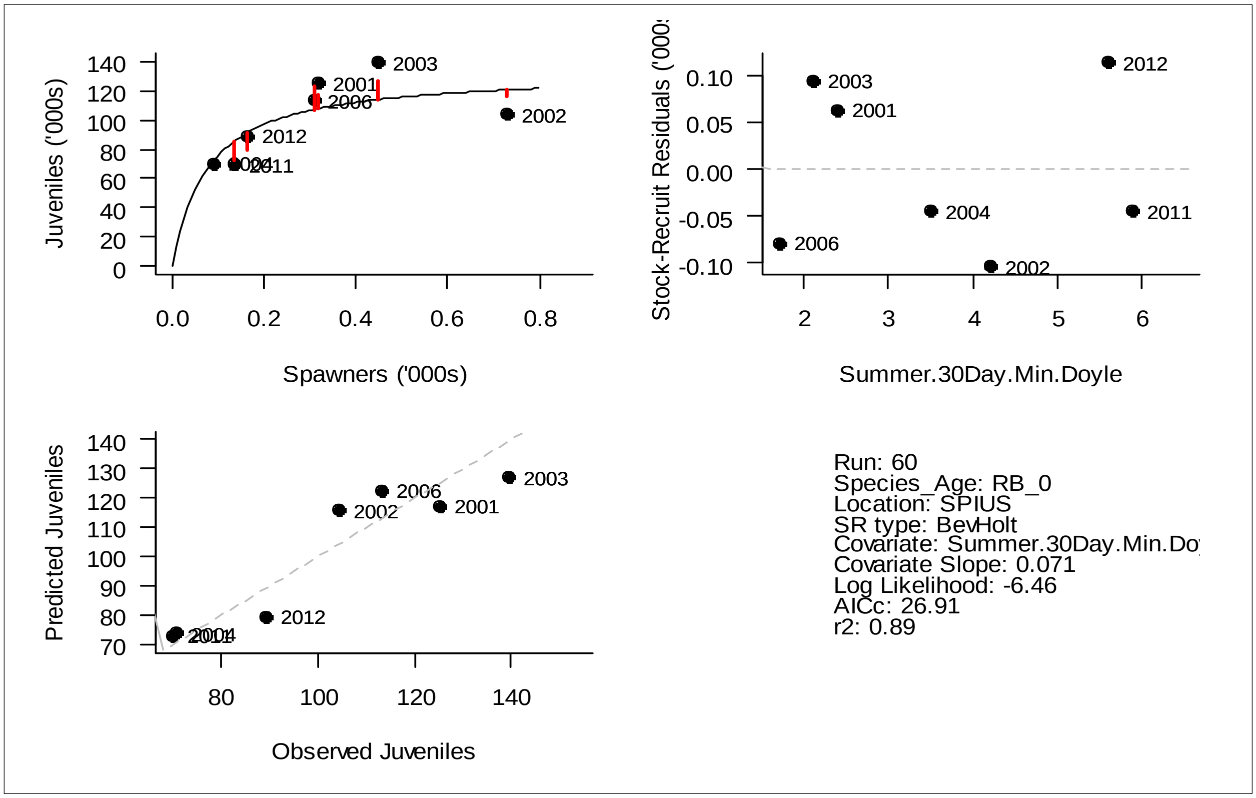
Run: 57
Species_Age: RB_0
Location: SPIUS
SR type: BevHolt
Covariate: None
Covariate Slope: NA
Log Likelihood: -6.49
AICc: 19.98
r2: 0.74



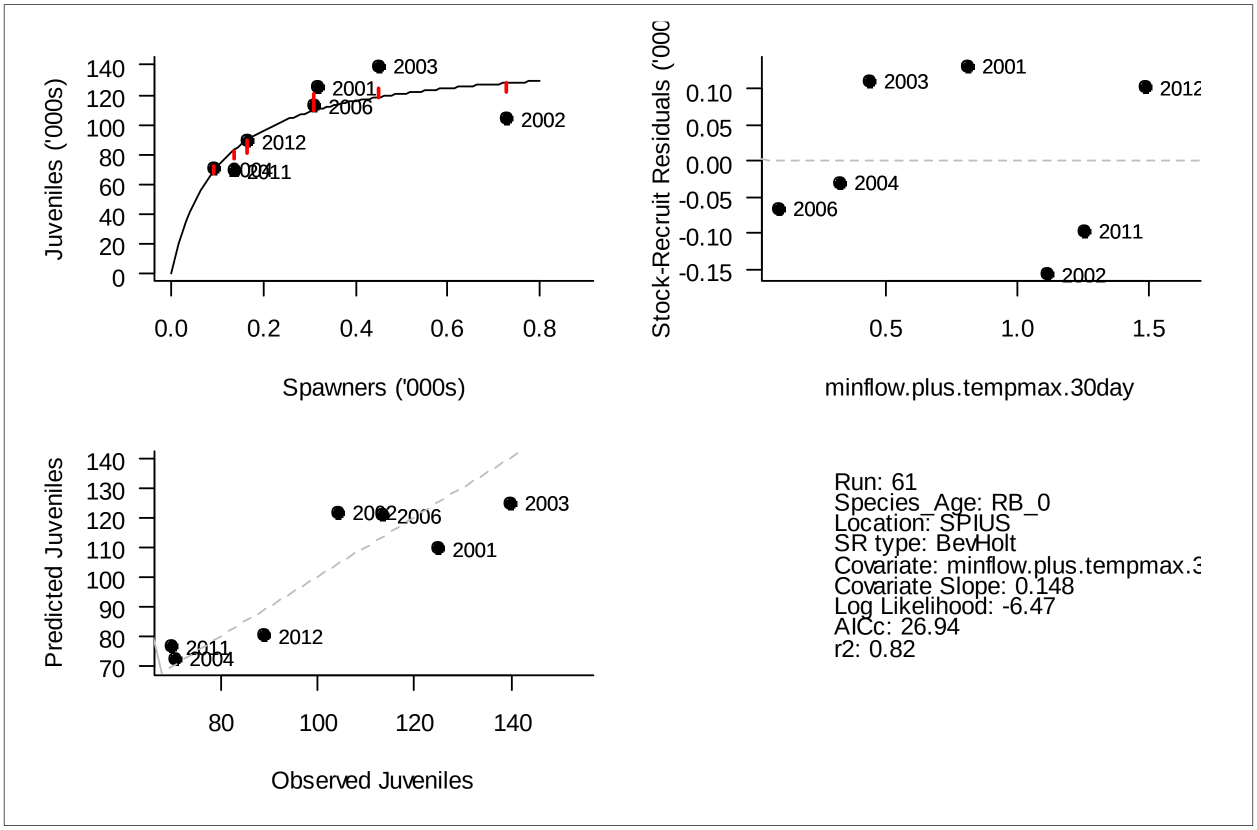
Run: 58
Species_Age: RB_0
Location: SPIUS
SR type: BevHolt
Covariate: TMax.30Day.norm
Covariate Slope: 0.034
Log Likelihood: -6.49
AICc: 26.98
r2: 0.74



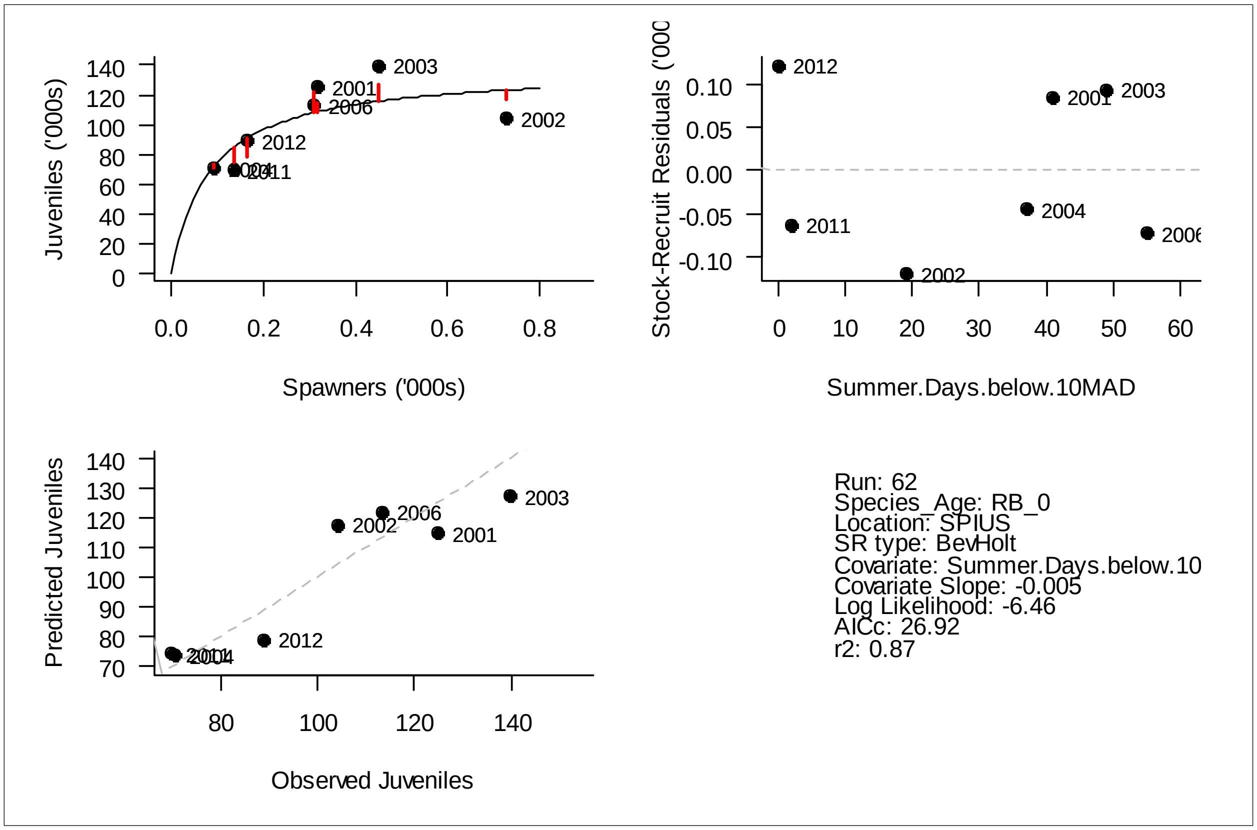
Run: 59
Species_Age: RB_0
Location: SPIUS
SR type: BevHolt
Covariate: Summer.30Day.Min.st
Covariate Slope: 2.71
Log Likelihood: -6.46
AICc: 26.92
r2: 0.89



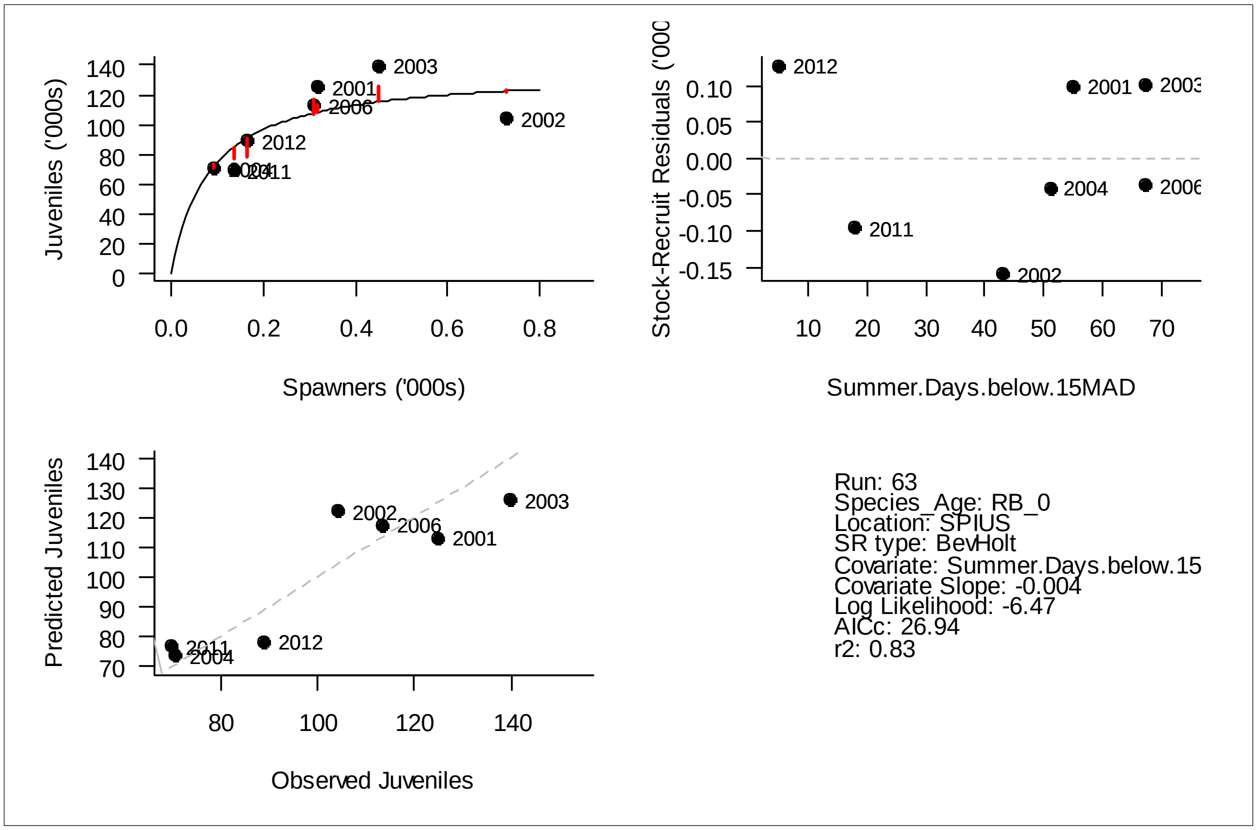
Run: 60
Species_Age: RB_0
Location: SPIUS
SR type: BevHolt
Covariate: Summer.30Day.Min.Do
Covariate Slope: 0.071
Log Likelihood: -6.46
AICc: 26.91
r2: 0.89



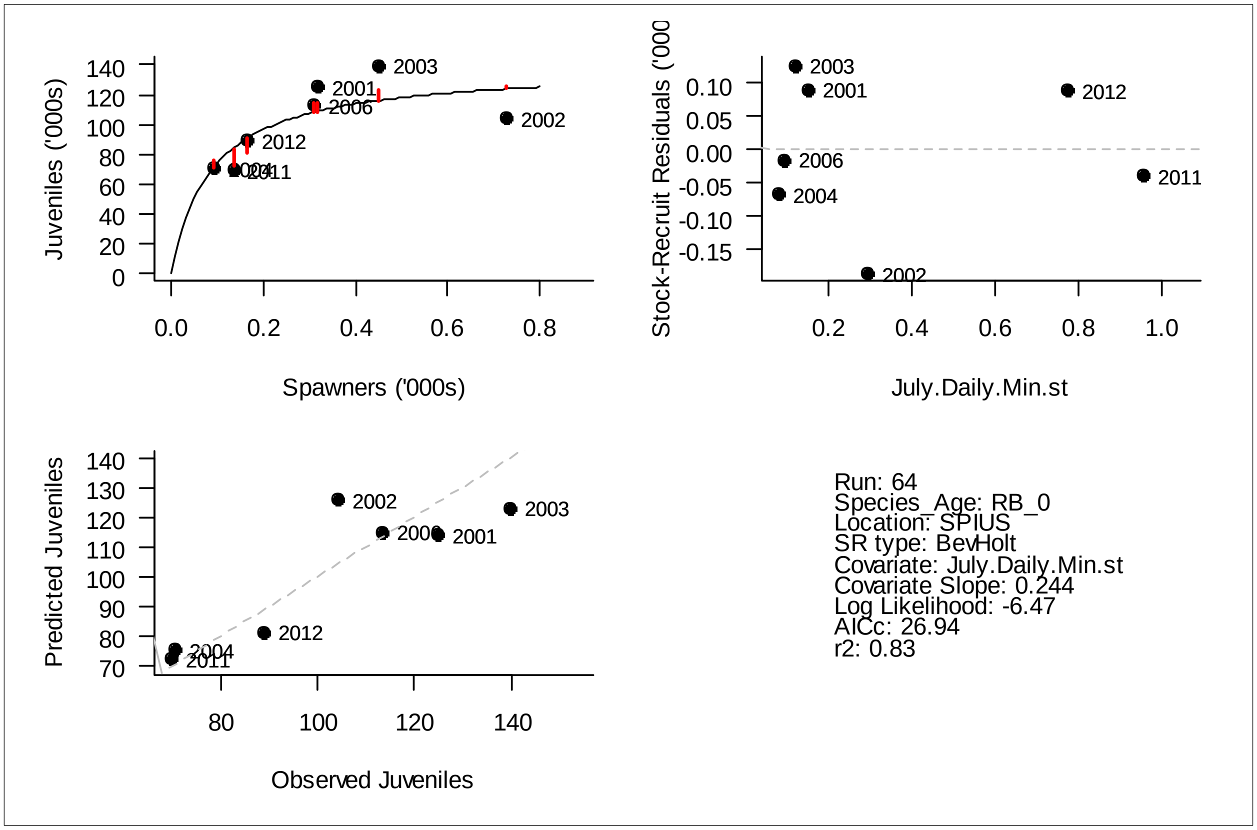
Run: 61
Species_Age: RB_0
Location: SPIUS
SR type: BevHolt
Covariate: minflow.plus.tempmax.3
Covariate Slope: 0.148
Log Likelihood: -6.47
AICc: 26.94
r2: 0.82



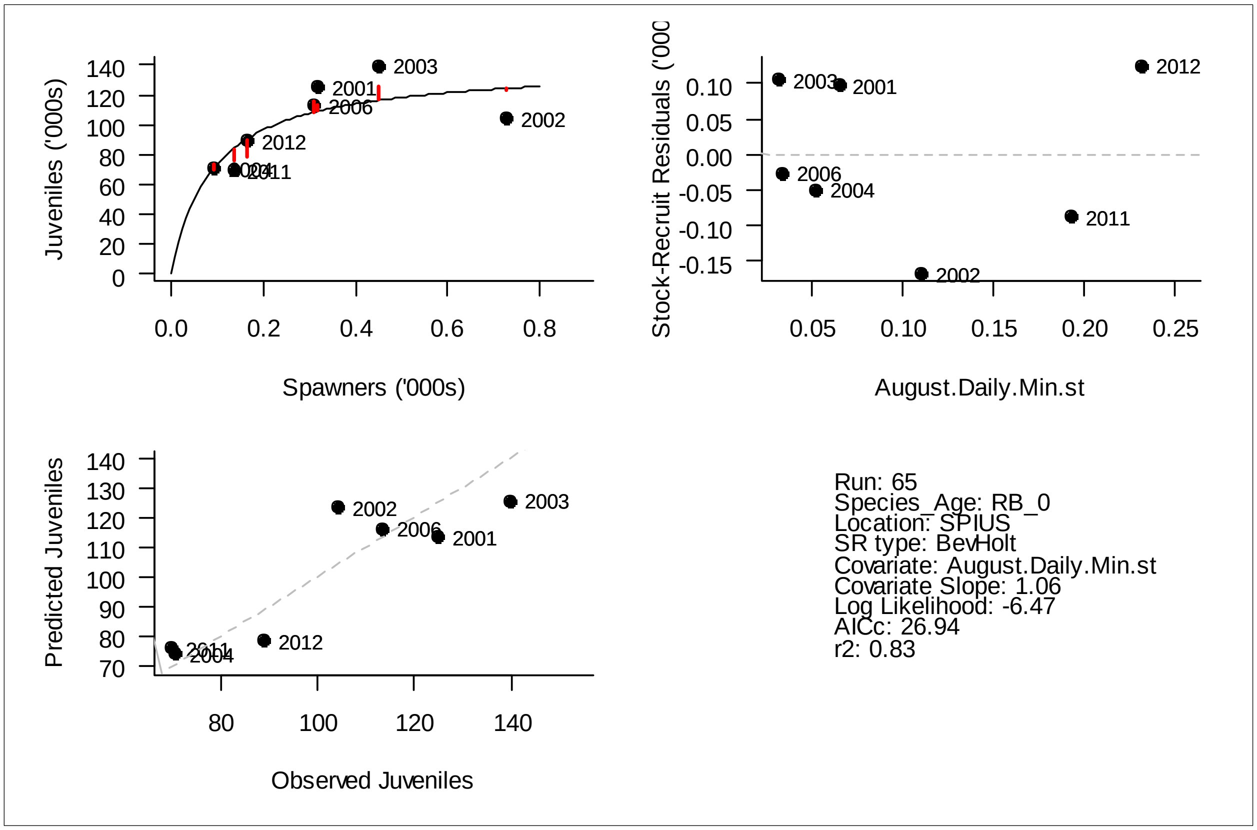
Run: 62
Species_Age: RB_0
Location: SPIUS
SR type: BevHolt
Covariate: Summer.Days.below.10
Covariate Slope: -0.005
Log Likelihood: -6.46
AICc: 26.92
r2: 0.87



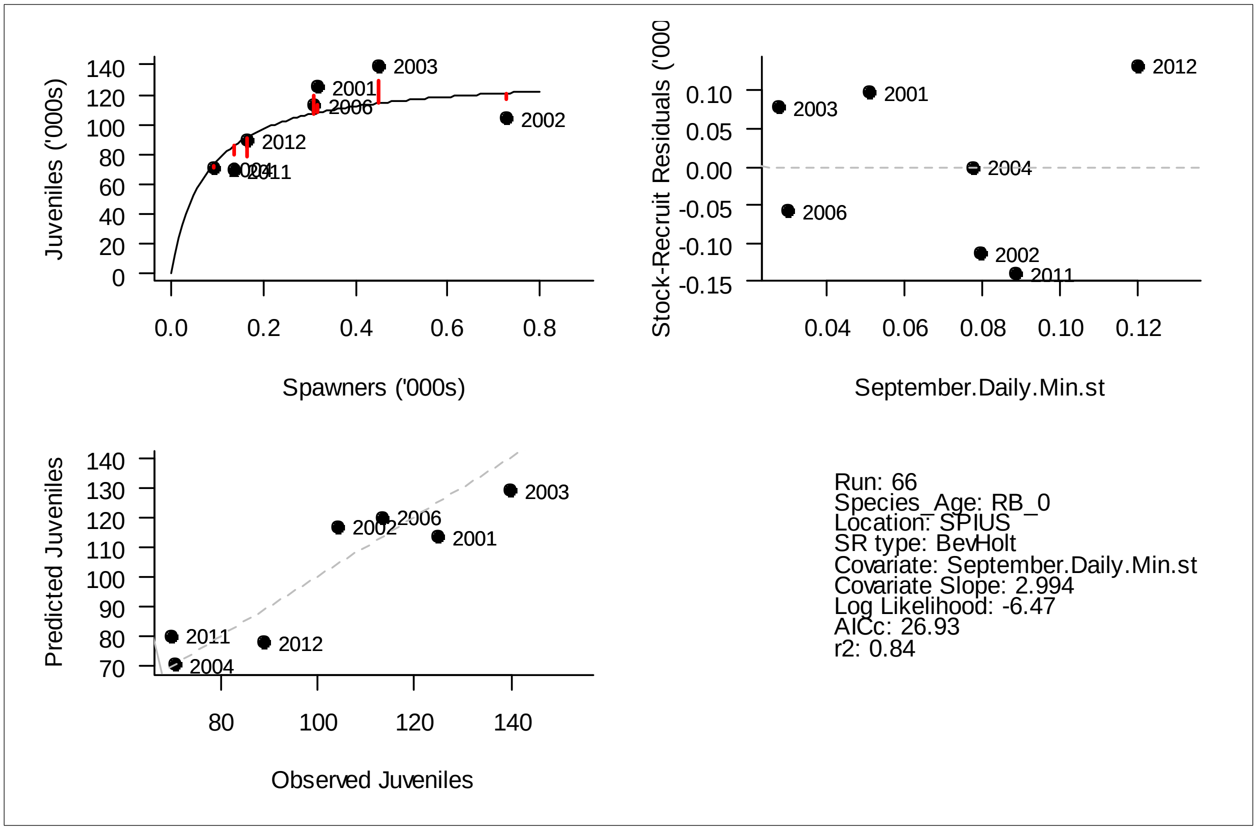
Run: 63
Species_Age: RB_0
Location: SPIUS
SR type: BevHolt
Covariate: Summer.Days.below.15
Covariate Slope: -0.004
Log Likelihood: -6.47
AICc: 26.94
r2: 0.83



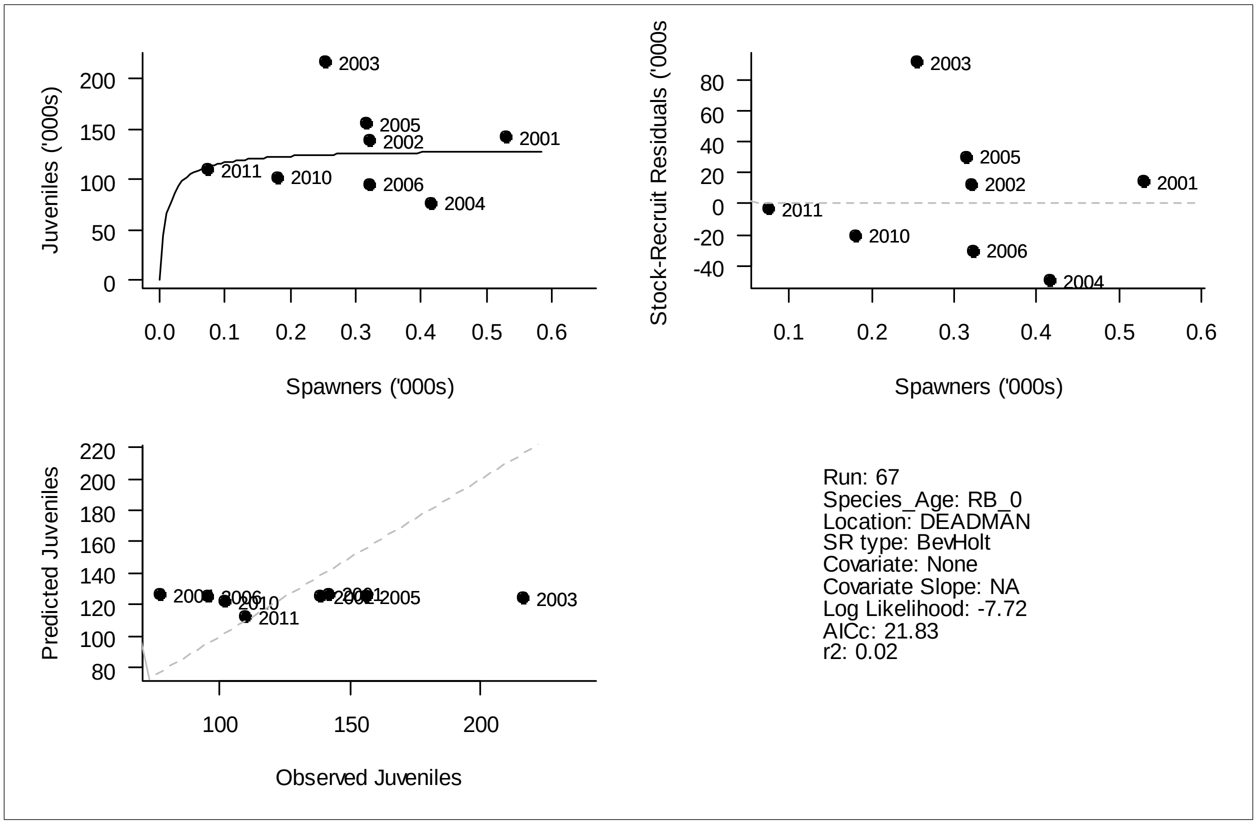
Run: 64
Species_Age: RB_0
Location: SPIUS
SR type: BevHolt
Covariate: July.Daily.Min.st
Covariate Slope: 0.244
Log Likelihood: -6.47
AICc: 26.94
r2: 0.83



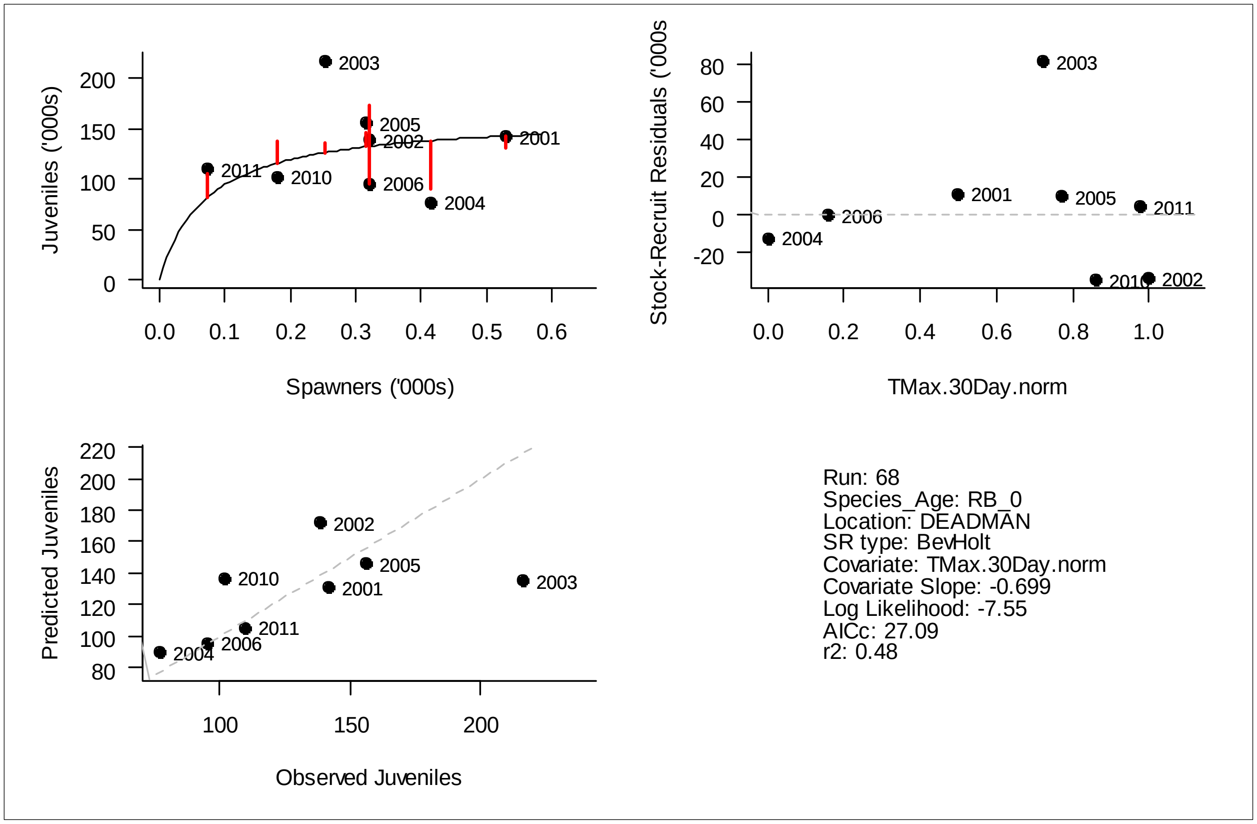
Run: 65
Species_Age: RB_0
Location: SPIUS
SR type: BevHolt
Covariate: August.Daily.Min.st
Covariate Slope: 1.06
Log Likelihood: -6.47
AICc: 26.94
r2: 0.83



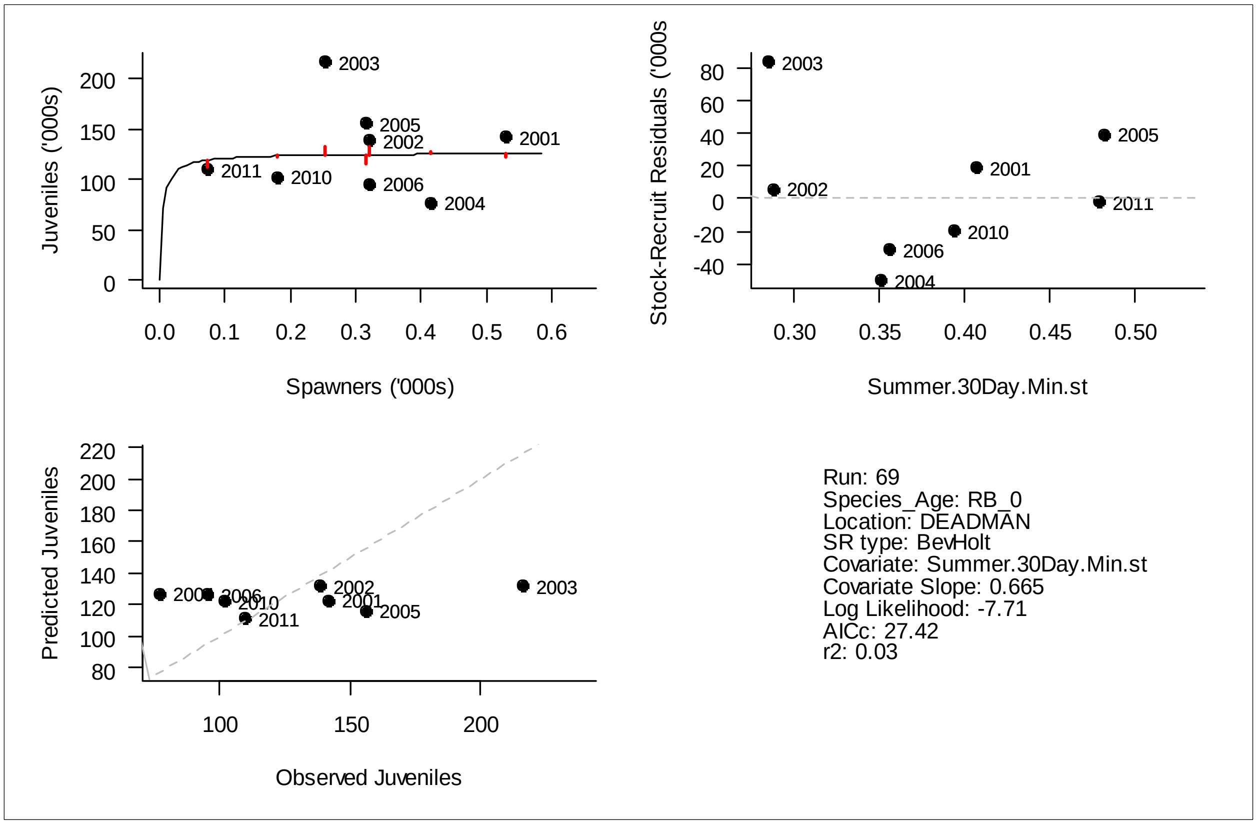
Run: 66
Species_Age: RB_0
Location: SPIUS
SR type: BevHolt
Covariate: September.Daily.Min.st
Covariate Slope: 2.994
Log Likelihood: -6.47
AICc: 26.93
r2: 0.84



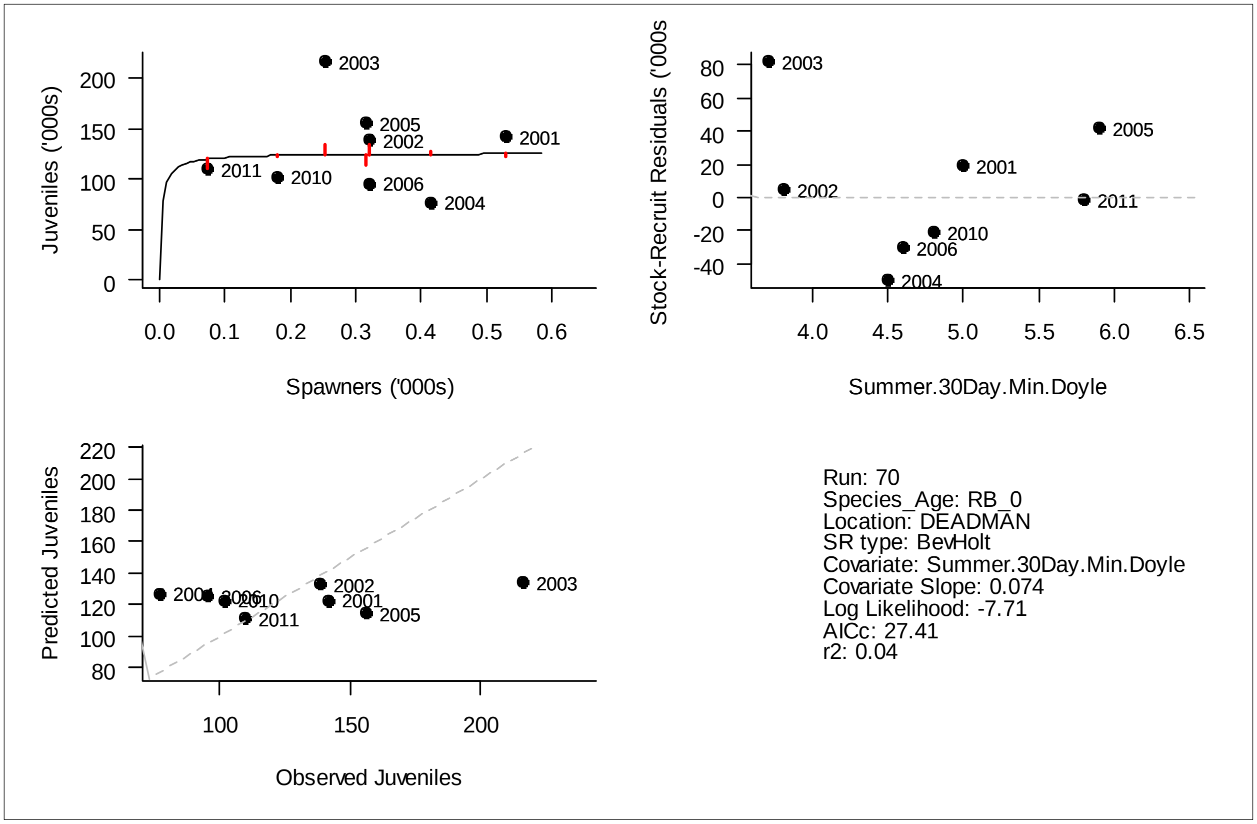
Run: 67
Species_Age: RB_0
Location: DEADMAN
SR type: BevHolt
Covariate: None
Covariate Slope: NA
Log Likelihood: -7.72
AICc: 21.83
r2: 0.02



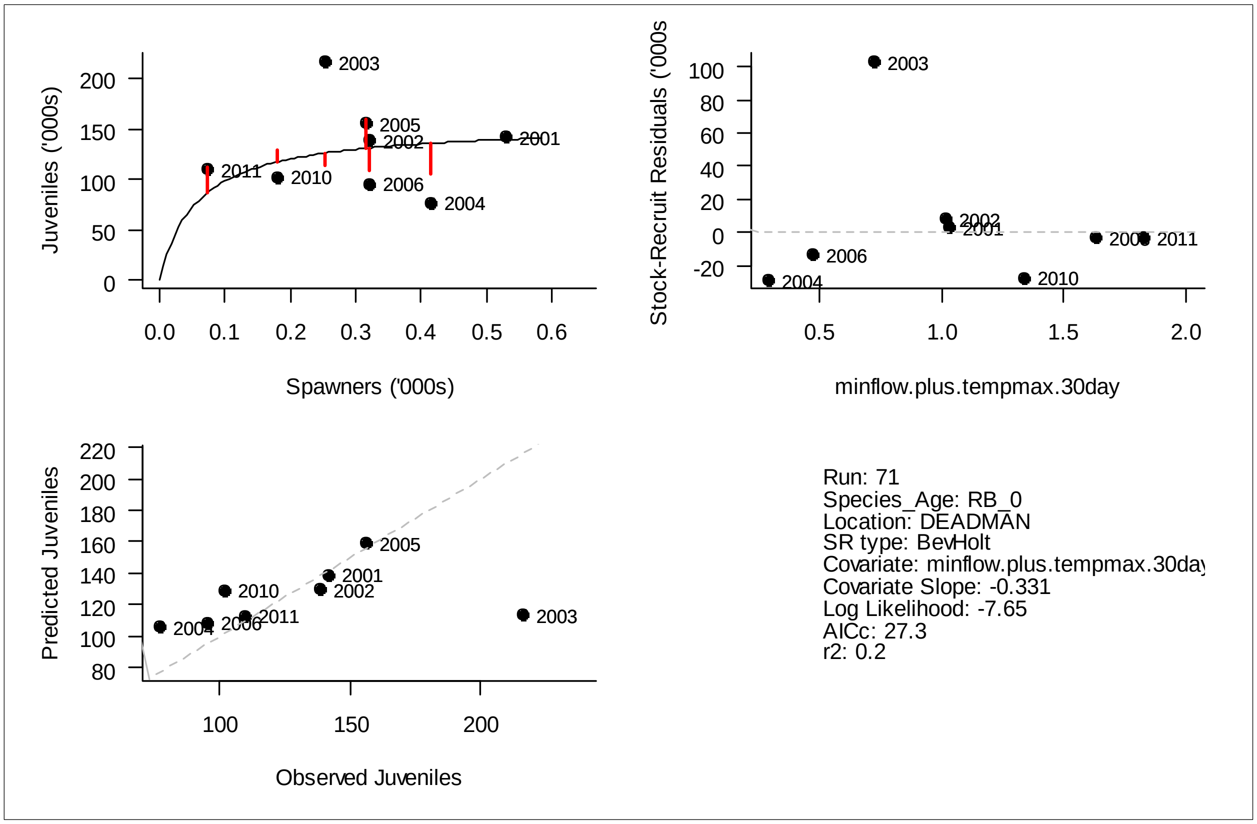
Run: 68
Species_Age: RB_0
Location: DEADMAN
SR type: BevHolt
Covariate: TMax.30Day.norm
Covariate Slope: -0.699
Log Likelihood: -7.55
AICc: 27.09
r2: 0.48



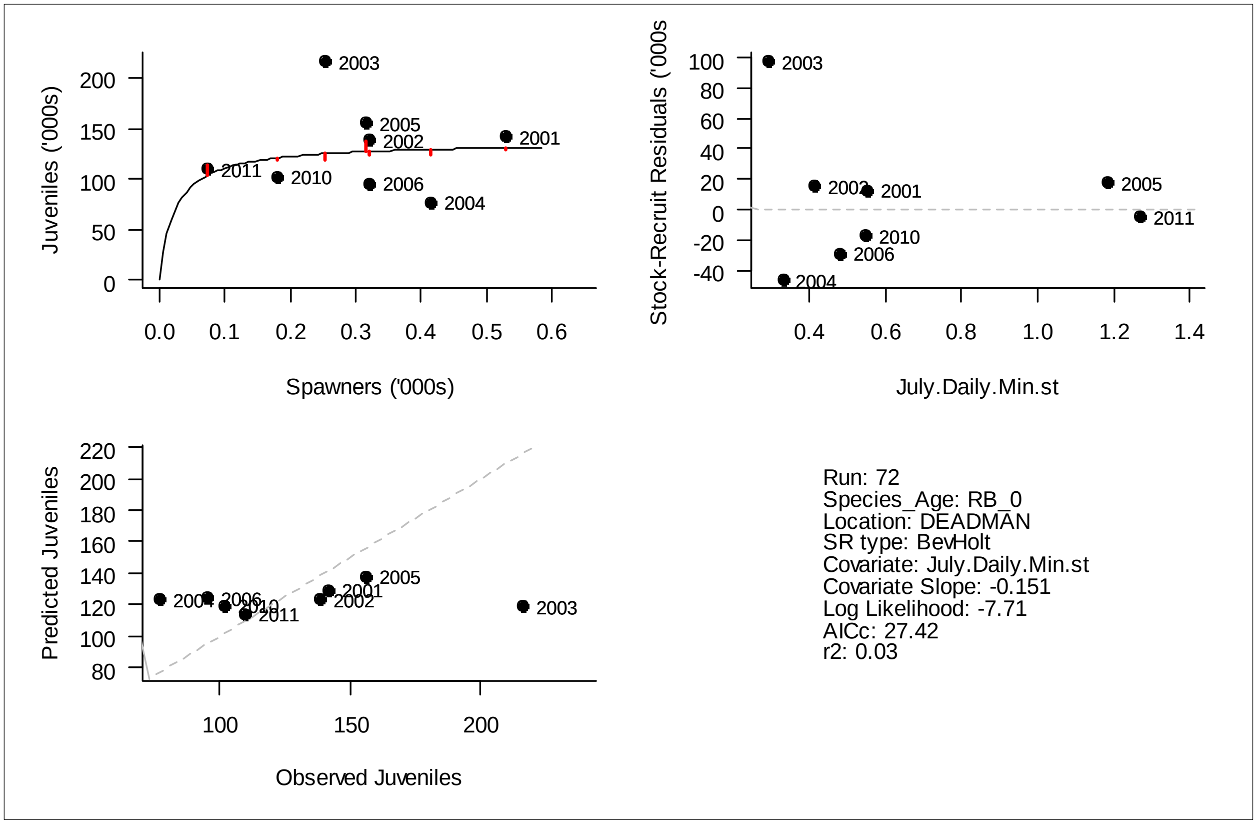
Run: 69
Species_Age: RB_0
Location: DEADMAN
SR type: BevHolt
Covariate: Summer.30Day.Min.st
Covariate Slope: 0.665
Log Likelihood: -7.71
AICc: 27.42
r2: 0.03



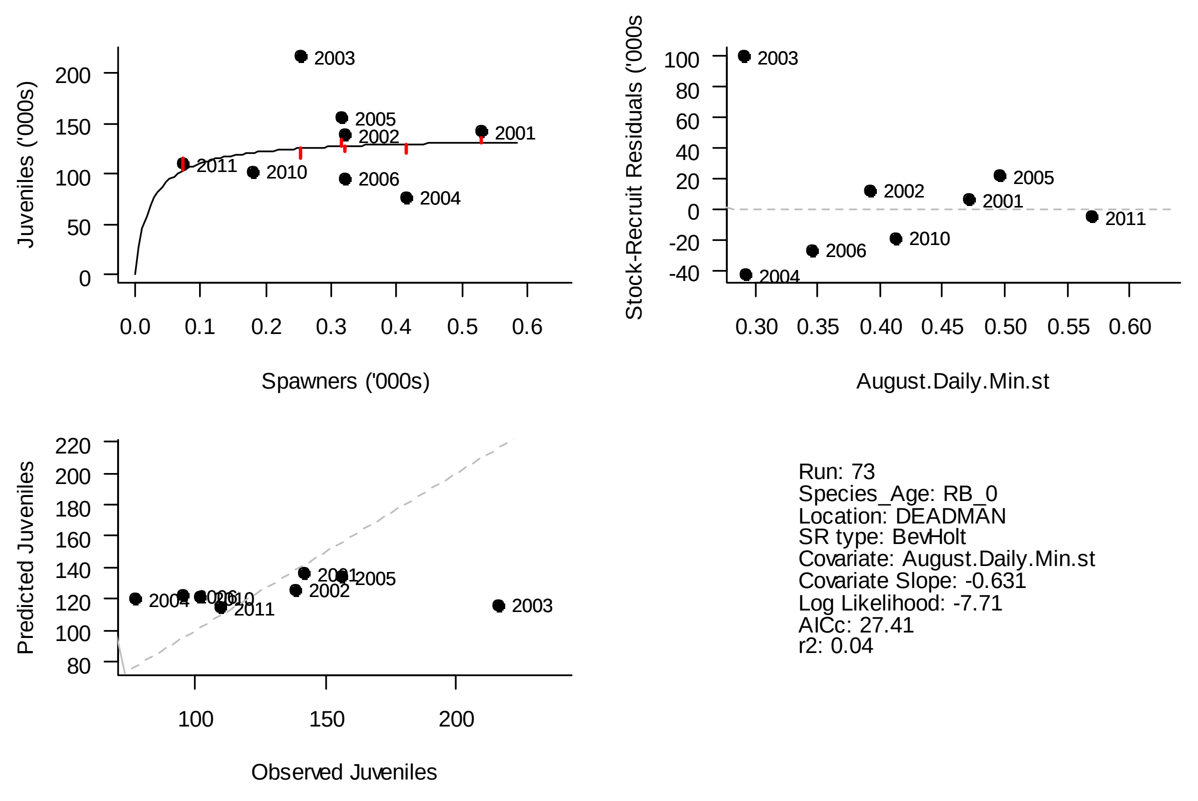
Run: 70
Species_Age: RB_0
Location: DEADMAN
SR type: BevHolt
Covariate: Summer.30Day.Min.Doyle
Covariate Slope: 0.074
Log Likelihood: -7.71
AICc: 27.41
r2: 0.04



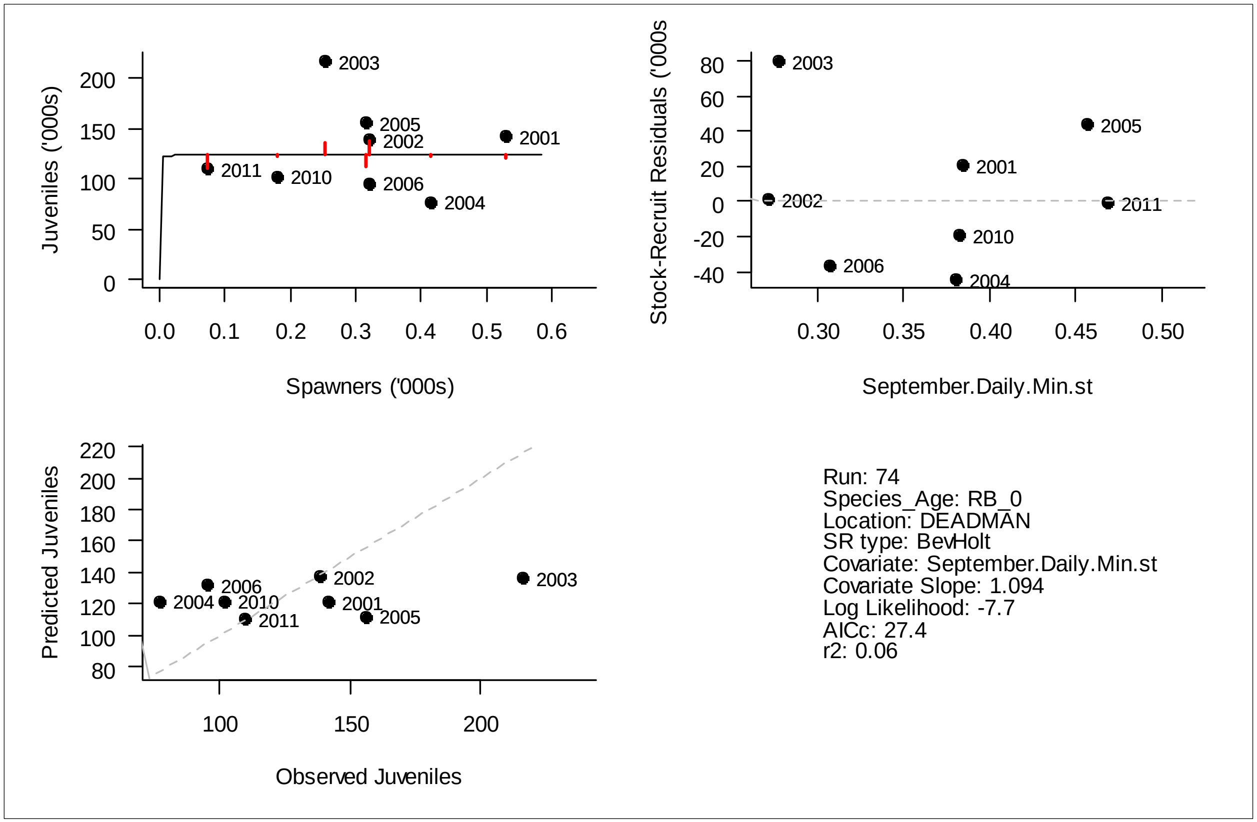
Run: 71
Species_Age: RB_0
Location: DEADMAN
SR type: BevHolt
Covariate: minflow.plus.tempmax.30day
Covariate Slope: -0.331
Log Likelihood: -7.65
AICc: 27.3
r2: 0.2



Run: 72
Species_Age: RB_0
Location: DEADMAN
SR type: BevHolt
Covariate: July.Daily.Min.st
Covariate Slope: -0.151
Log Likelihood: -7.71
AICc: 27.42
r2: 0.03

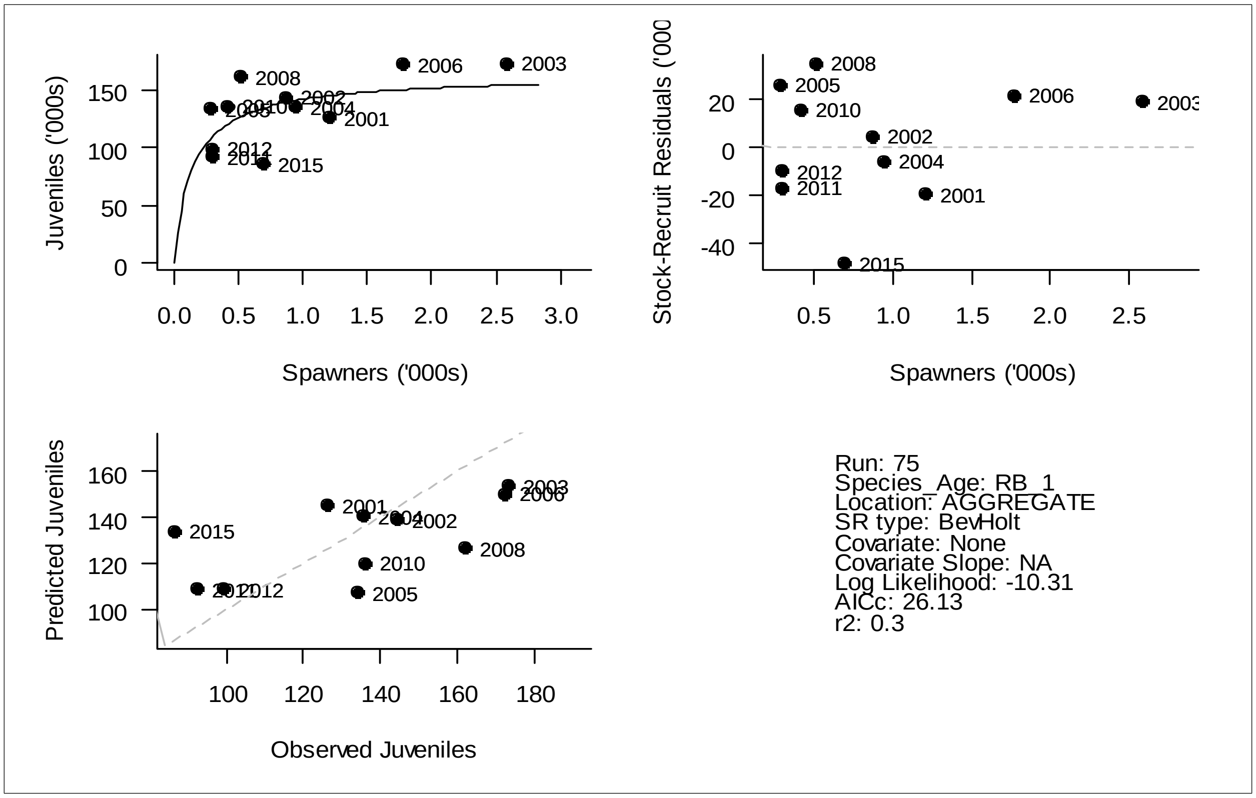


Run: 73
Species_Age: RB_0
Location: DEADMAN
SR type: BevHolt
Covariate: August.Daily.Min.st
Covariate Slope: -0.631
Log Likelihood: -7.71
AICc: 27.41
r2: 0.04

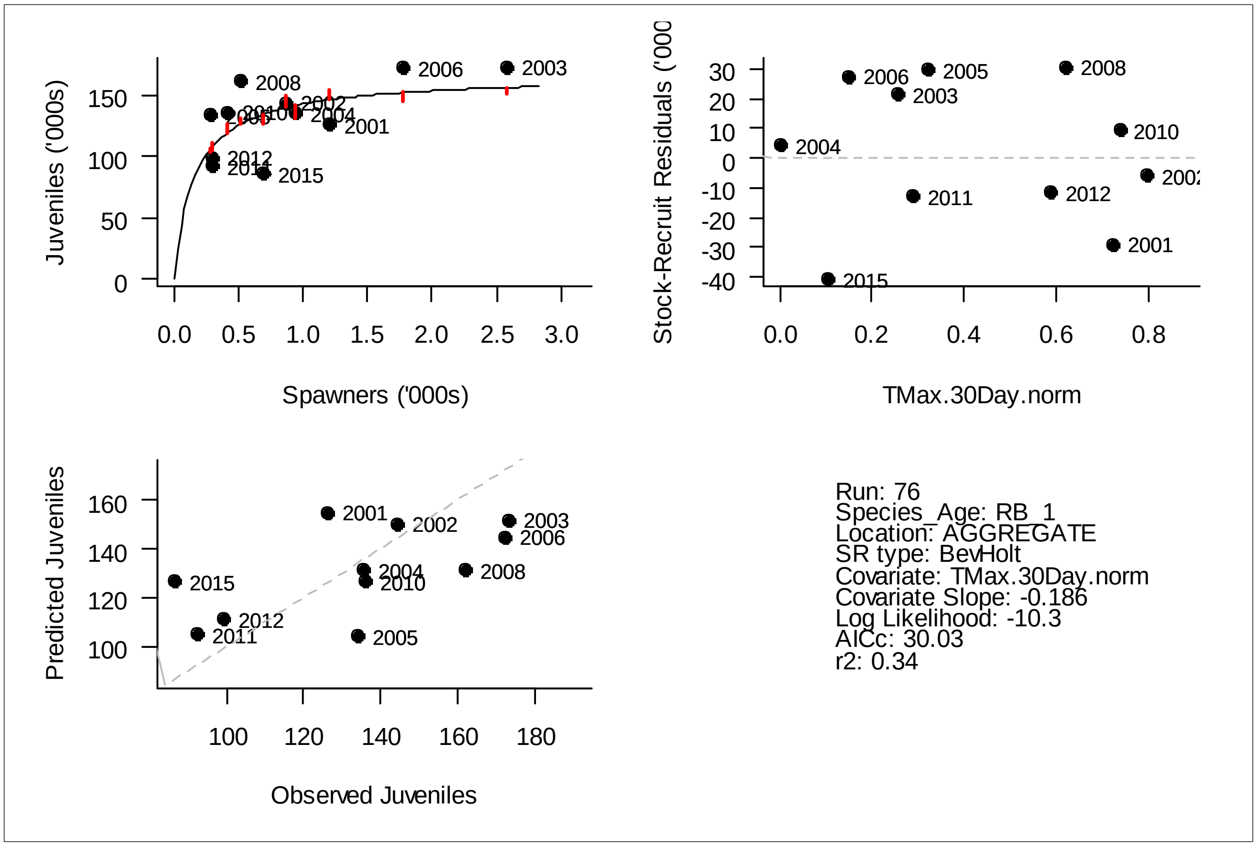


Run: 74
Species_Age: RB_0
Location: DEADMAN
SR type: BevHolt
Covariate: September.Daily.Min.st
Covariate Slope: 1.094
Log Likelihood: -7.7
AICc: 27.4
r2: 0.06

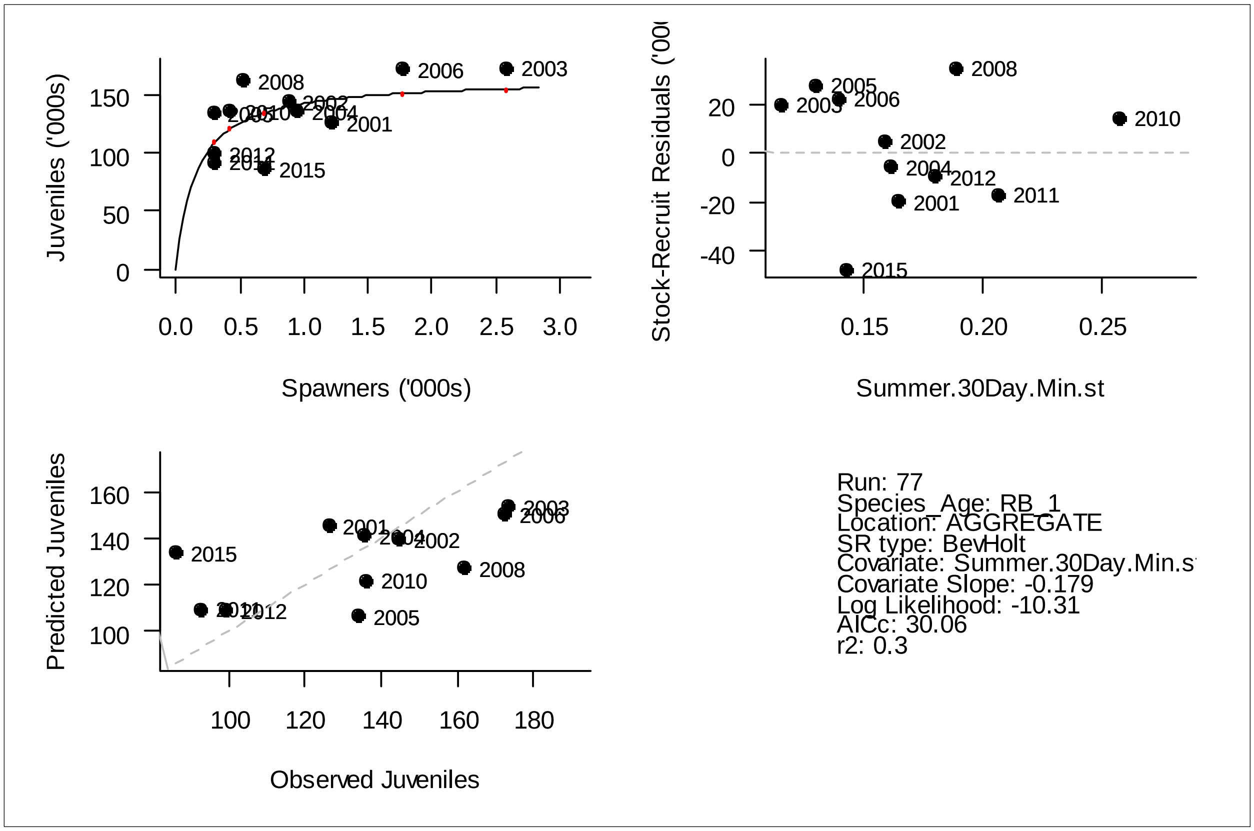
Appendix 5. Outputs from Beverton-Holt stock-recruitment models of Steelhead age 1+ parr for each stream section and fitted using only brood spawner abundance or in combination with one environmental covariate. Dots represent observed abundance, curves represent prediction based on spawner abundance and, when includeing a covariate, the vertical lines represent the prediction of the full model. AIC$_c$ and R^2 values of predected versus observed are also listed for each model.



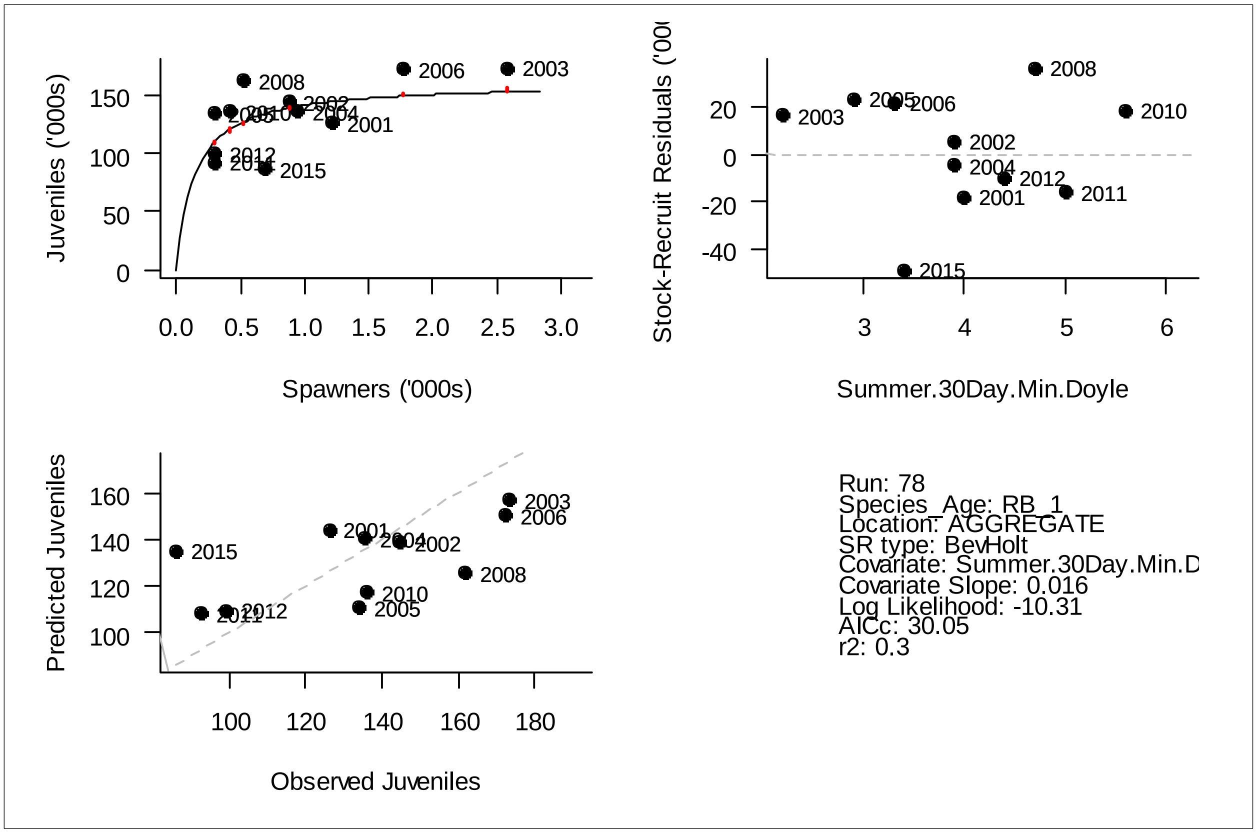
Run: 75
Species_Age: RB_1
Location: AGGREGATE
SR type: BevHolt
Covariate: None
Covariate Slope: NA
Log Likelihood: -10.31
AICc: 26.13
r2: 0.3



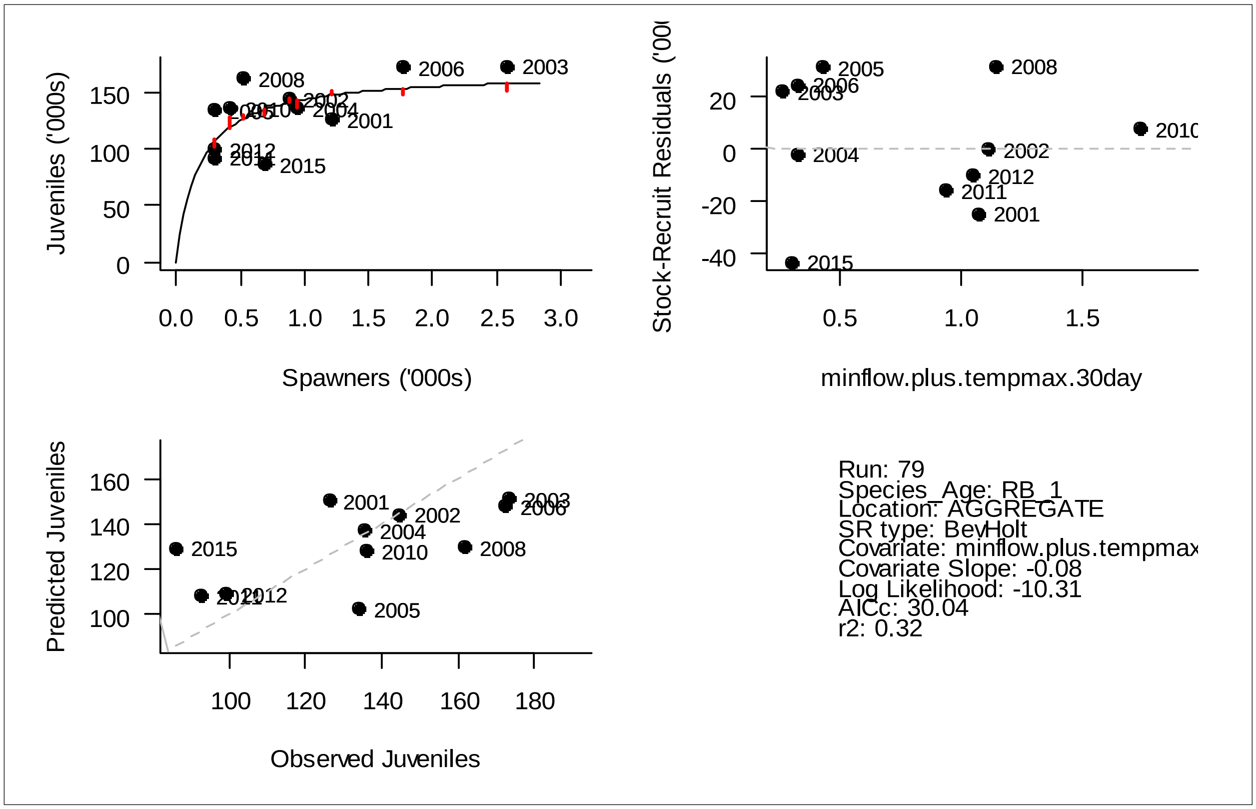
Run: 76
Species_Age: RB_1
Location: AGGREGATE
SR type: BevHolt
Covariate: TMax.30Day.norm
Covariate Slope: -0.186
Log Likelihood: -10.3
AICc: 30.03
r2: 0.34



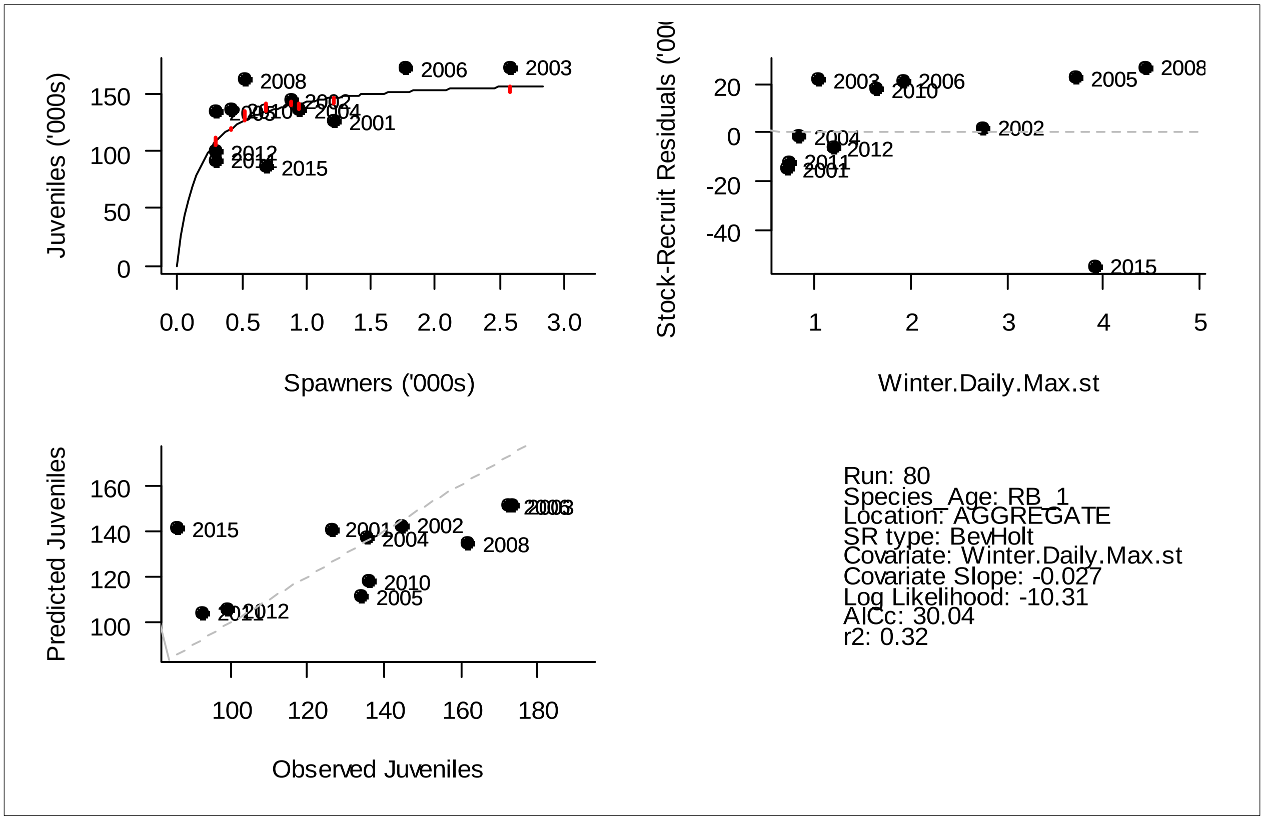
Run: 77
Species_Age: RB_1
Location: AGGREGATE
SR type: BevHolt
Covariate: Summer.30Day.Min.s
Covariate Slope: -0.179
Log Likelihood: -10.31
AICc: 30.06
r2: 0.3



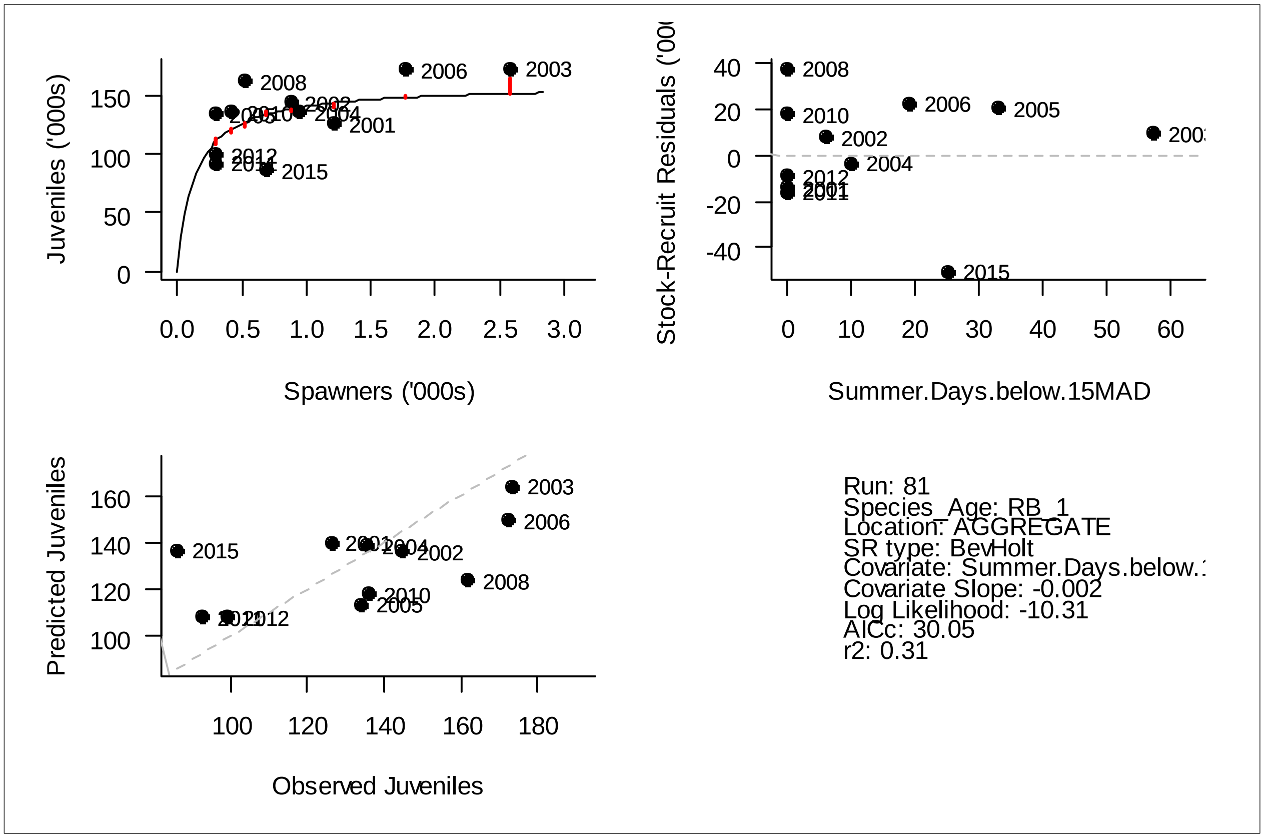
Juveniles ('000s)
Spawners ('000s)
Stock-Recruit Residuals ('00
Summer.30Day.Min.Doyle
Predicted Juveniles
Observed Juveniles
Run: 78
Species_Age: RB_1
Location: AGGREGATE
SR type: BevHolt
Covariate: Summer.30Day.Min.D
Covariate Slope: 0.016
Log Likelihood: -10.31
AICc: 30.05
r2: 0.3



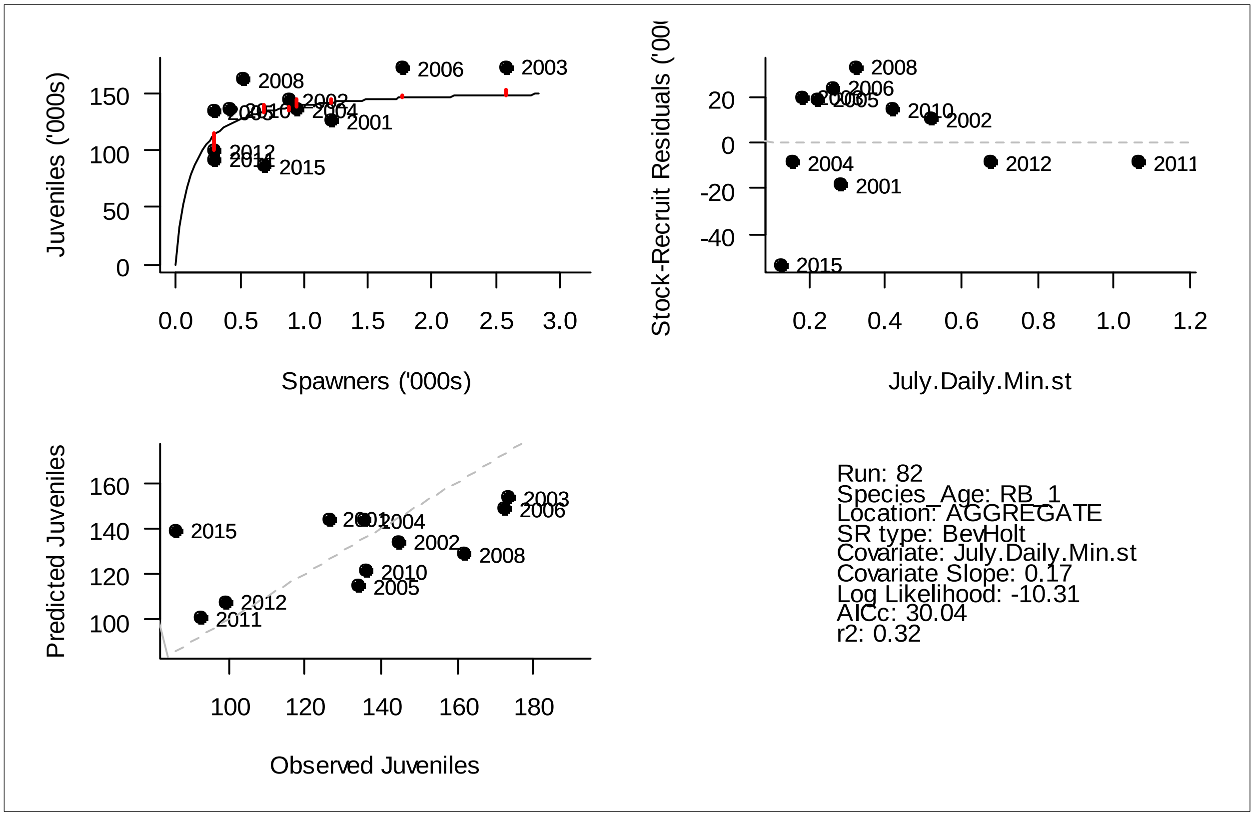
Juveniles ('000s)
Spawners ('000s)
Stock-Recruit Residuals ('00
minflow.plus.tempmax.30day
Predicted Juveniles
Observed Juveniles
Run: 79
Species_Age: RB_1
Location: AGGREGATE
SR type: BevHolt
Covariate: minflow.plus.tempmax
Covariate Slope: -0.08
Log Likelihood: -10.31
AICc: 30.04
r2: 0.32



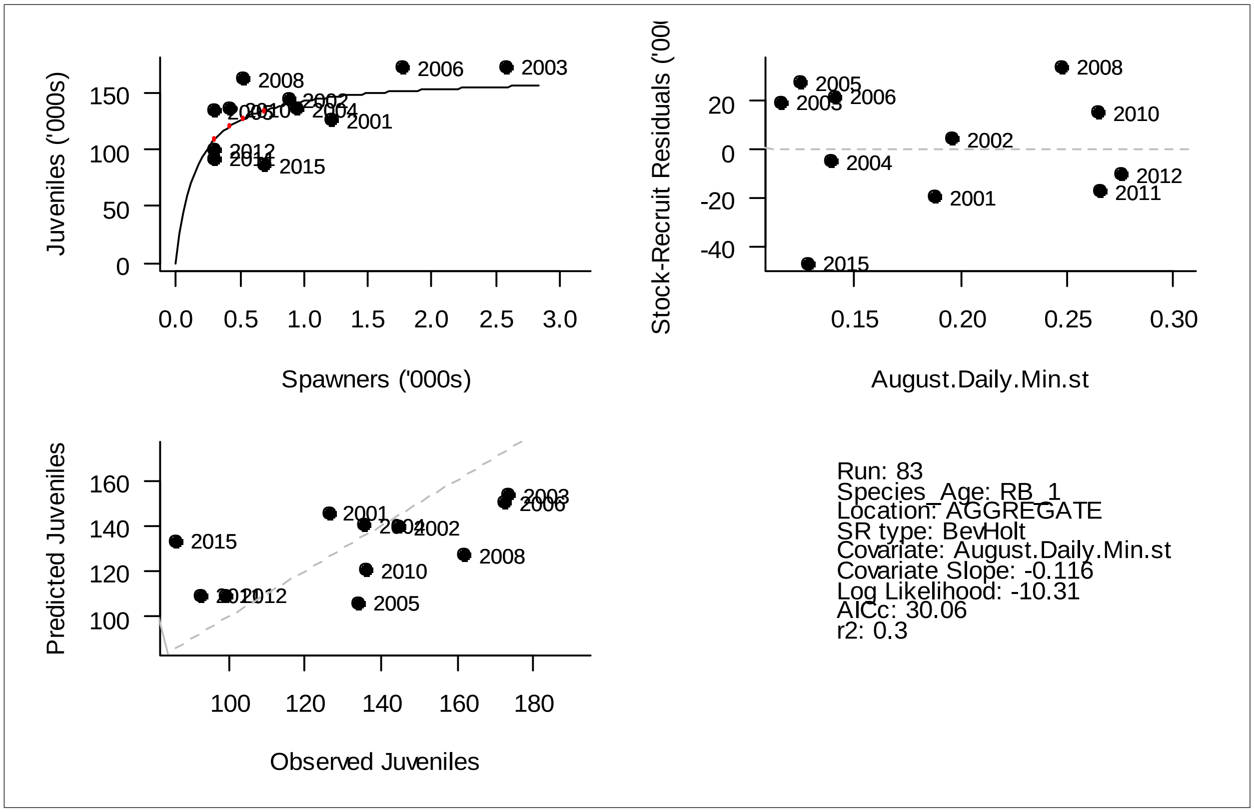
Run: 80
Species_Age: RB_1
Location: AGGREGATE
SR type: BevHolt
Covariate: Winter.Daily.Max.st
Covariate Slope: -0.027
Log Likelihood: -10.31
AICc: 30.04
r2: 0.32



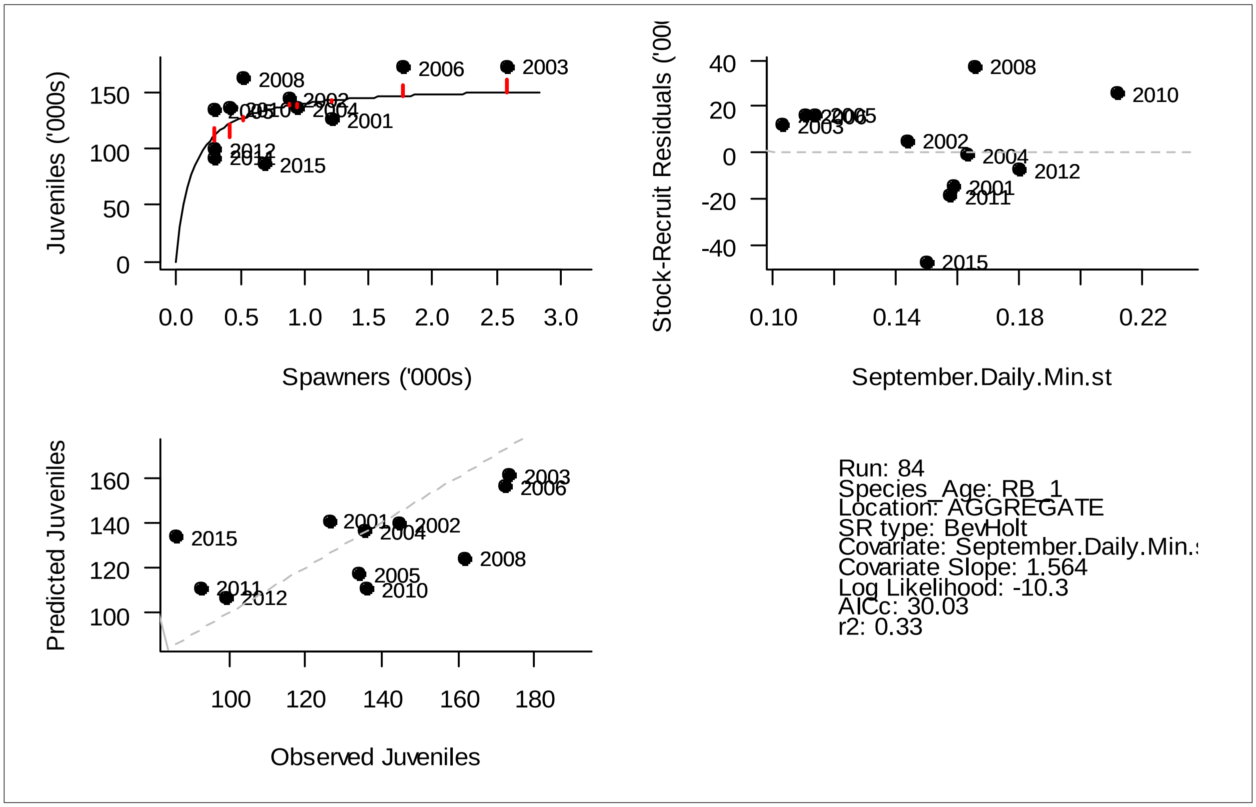
Run: 81
Species_Age: RB_1
Location: AGGREGATE
SR type: BevHolt
Covariate: Summer.Days.below.
Covariate Slope: -0.002
Log Likelihood: -10.31
AICc: 30.05
r2: 0.31



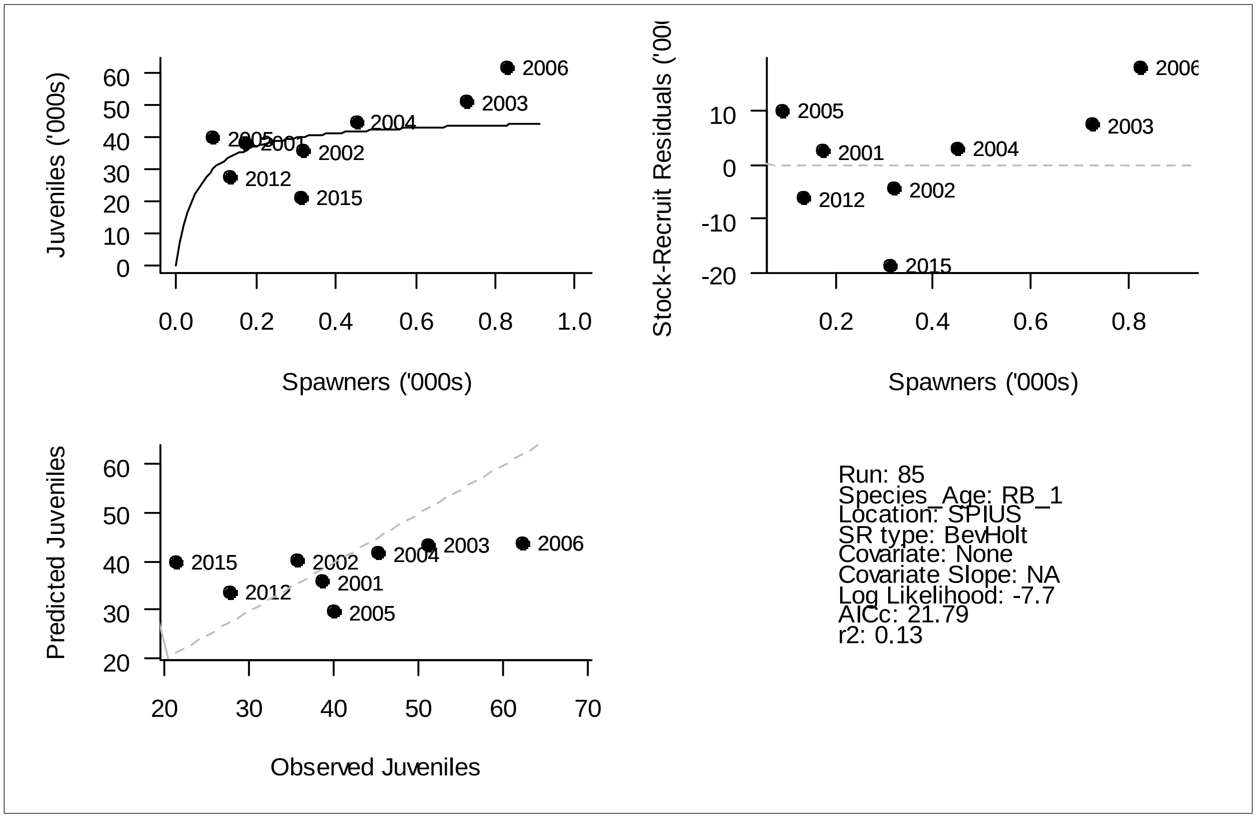
Run: 82
Species_Age: RB_1
Location: AGGREGATE
SR type: BevHolt
Covariate: July.Daily.Min.st
Covariate Slope: 0.17
Log Likelihood: -10.31
AICc: 30.04
r2: 0.32



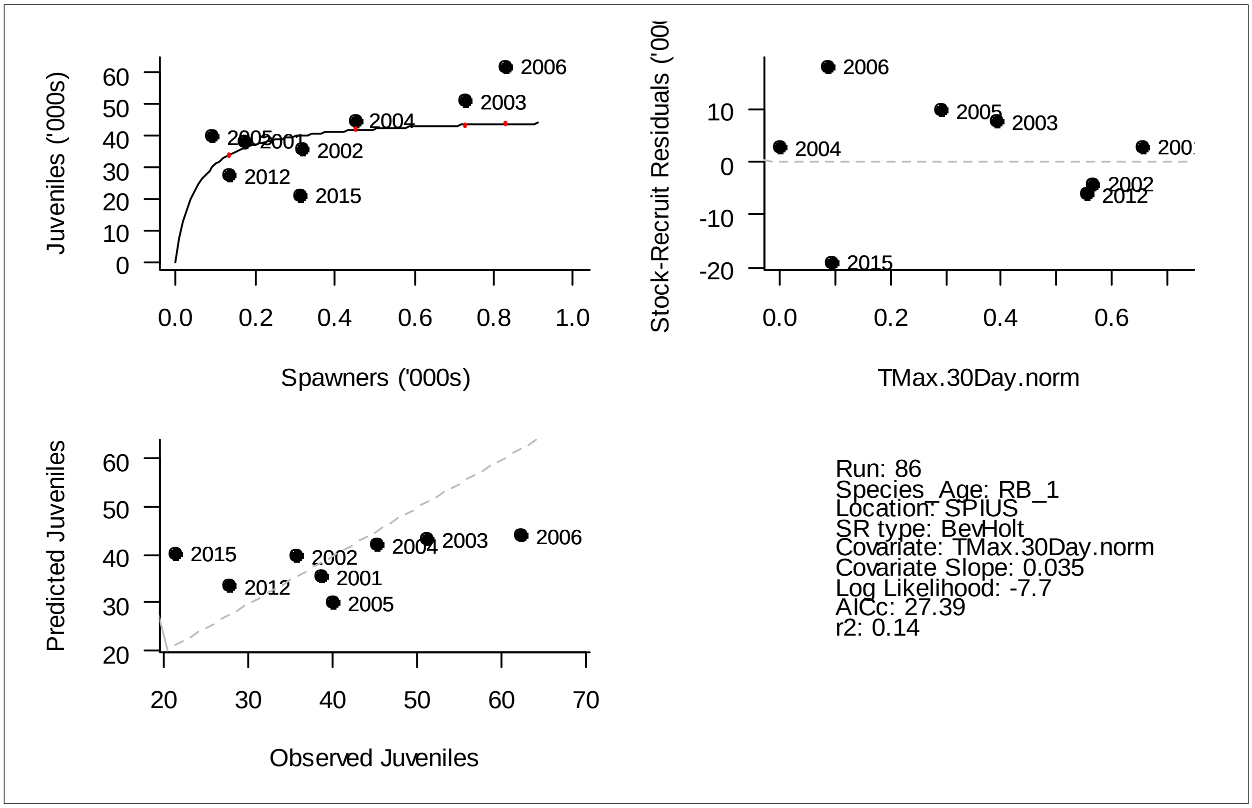
Run: 83
Species_Age: RB_1
Location: AGGREGATE
SR type: BevHolt
Covariate: August.Daily.Min.st
Covariate Slope: -0.116
Log Likelihood: -10.31
AICc: 30.06
r2: 0.3



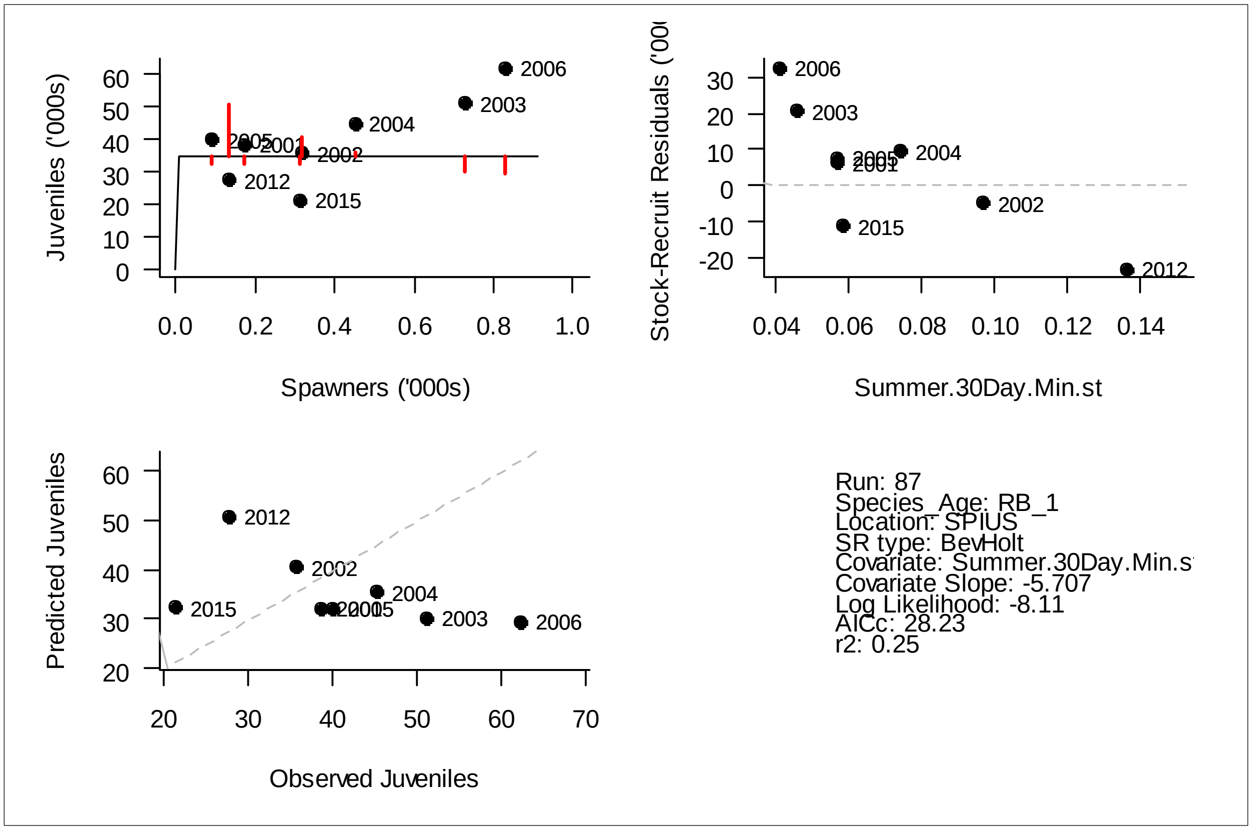
Run: 84
Species_Age: RB_1
Location: AGGREGATE
SR type: BevHolt
Covariate: September.Daily.Min.
Covariate Slope: 1.564
Log Likelihood: -10.3
AICc: 30.03
r2: 0.33



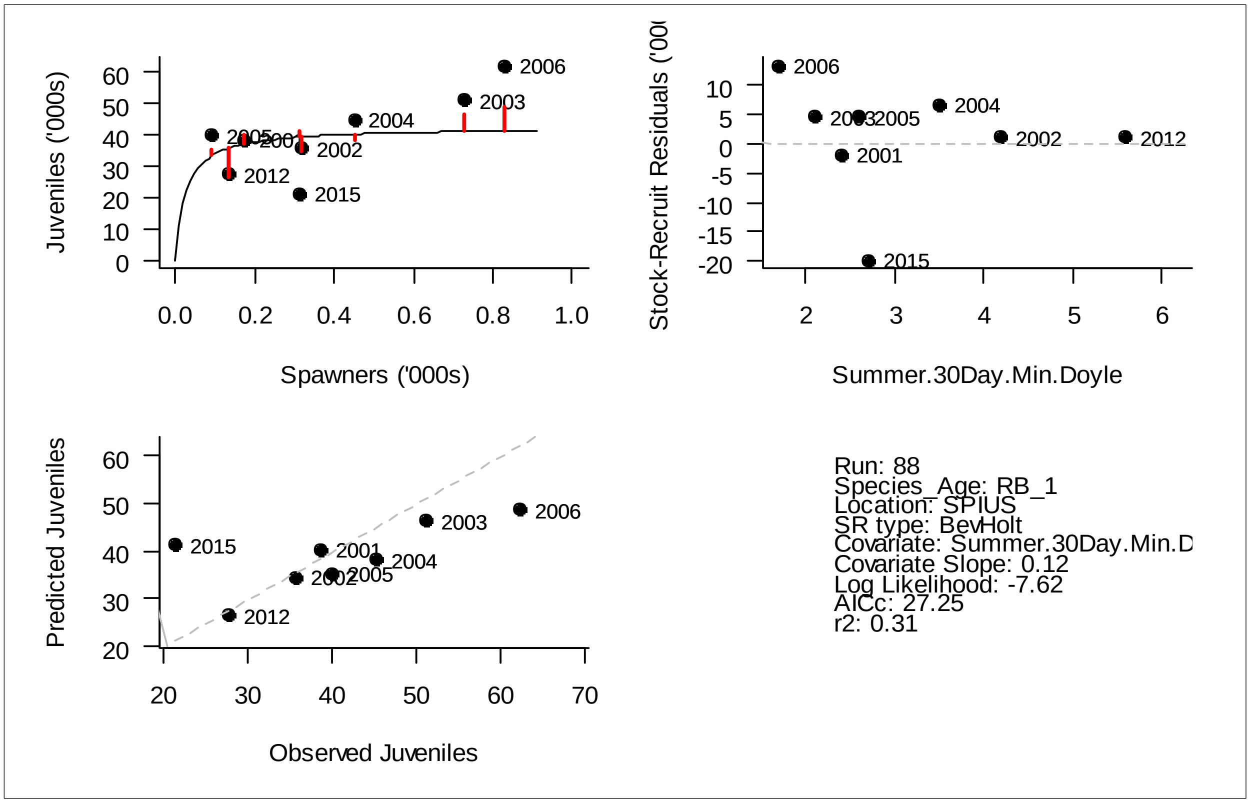
Run: 85
Species_Age: RB_1
Location: SPIUS
SR type: BevHolt
Covariate: None
Covariate Slope: NA
Log Likelihood: -7.7
AICc: 21.79
r2: 0.13



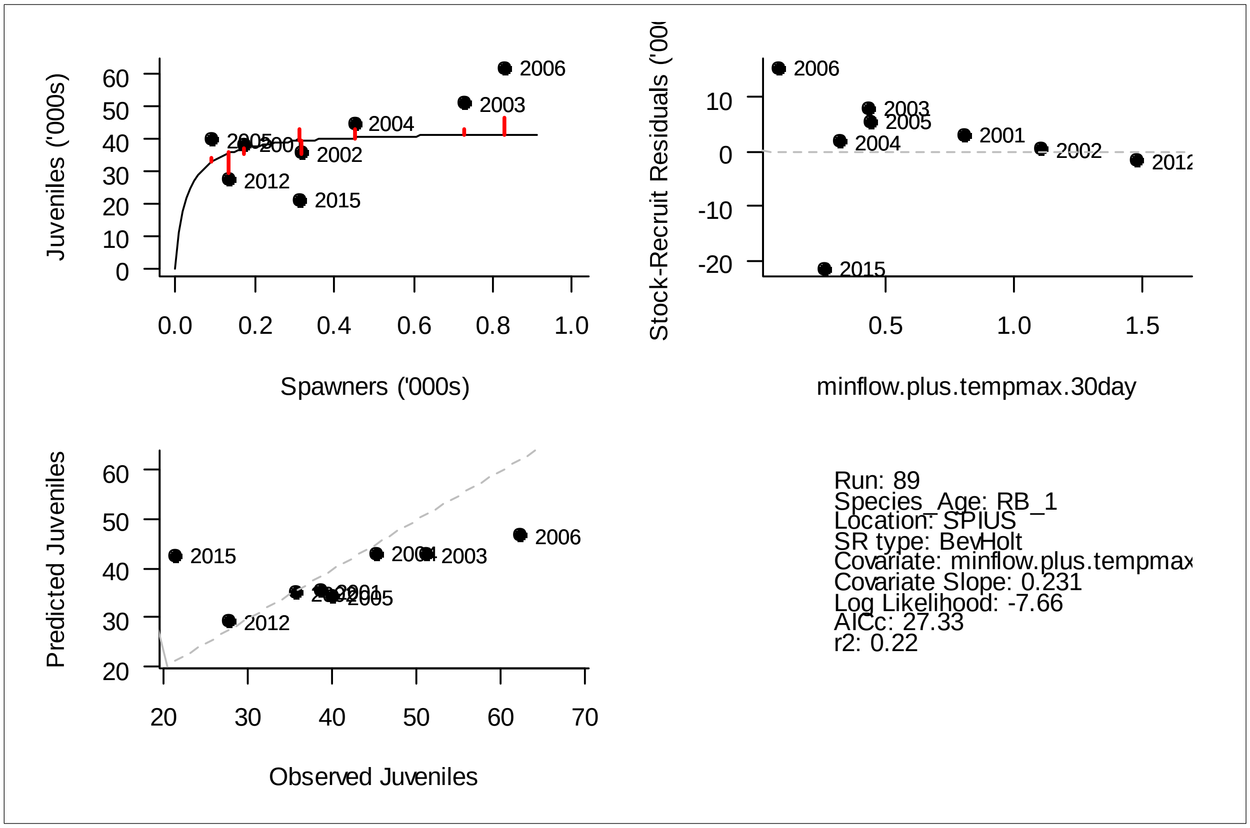
Run: 86
Species_Age: RB_1
Location: SPIUS
SR type: BevHolt
Covariate: TMax.30Day.norm
Covariate Slope: 0.035
Log Likelihood: -7.7
AICc: 27.39
r2: 0.14



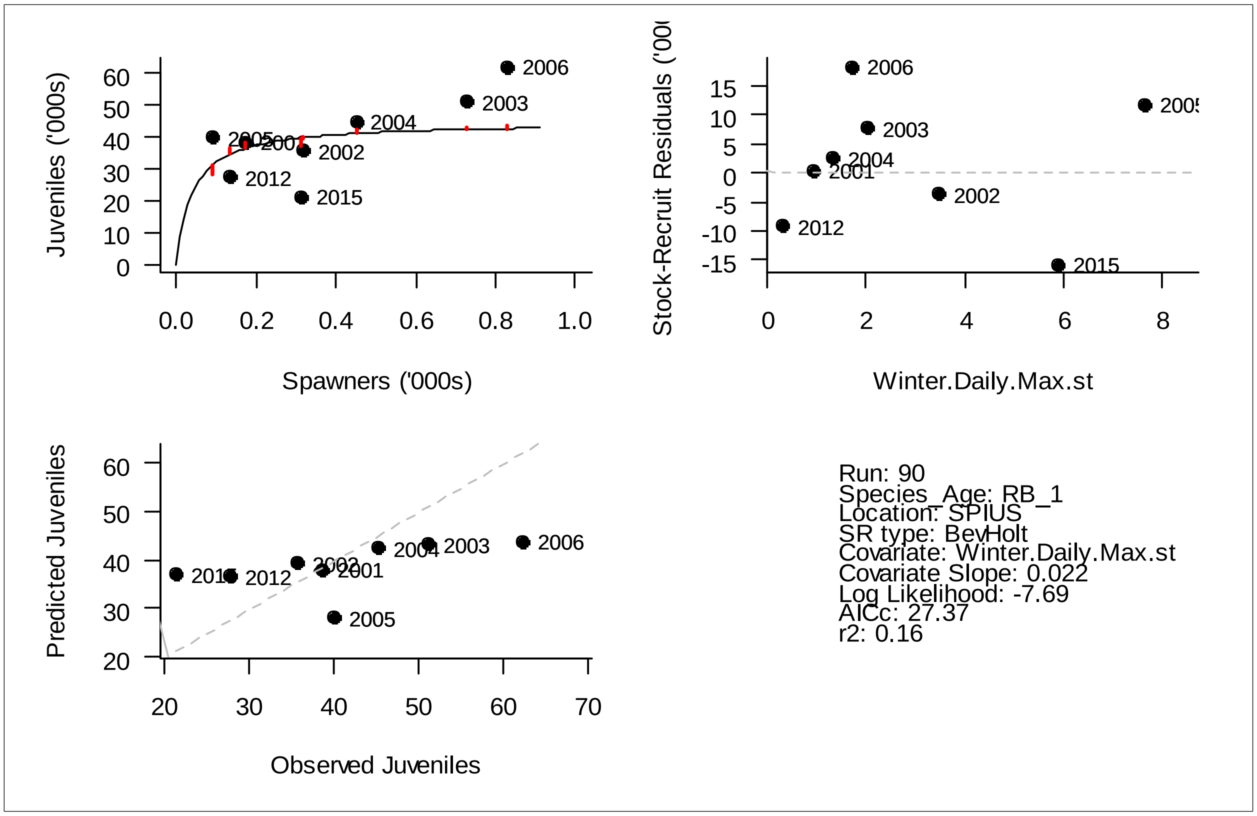
Run: 87
Species_Age: RB_1
Location: SPIUS
SR type: BevHolt
Covariate: Summer.30Day.Min.s
Covariate Slope: -5.707
Log Likelihood: -8.11
AICc: 28.23
r2: 0.25



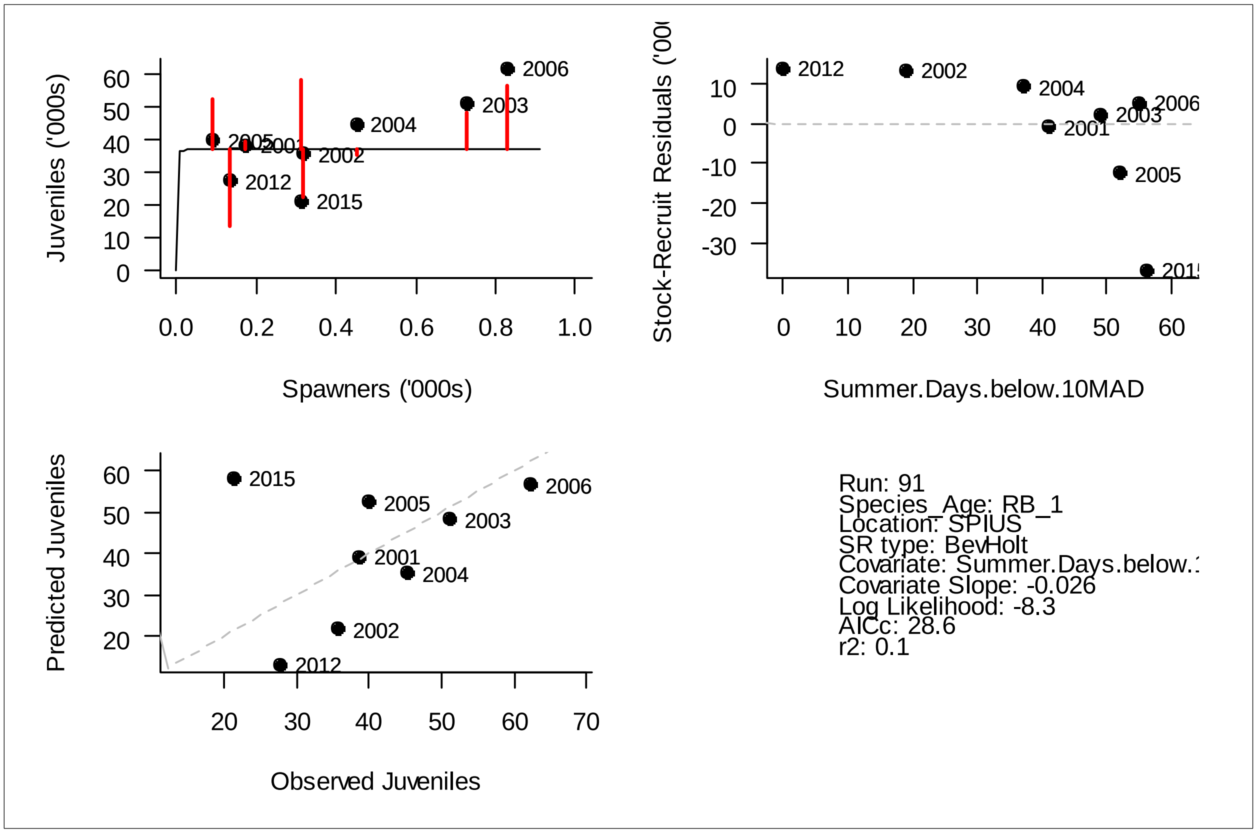
Run: 88
Species_Age: RB_1
Location: SPIUS
SR type: BevHolt
Covariate: Summer.30Day.Min.D
Covariate Slope: 0.12
Log Likelihood: -7.62
AICc: 27.25
r2: 0.31



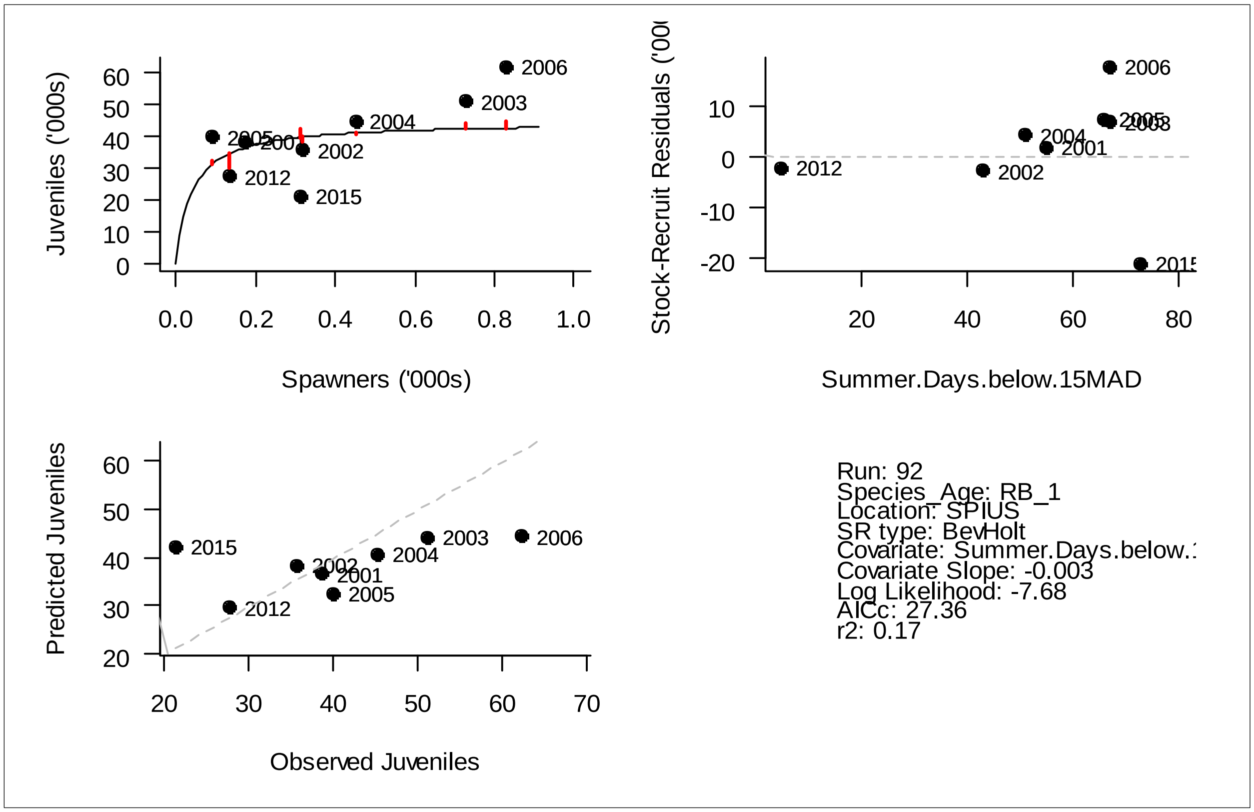
Run: 89
Species_Age: RB_1
Location: SPIUS
SR type: BevHolt
Covariate: minflow.plus.tempmax
Covariate Slope: 0.231
Log Likelihood: -7.66
AICc: 27.33
r2: 0.22



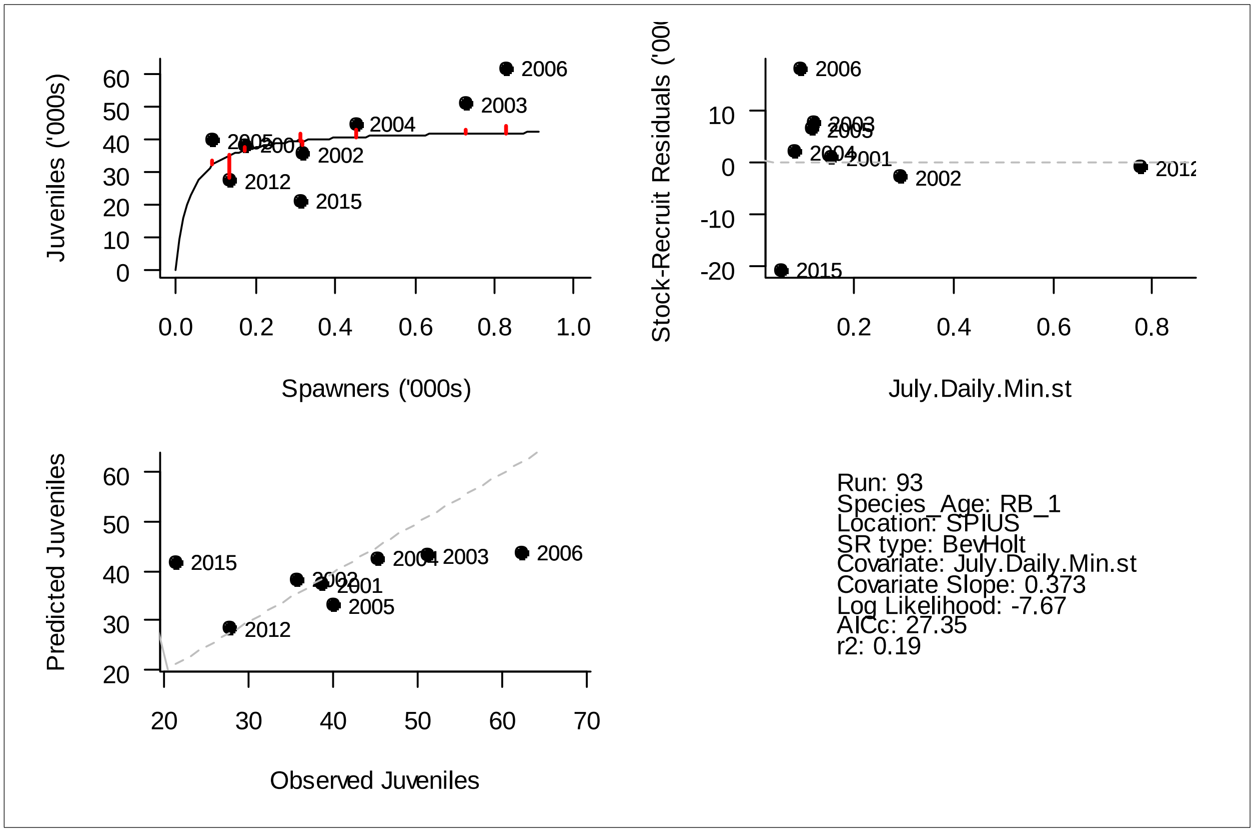
Run: 90
Species_Age: RB_1
Location: SPIUS
SR type: BevHolt
Covariate: Winter.Daily.Max.st
Covariate Slope: 0.022
Log Likelihood: -7.69
AICc: 27.37
r2: 0.16



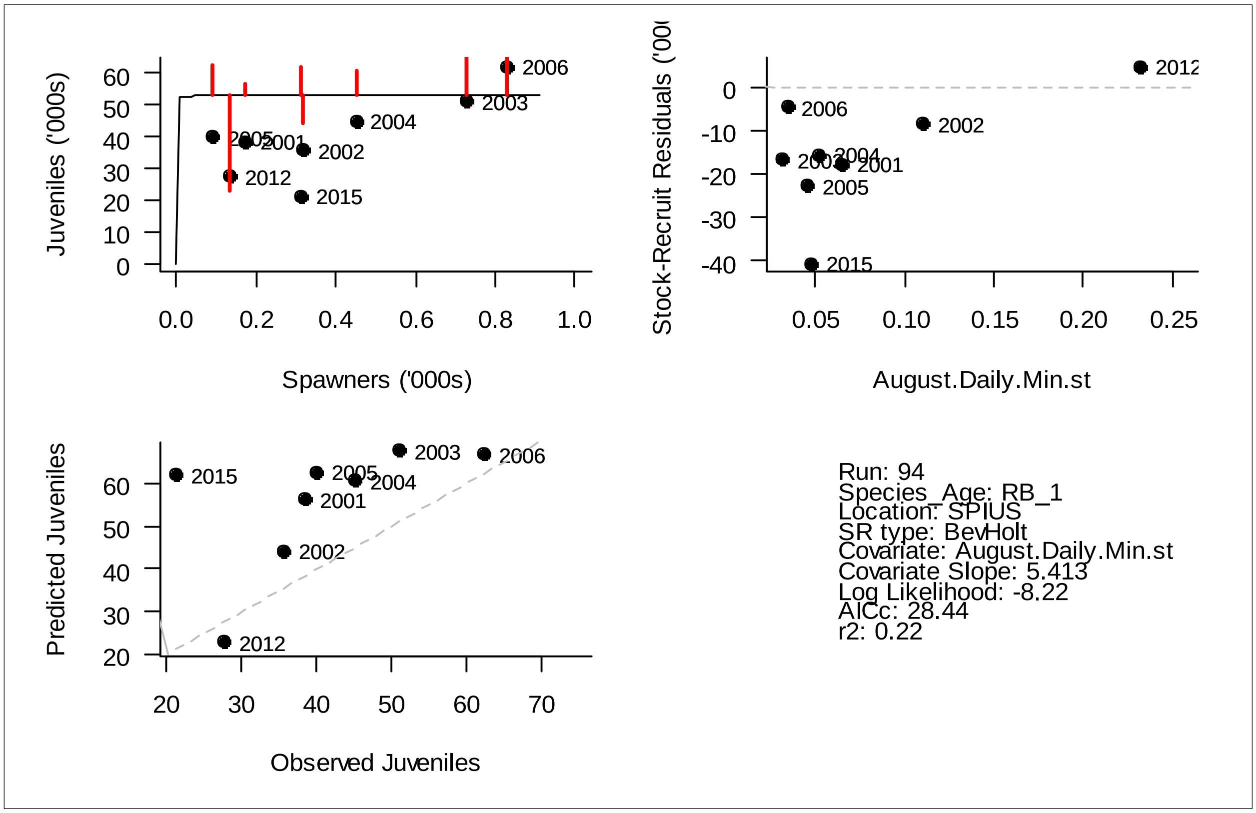
Run: 91
Species_Age: RB_1
Location: SPIUS
SR type: BevHolt
Covariate: Summer.Days.below.
Covariate Slope: -0.026
Log Likelihood: -8.3
AICc: 28.6
r2: 0.1



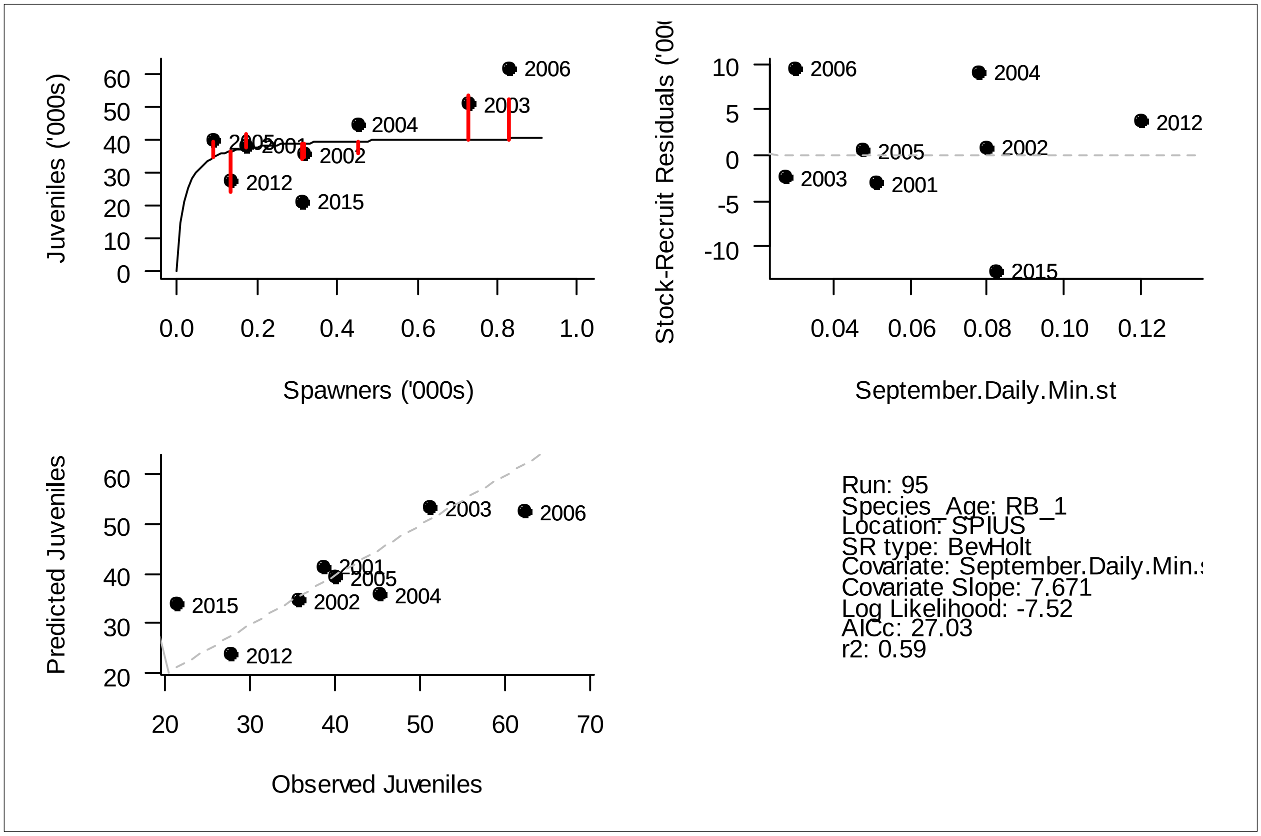
Run: 92
Species_Age: RB_1
Location: SPIUS
SR type: BevHolt
Covariate: Summer.Days.below.1
Covariate Slope: -0.003
Log Likelihood: -7.68
AICc: 27.36
r2: 0.17



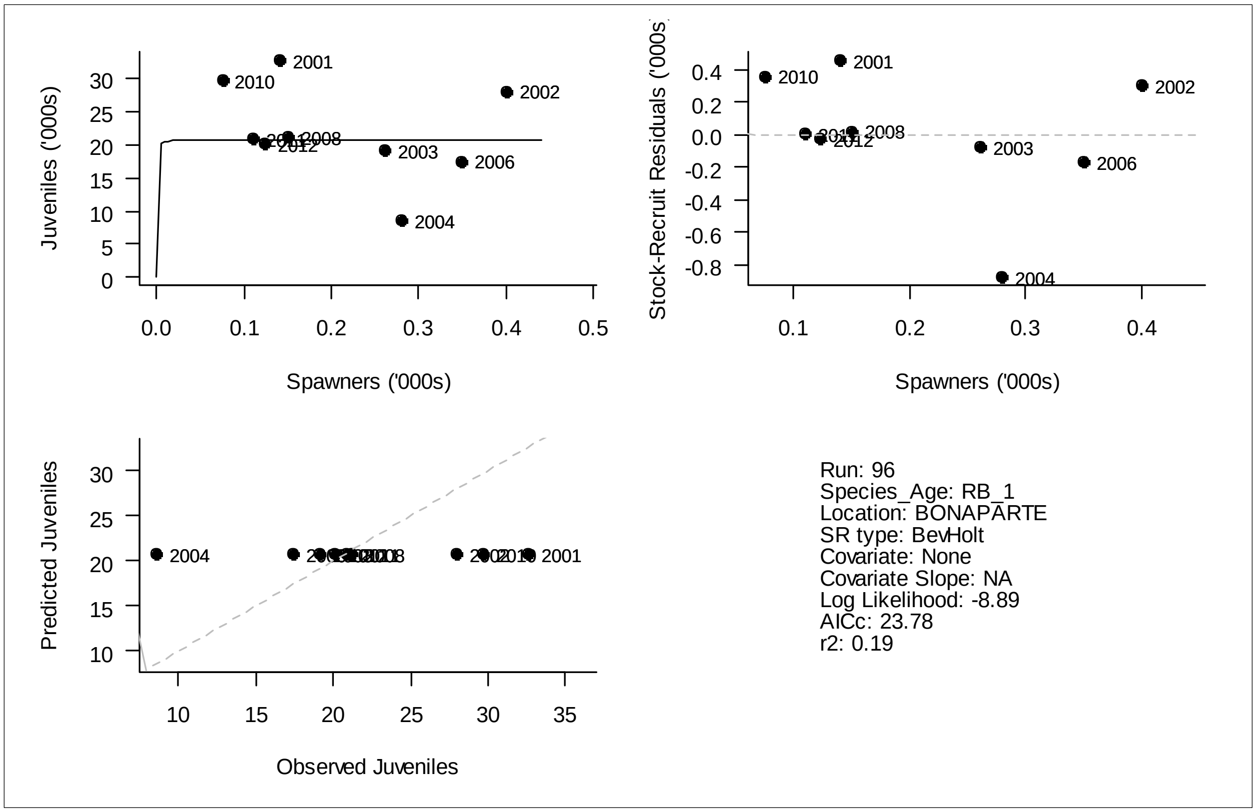
Run: 93
Species_Age: RB_1
Location: SPIUS
SR type: BevHolt
Covariate: July.Daily.Min.st
Covariate Slope: 0.373
Log Likelihood: -7.67
AICc: 27.35
r2: 0.19



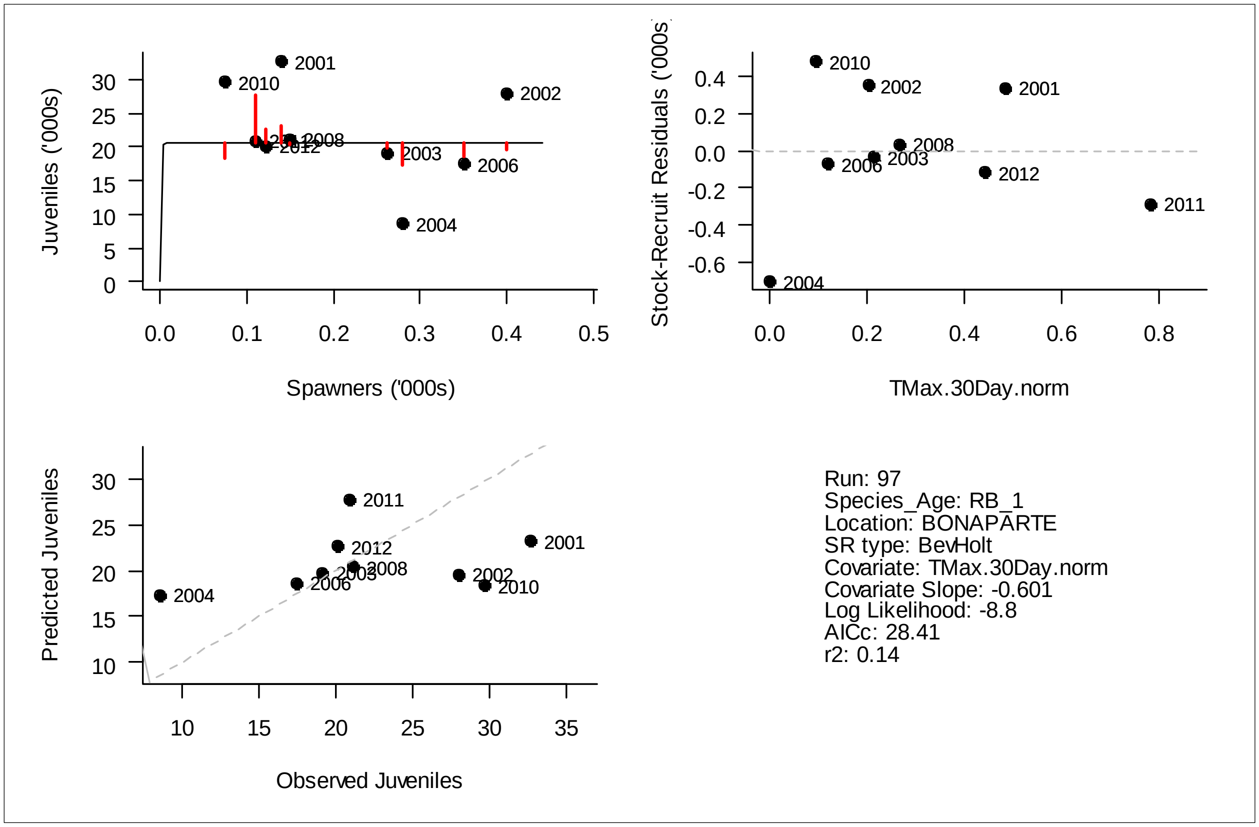
Run: 94
Species_Age: RB_1
Location: SPIUS
SR type: BevHolt
Covariate: August.Daily.Min.st
Covariate Slope: 5.413
Log Likelihood: -8.22
AICc: 28.44
r2: 0.22



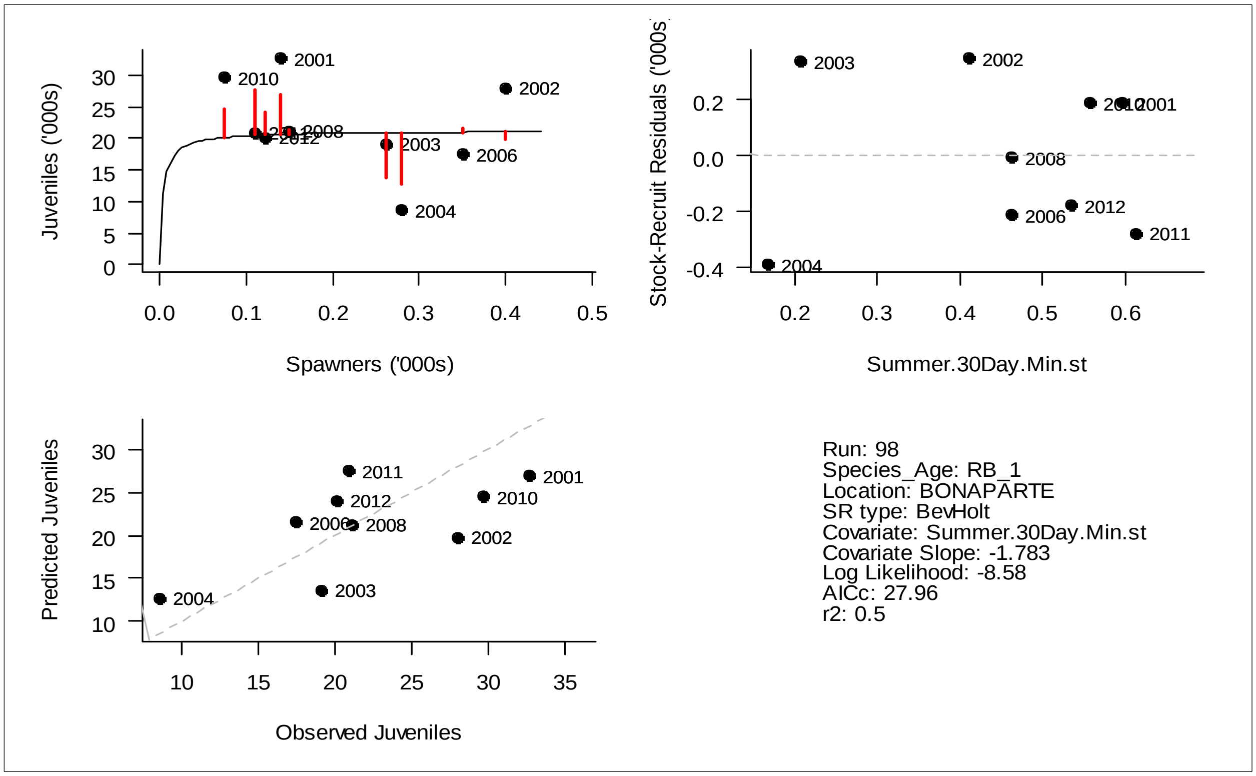
Run: 95
Species_Age: RB_1
Location: SPIUS
SR type: BevHolt
Covariate: September.Daily.Min.s
Covariate Slope: 7.671
Log Likelihood: -7.52
AICc: 27.03
r2: 0.59



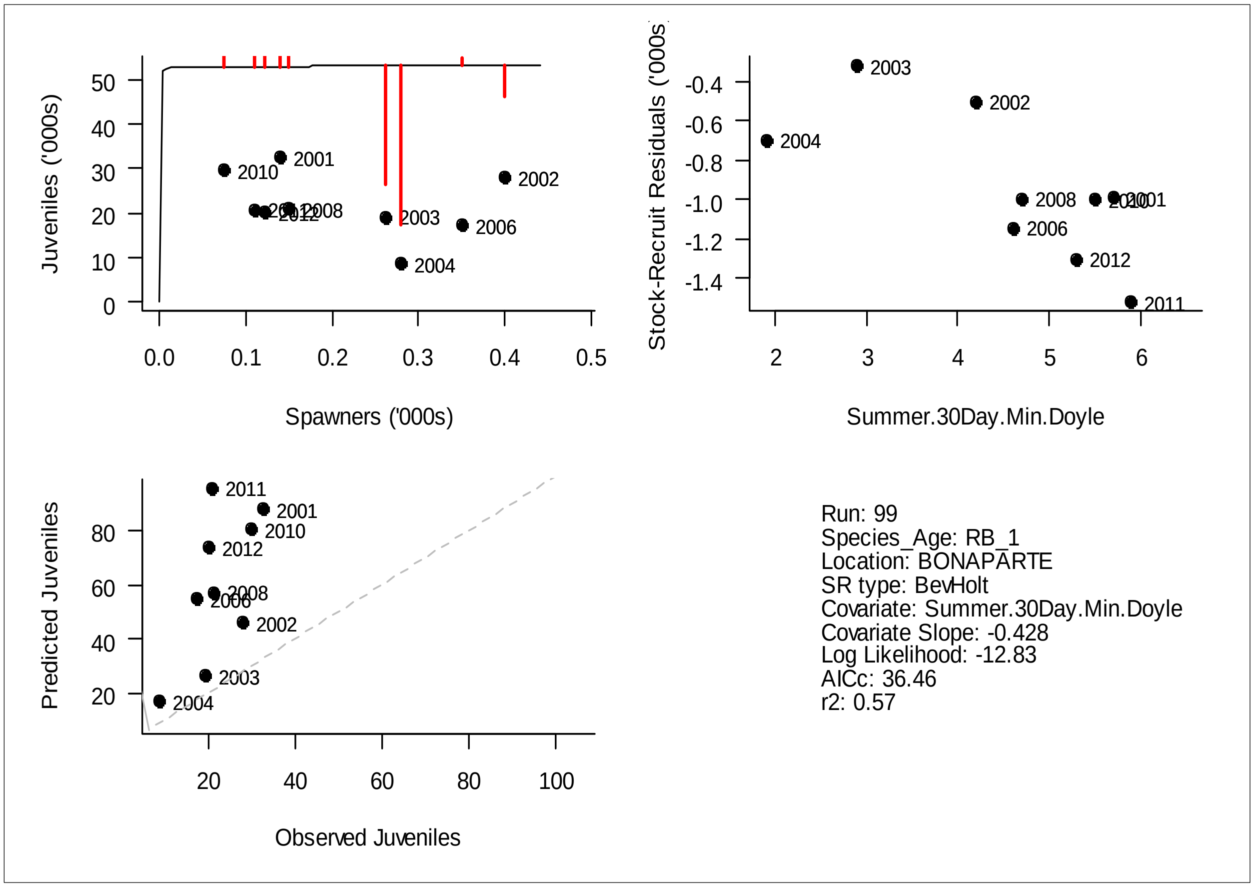
Run: 96
Species_Age: RB_1
Location: BONAPARTE
SR type: BevHolt
Covariate: None
Covariate Slope: NA
Log Likelihood: -8.89
AICc: 23.78
r2: 0.19



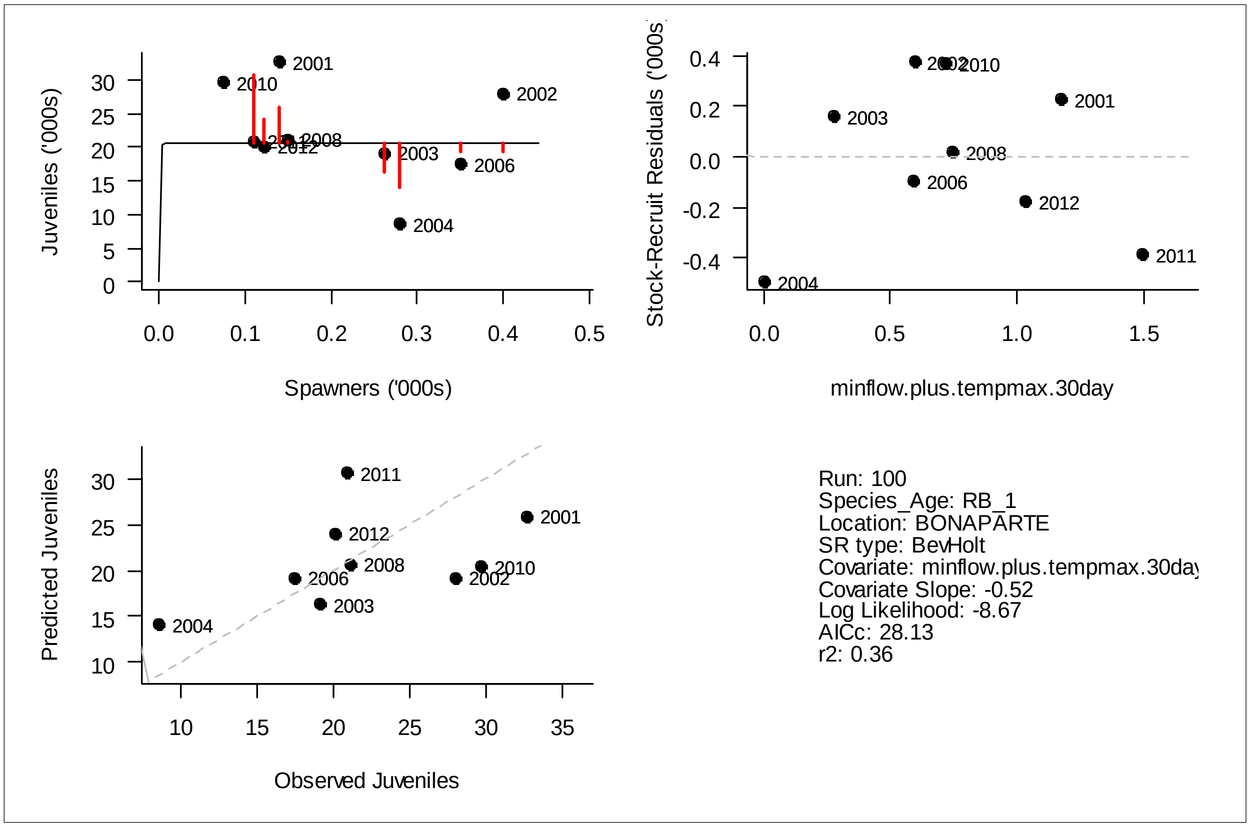
Run: 97
Species_Age: RB_1
Location: BONAPARTE
SR type: BevHolt
Covariate: TMax.30Day.norm
Covariate Slope: -0.601
Log Likelihood: -8.8
AICc: 28.41
r2: 0.14



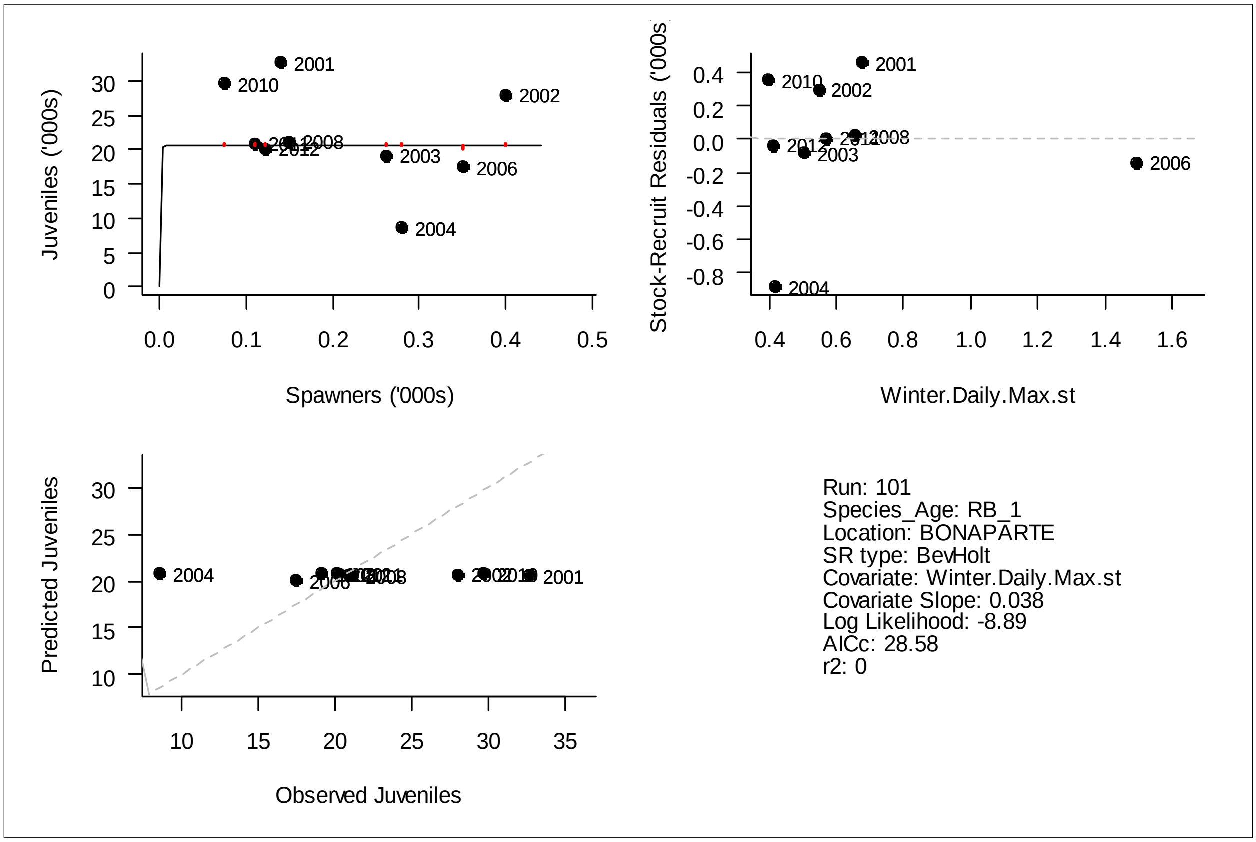
Run: 98
Species_Age: RB_1
Location: BONAPARTE
SR type: BevHolt
Covariate: Summer.30Day.Min.st
Covariate Slope: -1.783
Log Likelihood: -8.58
AICc: 27.96
r2: 0.5



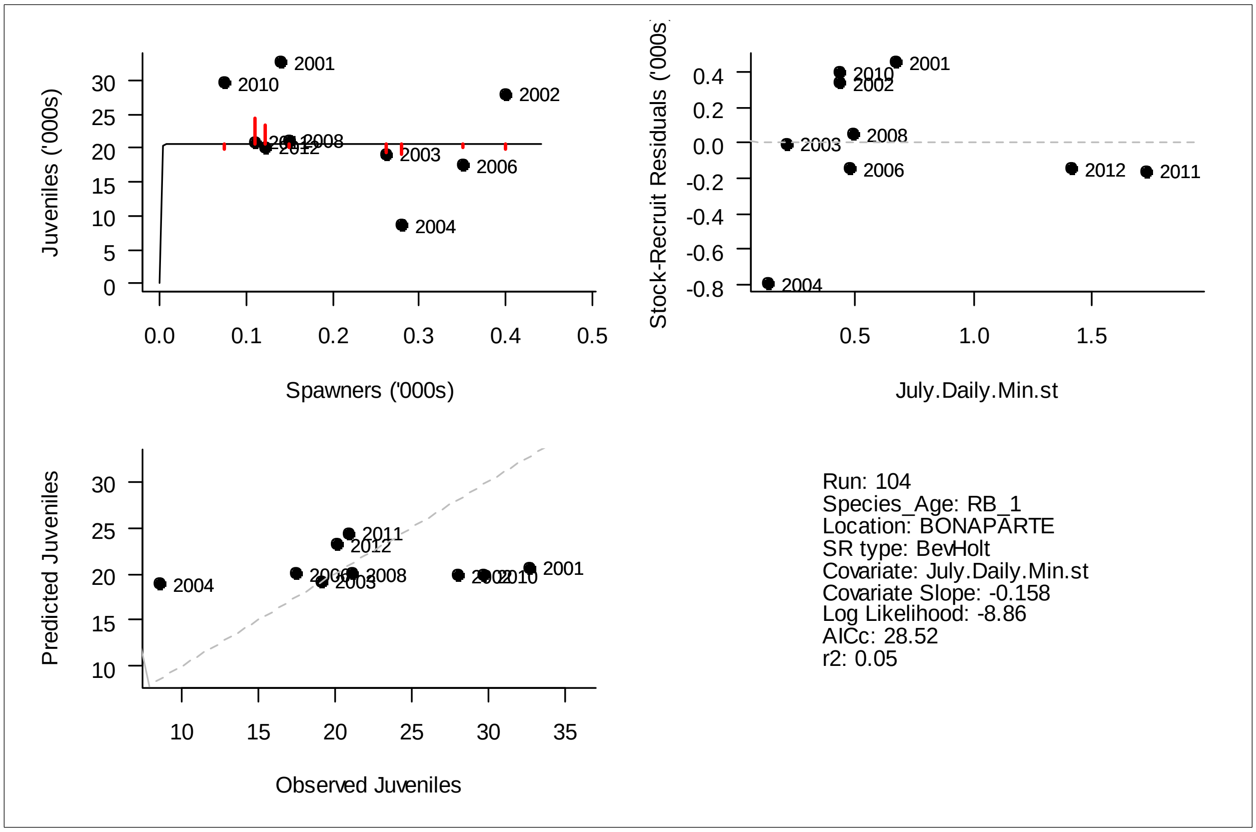
Run: 99
Species_Age: RB_1
Location: BONAPARTE
SR type: BevHolt
Covariate: Summer.30Day.Min.Doyle
Covariate Slope: -0.428
Log Likelihood: -12.83
AICc: 36.46
r2: 0.57



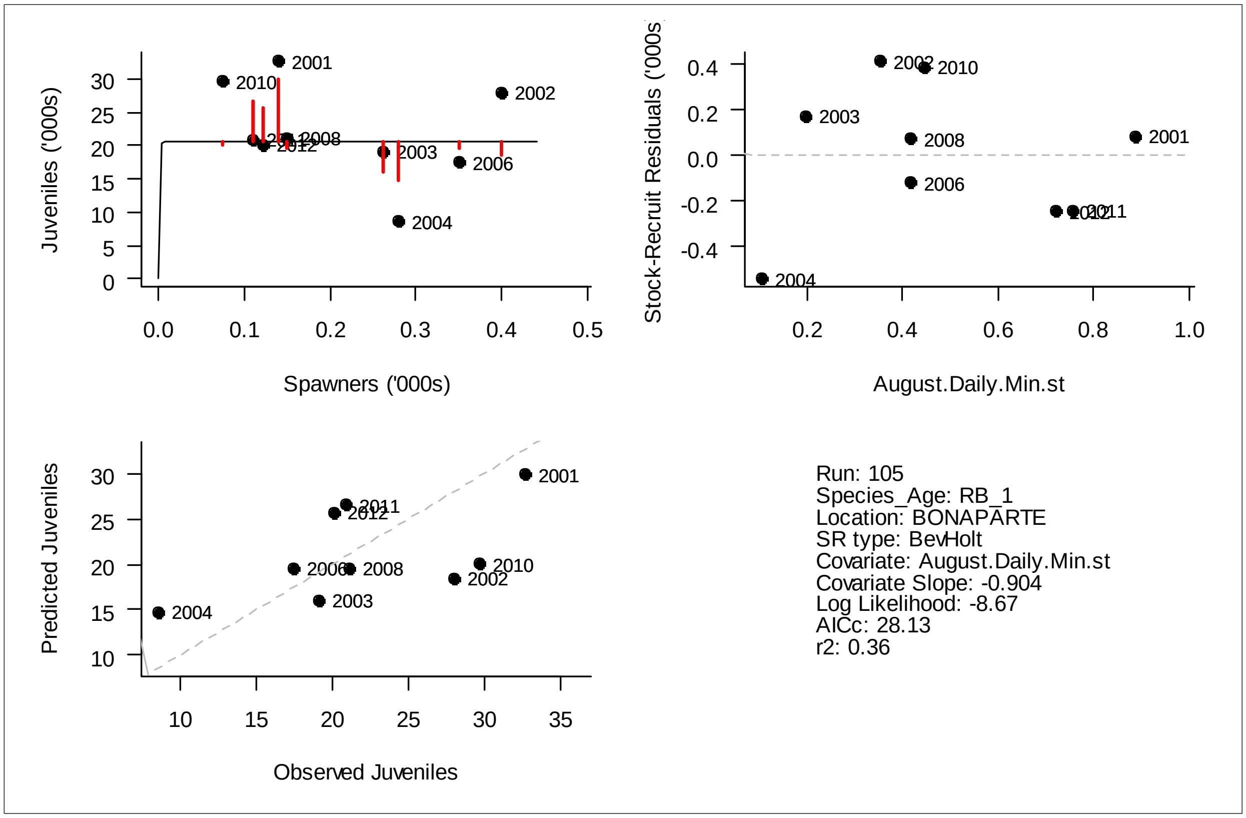
Run: 100
Species_Age: RB_1
Location: BONAPARTE
SR type: BevHolt
Covariate: minflow.plus.tempmax.30day
Covariate Slope: -0.52
Log Likelihood: -8.67
AICc: 28.13
r2: 0.36



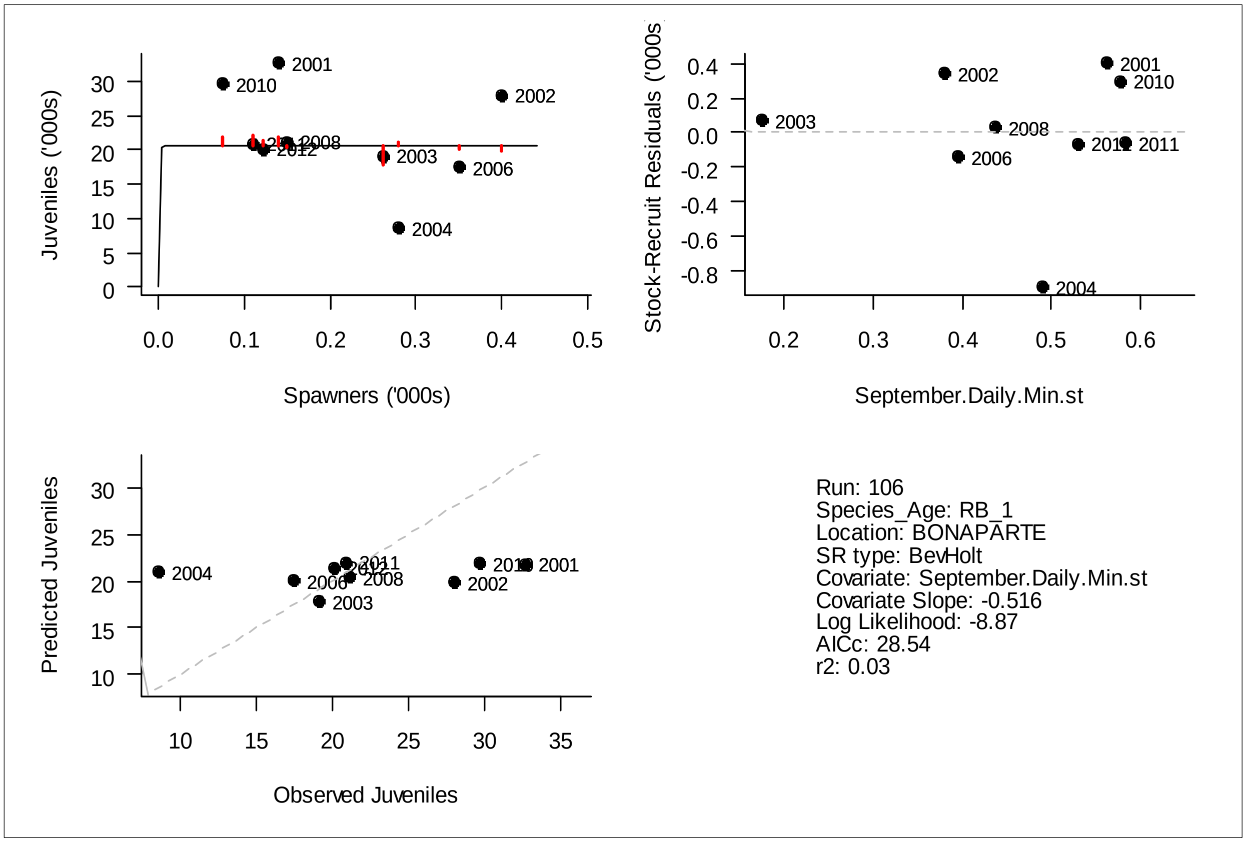
Run: 101
Species_Age: RB_1
Location: BONAPARTE
SR type: BevHolt
Covariate: Winter.Daily.Max.st
Covariate Slope: 0.038
Log Likelihood: -8.89
AICc: 28.58
r2: 0



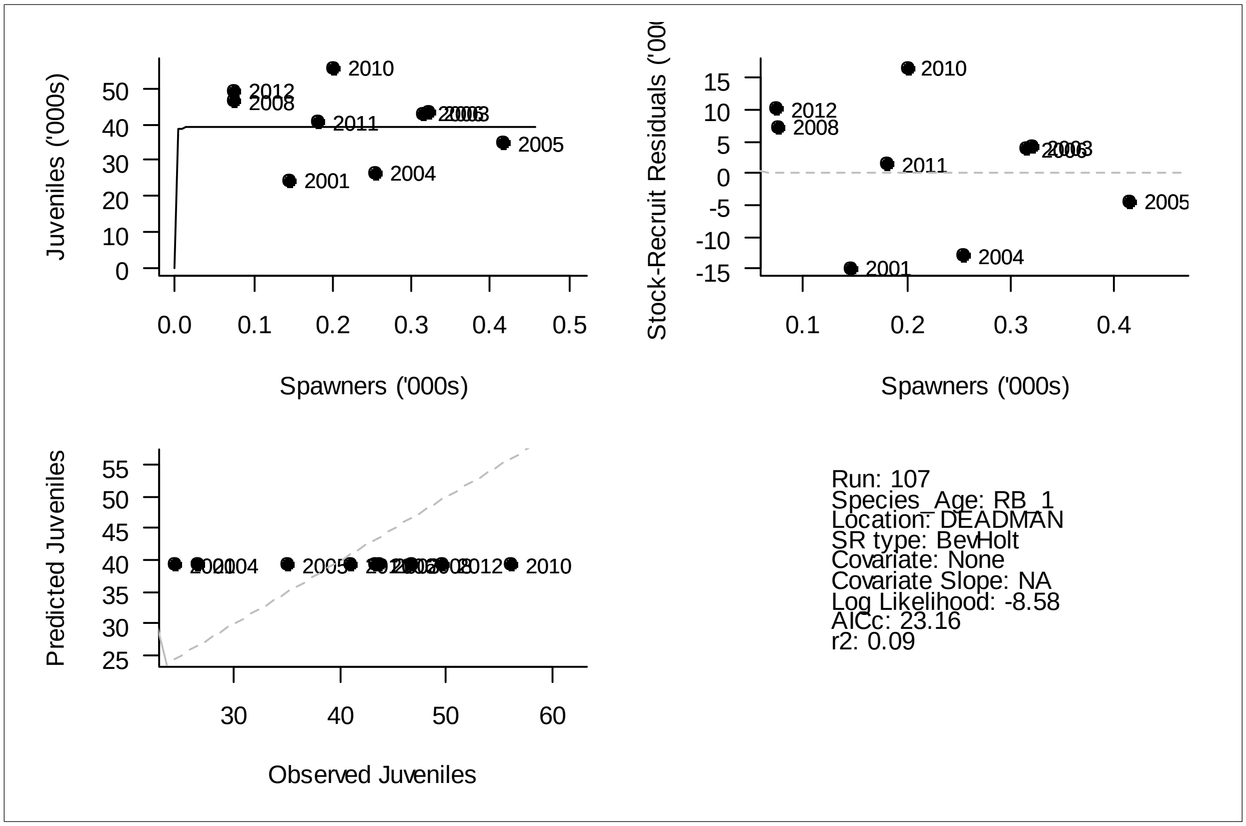
Run: 104
Species_Age: RB_1
Location: BONAPARTE
SR type: BevHolt
Covariate: July.Daily.Min.st
Covariate Slope: -0.158
Log Likelihood: -8.86
AICc: 28.52
r2: 0.05



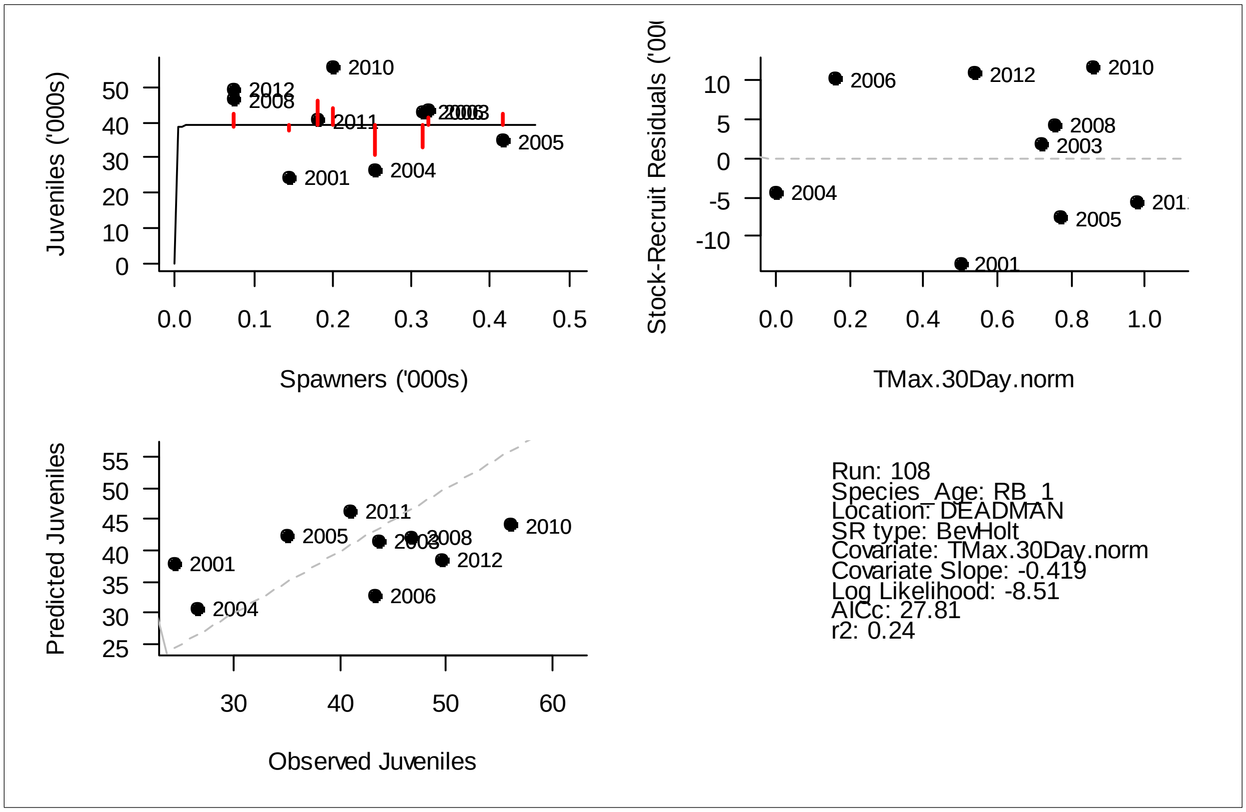
Run: 105
Species_Age: RB_1
Location: BONAPARTE
SR type: BevHolt
Covariate: August.Daily.Min.st
Covariate Slope: -0.904
Log Likelihood: -8.67
AICc: 28.13
r2: 0.36



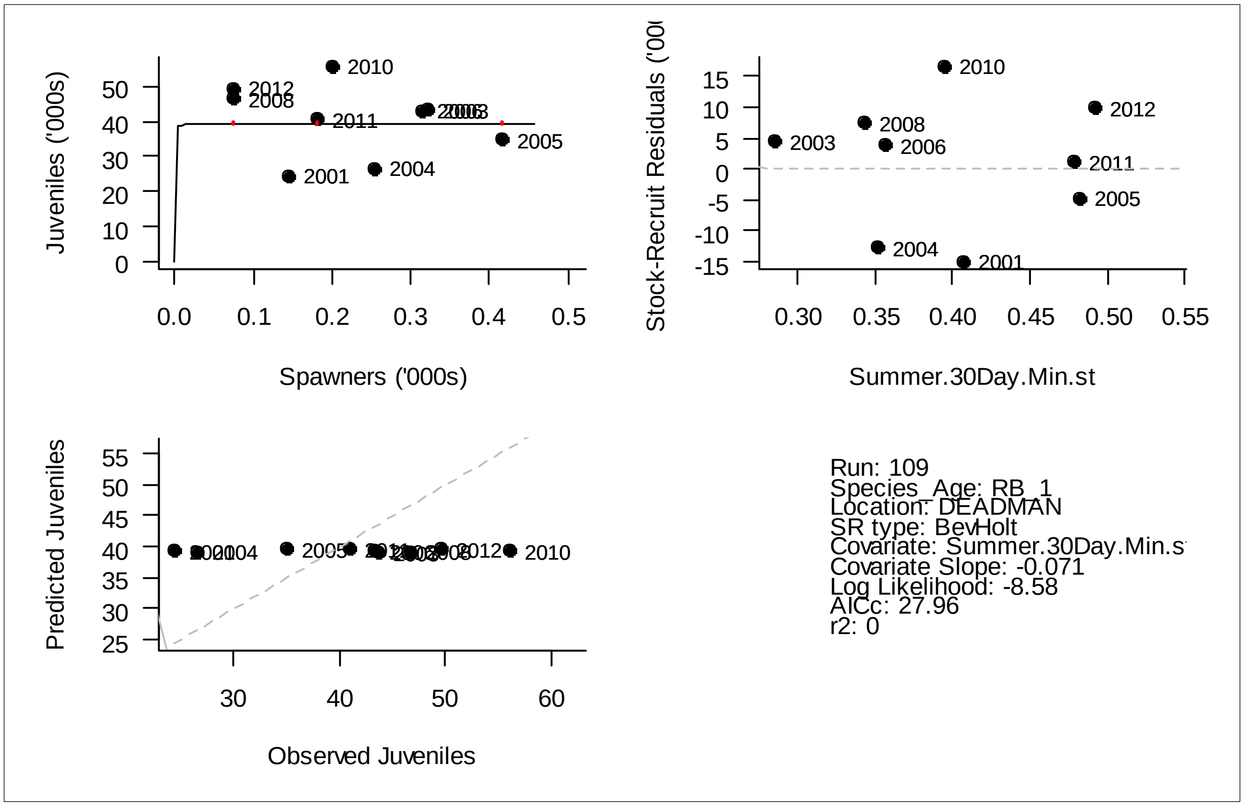
Run: 106
Species_Age: RB_1
Location: BONAPARTE
SR type: BevHolt
Covariate: September.Daily.Min.st
Covariate Slope: -0.516
Log Likelihood: -8.87
AICc: 28.54
r2: 0.03



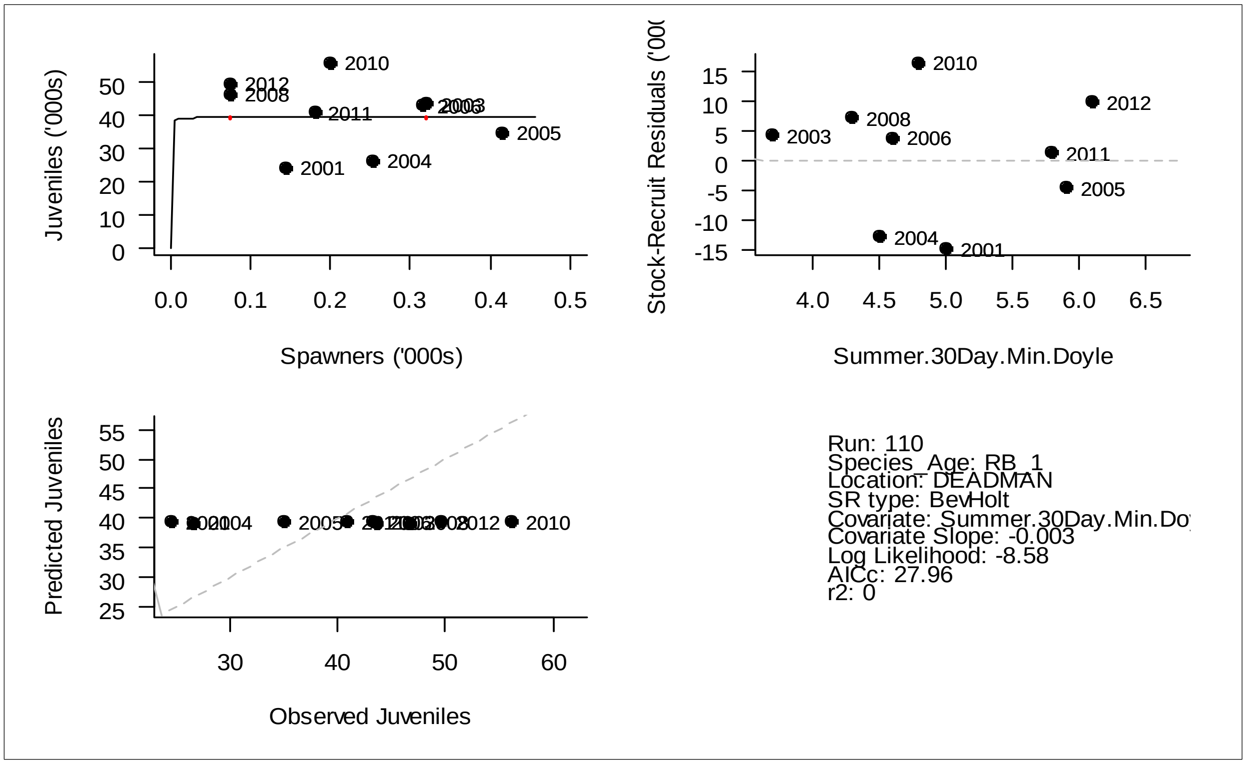
Run: 107
Species_Age: RB_1
Location: DEADMAN
SR type: BevHolt
Covariate: None
Covariate Slope: NA
Log Likelihood: -8.58
AICc: 23.16
r2: 0.09

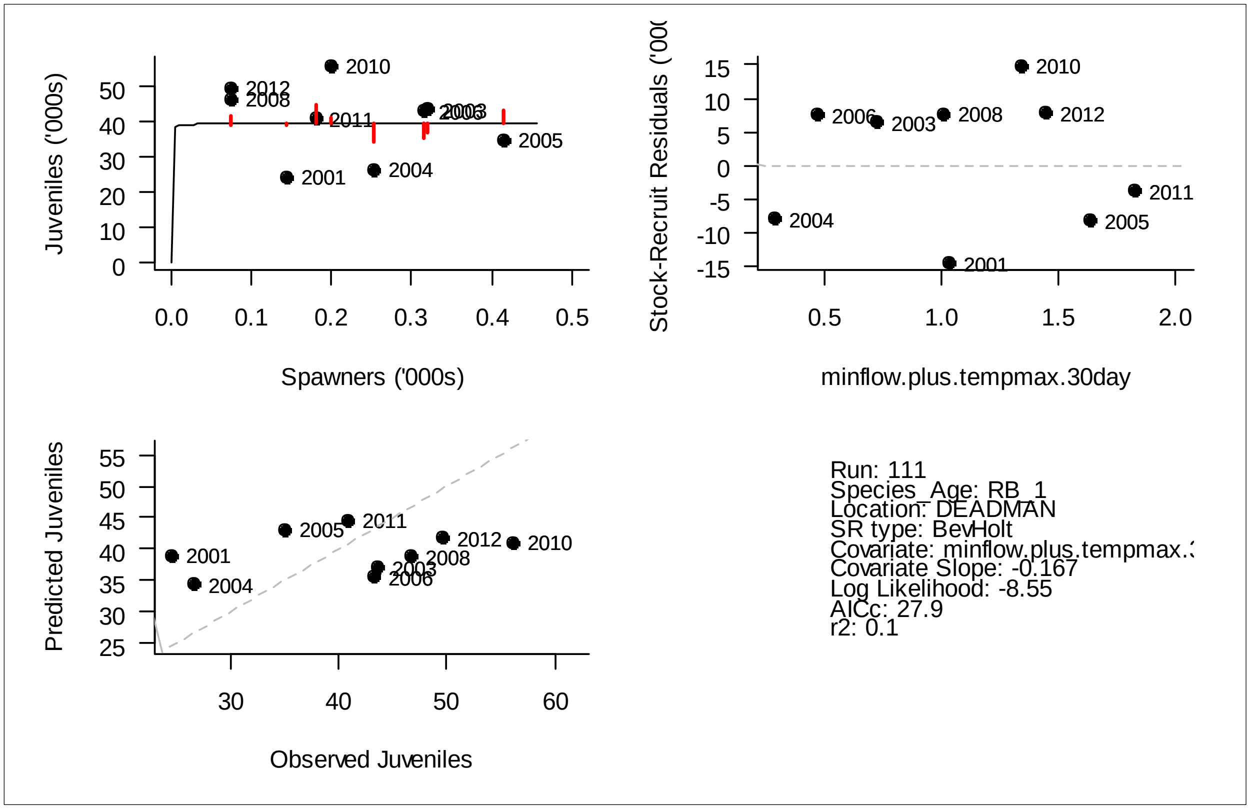


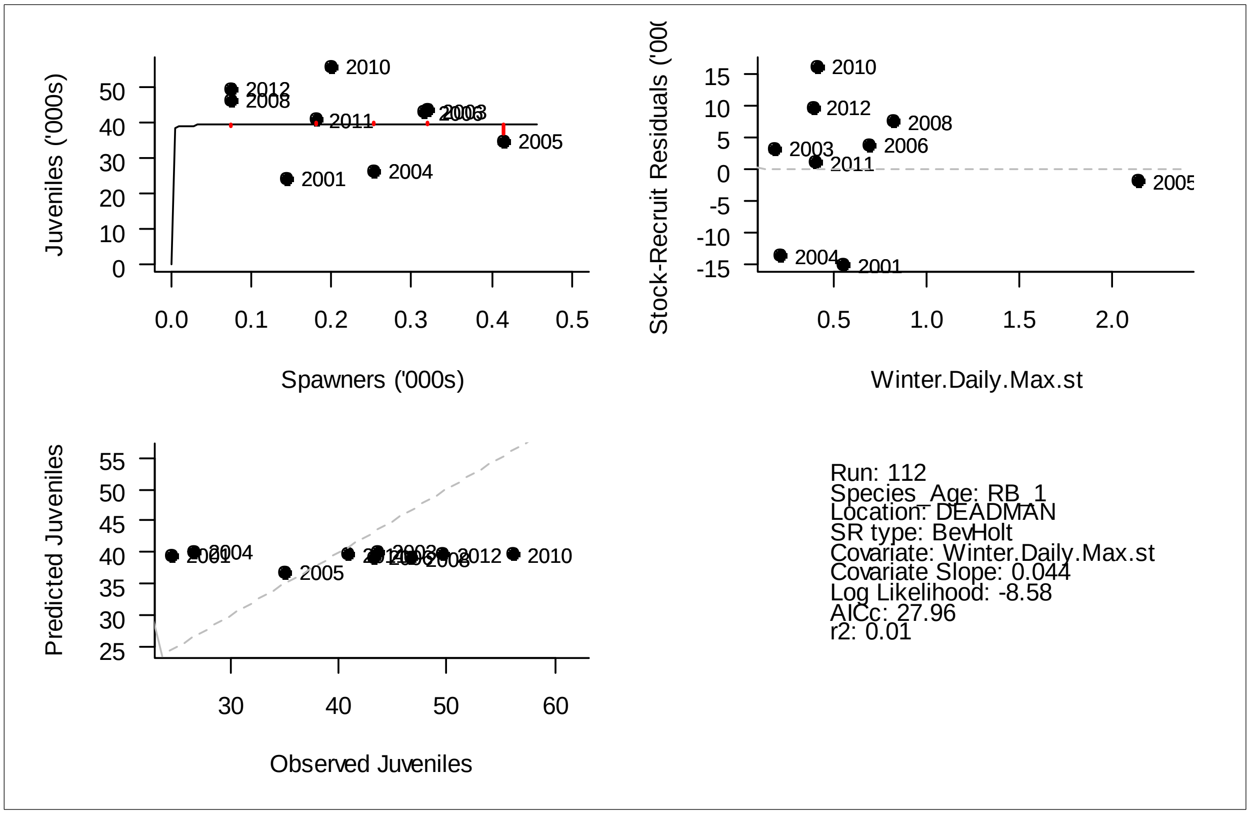
Run: 108
Species_Age: RB_1
Location: DEADMAN
SR type: BevHolt
Covariate: TMax.30Day.norm
Covariate Slope: -0.419
Log Likelihood: -8.51
AICc: 27.81
r2: 0.24



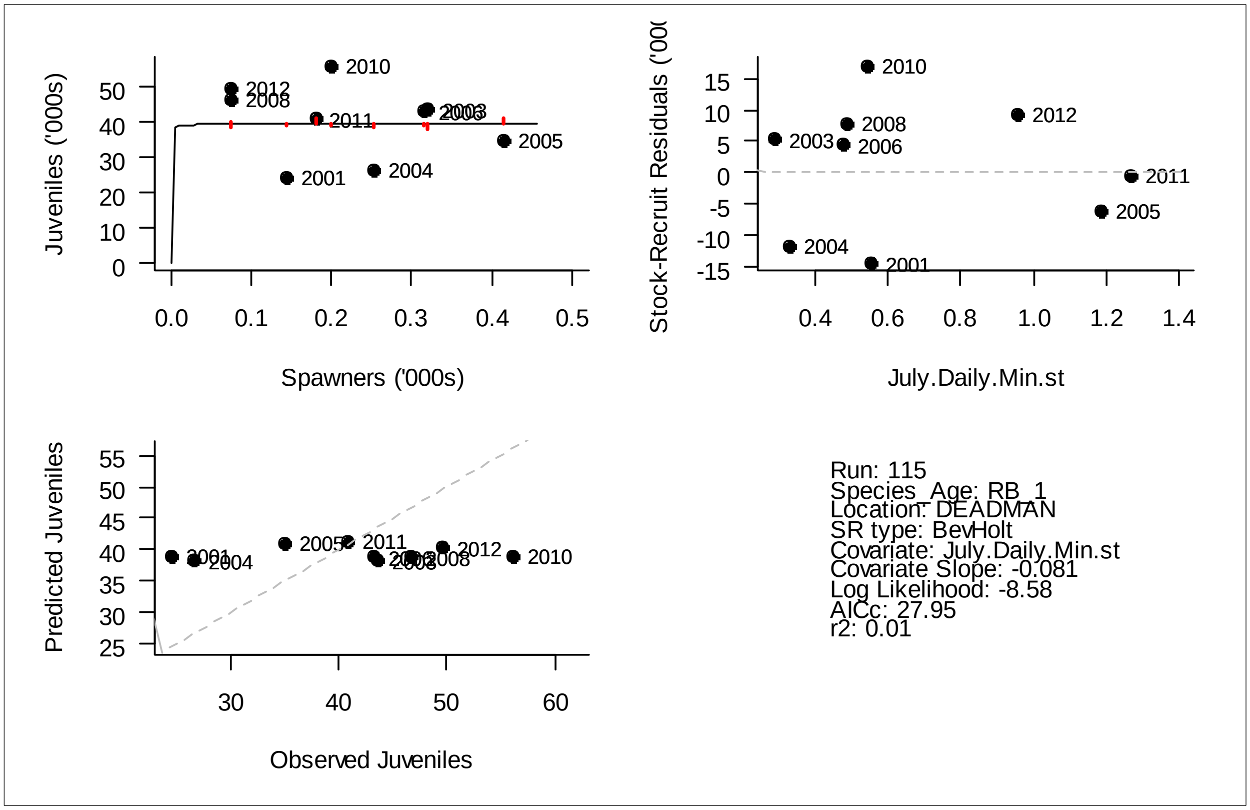
Run: 109
Species_Age: RB_1
Location: DEADMAN
SR type: BevHolt
Covariate: Summer.30Day.Min.s
Covariate Slope: -0.071
Log Likelihood: -8.58
AICc: 27.96
r2: 0


Juveniles ('000s)
Spawners ('000s)
0.0
0.1
0.2
0.3
0.4
0.5
0
10
20
30
40
50
2010
2012
2008
2011
2003
2006
2005
2001
2004
Stock-Recruit Residuals ('00
Summer.30Day.Min.Doyle
4.0
4.5
5.0
5.5
6.0
6.5
15
10
5
0
-5
-10
-15
2010
2012
2008
2003
2006
2011
2005
2004
2001
Predicted Juveniles
Observed Juveniles
30
40
50
60
25
30
35
40
45
50
55
2001
2004
2005
2011
2003
2006
2008
2012
2010
Run: 110
Species_Age: RB_1
Location: DEADMAN
SR type: BevHolt
Covariate: Summer.30Day.Min.Do
Covariate Slope: -0.003
Log Likelihood: -8.58
AICc: 27.96
r2: 0

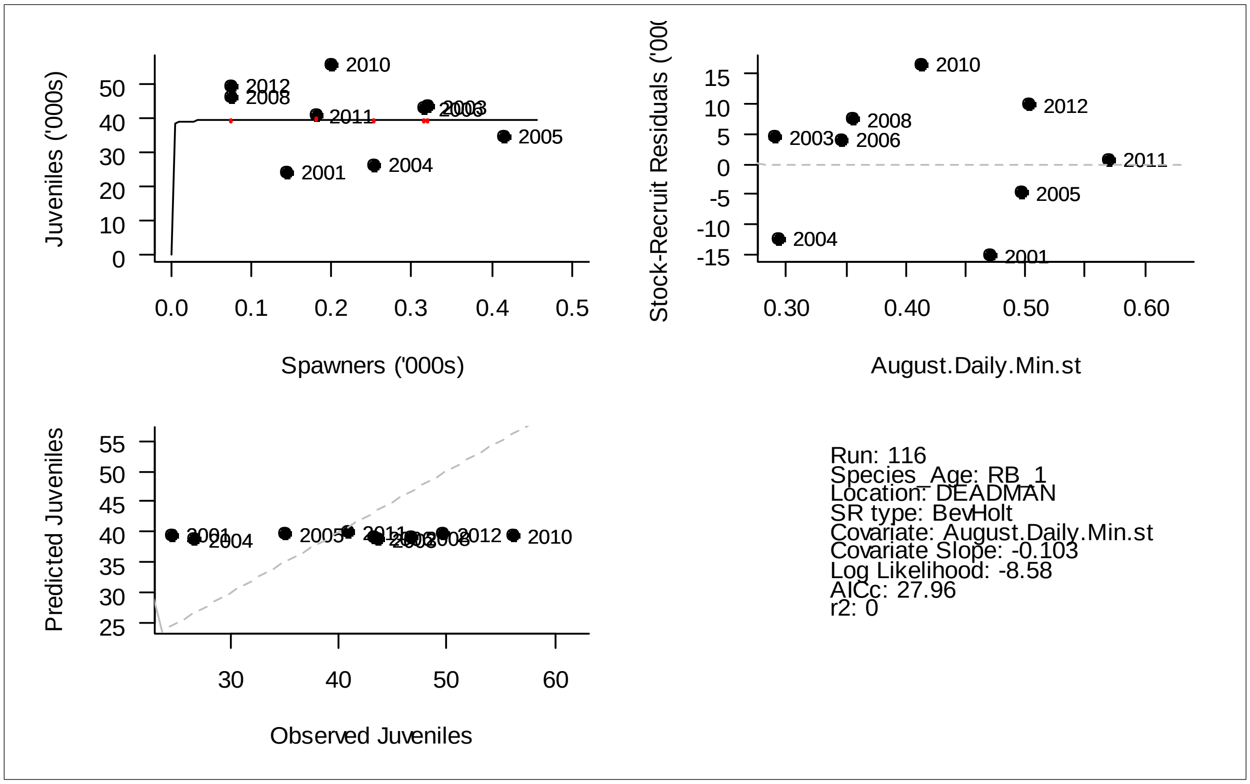

Juveniles ('000s)
Spawners ('000s)
0.0
0.1
0.2
0.3
0.4
0.5
0
10
20
30
40
50
2010
2012
2008
2011
2003
2006
2005
2001
2004
Stock-Recruit Residuals ('00
minflow.plus.tempmax.30day
0.5
1.0
1.5
2.0
15
10
5
0
-5
-10
-15
2010
2006
2003
2008
2012
2011
2004
2005
2001
Predicted Juveniles
Observed Juveniles
30
40
50
60
25
30
35
40
45
50
55
2005
2011
2012
2010
2001
2008
2003
2006
2004
Run: 111
Species_Age: RB_1
Location: DEADMAN
SR type: BevHolt
Covariate: minflow.plus.tempmax.3
Covariate Slope: -0.167
Log Likelihood: -8.55
AICc: 27.9
r2: 0.1



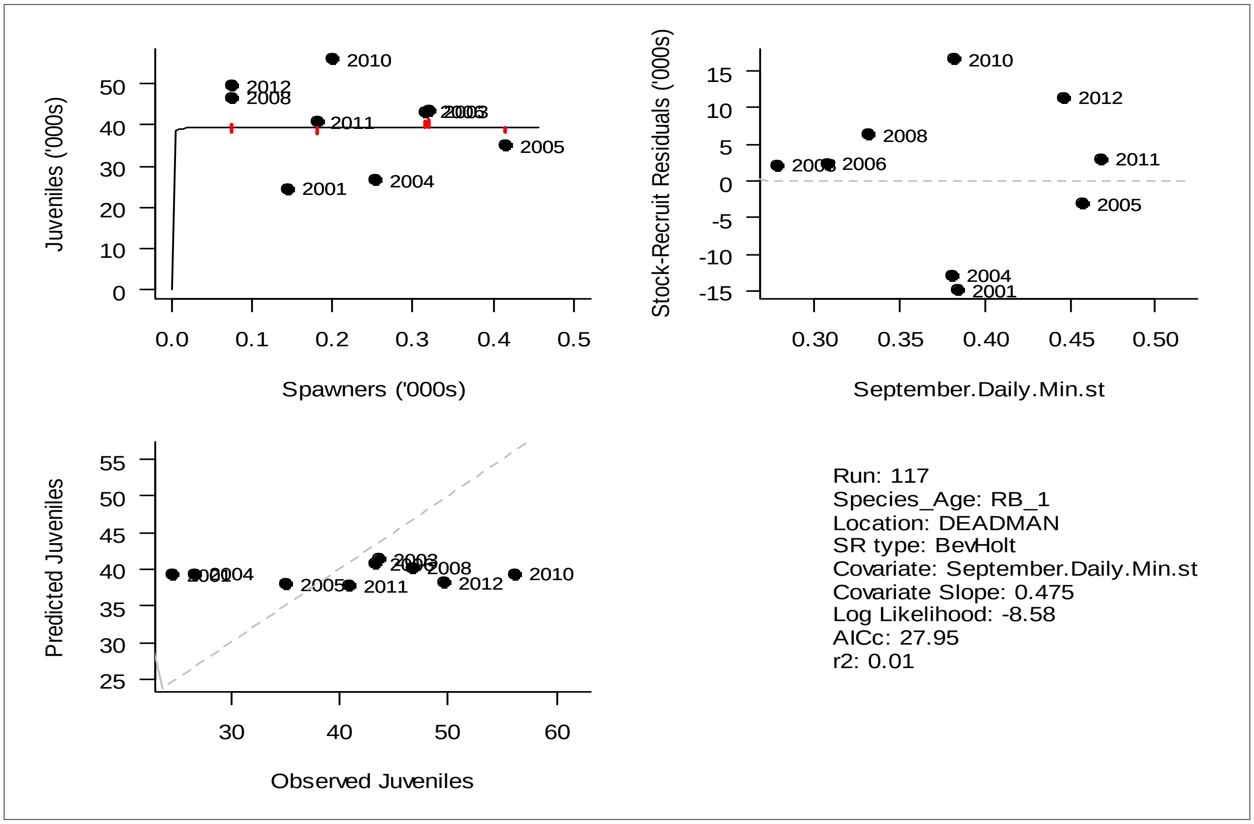
Run: 112
Species_Age: RB_1
Location: DEADMAN
SR type: BevHolt
Covariate: Winter.Daily.Max.st
Covariate Slope: 0.044
Log Likelihood: -8.58
AICc: 27.96
r2: 0.01



Run: 115
Species_Age: RB_1
Location: DEADMAN
SR type: BevHolt
Covariate: July.Daily.Min.st
Covariate Slope: -0.081
Log Likelihood: -8.58
AICc: 27.95
r2: 0.01



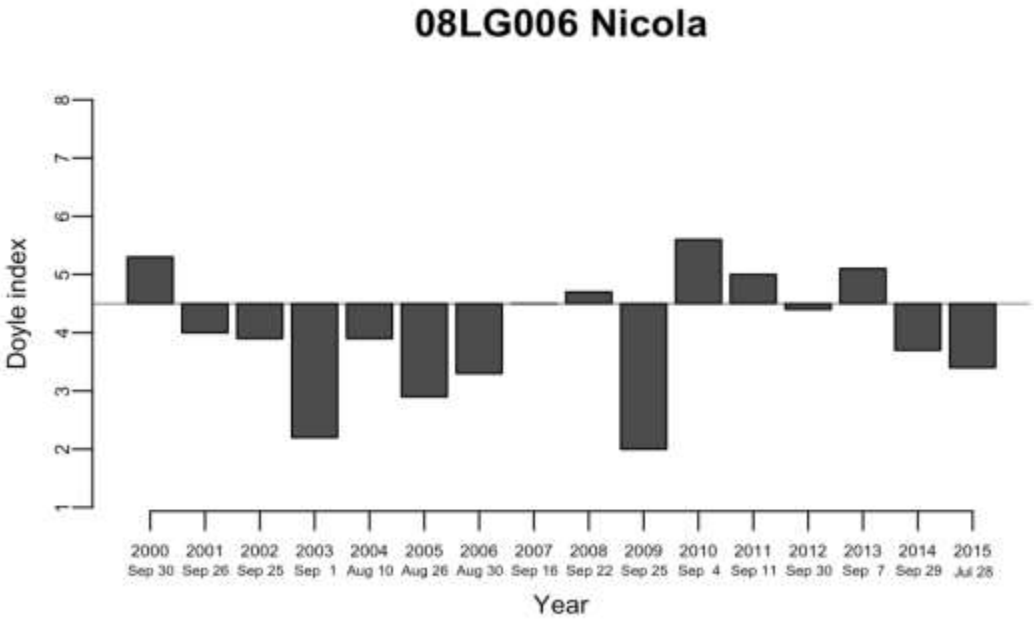
Run: 116
Species_Age: RB_1
Location: DEADMAN
SR type: BevHolt
Covariate: August.Daily.Min.st
Covariate Slope: -0.103
Log Likelihood: -8.58
AICc: 27.96
r2: 0



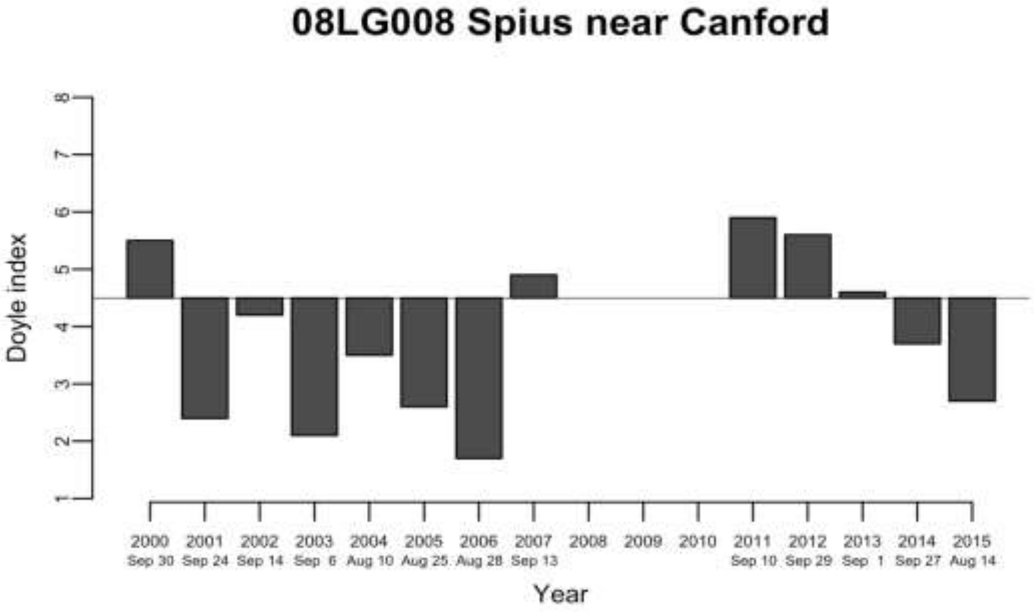
Run: 117
Species_Age: RB_1
Location: DEADMAN
SR type: BevHolt
Covariate: September.Daily.Min.st
Covariate Slope: 0.475
Log Likelihood: -8.58
AICc: 27.95
r2: 0.01

Appendix 6a-f. Minimum 30-day summer discharge using the Doyle (see Appendix 1) and the central date of the minimum 30- day period for WSC stations used as covariates in stock-recruitment models.

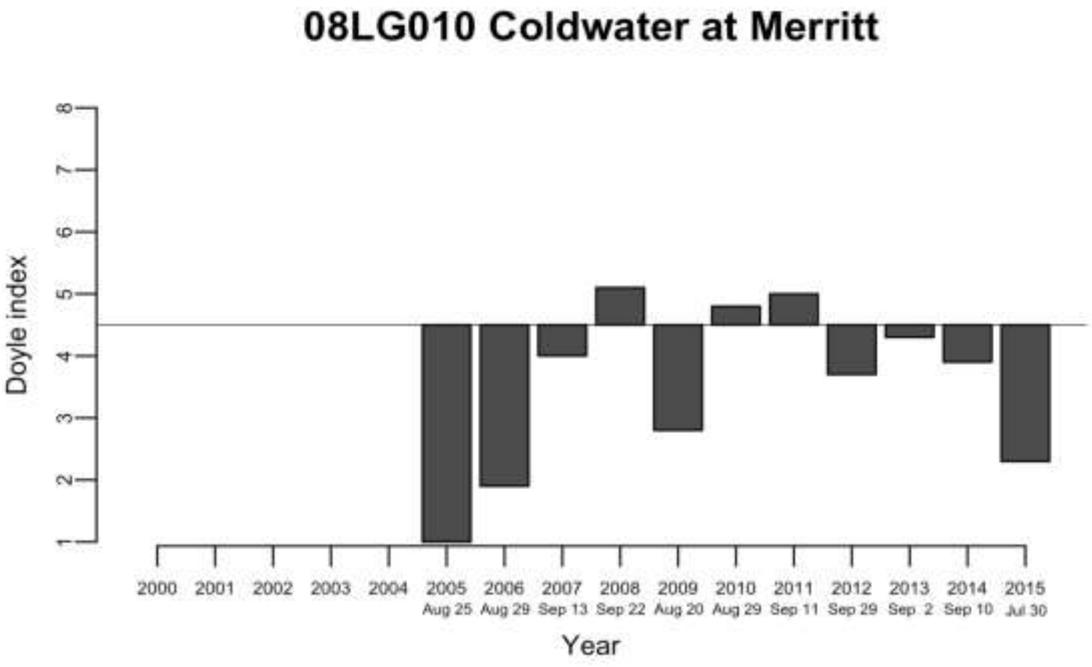
a.



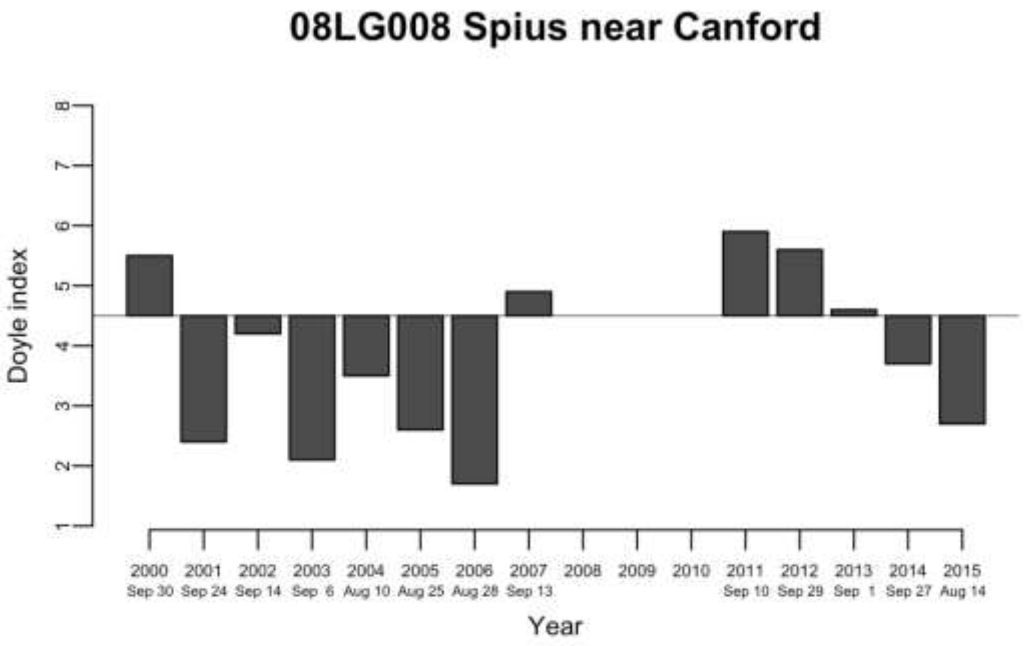
b.



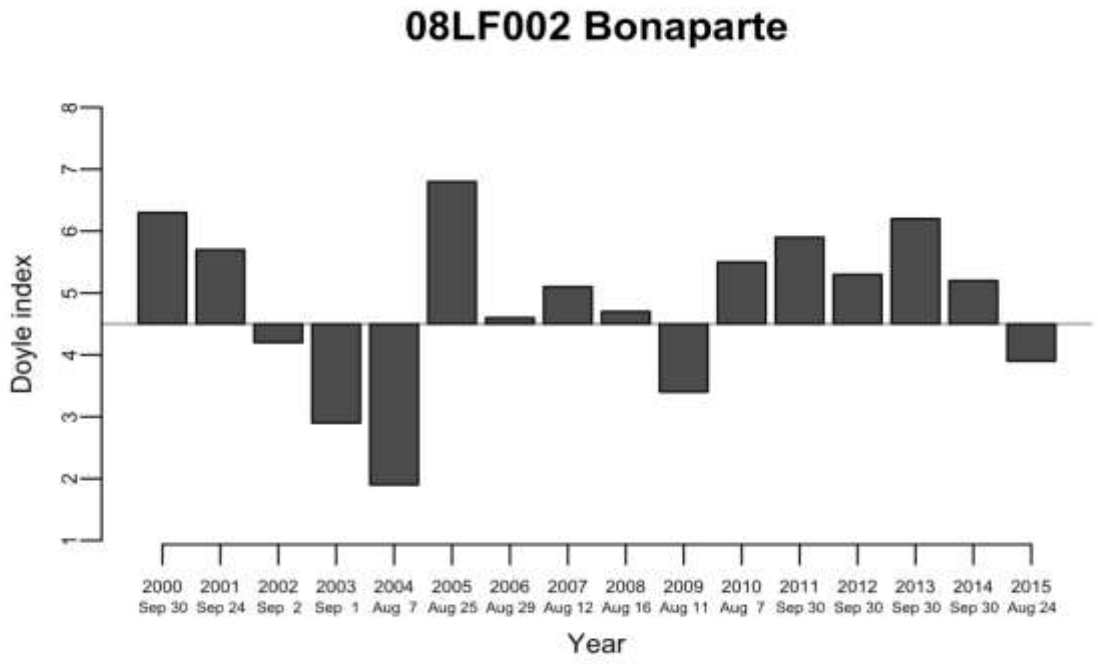
c.


08LG010 Coldwater at Merritt
Doyle index
1
2
3
4
5
6
7
8
2000
2001
2002
2003
2004
2005 Aug 25
2006 Aug 29
2007 Sep 13
2008 Sep 22
2009 Aug 20
2010 Aug 29
2011 Sep 11
2012 Sep 29
2013 Sep 2
2014 Sep 10
2015 Jul 30
Year

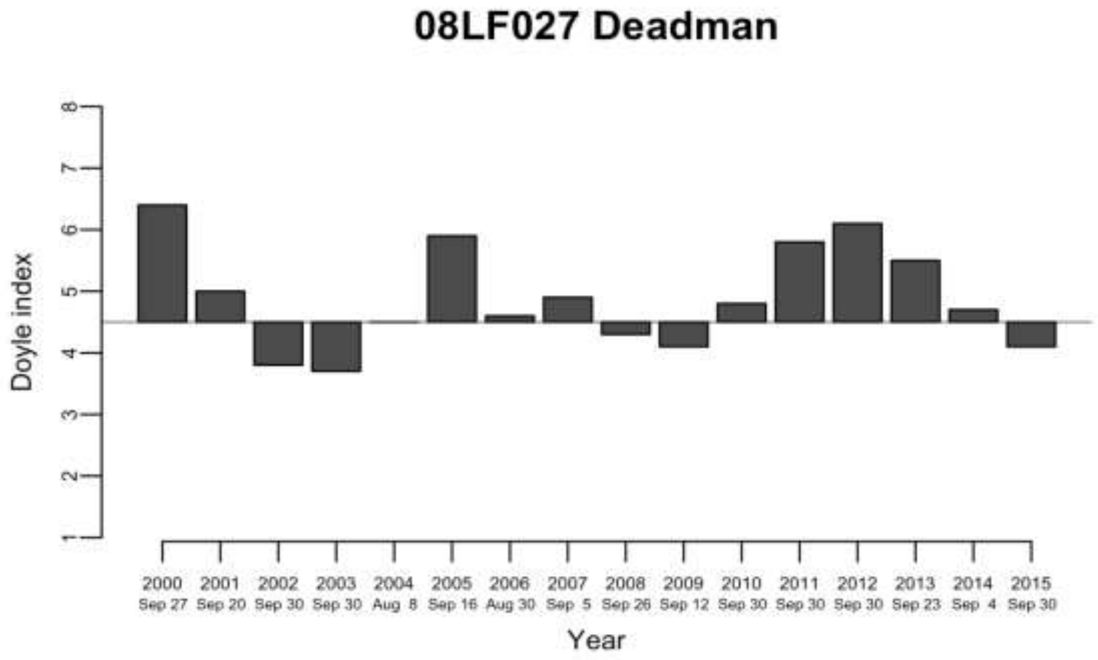
d.


08LG008 Spius near Canford
Doyle index
1
2
3
4
5
6
7
8
2000 Sep 30
2001 Sep 24
2002 Sep 14
2003 Sep 6
2004 Aug 10
2005 Aug 25
2006 Aug 28
2007 Sep 13
2008
2009
2010
2011 Sep 10
2012 Sep 29
2013 Sep 1
2014 Sep 27
2015 Aug 14
Year

e.

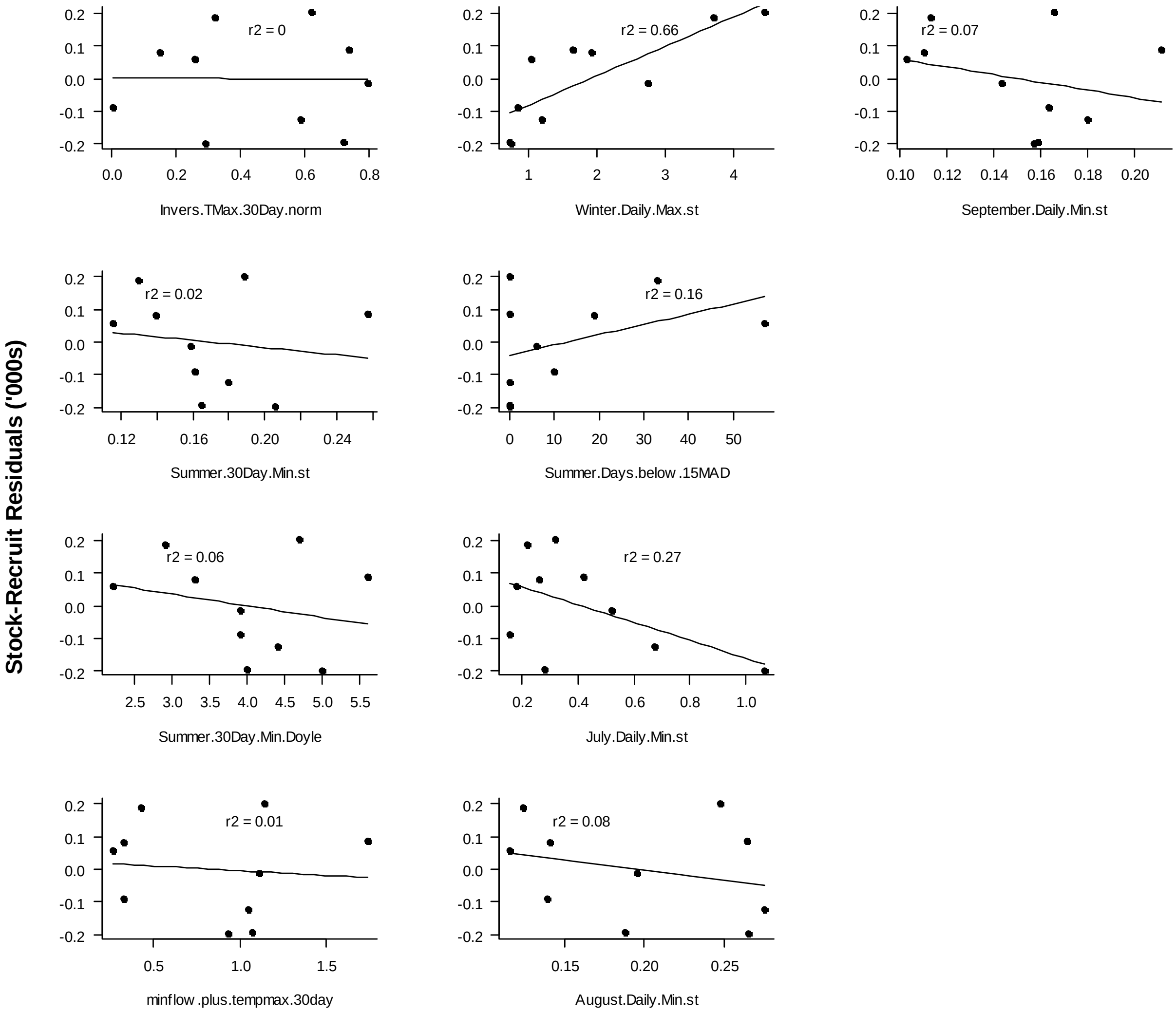

08LF002 Bonaparte
Doyle index
1
2
3
4
5
6
7
8
2000 Sep 30
2001 Sep 24
2002 Sep 2
2003 Sep 1
2004 Aug 7
2005 Aug 25
2006 Aug 29
2007 Aug 12
2008 Aug 16
2009 Aug 11
2010 Aug 7
2011 Sep 30
2012 Sep 30
2013 Sep 30
2014 Sep 30
2015 Aug 24
Year

f.

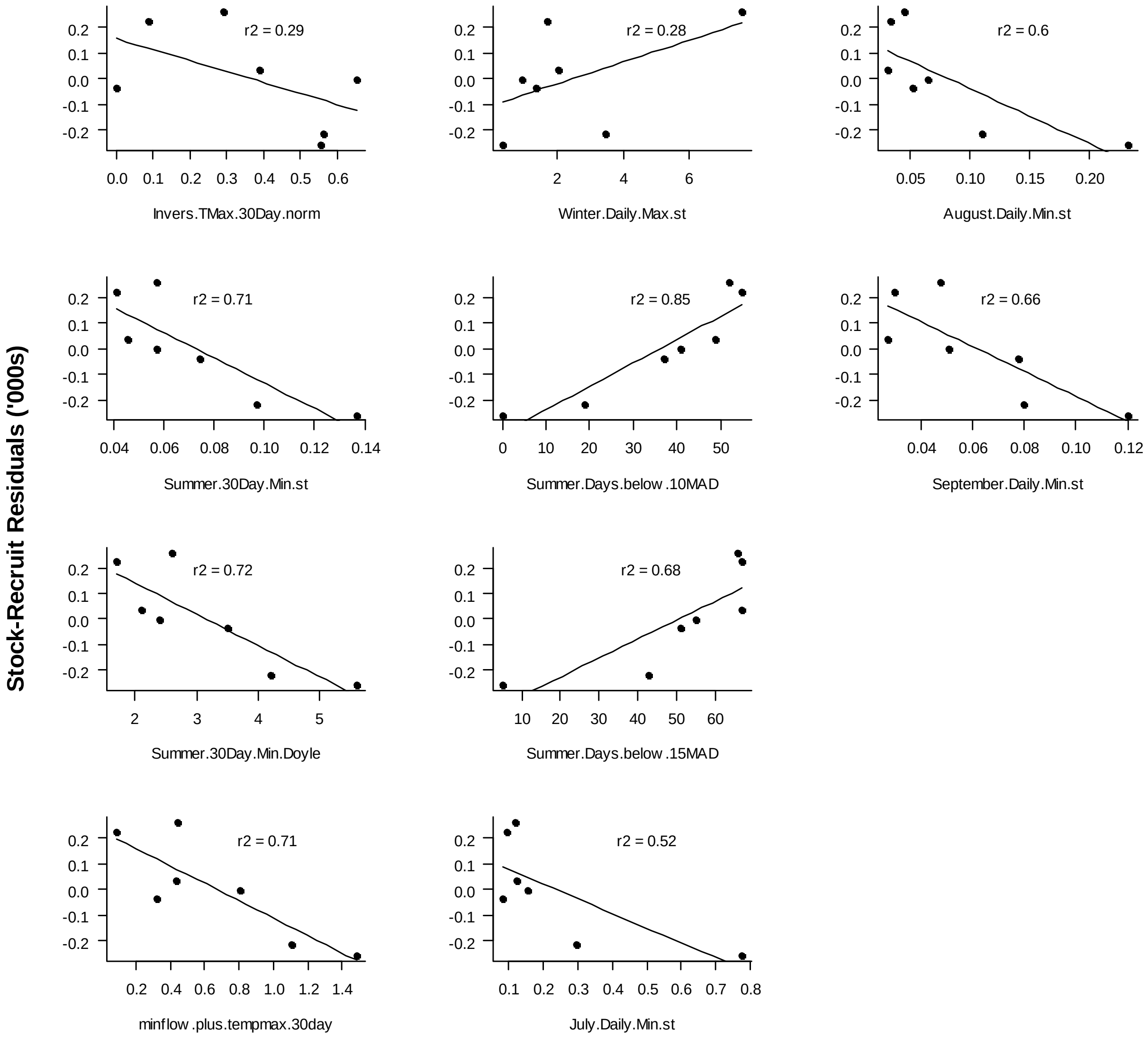

08LF027 Deadman
Doyle index
1
2
3
4
5
6
7
8
2000 Sep 27
2001 Sep 20
2002 Sep 30
2003 Sep 30
2004 Aug 8
2005 Sep 16
2006 Aug 30
2007 Sep 5
2008 Sep 26
2009 Sep 12
2010 Sep 30
2011 Sep 30
2012 Sep 30
2013 Sep 23
2014 Sep 4
2015 Sep 30
Year

Appendix 7a-b Residuals of the adult-only stock-recruitment model plotted against environmental covariates using Steelhead age 1+ parr for the Nicola Aggregate (a) and Spius (b) comparison groups excluding the 2015 juvenile cohort (2001 – 2012).

a. Nicola Aggregate



b. Spius


Stock-Recruit Residuals ('000s)
r2 = 0.29
Invers.TMax.30Day.norm
0.0 0.1 0.2 0.3 0.4 0.5 0.6
r2 = 0.28
Winter.Daily.Max.st
2 4 6
r2 = 0.6
August.Daily.Min.st
0.05 0.10 0.15 0.20
r2 = 0.71
Summer.30Day.Min.st
0.04 0.06 0.08 0.10 0.12 0.14
r2 = 0.85
Summer.Days.below.10MAD
0 10 20 30 40 50
r2 = 0.66
September.Daily.Min.st
0.04 0.06 0.08 0.10 0.12
r2 = 0.72
Summer.30Day.Min.Doyle
2 3 4 5
r2 = 0.68
Summer.Days.below.15MAD
10 20 30 40 50 60
r2 = 0.71
minflow.plus.tempmax.30day
0.2 0.4 0.6 0.8 1.0 1.2 1.4
r2 = 0.52
July.Daily.Min.st
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8
0.2 0.1 0.0 -0.1 -0.2

Appendix 8 Covariate values for Water Survey of Canada stations for the years 2000 - 2015.

Station	Year	Inv Tmax 30Day norm	Summer 30Day Min st	Summer 30Day Min Doyle	minflow plus tempmax 30day	Winter Daily Max st	Summer Days below 5MAD	Summer Days below 10MAD	Summer Days below 15MAD	July Daily Min st	August Daily Min st	September Daily Min st
Nicola at Spences Br	2000	1.00	0.23	5.3	1.84	4.06	0	0	0	0.69	0.27	0.21
Nicola at Spences Br	2001	0.72	0.16	4	1.08	0.72	0	0	0	0.28	0.19	0.16
Nicola at Spences Br	2002	0.80	0.16	3.9	1.11	2.75	0	0	6	0.52	0.20	0.14
Nicola at Spences Br	2003	0.26	0.12	2.2	0.26	1.03	0	0	57	0.18	0.12	0.10
Nicola at Spences Br	2004	0.00	0.16	3.9	0.33	0.84	0	0	10	0.16	0.14	0.16
Nicola at Spences Br	2005	0.32	0.13	2.9	0.43	3.71	0	0	33	0.22	0.12	0.11
Nicola at Spences Br	2006	0.15	0.14	3.3	0.33	1.92	0	0	19	0.26	0.14	0.11
Nicola at Spences Br	2007	0.81	0.19	4.5	1.31	5.98	0	0	1	0.36	0.21	0.15
Nicola at Spences Br	2008	0.62	0.19	4.7	1.14	4.44	0	0	0	0.32	0.25	0.17
Nicola at Spences Br	2009	0.69	0.11	2	0.69	0.90	0	9	35	0.18	0.13	0.10
Nicola at Spences Br	2010	0.74	0.26	5.6	1.74	1.65	0	0	0	0.42	0.26	0.21
Nicola at Spences Br	2011	0.29	0.21	5	0.93	0.74	0	0	0	1.06	0.27	0.16
Nicola at Spences Br	2012	0.59	0.18	4.4	1.05	1.19	0	0	0	0.67	0.28	0.18
Nicola at Spences Br	2013	0.28	0.22	5.1	0.99	1.85	0	0	0	0.38	0.20	0.19
Nicola at Spences Br	2014	0.67	0.16	3.7	0.96	0.54	0	0	7	0.34	0.19	0.14
Nicola at Spences Br	2015	0.10	0.14	3.4	0.30	3.91	0	0	25	0.13	0.13	0.15
Coldwater at Merritt	2000	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Coldwater at Merritt	2001	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Coldwater at Merritt	2002	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Coldwater at Merritt	2003	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Coldwater at Merritt	2004	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Coldwater at Merritt	2005	0.35	0.02	1	0.35	NA	36	59	68	0.06	0.01	0.01
Coldwater at Merritt	2006	0.06	0.03	1.9	0.18	2.19	32	66	71	0.09	0.02	0.02
Coldwater at Merritt	2007	1.00	0.07	4	1.58	13.28	0	37	48	0.27	0.08	0.06
Coldwater at Merritt	2008	0.91	0.11	5.1	1.91	6.59	0	11	37	0.21	0.09	0.08
Coldwater at Merritt	2009	0.08	0.04	2.8	0.30	1.90	40	67	76	0.08	0.02	0.02
Coldwater at Merritt	2010	0.74	0.10	4.8	1.63	2.33	0	14	33	0.23	0.07	0.09
Coldwater at Merritt	2011	0.35	0.11	5	1.34	0.95	0	16	26	0.93	0.15	0.07
Coldwater at Merritt	2012	0.79	0.06	3.7	1.20	0.71	5	34	43	0.50	0.09	0.05
Coldwater at Merritt	2013	0.19	0.08	4.3	0.91	3.33	0	37	49	0.15	0.06	0.07
Coldwater at Merritt	2014	0.60	0.06	3.9	1.10	0.44	4	42	56	0.23	0.06	0.05
Coldwater at Merritt	2015	0.00	0.04	2.3	0.19	5.44	36	67	76	0.03	0.02	0.08

Appendix 8 continued

Station	Year	Inv Tmax 30Day norm	Summer 30Day Min st	Summer 30Day Min Doyle	minflow plus tempmax 30day	Winter Daily Max st	Summer Days below 5MAD	Summer Days below 10MAD	Summer Days below 15MAD	July Daily Min st	August Daily Min st	September Daily Min st
Coldwater at Brookmere	2000	0.90	0.16	6	1.89	7.94	0	0	13	0.46	0.13	0.13
Coldwater at Brookmere	2001	0.59	0.07	2.3	0.72	0.86	0	42	56	0.16	0.08	0.06
Coldwater at Brookmere	2002	0.65	0.10	4.2	1.10	5.80	0	15	33	0.51	0.12	0.09
Coldwater at Brookmere	2003	0.23	0.06	1.9	0.28	2.44	0	49	65	0.13	0.06	0.05
Coldwater at Brookmere	2004	0.00	0.09	3.9	0.36	0.92	0	18	44	0.10	0.07	0.11
Coldwater at Brookmere	2005	0.23	0.07	2.5	0.37	7.19	0	43	60	0.11	0.06	0.06
Coldwater at Brookmere	2006	0.13	0.06	1.7	0.13	2.43	6	57	66	0.12	0.05	0.05
Coldwater at Brookmere	2007	0.61	0.11	4.8	1.15	12.33	0	8	35	0.34	0.13	0.09
Coldwater at Brookmere	2008	0.56	0.15	5.2	1.42	5.76	0	0	18	0.27	0.14	0.12
Coldwater at Brookmere	2009	1.00	0.07	2.9	1.16	2.15	0	42	65	0.13	0.06	0.06
Coldwater at Brookmere	2010	0.43	0.15	5.4	1.32	2.53	0	0	19	0.41	0.12	0.13
Coldwater at Brookmere	2011	0.26	0.16	6.1	1.26	1.62	0	0	17	1.21	0.20	0.12
Coldwater at Brookmere	2012	0.50	0.08	3.1	0.68	0.39	0	19	36	0.59	0.13	0.07
Coldwater at Brookmere	2013	0.25	0.11	4.5	0.77	3.89	0	12	42	0.19	0.10	0.08
Coldwater at Brookmere	2014	0.53	0.09	3.5	0.81	0.32	0	26	49	0.25	0.09	0.07
Coldwater at Brookmere	2015	0.08	0.07	2.8	0.24	6.02	2	46	66	0.06	0.05	0.11
Spius at Silver Cr	2000	0.89	0.08	6.2	1.39	NA	1	30	48	0.27	0.05	0.07
Spius at Silver Cr	2001	1.00	0.03	3.4	1.17	0.36	35	53	64	0.12	0.04	0.03
Spius at Silver Cr	2002	0.74	0.04	4.4	0.98	6.36	32	48	55	0.21	0.04	0.03
Spius at Silver Cr	2003	0.31	0.02	2.3	0.40	2.73	62	72	76	0.05	0.02	0.02
Spius at Silver Cr	2004	0.00	0.15	8	1.00	1.26	6	12	31	0.04	0.02	0.11
Spius at Silver Cr	2005	0.43	0.05	4.7	0.72	16.94	20	61	70	0.09	0.04	0.04
Spius at Silver Cr	2006	0.23	0.03	2.9	0.36	4.40	46	66	72	0.07	0.02	0.02
Spius at Silver Cr	2007	0.75	0.07	5.7	1.20	10.55	0	43	56	0.22	0.08	0.06
Spius at Silver Cr	2008	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Spius at Silver Cr	2009	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Spius at Silver Cr	2010	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Spius at Silver Cr	2011	0.43	0.01	1	0.43	NA	41	50	53	0.39	0.01	0.00
Spius at Silver Cr	2012	0.85	0.03	3.8	1.02	0.15	30	46	51	0.38	0.05	0.03
Spius at Silver Cr	2013	0.47	0.04	4.1	0.68	3.28	37	50	56	0.11	0.02	0.02
Spius at Silver Cr	2014	0.64	0.05	5	0.93	0.34	22	61	74	0.09	0.04	0.04
Spius at Silver Cr	2015	0.00	0.05	5.3	0.31	7.71	30	81	88	0.03	0.01	0.03

Appendix 8 continued

Station	**Year**	**Inv Tmax 30Day norm**	**Summer 30Day Min st**	**Summer 30Day Min Doyle**	**minflow plus tempmax 30day**	**Winter Daily Max st**	**Summer Days below 5MAD**	**Summer Days below 10MAD**	**Summer Days below 15MAD**	**July Daily Min st**	**August Daily Min st**	**September Daily Min st**
Spius at Canford	2000	1.00	0.13	5.5	1.90	9.13	0	0	37	0.36	0.12	0.13
Spius at Canford	2001	0.65	0.06	2.4	0.81	0.91	0	41	55	0.16	0.07	0.05
Spius at Canford	2002	0.56	0.10	4.2	1.11	3.45	0	19	43	0.30	0.11	0.08
Spius at Canford	2003	0.39	0.05	2.1	0.44	2.03	25	49	67	0.12	0.03	0.03
Spius at Canford	2004	0.00	0.07	3.5	0.33	1.33	0	37	51	0.08	0.05	0.08
Spius at Canford	2005	0.29	0.06	2.6	0.44	7.63	7	52	66	0.12	0.05	0.05
Spius at Canford	2006	0.09	0.04	1.7	0.09	1.70	24	55	67	0.10	0.03	0.03
Spius at Canford	2007	0.68	0.12	4.9	1.41	10.40	0	11	35	0.32	0.12	0.08
Spius at Canford	2008	NA	NA	NA	NA	6.33	NA	NA	NA	0.22	NA	NA
Spius at Canford	2009	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Spius at Canford	2010	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Spius at Canford	2011	0.25	0.14	5.9	1.25	NA	0	2	18	0.96	0.19	0.09
Spius at Canford	2012	0.56	0.14	5.6	1.48	0.32	0	0	5	0.78	0.23	0.12
Spius at Canford	2013	0.19	0.11	4.6	0.84	2.76	2	14	37	0.24	0.09	0.04
Spius at Canford	2014	0.62	0.08	3.7	0.95	0.25	0	39	59	0.16	0.09	0.07
Spius at Canford	2015	0.09	0.06	2.7	0.26	5.90	6	56	73	0.06	0.05	0.08
Deadman	2000	0.75	0.51	6.4	1.75	0.88	0	0	0	0.86	0.55	0.49
Deadman	2001	0.50	0.41	5	1.03	0.55	0	0	0	0.55	0.47	0.38
Deadman	2002	1.00	0.29	3.8	1.01	NA	0	0	0	0.41	0.39	0.27
Deadman	2003	0.72	0.29	3.7	0.72	0.18	0	0	0	0.29	0.29	0.28
Deadman	2004	0.00	0.35	4.5	0.29	0.21	0	0	0	0.33	0.29	0.38
Deadman	2005	0.77	0.48	5.9	1.63	2.14	0	0	0	1.18	0.50	0.46
Deadman	2006	0.16	0.36	4.6	0.47	0.70	0	0	0	0.48	0.35	0.31
Deadman	2007	0.43	0.40	4.9	0.91	0.54	0	0	0	0.51	0.38	0.38
Deadman	2008	0.76	0.34	4.3	1.01	0.82	0	0	0	0.49	0.36	0.33
Deadman	2009	0.26	0.32	4.1	0.42	0.30	0	0	0	0.43	0.30	0.29
Deadman	2010	0.86	0.39	4.8	1.34	0.41	0	0	0	0.55	0.41	0.38
Deadman	2011	0.98	0.48	5.8	1.82	0.40	0	0	0	1.27	0.57	0.47
Deadman	2012	0.54	0.49	6.1	1.44	0.39	0	0	0	0.95	0.50	0.45
Deadman	2013	0.72	0.45	5.5	1.43	0.31	0	0	0	0.60	0.44	0.41
Deadman	2014	0.37	0.37	4.7	0.74	0.50	0	0	0	0.45	0.31	0.35
Deadman	2015	0.92	0.33	4.1	1.10	2.44	0	0	0	0.37	0.32	0.32

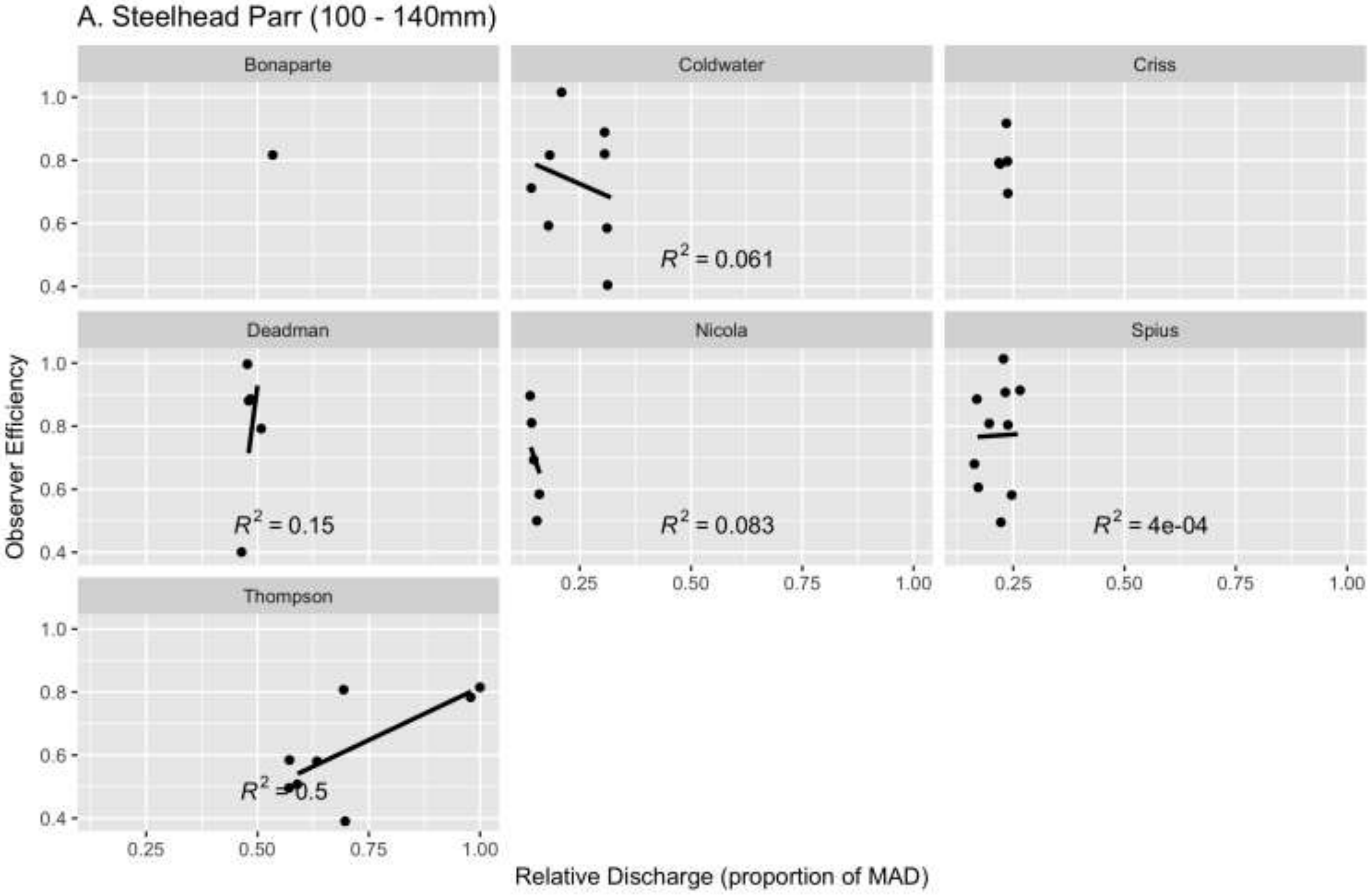
Appendix 8 continued

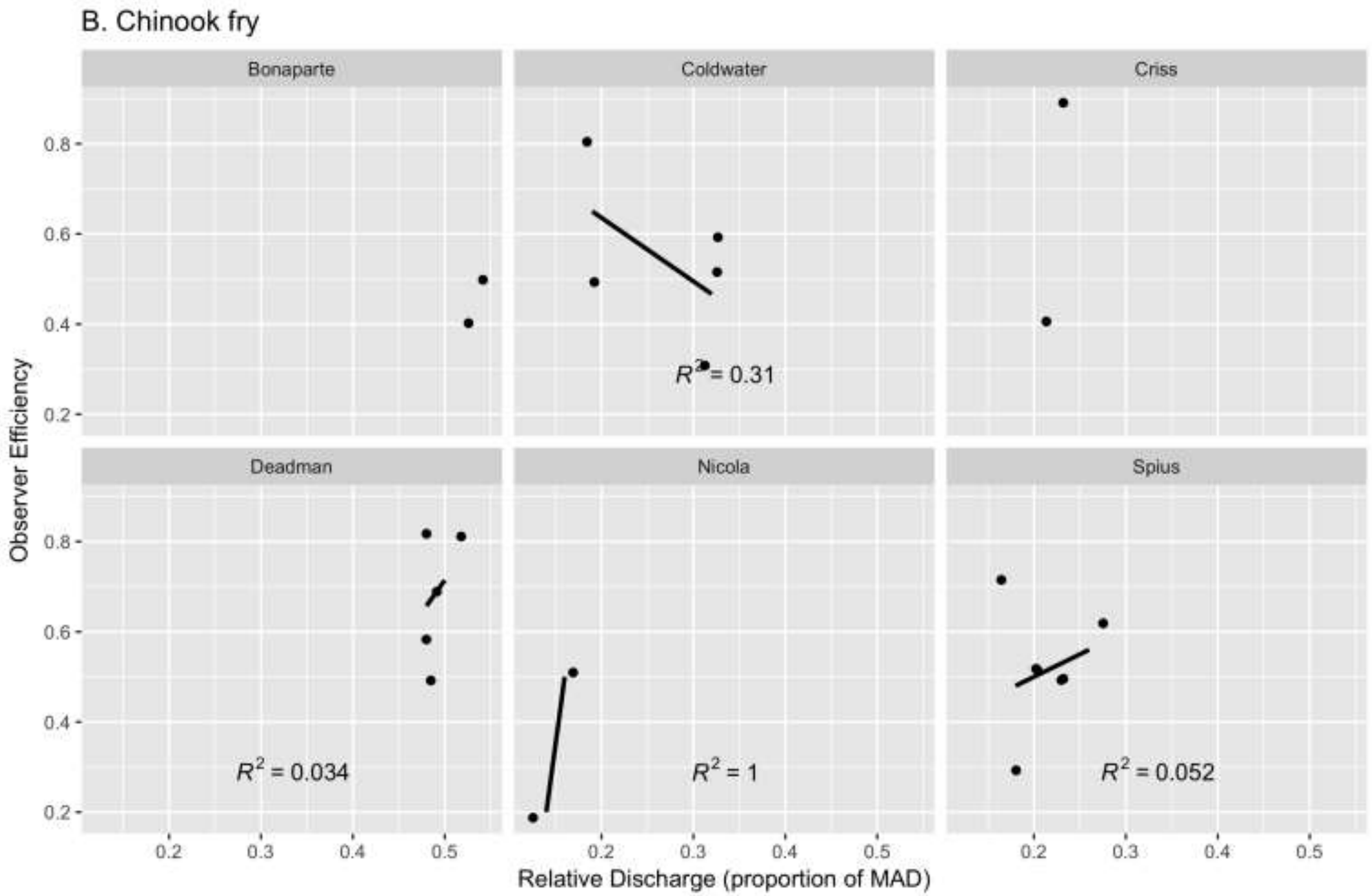
Station	Year	Inv Tmax 30Day norm	Summer 30Day Min st	Summer 30Day Min Doyle	minflow plus tempmax 30day	Winter Daily Max st	Summer Days below 5MAD	Summer Days below 10MAD	Summer Days below 15MAD	July Daily Min st	August Daily Min st	September Daily Min st
Bonaparte	2000	0.72	0.65	6.3	1.49	0.75	0	0	0	1.18	0.74	0.63
Bonaparte	2001	0.48	0.60	5.7	1.17	0.68	0	0	0	0.67	0.89	0.56
Bonaparte	2002	0.20	0.41	4.2	0.59	0.55	0	0	0	0.43	0.35	0.38
Bonaparte	2003	0.21	0.21	2.9	0.28	0.50	0	0	0	0.21	0.20	0.17
Bonaparte	2004	0.00	0.17	1.9	0.00	0.42	0	0	7	0.13	0.11	0.49
Bonaparte	2005	0.24	0.79	6.8	1.24	1.43	0	0	0	1.24	0.76	0.74
Bonaparte	2006	0.12	0.46	4.6	0.59	1.50	0	0	0	0.48	0.42	0.39
Bonaparte	2007	0.24	0.51	5.1	0.79	0.95	0	0	0	0.58	0.43	0.54
Bonaparte	2008	0.27	0.46	4.7	0.74	0.66	0	0	0	0.49	0.42	0.44
Bonaparte	2009	0.10	0.29	3.4	0.30	0.53	0	0	0	0.29	0.25	0.30
Bonaparte	2010	0.10	0.56	5.5	0.72	0.40	0	0	0	0.44	0.45	0.58
Bonaparte	2011	0.78	0.61	5.9	1.50	0.57	0	0	0	1.73	0.75	0.58
Bonaparte	2012	0.44	0.53	5.3	1.03	0.41	0	0	0	1.42	0.72	0.53
Bonaparte	2013	1.00	0.64	6.2	1.75	0.58	0	0	0	0.91	0.65	0.58
Bonaparte	2014	0.54	0.52	5.2	1.09	0.60	0	0	0	0.73	0.60	0.52
Bonaparte	2015	0.24	0.37	3.9	0.57	2.82	0	0	0	0.44	0.34	0.37

Appendix 9 Long-term mean annual discharge (LT MAD) for Water Service of Canada stations for streams in the study area. Station locations and period of record are included in Table 2.

WSC Station	Long-term Mean Annual Discharge (cms)
Bonaparte	5.96
Deadman	1.88
Nicola	26.68
Coldwater at Merritt	8.5
Coldwater at Brookmere	6.81
Spius at Canford	10.41
Spius at Silver Creek	3.56

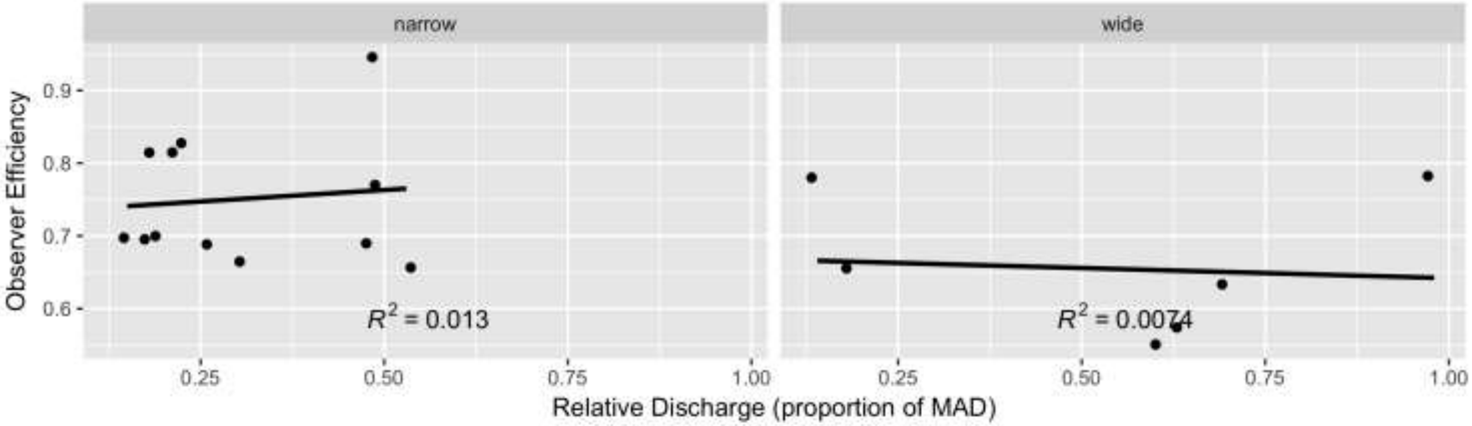
Appendix 10a-b Relationship between snorkeler observer efficiency and relative discharge (% of long term MAD) by river for Steelhead parr (forklength 100-140mm) and Chinook fry. Observer efficiency estimates derived from mark-recapture experiments with more than 5 marked fish, to reduce the uncertainty for each data point, and underwater visibility above the minimum for snorkel surveys(≥ 3m). See Hagen et al. 2010 for information on mark-recapture methods.



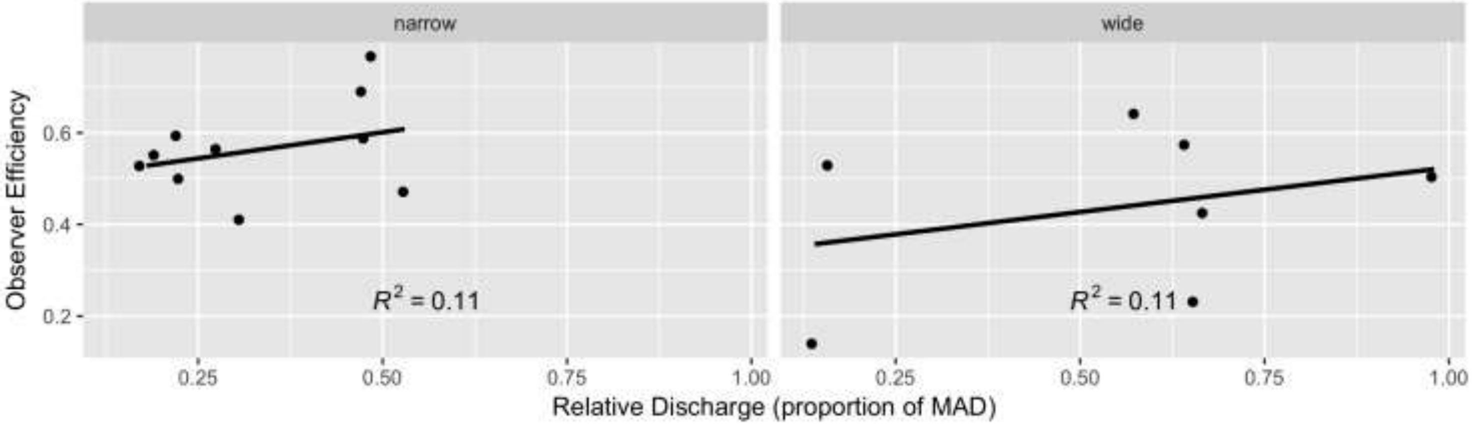

B. Chinook fry
Bonaparte
Coldwater
Criss
Deadman
Nicola
Spius
$R^2 = 0.31$
$R^2 = 0.034$
$R^2 = 1$
$R^2 = 0.052$
Observer Efficiency
0.2
0.4
0.6
0.8
Relative Discharge (proportion of MAD)
0.2
0.3
0.4
0.5

Appendix 11a-b Relationship between snorkeler observer efficiency and relative discharge (% of long term MAD) by river width for Steelhead parr (forklength 100-140mm) and Chinook fry. Observer efficiency estimates derived from mark-recapture experiments with more than 5 marked fish, to reduce the uncertainty for each data point, and underwater visibility above the minimum for snorkel surveys(≥ 3m). See Hagen et al. 2010 for information on mark-recapture methods.

A. Steelhead parr 100 - 140mm (pooled by River Width)



B. Chinook fry (pooled by River Width)



Appendix 12. The relative discharge conditions during snorkel surveys (2001-2015) and snorkeler observer efficiency calibration (2003-2005) by river and groupings of rivers categorized as either wide (Thompson and Nicola) or narrow (all others). Bars represent the counts of survey sites by relative discharge (proportion of MAD). The dashed lines represent the range of discharge during mark-recapture experiments or, in the case of a single dashed line, the discharge condition during the single day of mark-recapture experiments.