PACIFIC SALMON COMMISSION
JOINT CHINOOK TECHNICAL COMMITTEE

SPECIAL REPORT
INVESTGATION OF MATURATION-RATE ESTIMATION MODELS AND THEIR INFLUENCE ON PSC CHINOOK MODEL ABUNDANCE INDICES

TCCHINOOK (16)-1

February 11, 2016

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List of Acronyms and Abbreviations

AABM	Aggregate Abundance Based Management
AC	Allowable Catch
AKS	Chinook Model stock - SE Alaska stocks
AEQ	Adult Equivalent
AUC	Area-Under-the-Curve
AWG	CTC Analytical Working Group
BON	Chinook Model stock - Bonneville
BTR	Base Terminal Run
BY	Brood Year
BYER	brood year exploitation rate
CAS	cohort analysis database
CI	Confidence Interval
CLB	Calibration
CNR	Chinook Non-retention
CPUE	Catch per unit effort
CR	Columbia River
CTC	Chinook Technical Committee
CV	Coefficient of Variation
CWF	Chinook Model stock - Cowlitz Tule
CWT	Coded Wire Tag
CY	Calendar Year
ESC	Escapement
ETS	Exponential Smoothing Model (Error, Trend, Seasonal)
ERA	Exploitation Rate Analysis
EV	Environmental Variable scalar
FI	Fishery Index
FR	Fraser River
FRL	Chinook Model stock - Fraser Late
GS	Strait of Georgia
GSH	Chinook Model stock – strait of Georgia hatchery
HOR	Hatchery Origin Returns
IM	Incidental Mortality
ISBM	Individual Stock Based Management
LFR	Lower Fraser river
LGS	Lower Strait of Georgia
LRW	Chinook Model stock – Lewis River Wild
MATAEQ	Mature run equivalent, also a Chinook model input file
MR	Maturation Rate
MRE	Mature-Run Equivalent
MSE	Mean squared error
MSF	Mark Selective Fishery
MSH	Maximum Sustainable Harvest
MSY	Maximum Sustainable Yield for a stock, in adult equivalents
NA	Not Available
NC	North Coastal
NBC	Northern British Columbia (Dixon Entrance to Kitimat including Haida Gwaii)
NPS	North Puget Sound
NPS-S/F	North Puget Sound Summer/Fall Chinook stock
NR	Not Representative
ORC	Chinook Model stock – northern Oregon Coast aggregate
PNV	Proportion non-vulnerable
PS	Puget Sound
PSC	Pacific Salmon Commission
PST	Pacific Salmon Treaty
RBH	Chinook Model stock - Robertson Creek Hatchery
RBT	Chinook Model stock - Robertson Creek
RER	Recovery Exploitation Rate
ROM	Ratio of means
SA	Stock Aggregates
SE	Standard Error
SEAK	Southeast Alaska Cape Suckling to Dixon Entrance
SMSY	Escapement producing MSY
SPR	Chinook Model stock – South Puget Sound Recovery
SPS	South Puget Sound
SPFI	Stratified Proportional Index
TAC	Total Allowable Catch
TR	Terminal Run
UFR	Upper Fraser River
UGS	Upper Strait of Georgia
UMT	Upper Management Threshold
UMSY	Exploitation Rate at MSY
URB	Chinook Model stock - Columbia Upriver Bright
WAC	Washington Coast
WCVI	West Coast Vancouver Island excluding Area 20
WSH	Chinook Model stock – Willamette Spring
YA	Year Average

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EXECUTIVE SUMMARY

During the October 2015 Pacific Salmon Commission (PSC) Executive Session held in Suquamish, Washington the following assignment was given to the Chinook Technical Committee (CTC) by the PSC Commissioners:

The PSC Chinook Model performance over the last several years has been highly variable based on the wide swings in estimated abundance as expressed within the model calibration abundance indices. The amount of technical debate that has ensued over the last 8 months has been cause for the CTC and AWG to request of the Commission instruction on several aspects of technical work moving forward (Memo to Commissioners from CTC dated September 4, 2015). There were two elements that were transmitted relative to the US Section meeting on June 10, 2015: one was timeliness of release of the preseason abundance index and the other was stability of the model calibration results. There are also several work products that are of immediate and longer term value for the Commission that we request you complete as best possible within the prescribed timelines as depicted below. We have heard discussion and received reasonable correspondence specific to the timing element; however the model stability element has not been adequately addressed.

The Commission is requesting that the AWG embark on investigating both the maturation rates and environmental variables to update and document the analyses performed in 2012 with the last two years of data. The objective is to provide for improved preseason and postseason abundance indices to be generated for the 2016 season and postseason AI's for both the 2014 and 2015 seasons. We understand it is important to start this work soon to inform the current year calibration, and suggest the work completed by December 15, 2015 and no later than January 1, 2016 so that we can be assured that a preseason AI can be generated, evaluated and released for fishery planning purposes.

The CTC-AWG updated the 2012 maturation rate (MR) and environmental variable (EV) analysis, which used results from the 2004 through 2012 calibrations of the PSC Coast Wide Chinook Model with results from the 2013 and 2014 calibrations (see TCCHINOOK(14)-01 V.1, section 3.1.4 for a description of the original work). The new analyses were based on pairings of MR estimates with the EV of the most recently completed brood. This decision was made because the 2012 analysis showed that the estimates of the age-specific MRs used to represent a stock's incomplete brood years had a much greater influence on AIs compared to the EV. In order to determine if the discrepancy between the preseason and post-season Chinook Model AIs could be reduced from the 5-year average (YA) model chosen in the 2012 analysis, the investigation was expanded to include more MR estimates. In addition to the long-term average (starting in 1979), stock- and age-specific MR averages ranging from 3 to 11 years from recent completed broods were evaluated. An approach to estimating the MRs for incomplete broods based on a time series exponential smoothing model (ETS) was also explored as a potential alternative to the method based on a simple average of a specified number of completed broods.

Model calibration results based on the above MR estimates were evaluated using four statistics (squared error, percent error, median error and absolute scaled error) which quantify the magnitude and direction of the discrepancy between two AIs. The statistics were calculated for the discrepancy observed between (1) the preseason AI for each AABM fishery and the first post-season AI, (2) the preseason AI and an average of the post-season AIs for that same year from calibrations completed three or more years after that preseason, and (3) the first post-season AI and the average AI from calibrations completed three or more years after that preseason calibration. Although the three types of discrepancies above were investigated, the one which carried the most weight in our findings was the discrepancy between the preseason AI and the first postseason AI due to the fact that the measures of compliance in the AABM fisheries are the allowable catches associated with the first postseason AIs.

Means (or median) of the error statistics were then computed to show which of the MR estimation models resulted in the greatest reduction in the discrepancy between AIs obtained from the Chinook Model calibrations. These results are documented in this report as well as other data and results considered relevant. The main findings of the MR-EV investigation are:

- Based on the composite mean squared error statistic (MSE), the 9-year average model (9YA) emerged as the estimation model that most reduced the discrepancy between the preseason and first post-season AI across Chinook Model calibrations and AABM fisheries (Table 1).
- The sensitivity of the above conclusion to the number of contributing calibrations was examined and the 9 YA again emerged as the best overall estimation model based on the composite MSE statistic (Table 2).
- The 9YA, 3-year average model (3YA), and time series model (ETS) most reduced the discrepancy between the preseason and first postseason AI across Chinook Model calibrations for the SEAK, NBC, and WCVI AABM fisheries respectively. However, further work is warranted since the difference in performance of a number of the models was small.
- The model used to estimate the MRs noticeably affected the time series of preseason and first post-season AIs for each AABM fishery, but the overall effect on the magnitude and direction of errors compared to the original calibration results was relatively small.
- An analysis using the North Oregon Coast stock aggregate demonstrated a method to estimate naturally-produced stock aggregate MRs by extrapolation from hatchery CWT indicator stock exploitation analysis, and the hatchery CWT indicator stock MRs differed quite substantially from the naturally-produced stock aggregate MRs.

The CTC recommends the utilization of the 9YA for the MRs and 1 year EV as the basis for estimating the stock- and age-specific MRs for the annual Chinook Model calibration (Table 1), and further recommends that the MR and EV analysis is repeated in subsequent years so that perceived potential improvements can be realized.

Table 1. Mean squared error between the preseason and first postseason AI assuming a 1 year EV. Each MR model depicts how the assumptions around incomplete brood years are modeled, including 3 to 11 year averages (e.g., 3YA), long-term averages (LTA) or via exponential smoothing (ETS). The composite MSE metric is the summation of the MSEs across the 3 fisheries. The scenario that minimized the MSE is highlighted in darker shading and the second best scenario is highlighted lighter shading.

Model	SEAK	NBC	WCVI	Composite
3YA	0.0289	0.0233	0.0161	0.0683
5YA	0.0309	0.0238	0.0157	0.0704
7YA	0.0300	0.0246	0.0132	0.0678
8YA	0.0299	0.0248	0.0134	0.0681
9YA	0.0268	0.0234	0.0125	0.0627
10YA	0.0320	0.0252	0.0125	0.0696
11YA	0.0357	0.0277	0.0131	0.0765
LTA	0.0374	0.0283	0.0180	0.0836
ETS	0.0333	0.0239	0.0122	0.0695

Table 2. The best MR estimation model in response to the number of calibrations included in MSE calculations. The earliest calibration year is 2004 in all cases. The composite is based on the sum of MSE values across fisheries. Abbreviations used in Table 1 are identical to those used in this table as well.

Last Year	# Calibrations	SEAK	NBC	WCVI	Composite
2013	10	9YA	3YA	ETS	9YA
2012	9	9YA	5YA	9YA	9YA
2011	8	9YA	5YA, 9YA	9YA	9YA
2010	7	9YA	9YA	9YA	9YA
2009	6	9YA	9YA	9YA, 10YA	9YA
2008	5	9YA	9YA	9YA	9YA

In summary, this investigation did show that improved performance of the Chinook Model, as measured by a reduction in the across-calibration discrepancy between the preseason and postseason AABM fishery AIs, could be achieved through use of MRs based on a 9YA from completed broods for each stock and age in the MATAEQ file. No analyses were undertaken to determine why any particular MR model performed better or worse than others.

1 INTRODUCTION

During the October 2015 Pacific Salmon Commission (PSC) Executive Session held in Suquamish, Washington the following assignment was given to the Chinook Technical Committee (CTC) by the PSC Commissioners:

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The Commission is requesting that the AWG embark on investigating both the maturation rates and environmental variables to update and document the analyses performed in 2012 with the last two years of data. The objective is to provide for improved preseason and postseason abundance indices to be generated for the 2016 season and postseason AI's for both the 2014 and 2015 seasons. We understand it is important to start this work soon to inform the current year calibration, and suggest the work completed by December 15, 2015 and no later than January 1, 2016 so that we can be assured that a preseason AI can be generated, evaluated and released for fishery planning purposes.

The PSC Chinook Model relies on a number of data inputs and assumptions which impact the preseason Abundance Index (AI). Annual inputs include, but are not limited to, hatchery enhancement, stock specific forecasts of escapements or terminal returns, assumed values of stock- and brood-specific environmental variables (EVs), and assumed values of maturations rates (MRs) by stock and age. The last two inputs are the focus of this investigation. Twelve stocks in the PSC Chinook Model have yearly MRs provided. Historically, only 12 stocks were chosen because reliable MR estimates require Coded-Wire-Tag (CWT) data that are both available and of high enough quality for statistical analysis. More recent analysis to improve the base period representation of stocks in the model will allow for the expansion from these original 12 stocks, but until the new base period work is complete and adopted, our analysis is limited to the present 12 stocks.

In 2012, numerous Chinook Model calibrations were performed using different combinations of MR and EV averages to identify the MR-EV combination that minimizes the discrepancy between the preseason and postseason AIs generated by the PSC Chinook Model. Due to the large number of model calibrations required to investigate the performance of each MR-EV average, an exhaustive set of combinations was not performed, but of the combinations that were investigated, the Analytical Work Group (AWG) of the CTC concluded that a recent 5-year average (5YA) MR and a 1-year (1Y) EV minimized the mean squared error (MSE) between the preseason and postseason AIs across the three Aggregate Abundance-Based Management (AABM) fisheries – SEAK, NBC, and WCVI.

Beginning in 2013, the 5YA MR and 1Y EV combination was used as the default configuration for PSC Chinook Model runs. Prior to 2013, the default configuration consisted of the long-term average MR and 5YA EV. The 2012 MR-EV analysis and the 2013 configuration change is documented in the 2013 CTC Calibration and Exploitation Rate Analysis report TCCHINOOK(14)-1_V1 in section 3.1.4. In this analysis, the AWG updated the 2012 MR and EV analysis with two more years of information (2013 and 2014) and investigated additional MR-EV combinations in order to determine if the discrepancy between preseason and postseason AIs could be reduced further. In addition, this report describes an alternative approach to estimating MRs by comparing a hatchery CWT indicator stocks' MRs to its naturally-produced stock aggregates' MRs estimated by extrapolation from exploitation analysis of the CWT indicator stock, additional material on the program the AWG uses to create the MATAEQ Chinook Model input file, and stock and age-specific graphs of MRs.

2 MATURATION RATE AND ENVIRONMENTAL VARIABLE EVALUATION METHODS

2.1 ENVIRONMENTAL VARIABLE AVERAGE METHOD

The PSC Chinook Model calibration procedure uses stock- and brood-specific EV scalars to adjust the model estimated stock- and brood- specific terminal run size or escapement to the empirical stock- and brood-specific estimates of terminal run size or escapement. More specifically, the EV scalars are used to adjust the stock- and brood-specific age-1 abundances that are calculated with stock-specific spawner-recruit functions. EV scalars can be thought of as survival scalars; however, EV scalars also adjust for biases resulting from errors in the data or assumptions used to estimate the stock-specific spawner-recruit parameters. The EV for incomplete broods uses the average of EVs from the most recently available complete broods. The equation is:

$$AvgEV_s = \frac{1}{n} \sum_{i=BY-n+1}^{BY} EV_{s,i}$$

where $AvgEV_{s,BY}$ is the average EV for a particular stock, $EV_{s,i}$ is the EV for a particular stock, *BY* denotes the brood year, *n* is the number of years to use in the average, and *i* is an indexing variable. The most recent EV that can be used in the analysis depends on the age of the stock. For example, the most recent available incomplete brood year used in the 2015 model calibration is either an EV from 2011 or 2012 depending on whether the maximum age for a stock is age-6 or age-5. EV estimates in subsequent calibrations remain in flux until broods are complete.

2.2 MATURATION RATE AND ADULT EQUIVALENT AVERAGE METHOD

MR and AEQ factors for broods that are incomplete (i.e. when not all ages of a particular brood have returned) are equal to the average of the most recent, valid, complete brood year MR and AEQ values. The MR and AEQ average method is a stock- and age-specific method. MR and AEQ values used in the calculation of the MR and AEQ averages are output from the yearly CTC Exploitation Rate Analysis. The equations are:

$$AvgMatRte_{s,a} = \frac{1}{n - \sum_{i=CY-n+1}^{CY} I(valid_{s,a,CY} = 0)} \sum_{i=CY-n+1}^{CY} I(MatRte_{s,a,i} | valid_{s,a,i} = 1)$$

and

$$AvgAEQ_{s,a} = \frac{1}{n - \sum_{i=CY-n+1}^{CY} I(valid_{s,a,CY} = 0)} \sum_{i=CY-n+1}^{CY} I(AEQ_{s,a,i} | valid_{s,a,i} = 1)$$

where $AvgMatRte_{s,a}$ is the average MR for a particular stock and age, $MatRte_{s,a,i}$ is the MR for a particular stock and age given that the brood is valid (i.e. *valid* = 1 and otherwise $MatRte_{s,a,i} = 0$), $AvgAEQ_{s,a}$ is the average AEQ for a particular stock and age, $AEQ_{s,a,CY}$ is the AEQ factor for a particular stock and age given that the brood is valid (i.e. *valid* = 1 and otherwise $AEQ_{s,a,i} = 0$), *CY* denotes calendar year, *s* is stock, *a* is age class, $valid_{s,a,i}$ is a dummy variable that indicates whether a particular stock and age brood is valid or not (if the brood is valid, $valid_{s,a,i} = 1$ and $valid_{s,a,i} = 0$ otherwise), *n* is the number years to use in the average, *i* is an indexing variable, and $I(\bullet)$ is an indicator function that when evaluated returns a value of 1 or 0. See Observed MR values in Appendix A for details on the stock-specific valid brood years.

2.3 Stock and Age-Specific Projections of Maturation Rates

2.3.1 Background

Explorations of time series of MRs have shown that: (1) there are different trends in the trajectories of various stocks; (2) these trends can differ among age-classes for a given stock; and, (3) some stocks exhibit more variability in their MRs than others (see Appendix B). Stock- and age-specific projections of MRs might be more appropriate than the application of a naïve model (e.g., most recent year, 3YA, 5YA, etc.) to all stocks and ages. Stock- and age-specific projections of MRs were produced with exponential smoothing (ETS) models and trend analysis. The former was applied to the last few years in the time series to address the effect of incomplete brood years whereas the later was used to project MRs “one” year in the future. All analyses were based on calendar-year time series of MRs in the 2004-2014 MATAEQ files, which include data for Chinook Model stocks AKS, BON, CWF, GSH, LRW, ORC, RBH, RBT, SPR, URB, WSH, and FRL. Although MRs are originally calculated at the brood year level, the application of statistical models such as the time series and trend analyses conducted herein can directly use calendar-year data in a forecasting fashion.

2.3.2 Addressing the effect of incomplete broods on time series of calendar-year maturation rates in MATAEQ files

The exponential smoothing models (ETS) described herein are a general class of state space models for forecasting univariate time series (Gelper et al. 2010). The acronym ETS denotes the error (E), trend (T), and seasonal components (S) which can be used to describe the time series to be forecasted. The trend component represents the growth or the decline of the time series over an extended period of time. For time series defined at time intervals which are not fractions of a year (e.g., months), the seasonal component is a pattern of change that repeats itself every number of years (i.e., a cycle). The error component captures irregular, short-term fluctuations present in the series, which cannot be attributed to the trend and seasonal components.

ETS models can be classified according to the nature of the error, trend and seasonal components of the underlying time series. The error (E) component can be either additive (A) or multiplicative (M). The trend (T) component can be additive (A), multiplicative (M) or inexistent (N). The trend (T) component can also be dampened additively (Ad) or multiplicatively (Md). The seasonal (S) component can be either additive (A), multiplicative (M) or inexistent (N).

Each particular combination of options for the error, trend and seasonal components of a time series gives rise to a specific ETS model. Since the possibilities for each component are Error = {A,M}, Trend = {N,A,Ad,M,Md} and Seasonal = {N,A,M}, in total there exist 2 x 5 x 3 = 30 such ETS models. Components designated by the letter N are not present in the time series of interest. Components designated by the letter A are present and are combined with the other components via addition. Components designated by the letter M are present and are combined with the other components via multiplication.

For example, the ETS model ETS(AAN) has E(A), T(A) and S(N) structures, where E(A) stands for additive error, T(A) stands for additive trend and S(N) stands for inexistent seasonality. One can show that ETS(AAN) is Holt's linear model with additive errors according to the classification of methods described in Hyndman et al. (2002) and Hyndman et al. (2008).

The R (R version 3.2.3; R Core Team 2015) package *forecast* (Hyndman 2015) was used to implement exponential smoothing on time series of calendar-year MRs (and AEQs) for all stocks in the 2004-2014 MATAEQ files (see Appendix C). The application of the ETS for a given MATAEQ yearly file was applied to sequential subsets of time series *M* and starting with the subset not affected by incomplete brood years (usually $M_{s,a,t=i}^{s,a,t=z-4}$, where *s* is stock, *a* is age, *t* is time (i.e., calendar year), *i* is the start of the time series [1979 in all cases], and z is the "current" calendar year). Given an input time series, the projections were generated by applying the function *forecast()* directly to each of the time series $M_{s,a,t=i}^{s,a,t=z-4}$, $M_{s,a,t=i}^{s,a,t=z-3}$, $M_{s,a,t=i}^{s,a,t=z-2}$, $M_{s,a,t=i}^{s,a,t=z-1}$, and $M_{s,a,t=i}^{s,a,t=z}$ to sequentially populate projected stock- and age-specific data starting from the youngest age through the calendar year *z* as shown in Figure 2.1. This function selects an ETS model using the AIC, estimates the parameters, and generates forecasts. Although this function returns prediction intervals, only point forecasts were extracted from the forecast distribution. The methodology is fully automatic. The only required argument for *forecast()* is the time series. The ETS model is chosen automatically if not specified.

2.3.3 Projecting calendar-year maturation rates (and adult equivalents) in MATAEQ files using trend analysis

The evaluation of trends in MRs was based on the time series updated to the current calendar year through the aforementioned ETS projections (i.e., $M_{s,a,t=i}^{s,a,t=z}$; see Figure 2.1). The projection of MRs (and AEQs) for year *z*+1 was based on a state-space exponential growth model (Dennis et al. 2006) parameterized through state-space restricted maximum likelihood (SSRML, Humbert et al. 2009), which produces rates of change estimates that are generally superior to those produced through maximum likelihood (Staples et al. 2004). This method assumes both observation error and process noise and therefore produces variances and confidence intervals that fully represent the annual variability associated to environmental stochasticity and sampling or observation error (Humber et al. 2009). Analyses were conducted using the R package *MASS* (Ripley 2015) with the selected time period for the characterization of trends starting in 1979 in all cases and ending in the calibration year represented by each of the original MATAEQ files. Although stock- and age-specific projections would be characterized by both long-term mean rate of change (μ) and corresponding 95% confidence intervals, only μ was reported. The value of μ can be positive or negative, indicating the direction and proportional change in MRs expected given the full extent of the time series, with μ = 0.00 indicating equilibrium. Therefore projected MRs for year z+1 were computed as:

$$\hat{M}_{s,a,t=z+1} = M_{s,a,t=z} * \left(1 + \mu_{s,a}\right)$$

2.3.4 Constraints in projected values

Projected values of MRs and AEQs were constrained to the range 0 to 1. The application of the ETS-SSRML model to calendar-year MRs (and AEQs) showed only one case of a slightly negative ETS projected value for the first age for the ORC stock for year 2008, thus highlighting the need to constrain projections to abide by the biological scale in which these rates are expressed. A value of zero is a legitimate possibility in time series of MRs (and AEQs), as shown in the original 2008 ORC time series. In addition, the original time series of MRs for 2013 LRW also showed a value of zero for the first age but projections were positive in this case. Although there were no projected values of 1 or greater than 1 for either MRs or AEQs, a value of 1 is frequently a legitimate value for AEQs in the MATAEQ files. Other possible types of constraints such as constraining values to the observed range for individual time series were not included because the existence of trends in some time series is expected to produce projections that could be out of the range of the time series of observed values. The very essence of the time series and trend analysis methods is to identify patterns and trends, if present, and convey this information into the projected values.

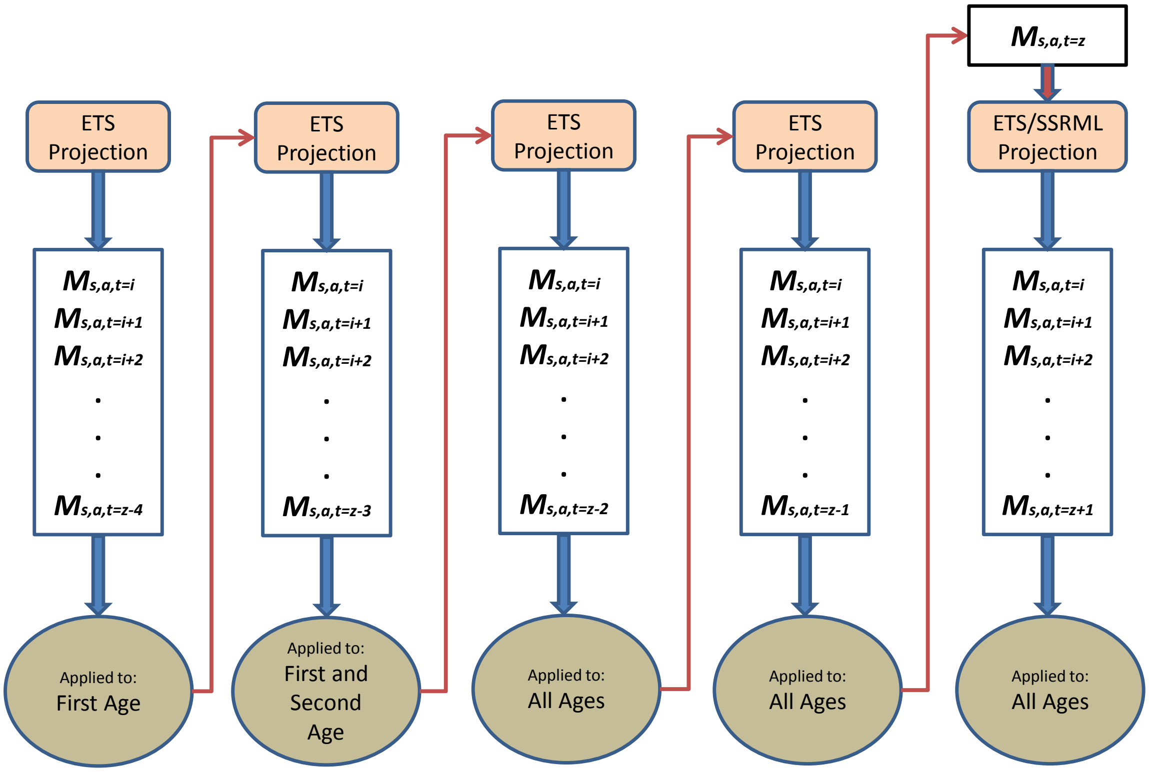

Figure 2.1. Schematic of model used to project stock- and age-specific calendar-year MRs. The methodology uses (1) exponential smoothing (ETS) to complete time series for years affected by incomplete brood years and project MRs for calendar year *z*, and (2) state-space restricted maximum likelihood (SSRML) trend analysis to project MRs for calendar year *z*+1.

Note: The method started with time series $M_{s,a,t=i}^{s,a,t=z-3}$ for the 2013 and 2014 MATAEQ files because there was an extra year of projection-free calendar-year MRs.

For convenience, the combination of ETS and SSRML models above described is simply referred to as ETS in the next sections, including figures and tables.

2.4 Differences between Maturation Rates for CWT Indicator Stocks and for Stock Aggregates

2.4.1 Background

In producing Abundance Indices (AIs) for pre-terminal marine fishing areas, the PSC Chinook Model fits to inputs of escapement (ESC) or terminal return (TR) of the various stock aggregates (SA) and to inputs of MRs for the CWT indicator stocks representing the SAs. Because of the importance of accurate estimates and forecasts of TR, in this report the CTC-AWG investigates differences between preseason and postseason AIs over the period of years over which CWT indicator stock MRs are averaged to forecast MRs for incomplete broods. However, almost all CWT indicator stocks are hatchery populations and it is well established that hatchery populations generally exhibit earlier maturation and return by age than nearby natural populations. In contrast, the sum of TR by age for its component river populations best represents the SA and thus should provide for the best estimates of MRs.

2.4.2 Estimation of stock aggregate maturation rates by extrapolation from CWT indicator stock exploitation analysis

A method to estimate MRs for a SA using TRs summed across rivers in combination with CWT indicator stock exploitation analysis is demonstrated here. This demonstration example employs the Salmon River Hatchery (SRH) CWT indicator stock and the North Oregon Coast (NOC) SA, for which five BYs were randomly selected for this analysis. However, the method can be applied to any BY for any SA (or a subset of rivers of an SA) and its CWT indicator stock. Terms used in this demonstration are defined in Table 2.1.

Table 2.1. *Term definitions used in the CWT indicator and stock aggregate analysis.*

Term	**Definition**
TF	terminal fishing total mortality
ESC	spawning escapement
TR	terminal fishing total mortality plus spawning escapement (TF+ESC)
TRprop	the proportion of total TR of a specific age
PTF	pre-terminal fishery total mortality
CO	cohort size before PTF occurs
PTFR	pre-terminal fishery total mortality rate (PTF/CO)
MR	(TR/(CO-PTF))

For the SA, the TRs consist of the sum across NOC rivers of ESC apportioned by age based on spawner survey peak counts and carcass/scale sampling, plus a TF component reflecting the CWT indicator stock TF/ESC ratio

NOC TF = NOC ESC * (CWT TF/CWT ESC), by age

As done in the CTC's exploitation rate analysis and the PSC Chinook Model, we assume that exploitation of the CWT indicator stock reflects that of the SA

CWT stock PTFR = SA PTFR, by age

Estimates for the SA complimentary to those for the CWT indicator stock were derived using Coshak (the CWT cohort reconstruction program used by the CTC) backwards run reconstruction (exploitation analysis) methods, starting with age 6 since the age 7 cohort is approximately 0.

Finally, ratios for TRprop and MR between the CWT stock and the SA for each brood-year and age simplify comparisons

CWT stock TRprop/SA TRprop

and

CWT stock MR/SA MR

The computations are simple arithmetic, and below are calculations of CO, PTF, and MR for the SA 1992 brood-year (some small rounding error is present, see Results section for figures used). First, one estimates CO for the SA, assuming exploitation of the CWT indicator stock represents that of the SA:

CO age 7 ~ 0

CO age 6 = (CO age 7/0.9+TR age 6)/(1-PTF rate age 6) = (0+19,162)/(1-0.186) = 23,552

CO age 5 = (CO age 6/0.9+TR age 5)/(1-PTF rate age 5) = (23,552/0.9+54,009)/(1-0.275) = 110,514

CO age 4 = (CO age 5/0.9+TR age 4)/(1-PTF rate age 4) = (110,514/0.9+191,224)/(1-0.118) = 355,850

CO age 3 = (CO age 4/0.8+TR age 3)/(1-PTF rate age 3) = (355,850/0.8+37,893)/(1-0.049) = 507,338

CO age 2 = (CO age 3/0.7+TR age 2)/(1-PTF rate age 2) = (507,338/0.7+11,187)/(1-0.055) = 778,665

Next, one estimates PTF for the SA by applying CWT stock PTFR:

PTF age 6 = CO age 6*PTFR age 6 = 23,552*0.186 = 4,390

PTF age 5 = CO age 5*PTFR age 5 = 110,514*0.275 = 30,336

PTF age 4 = CO age 4*PTFR age 4 = 355,850*0.118 = 41,832

PTF age 3 = CO age 3*PTFR age 3 = 507,338*0.049 = 24,632

PTF age 2 = CO age 2*PTFR age 2 = 778,665*0.055 = 42,710

One can then estimate MRs for the SA using the estimates above:

MR age 6 = TR age 6/(CO age 6-PTF age 6) = 19,162/(23,552-4,390) = 1.000

MR age 5 = TR age 5/(CO age 5-PTF age 5) = 54,009/(110,514-30,336) = 0.674

MR age 4 = TR age 4/(CO age 4-PTF age 4) = 191,224/(355,850-341,832) = 0.571

MR age 3 = TR age 3/(CO age 3-PTF age 3) = 37,893/(507,338-24,632) = 0.073

MR age 2 = TR age 2/(CO age 2-PTF age 2) = 11,187/(778,665-42,710) = 0.016

3 RESULTS

3.1 EVALUATION OF RESULTS

3.1.1 Summary of results

We evaluated the performance of each MR on its ability to adequately predict abundance indices (AIs) based on three different metrics each using four different model evaluation criteria. The three metrics were:

1. The discrepancy between a predicted, preseason AI and the average AI 3-10 years postseason for the fishery, when AI values from the model have stabilized. The preseason value is a model predicted AI and the 3-10 year average is considered the observed or true AI.
2. The discrepancy between the first postseason AI estimate and the 3-10 year postseason AI values for the fishery. The first postseason value is a model predicted AI and the average of the 3-10 postseason AIs is considered the observed or true AI.
3. The discrepancy between the preseason and the first postseason AI. The preseason value is the model prediction and the first postseason AI is considered the true value.

The last metric has two more years of data than the other two for each AABM fishery. Each of the three metrics was analyzed by comparing four different criteria across the range of MRs estimated used to calculate AI values. The model evaluation criteria are:

1. The mean squared error (MSE) is an average of the squared differences between predicted and observed (true) AIs. It is a measure of the variability of predicted AIs values. The MSE is always positive and hence does not indicate if a MR estimate tends to under- or overestimate the AI. The best MR estimate is the one that minimizes the MSE.
2. The median error is the median value of the difference between predicted and observed AIs. It is less sensitive to outlier values of differences than a mean and provides information on whether a MR tends to under- or over-estimate AIs. The best MR estimate is the one that produces median values closest to zero.
3. The mean absolute scaled error (MASE; Hyndman and Koehler 2006) is a generally applicable, scale-free measure of forecast accuracy. Ideally, the value of MASE will be significantly less than 1. The MASE is always positive and unlike other metrics that are based on averages, it weighs differences between predicted and observed values evenly, regardless of magnitude. The best MR estimate is the one that minimizes the MASE.
4. The mean percent error (MPE) is the average of the difference between predicted and observed (true) AIs divided by the true AI and multiplied by 100%. Because small AI values can correspond to small MSE values, the MPE is a good metric to accompany an MSE as it scales the average differences between predicted and observed AIs accordingly. The best MR estimate is the one that produces MPE values closest to zero.

More information on each of the evaluation criteria and the equations used in the calculations are provided in Appendix D. Results of the analysis are based on MRs that either minimize an evaluation criterion or provide values close to one. Hence, we present and evaluate the results graphically, by metric (Figures 3.1-3.3).

3.1.2 Preseason AI to Average 3-10 years postseason AI

Of all the MRs examined in the analysis, model evaluation criteria were most often minimized using the 9YA across all fisheries based on discrepancies between preseason and average 3-10 years postseason AIs (Table 3.1, Figure 3.1). MR estimates that minimize model evaluation criteria most often were the 7YA – 11YA estimates. The notable exception is in the SEAK fishery where the MPE and Median error were minimized using the 3YA MR. However, the difference between the median error resulting from the 3YA and the 9YA was small. The predominance of positive values for the median error and MPE indicate that preseason AIs are overestimated relative to the average 3-10 year postseason AI.

3.1.3 First postseason AI to average 3-10 years postseason AI

Discrepancies between the first postseason AI and the average 3-10 year postseason AI are most often minimized using the 3YA MR estimate (Table 3.2, Figure 3.2). However, the differences are small among the model evaluation criteria for the MRs used in the analysis, indicating that this metric may not be sensitive to the 3YA to 11YA MRs. In SEAK, the 10YA minimized both the MSE and MPE and the MASE in NBC. The largest differences are observed using the ETS and LTA MR estimates.

3.1.4 Preseason AI to first postseason AI

In the SEAK fishery, preseason to postseason AIs discrepancies were most often minimized when the Chinook Model used the 9YA MR estimates (Table 3.3, Figure 3.3). However, preseason AI values are slightly overestimated when compared to the first postseason AI.

In the WCVI fishery, the 9YA MR estimate minimizes 2 of the 4 model evaluation criteria. The 8YA MR minimizes the WCVI Median error; however the value is close to that obtained when using the 9YA. The MSE for the WCVI fishery is lowest when using the ETS MR, but the difference from the MSE using the 9YA is small.

Results from the NBC fishery are not as clear. MRs based on the 3YA minimizes the MSE, but the 11YA and ETS MRs minimize the median error and MPE, respectively. Differences from the 9YA for both of these metrics are small.

Table 3.1. Values of the model evaluation metrics for the preseason AI to the average 3-10 year postseason AI discrepancy. Lowest values indicate the MR estimates that create the best predictions from the Chinook model.

MR Estimate	SEAK				NBC				WCVI			
	MSE	Median Error	Mean Percent Error	MASE	MSE	Median Error	Mean Percent Error	MASE	MSE	Median Error	Mean Percent Error	MASE
3YA	0.049	**0.093**	**0.080**	0.718	0.034	0.072	0.084	0.760	0.020	0.113	0.154	1.153
5YA	0.039	0.097	0.083	0.674	0.024	0.088	0.081	0.603	0.022	0.117	0.154	1.203
7YA	0.041	0.094	0.085	0.664	0.027	0.071	**0.076**	0.641	0.022	0.112	0.137	1.186
8YA	0.037	0.099	0.090	0.657	0.024	0.080	0.078	0.598	0.021	0.106	0.133	1.108
9YA	**0.033**	0.094	0.092	**0.632**	**0.022**	0.078	0.080	**0.561**	0.019	0.103	**0.131**	1.052
10YA	0.038	0.119	0.108	0.716	0.023	**0.068**	0.090	0.599	0.019	**0.101**	0.136	1.055
11YA	0.043	0.141	0.118	0.762	0.027	0.083	0.100	0.647	**0.018**	0.101	0.140	**1.052**
ETS	0.057	0.181	0.149	0.907	0.035	0.112	0.133	0.809	0.019	0.113	0.148	1.090
LTA	0.071	0.214	0.172	1.004	0.047	0.145	0.160	0.916	0.032	0.144	0.215	1.434

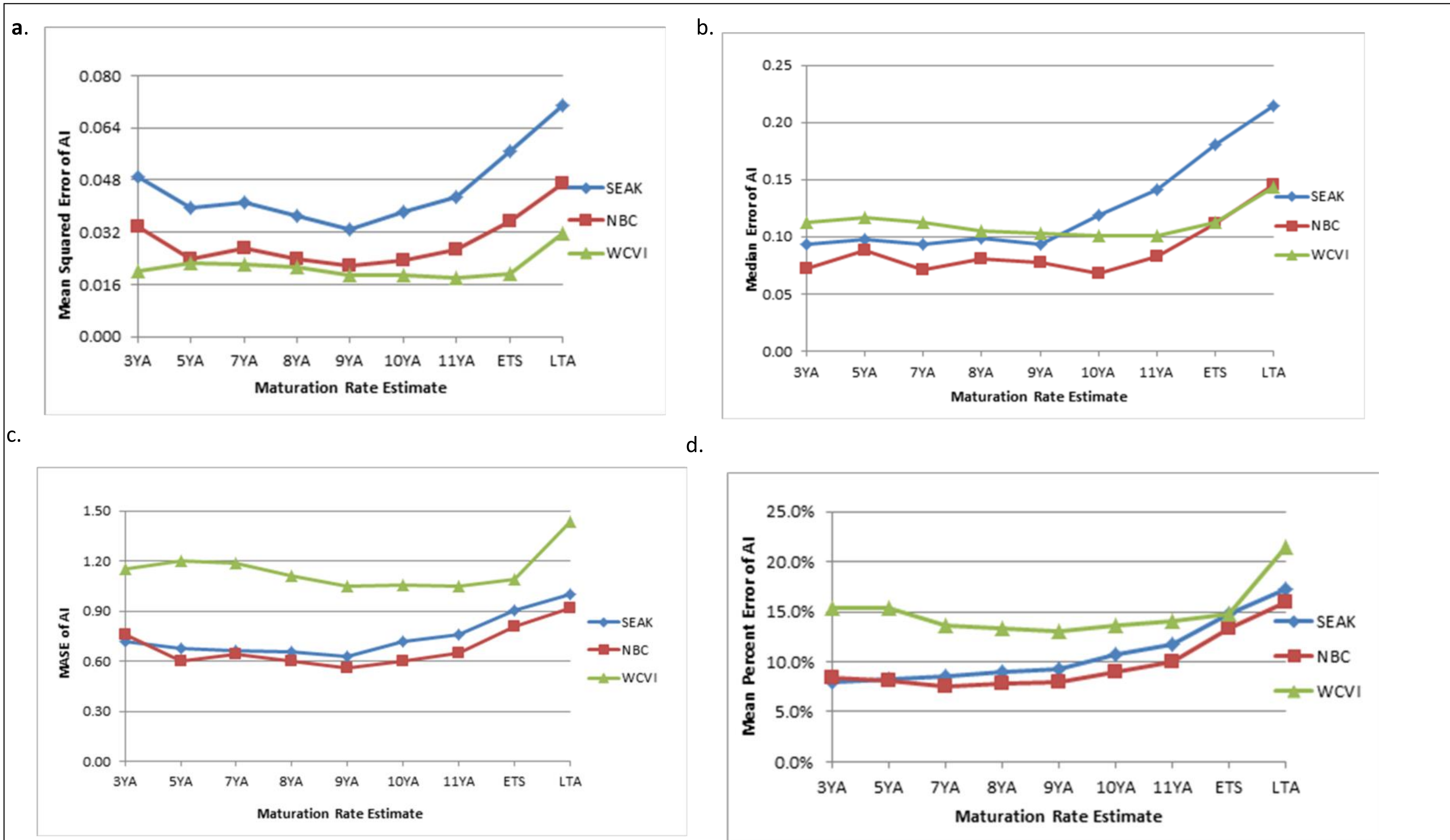

Figure 3.1. *Model evaluation metrics of the discrepancy between the preseason AI and the average 3-10 year postseason AI for different MR estimates, a. Mean squared error, b. Median error, c. Mean absolute scaled error, and d. Mean percent error.*

Table 3.2. Values of the model evaluation metrics for the first postseason AI to the average 3-10 year postseason AI discrepancy. Lowest values indicate the MR estimates that create the best predictions from the Chinook model.

MR Estimate	SEAK				NBC				WCVI			
	MSE	Median Error	Mean Percent Error	MASE	MSE	Median Error	Mean Percent Error	MASE	MSE	Median Error	Mean Percent Error	MASE
3YA	0.017	**0.061**	**0.051**	0.520	0.015	**0.078**	**0.074**	0.670	**0.003**	**0.034**	**0.053**	0.433
5YA	0.010	0.084	0.055	0.443	**0.011**	0.089	0.074	0.535	0.004	0.039	0.058	0.426
7YA	0.014	0.110	0.059	0.495	0.013	0.080	0.075	0.567	0.005	0.043	0.060	0.521
8YA	0.012	0.105	0.060	0.467	0.012	0.081	0.075	0.536	0.005	0.040	0.057	0.481
9YA	0.012	0.102	0.060	0.454	0.011	0.082	0.075	0.531	0.004	0.039	0.057	0.469
10YA	**0.010**	0.108	0.067	**0.409**	0.011	0.081	0.080	**0.489**	0.004	0.038	0.058	0.437
11YA	0.011	0.112	0.074	0.430	0.012	0.080	0.086	0.504	0.004	0.037	0.061	**0.424**
ETS	0.022	0.154	0.111	0.575	0.021	0.117	0.120	0.669	0.005	0.039	0.074	0.487
LTA	0.025	0.157	0.117	0.601	0.024	0.122	0.129	0.717	0.006	0.053	0.088	0.487

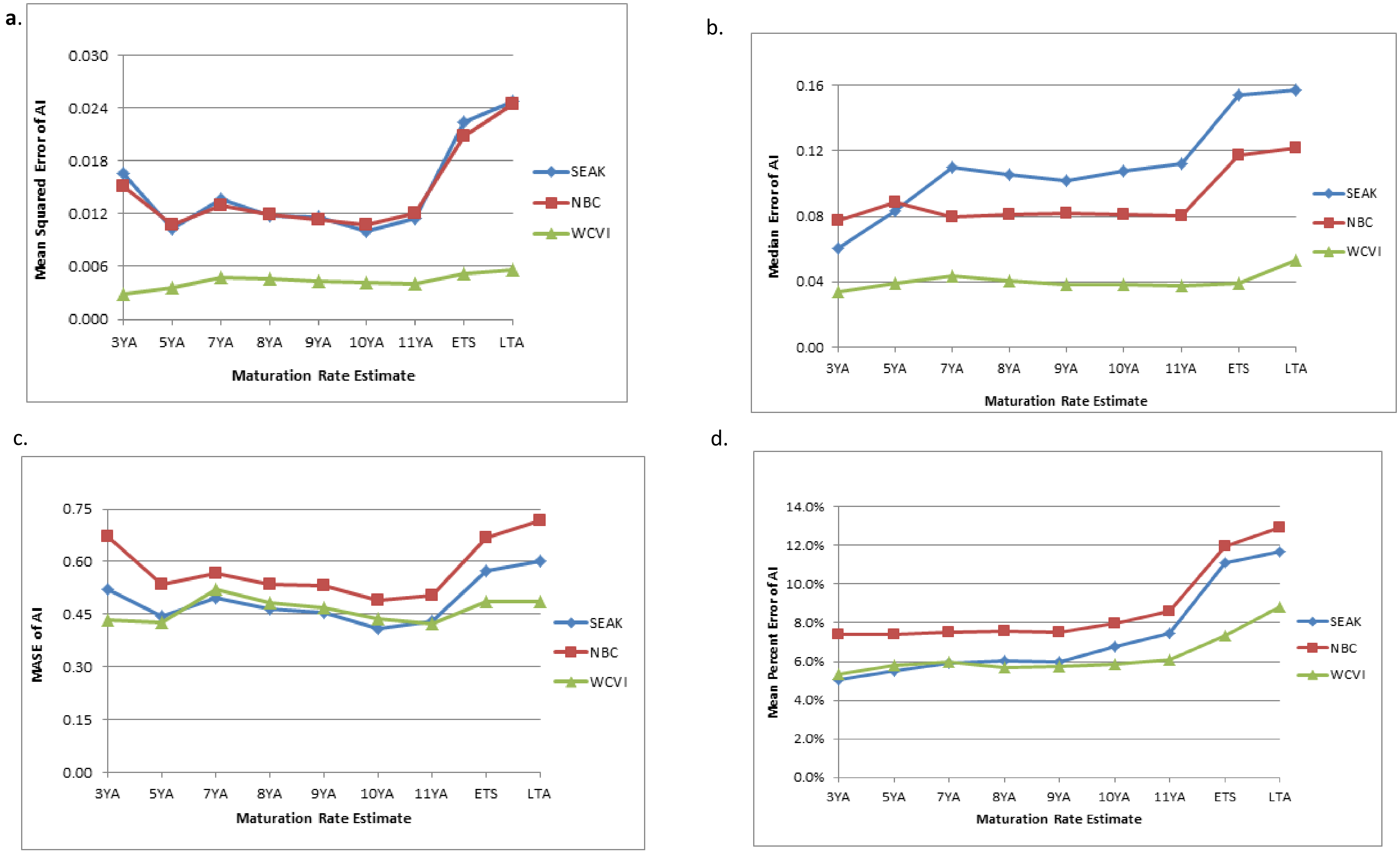

Figure 3.2. Model evaluation metrics of the discrepancy between the first postseason AI and the average 3-10 year postseason AI for different MR estimates. a. Mean squared error, b. Median error, c. Mean absolute scaled error, and d. Mean percent error.

Table 3.3. Values of the model evaluation metrics for the preseason AI to the first postseason AI discrepancy. Lowest values indicate the MR estimates that create the best predictions from the Chinook Model.

MR Estimate	SEAK				NBC				WCVI			
	MSE	Median Error	Mean Percent Error	MASE	MSE	Median Error	Mean Percent Error	MASE	MSE	Median Error	Mean Percent Error	MASE
3YA	0.029	-0.022	-0.002	0.508	**0.023**	-0.023	-0.016	0.546	0.016	0.043	0.050	0.727
5YA	0.031	0.030	**-0.001**	0.489	0.024	-0.008	-0.017	**0.443**	0.016	0.059	0.050	0.694
7YA	0.030	0.023	0.004	0.487	0.025	-0.039	-0.017	0.510	0.013	0.050	0.045	0.642
8YA	0.030	0.030	0.006	0.510	0.025	-0.019	-0.016	0.479	0.013	**0.035**	**0.043**	0.594
9YA	**0.027**	**0.011**	0.008	**0.435**	**0.023**	-0.015	-0.014	0.451	0.013	0.040	**0.043**	**0.582**
10YA	0.032	0.026	0.013	0.479	0.025	-0.013	-0.012	0.459	0.013	0.044	0.045	0.585
11YA	0.036	0.033	0.015	0.501	0.028	**-0.007**	-0.009	0.467	0.013	0.046	0.047	0.593
ETS	0.033	0.026	0.027	0.506	0.024	-0.011	**0.004**	0.459	**0.012**	0.058	0.049	0.598
LTA	0.037	0.054	0.033	0.536	0.028	0.013	0.008	0.483	0.018	0.072	0.086	0.747

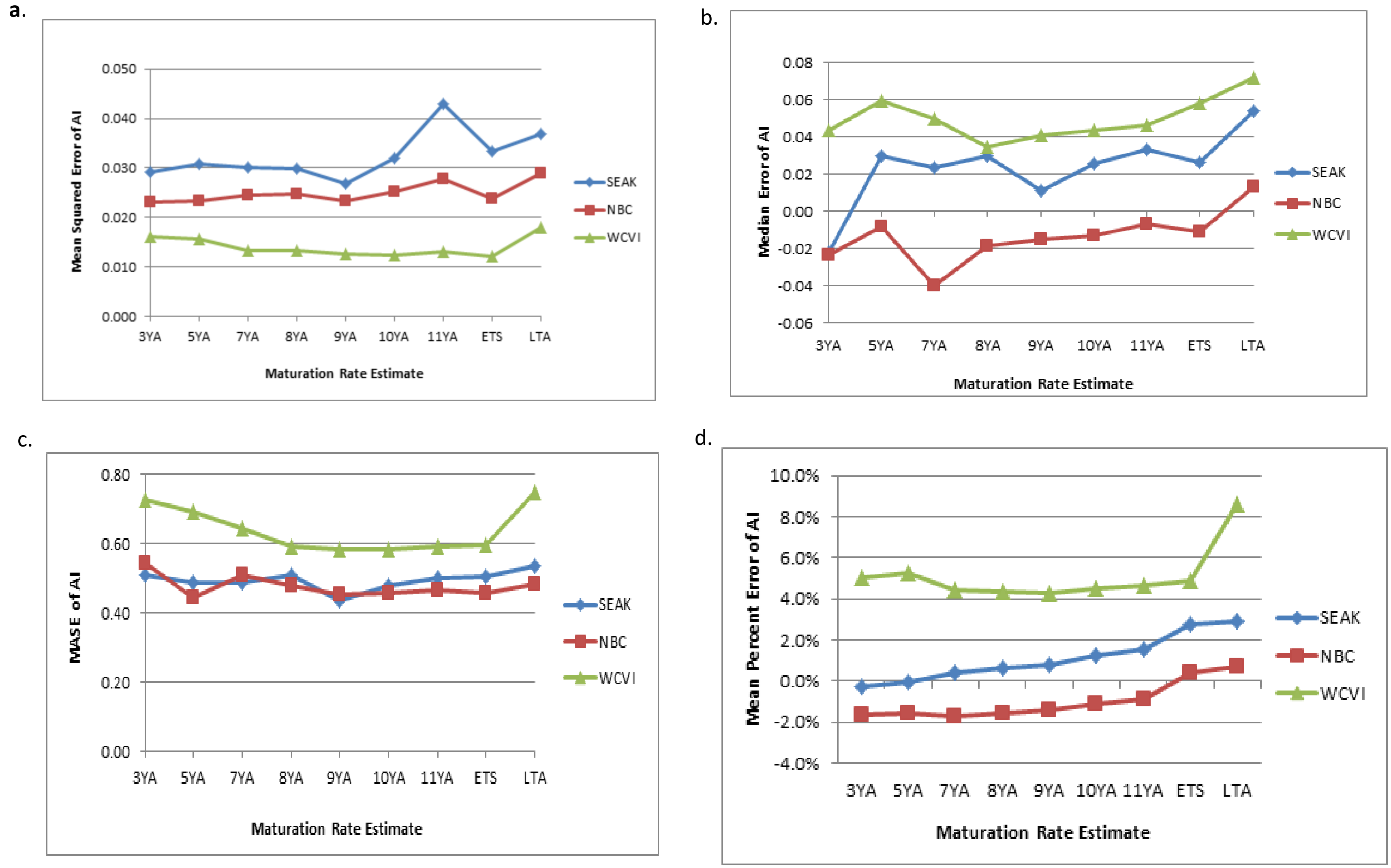

Figure 3.3. Model evaluation metrics of the discrepancy between the preseason and first postseason AI for different MR estimates, a. Mean squared error, b. Median error, c. Mean absolute scaled error, and d. Mean percent error.

3.2 Best Model Choice under Different Data Availability Scenarios

In addition to the evaluation of models for preseason- first postseason discrepancies based on MSE calculations encompassing the 2004-2013 calibration time series, uncertainty in the best projection model was evaluated in response to the extent of time series (i.e., number of calibrations) used for MSE calculations. In some years, more than one model was identified as best because they had identical MSE values but in general the 9YA remained the overall best model (Table 3.4). The first row in this table corresponds to the individual-fishery best model in Table 5.1.

Table 3.4. Best MR projection model for each AABM fishery in response to the number of calibrations included in MSE calculations. The earliest calibration year is 2004 in all cases. The composite is based on the sum of MSE values across fisheries. All models assume a 1Y EV.

Last Year	# Calibrations	SEAK	NBC	WCVI	Composite
2013	10	9YA	3YA	ETS	9YA
2012	9	9YA	5YA	9YA	9YA
2011	8	9YA	5YA, 9YA	9YA	9YA
2010	7	9YA	9YA	9YA	9YA
2009	6	9YA	9YA	9YA, 10YA	9YA
2008	5	9YA	9YA	9YA	9YA

3.3 AI Projections of Alternative Models

Preseason and first postseason AIs from the original annual calibrations were compared to the AIs generated from calibrations using MR and EV combinations with the lowest MSE for the AABMs as a group (9YA MR, 1Y EV) and for the individual AABM fisheries (Table 3.5). The AIs from the original annual calibrations were developed using a LTA MR and 5YA EV prior to 2013 and changed to a 5YA MR and 1Y EV in 2013 following the CTC 2012 MR and EV analysis. The AIs from the original calibrations are generally higher in both preseason and postseason calibrations than those produced using MR and EV from more recent year data for all three AABMs (Figure 3.4). The exception to this pattern occurred for all three AABM fisheries with the 2013 calibration; this corresponded with a change MR and EV assumptions. The biggest difference between the original calibrations and calibrations performed with the 9YA MRs and 1Y EVs occurred in the preseason AIs (Figure 3.4). The effect on the postseason AI was relatively small. The postseason AIs produced by the original and 9YA MRs and 1Y EVs were almost identical for the WCVI AABM fishery.

The average of the preseason and postseason AIs generated from the 2004-2014 Model calibrations using the best fishery-specific MR and EV for the NBC AABM (3YA MRs and 1 Y EV) were similar to the average of the AIs generated by 9YA MR and 1Y EV. For the WCVI AABM, the best fishery-specific MR and EV combination (ETS MRs and 1Y EV) generated across-calibration averages of the preseason and postseason AIs that were identical to the averages using the 9YA MRs and 1Y EVs. The AIs generated using the best MR and EV combination overall AABMs are the same (SEAK) or very similar to the AIs generated using the best fishery-specific MR and EVs.

Table 3.5. Preseason and first postseason AIs from the annual Chinook Model calibration under three MR-EV models.

AABM	Year	Original Calibration a/		Best MR-EV Overall AABM (9YA MR; 1Y EV)		Best MR-EV SEAK (9YA MR; 1Y EV)	
		Preseason	First Post	Preseason	First Post	Preseason	First Post
SEAK	**2004**	1.88	2.06	1.81	1.90	1.81	1.90
	2005	2.05	1.90	1.87	1.81	1.87	1.81
	2006	1.69	1.73	1.58	1.62	1.58	1.62
	2007	1.60	1.34	1.51	1.27	1.51	1.27
	2008	1.07	1.01	0.99	0.96	0.99	0.96
	2009	1.33	1.20	1.23	1.16	1.23	1.16
	2010	1.35	1.31	1.22	1.23	1.22	1.23
	2011	1.69	1.62	1.53	1.54	1.53	1.54
	2012	1.52	1.24	1.38	1.26	1.38	1.26
	2013	1.20	1.63	1.30	1.72	1.30	1.72
	Average	**1.54**	**1.50**	**1.44**	**1.45**	**1.44**	**1.45**

AABM	Year	Original Calibration a/		Best MR-EV Overall AABM (9YA MR; 1Y EV)		Best MR-EV NBC (3YA MR; 1Y EV)	
		Preseason	First Post	Preseason	First Post	Preseason	First Post
NBC	**2004**	1.67	1.83	1.63	1.70	1.57	1.63
	2005	1.69	1.65	1.54	1.55	1.46	1.59
	2006	1.53	1.50	1.39	1.41	1.45	1.45
	2007	1.35	1.10	1.25	1.04	1.30	1.07
	2008	0.96	0.93	0.88	0.89	0.93	0.90
	2009	1.10	1.07	1.03	1.03	1.04	1.01
	2010	1.17	1.23	1.09	1.17	1.06	1.15
	2011	1.38	1.41	1.29	1.35	1.25	1.30
	2012	1.32	1.15	1.25	1.15	1.18	1.13
	2013	1.10	1.51	1.18	1.59	1.15	1.53
	Average	**1.33**	**1.34**	**1.25**	**1.29**	**1.24**	**1.28**

AABM	Year	Original Calibration a/		Best MR-EV Overall AABM (9YA MR; 1Y EV)		Best MR-EV WCVI (ETS Method)	
		Preseason	First Post	Preseason	First Post	Preseason	First Post
WCVI	**2004**	0.90	0.98	0.87	0.94	0.90	0.96
	2005	0.88	0.84	0.81	0.81	0.82	0.84
	2006	0.75	0.68	0.68	0.66	0.75	0.67
	2007	0.67	0.57	0.61	0.55	0.64	0.55
	2008	0.76	0.64	0.72	0.63	0.67	0.63
	2009	0.72	0.61	0.68	0.61	0.69	0.61
	2010	0.96	0.95	0.93	0.92	0.91	0.94
	2011	1.15	0.90	1.07	0.90	1.09	0.90
	2012	0.89	0.76	0.84	0.74	0.84	0.72
	2013	0.77	1.04	0.84	1.10	0.83	1.05
	Average	**0.85**	**0.80**	**0.81**	**0.79**	**0.81**	**0.79**

a/ Annual calibrations to determine preseason and first postseason AI in 2004-12 were made with a LTA MR and 5YA EV. In 2013, a 5YA MR and a 1Y EV was used in the annual calibration for preseason and first postseason AI.

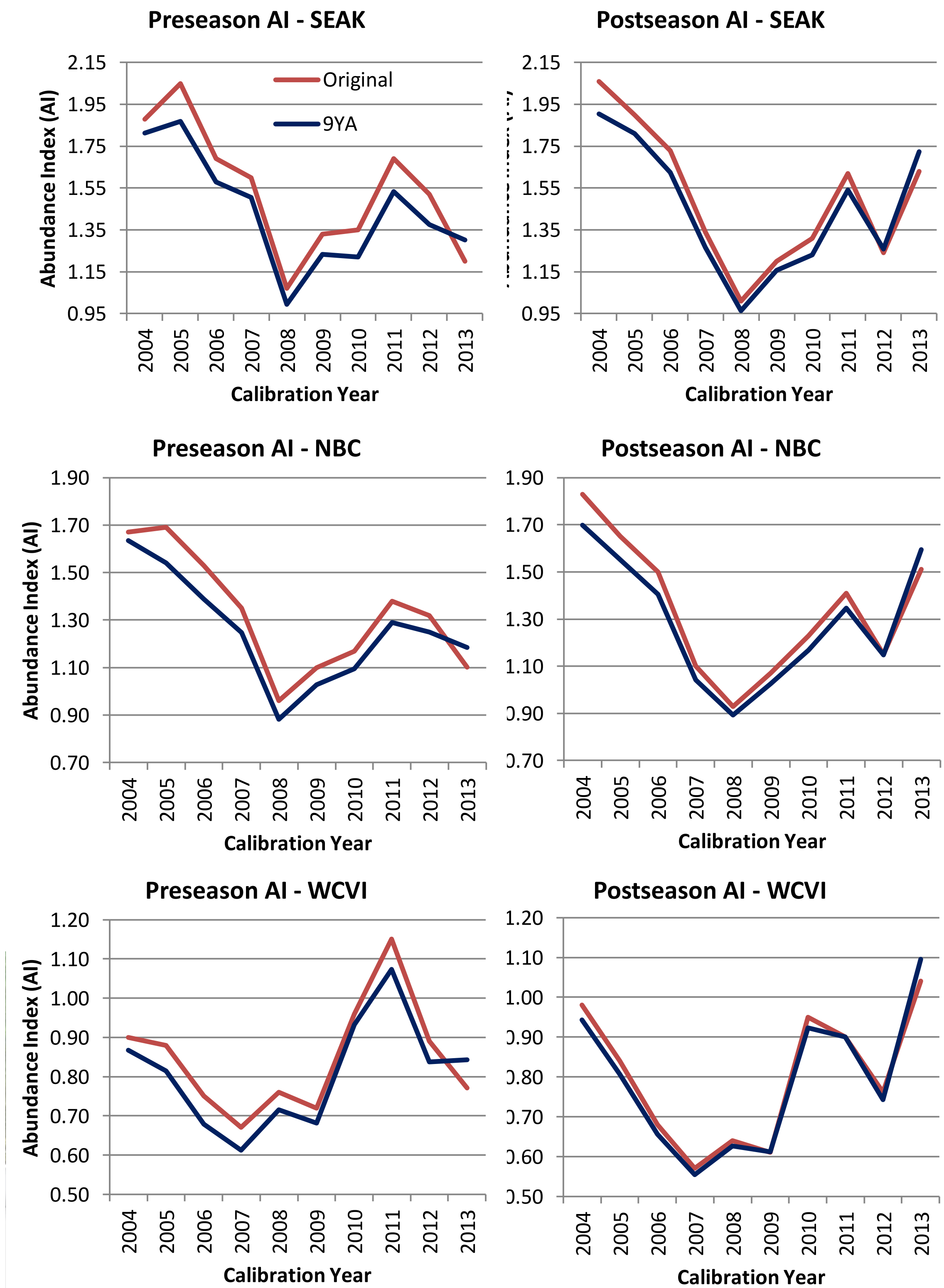

Figure 3.4. Preseason and postseason AIs for the SEAK, NBC and WCVI AABM fisheries from the original 2004-2013 Model calibrations and from calibrations using the 9YA MR and 1Y EV. Comparisons between preseason AIs are displayed in panels on the left, comparisons of postseason AIs in panels on the right. The original values are indicated by a red line in each panel. Values obtained using the 9YA and 1Y EV are indicated with a blue line in each panel.

3.4 Effect of Maturation Rate Estimates on Pattern of Discrepancies between Preseason and Postseason AIs

Two aspects of the discrepancies between the preseason and first postseason AI for each of the three AABM fisheries have been noted. The first is the magnitude of the discrepancies, with the discrepancy exceeding 20% for two calibrations in each of the three fisheries (see Table 3.6 under the heading Original). The second is that for the annual calibrations from 2005 until 2012, the discrepancies were primarily in one direction for all three AABM fisheries with the preseason AI exceeding the postseason AI (Table 3.6). This pattern was observed despite the occurrence of both decreasing and increasing periods of aggregate Chinook abundance. The most notable exception to the pattern of over-forecasting of the AIs occurred with the calibration in 2013 (see Table 3.5).

Comparison of the magnitude of the percent error between the preseason and first postseason AIs from the original Chinook Model calibrations and from calibrations based on the best fishery-specific estimation model as assessed using the MSE statistic (Table 3.6, compare values under Original and MSE) showed that the mean percentage error (MPE) was reduced for the SEAK and WCVI AABM fisheries but not for the NBC fishery. For the NBC fishery, the MPE was reduced most using ETS MRs and 1Y EVs. The MPE from the original calibrations for the NBC fishery was small and results from calibrations performed with MR-EV estimates from the two other estimation models included in Table 3.6 produced similar results. The estimation model that resulted in lowest fishery-specific MPE differed from the model that resulted in the lowest fishery-specific MSE for each AABM fishery. The difference between the two models was small in each case. The MR-EV estimation model did affect the magnitude of the calibration-specific percent error between the preseason and postseason AIs as well as the MPE. In terms of absolute percentage errors, the employment of the 9YA in SEAK and WCVI reduced the percentage errors by 33% and 30% on average, and the ETS and 3YA both reduced the percentage errors by 11% in the NBC fishery (bottom 2 rows in Table 3.6). The percent error could be reduced in most calibration years through adoption of a different estimation model than had been used in calibrations prior to 2013 and the 9YA MR and 1 Y EV emerged as the best overall choice. The MR-EV estimation model, however, did not substantially change the pattern of percent errors observed across consecutive calibrations in years 2004-2013 for the AABM fisheries (Figure 3.5), meaning other factors or model inputs beyond MR or the EV have had a causative effect. An actual change in sign of the error occurred in only some cases where the percent error was near zero in the original calibration (Table 3.6). There was a slightly greater effect for the WCVI AABM fishery but overall, the influence was relatively minor (Figure 3.5). For the purpose of illustrating that the overall pattern of errors was not really affected by the MR-EV estimation model, results from a limited selection of estimation models was selected for display in Figure 3.5. Results were similar, however, for any of the estimation models that were investigated.

Table 3.6. Percent error (PE) between the preseason and first postseason AI from Chinook Model calibrations 2004-2013 for the SEAK, NBC and WCVI AABM fisheries. For each fishery are shown PE values from 1) the original Chinook Model calibrations (for years 2004-2012, the LTA was used and in 2013 the 5YA/1EV was used); 2) from calibrations based on the fishery-specific estimation model resulting in the lowest MSE; and 3) from calibrations based on the fishery-specific estimation model with the lowest MPE. The bottom three rows contain the overall mean of the percent errors (MPE), the mean of the absolute percentage errors (MAPE) and the percentage reductions in errors compared to the Original column.

	SEAK AABM			NBC AABM			WCVI AABM		
Clb Year	Original	9YA (MSE-based)	5YA (MPE-based)	Original	3YA (MSE-based)	ETS (MPE-based)	Original	ETS (MSE-based)	9YA (MPE-based)
2004	-8.7	-4.7	-10.5	-8.7	-3.7	-6.4	-8.2	-5.9	-8.0
2005	7.9	3.2	3.9	2.4	-8.2	1.8	4.8	-3.0	0.9
2006	-2.3	-2.7	-3.1	2.0	0.0	-1.1	10.3	11.4	3.6
2007	19.4	18.9	16.5	22.7	21.5	21.3	17.5	15.2	10.4
2008	5.9	3.2	4.2	3.2	3.3	-0.5	18.8	7.0	14.3
2009	10.8	6.6	6.0	2.8	3.0	0.6	18.0	11.7	11.5
2010	3.1	-0.9	0.0	-4.9	-7.8	-5.6	1.1	-2.5	1.0
2011	4.3	-0.5	1.3	-2.1	-3.8	-1.7	27.8	20.1	19.3
2012	22.5	9.2	7.4	14.7	4.4	18.6	17.0	16.5	12.6
2013 [1]	-26.3	-24.4	-26.9	-27.1	-24.8	-23.1	-25.9	-21.4	-23.0
MPE	3.7	0.8	-0.1	0.5	-1.6	0.4	8.1	4.9	4.3
MAPE	11.1	7.4	8.0	9.1	8.1	8.1	14.9	11.5	10.5
% Reduction		33.2%	28.2%		11.1%	10.9%		23.2%	30.0%

[1] Note that a 5-yr average for SEAK and BC stocks and 4-yr average for SUS stocks was used in the 2013 CLB

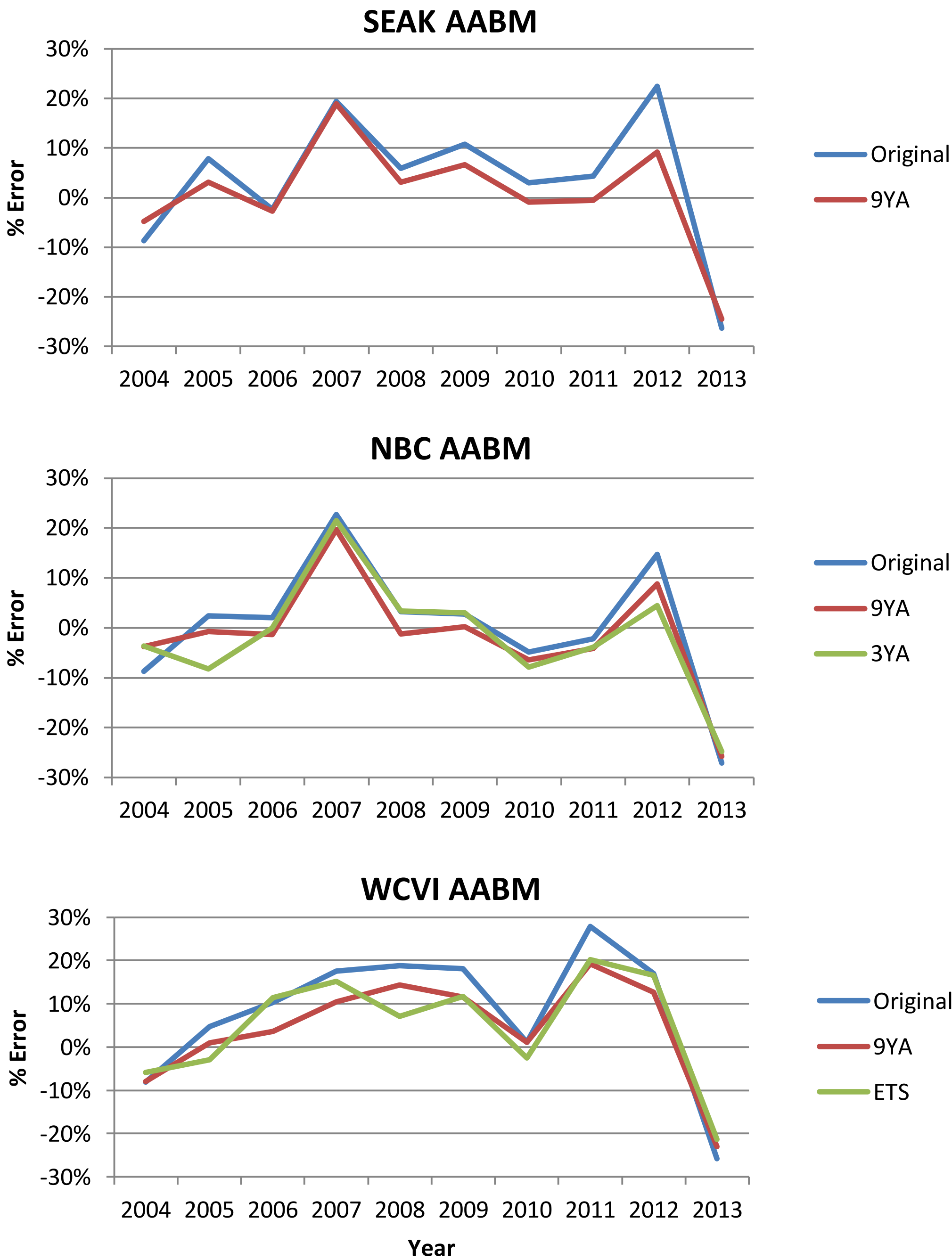

Figure 3.5. Percent error between the preseason and first postseason AI for SEAK, NBC and WCVI AABM fisheries from original 2004-2013 Model calibrations, from the calibrations performed using the 9YA MR-EV model (best overall according to composite MSE), and from best fishery-specific model (SEAK:9YA; NBC:3YA; WCVI:ETS) based on MSE. Blue line is original calibrations, red line is 9YA and green line is best fishery-specific model. Only two lines are shown for SEAK because 9YA was best overall and best fishery-specific.

3.5 DIFFERENCES BETWEEN MATURATION RATES FOR CWT INDICATOR STOCKS AND FOR STOCK AGGREGATES

For both the Salmon River Hatchery CWT indicator stock and the NOC SA, estimates by age of Cohort size (CO), pre-terminal fishery total mortality (PTF), pre-terminal fishery total mortality rate (PTFR), terminal return (TR), proportion of terminal return (TRprop), as well as MRs for the 1985, 1988, 1989, 1992, and 1999 brood-years are shown in Tables 3.7-3.11.

The CWT stock/SA ratios for TRprop and MR (Table 3.12) clearly demonstrate that the hatchery CWT stock estimates usually were dissimilar, often quite substantially, to the estimates for the naturally-produced SA, and that CWT stock fish much more often matured and returned at younger ages than did SA fish. The difference between the CWT stock and SA estimates generally decreased (i.e., the ratios became closer to 1.0) as age increased from 2 to 5, but the differences in TRprop for age 6 were similar to those for age 5. For ages 2 and 3, TRprop and MR were higher, usually substantially, for the CWT stock than for the SA, with the exception of age 2 of the 1999 BY and age 3 of the 1985 BY. The means of the ratios for TRprop and MR were 2.03 and 2.41, respectively, for age 2 and were 1.74 and 2.04 for age 3, with highest values of 3.52 for TRprop and 4.59 for MR (1988 BY). The mean of the TRprop ratios for age 4 was very near 1.0 (1.04), but the ratios were higher for 1985 (1.20), and 1988 (1.54) and much lower for 1992 (0.45). Age 4 MR ratios were generally higher with a higher mean (1.32) and were particularly high for 1988 (2.12) but particularly low for 1992 (0.69). For age 5, TRprop was lower for the CWT stock than the SA for all BYs but 1992 (1.30), with relatively substantial difference for 1989 (0.69) and, again particularly, 1988 (0.50), with mean of the ratios of 0.85. Age 5 MR ratios were little different than 1.0 for 1985 and 1988, but somewhat lower for 1989 (0.85) and higher for 1992 (1.34) and 1999 (1.42); the mean was 1.12. Age 6 TRprop was somewhat or much lower for the CWT stock for 1985 (0.80), 1988 (0.67), and particularly 1992 (0.28) and 1999 (0.26), but was substantially higher for 1989 (2.29); the mean of the ratios was 0.86. Because almost all fish mature by age 6, MR for age 6 was very similar for the CWT stock and SA for all brood-years (mean of 0.99).

Table 3.7. Salmon River Hatchery (SRH) CWT stock Coshak outputs by age 2-6, and complimentary North Oregon Coast (NOC) stock aggregate (SA) outputs derived using Coshak methods and estimated NOC Terminal Return (TR, spawning escapement plus terminal fishing mortality), 1985 brood-year. (CO = cohort number of fish, PTF=pre-terminal fishing mortality, PTFR = PTF/CO, TRprop = proportion of total returning fish, MR = maturation rates).

	SRH CWT stock						**NOC SA**					
Age	**CO**	**PTF**	**PTFR**	**TR**	**Trprop**	**MR**	**CO**	**PTF**	**PTFR**	**TR**	**TRprop**	**MR**
2	646	27	0.04	24	0.12	0.04	535,491	22,375	0.04	14,893	0.10	0.03
3	417	28	0.07	26	0.13	0.07	348,755	23,436	0.07	20,279	0.13	0.06
4	289	32	0.11	57	0.29	0.22	244,033	27,003	0.11	36,730	0.24	0.17
5	180	70	0.39	76	0.39	0.69	162,269	63,238	0.39	66,951	0.44	0.68
6	30	17	0.57	13	0.07	1.00	28,872	16,369	0.57	12,502	0.08	1.00

Table 3.8. Salmon River Hatchery (SRH) CWT stock Coshak outputs by age 2-6, and complimentary North Oregon Coast (NOC) stock aggregate (SA) outputs derived using Coshak methods and estimated NOC Terminal Return (TR, spawning escapement plus terminal fishing mortality), 1988 brood-year. (CO = cohort number of fish, PTF=pre-terminal fishing mortality, PTFR = PTF/CO, TRprop = proportion of total returning fish, MR = maturation rates).

	SRH CWT stock						NOC SA					
Age	**CO**	**PTF**	**PTFR**	**TR**	**Trprop**	**MR**	**CO**	**PTF**	**PTFR**	**TR**	**TRprop**	**MR**
2	2,089	86	0.04	91	0.14	0.05	990,514	40,770	0.04	9,401	0.04	0.01
3	1,339	120	0.09	75	0.12	0.06	658,240	59,000	0.09	26,927	0.11	0.04
4	915	201	0.22	304	0.47	0.43	457,850	100,534	0.22	71,829	0.30	0.20
5	369	177	0.48	164	0.25	0.85	256,938	123,238	0.48	119,373	0.50	0.89
6	24	7	0.29	17	0.03	0.97	12,895	3,693	0.29	9,203	0.04	1.00

Table 3.9. Salmon River Hatchery (SRH) CWT stock Coshak outputs by age 2-6, and complimentary North Oregon Coast (NOC) stock aggregate (SA) outputs derived using Coshak methods and estimated NOC Terminal Return (TR, spawning escapement plus terminal fishing mortality), 1989 brood-year. (CO = cohort number of fish, PTF=pre-terminal fishing mortality, PTFR = PTF/CO, TRprop = proportion of total returning fish, MR = maturation rates).

	SRH CWT stock						NOC SA					
Age	**CO**	**PTF**	**PTFR**	**TR**	**Trprop**	**MR**	**CO**	**PTF**	**PTFR**	**TR**	**TRprop**	**MR**
2	6,054	269	0.04	171	0.09	0.03	453,382	20,145	0.04	8,147	0.06	0.02
3	3,929	318	0.08	371	0.20	0.10	297,563	24,082	0.08	11,989	0.09	0.04
4	2,585	503	0.19	522	0.28	0.25	209,193	40,708	0.19	36,140	0.28	0.21
5	1,402	526	0.38	695	0.37	0.79	119,111	44,693	0.38	69,251	0.53	0.93
6	156	20	0.13	136	0.07	1.00	4,651	595	0.13	4,056	0.03	1.00

Table 3.10. Salmon River Hatchery (SRH) CWT stock Coshak outputs by age 2-6, and complimentary North Oregon Coast (NOC) stock aggregate (SA) outputs derived using Coshak methods and estimated NOC Terminal Return (TR, spawning escapement plus terminal fishing mortality), 1992 brood-year. (CO = cohort number of fish, PTF=pre-terminal fishing mortality, PTFR = PTF/CO, TRprop = proportion of total returning fish, MR = maturation rates).

	SRH CWT Stock						NOC SA					
Age	**CO**	**PTF**	**PTFR**	**TR**	**Trprop**	**MR**	**CO**	**PTF**	**PTFR**	**TR**	**TRprop**	**MR**
2	5,014	275	0.05	265	0.12	0.06	778,665	42,710	0.05	11,187	0.04	0.02
3	3,131	152	0.05	840	0.37	0.28	507,338	24,632	0.05	37,893	0.12	0.08
4	1,710	201	0.12	635	0.28	0.42	355,850	41,832	0.12	191,224	0.61	0.61
5	787	216	0.27	515	0.22	0.90	110,514	30,336	0.27	54,009	0.17	0.67
6	48	9	0.19	39	0.02	0.99	23,552	4,390	0.19	19,162	0.06	1.00

Table 3.11. Salmon River Hatchery (SRH) CWT stock Coshak outputs by age 2-6, and complimentary North Oregon Coast (NOC) stock aggregate (SA) outputs derived using Coshak methods and estimated NOC Terminal Return (TR, spawning escapement plus terminal fishing mortality), 1999 brood-year. (CO = cohort number of fish, PTF=pre-terminal fishing mortality, PTFR = PTF/CO, TRprop = proportion of total returning fish, MR = maturation rates).

	SRH CWT Stock						NOC SA					
Age	**CO**	**PTF**	**PTFR**	**TR**	**Trprop**	**MR**	**CO**	**PTF**	**PTFR**	**TR**	**TRprop**	**MR**
2	12,531	185	0.01	202	0.04	0.02	1,367,408	20,187	0.01	25,698	0.06	0.02
3	8,502	681	0.08	1,481	0.3	0.19	925,066	74,097	0.08	89,052	0.19	0.10
4	5,072	824	0.16	2,063	0.42	0.49	609,534	99,032	0.16	192,313	0.42	0.38
5	1,966	686	0.35	1,059	0.22	0.83	286,370	99,949	0.35	108,913	0.24	0.58
6	197	80	0.41	115	0.02	0.99	69,757	28,366	0.41	41,391	0.09	1.00

Table 3.12. SRH CWT stock/NOC SA ratios, by age, for Proportion of total Terminal Return and MRs, 1985, 1988, 1989, 1992, and 1999 brood years, with means.

	Proportion of Total Terminal Return						MR					
Age	**1985**	**1988**	**1989**	**1992**	**1999**	**Mean**	**1985**	**1988**	**1989**	**1992**	**1999**	**Mean**
2	1.24	3.52	1.44	3.24	0.73	2.03	1.34	4.59	1.57	3.68	0.86	2.41
3	0.99	1.01	2.12	3.03	1.55	1.74	1.07	1.37	2.34	3.59	1.81	2.04
4	1.20	1.54	0.99	0.45	1.00	1.04	1.31	2.12	1.17	0.69	1.29	1.32
5	0.88	0.50	0.69	1.30	0.90	0.85	1.03	0.96	0.85	1.34	1.42	1.12
6	0.80	0.67	2.29	0.28	0.26	0.86	1.00	0.97	1.00	0.99	0.99	0.99

4 DISCUSSION

4.1 RELEVANCE OF THE 9YA MODEL

This investigation showed that amongst the models used to project MRs, including the ETS models, the 9YA performed best across AABM fisheries and for different subsets of calibrations in terms of minimizing composite MSEs and maximizing percentage error reductions. The 2012 analysis identified the 5YA projections of MRs (and most recent EV) as the best, but the 9YA (and most recent EV) model was not examined in 2012. However, the biological or technical basis behind the good performance of the 9YA model at minimizing the discrepancies between preseason and first postseason AIs are unknown. At the core of this analysis is the examination of MR estimation models for incomplete broods. Two types of MR models were considered in the analysis. The average model (Section 2.2) is applied uniformly across all stock and ages, whereas the ETS model (Section 2.3) fits an exponential smoothing model to each stock and age. Both models are able to capture recent trends, but the ETS model also attempts to capture any long term trends that may be present. The ETS model is more complex in terms of the number of parameters to process. No examination of the biological or technical basis for the performance of either of the models was performed.

The analysis conducted herein did not seek to find the biological mechanism behind any of the models because such an exercise would be time intensive, outside the scope of the assignment, and due to the complexity would likely be inconclusive. There are some possible reasons why the best model, the 9YA MR and 1Y EV, outperformed all the rest. One potential biological explanation to the best MR model is that it incorporates the MR from the last two complete broods. And similarly, a technical explanation is that the 9YA MR model, across all stocks and ages, provides the optimal level of smoothing to minimize the preseason and postseason discrepancy.

4.2 AIs and Maturation Rates

MRs affect the number of fish estimated to remain available to ocean fisheries during the Chinook Model calibration process. This investigation examined the MR projection assumptions and its impact on the preseason and postseason AIs. From these comparisons, the quantification of preseason error relative to the first postseason AI is germane for PST monitoring of AABM fisheries performance. Ordinarily, the same assumptions have been employed for incomplete broods of all stocks and ages and for the one-year projection necessary for Chinook Model calibrations. These assumptions have been discussed given the detection of trends in MRs for some stocks and the different degree of variability in the time series of MRs display across stocks and ages (Appendix B). The development of models and methods to improve the ability to predict stock- and age-specific MRs is important to avoid confounding of inter-relationships between data involving multiple stock and fisheries across years. The exploration of stock- and age-specific methods (the average and ETS models) included in this report responds to this realization. However, additional investigation is important because robust projection of MRs transcends their influence on discrepancies between preseason and postseason AIs - i.e., the development of robust projections of MRs helping to cope with incomplete broods and future expectations of MR values would have a positive influence on the estimation of other relevant statistics derived from the exploitation rate analysis in addition to its relevance for AIs.

PSC Chinook Model AI forecasting involves a large number of data inputs, algorithms and assumptions, and only a systematic exploration of the interaction between these factors would help to understand and improve the forecasting abilities of the PSC Chinook Model and therefore enable the possibility of reducing even more AI discrepancies. More specifically, perfect information about MRs will not produce perfect AI forecasting or eliminate preseason-postseason discrepancies because many other factors affect the Chinook Model forecasting procedure. This observation points to the need for further investigation into other aspects of the Chinook Model that may influence its performance, including forecasts, estimates of terminal runs, delays in obtaining CWT and some escapement data, as well as base-period data and assumptions.

4.3 Data Quality

One limitation of projecting MRs is gaps in the brood-year time series of MRs of some stocks. These gaps are the consequence of no CWT releases for a given stock and year or invalid broods characterized by extremely poor marine survival and sparse CWT recoveries producing anomalous statistics in cohort analyses. The ETS methodology, as applied in this exercise, is the only one using calendar-year data directly from the MATAEQ files (see Appendix C for more detail), and therefore uses time series of MRs without gaps. However, the problem of gaps in time series of MRs affects all models used for projections. This situation arises because infilling or inputting assumptions are necessary (averages are currently used) in order to complete the time series of brood-year MRs and create the gap-free time series of calendar-year MRs necessary for the MATAEQ file. For the average models, the impact of invalid broods means less data is used to compute the recent average. Future investigations on the use time series models (including the ETS model) to estimate MRs can include their application at the brood-year level with or without infilling or inputting missing values in the time series. Without infilling, for instance, the time series algorithms used herein would be based on the longer string of subsequent brood-year MR values if the time series has gaps. Different infilling procedures could be explored in the future, including a revaluation of whether or not the data quality of MR time series warrants changes in the list of stocks currently in the MATAEQ file. Additionally, there are potential improvements to be realized with the incorporation of additional stocks into the MATAEQ file to better represent those stock groups present in contemporary fisheries.

4.4 Retrospective Comparisons with Complete-Brood Maturation Rates

The ability to produce robust projections of MRs for incomplete broods and for one-year forecasts is important for other analyses the CTC conducts annually, including statistics derived from exploitation rate analysis and the fitting procedures involved in Chinook Model calibrations. Finding models that take into consideration the unique characteristics of time series of observed MRs exhibited by each stock and age is therefore important. A straightforward way of evaluating the performance of models used to project MRs is to compare the projected values with those obtained by cohort analysis of completed broods. An example of such comparisons is shown in Appendix A and appendices E to H for a subset of models. This kind of retrospective evaluation has the potential of providing insights about the effect assumptions intrinsic in estimation models have on the magnitude of discrepancies with observed (actual) MR values. A thorough evaluation of these discrepancies could increase the reliability of selected models and improve the quality of all statistics affected by incomplete broods.

4.5 Differences between Maturation Rates for CWT Indicator Stocks and for Stock Aggregates

A complication to the MR analysis above is that the MR estimates used in the PSC Chinook Model assume that a stock aggregate (SA) and its CWT indicator stock share the same maturation and exploitation rates. This demonstration analysis shows that if the age structure of a CWT indicator stock is substantially different from that of the natural populations it is meant to represent then it is unavoidable that MRs of the CWT indicator stock will improperly represent those of its stock aggregate. If such is common for the stock aggregates in the Chinook Model, almost all of which have hatchery CWT indicator stocks, then the Chinook Model’s ability to accurately estimate pre-terminal fishery AIs, both preseason and postseason, would be compromised because the Model will fit to the inputted CWT indicator stock MRs.

Estimation of AIs would likely be improved by using stock aggregate MR inputs based on summed estimates of terminal return for the component populations of the stock aggregates. There are some stock aggregates for which data to do this for the various component populations is extremely limited or absent. For such stock aggregates, however, it may still be preferable to use the method shown here to estimate MRs for those natural populations for which data is available and to use those MR estimates as more likely representative of the MRs of the entire natural stock aggregate than the MRs for the CWT indicator stock.

The time-frame for potential implementation of the methodology demonstrated here is uncertain because the method has only very recently been developed and must be considered by the full CTC under PSC Commission guidance. It is unknown how adjustment to using naturally-produced stock aggregate MRs will influence the Chinook Model's forecasting abilities, but this seems likely to result in improvement in AI estimates. In any case, going through the exercise of calculating SA MRs will better inform the Chinook Model and its underlying assumptions as well as increase our understanding of the processes driving changes to AIs.

5 SUMMARY

Recent discrepancies between the preseason and postseason AI prompted the PSC Commissioners to task the CTC-AWG to update the previous MR-EV analysis. The previous MR and EV investigation conducted by the CTC in 2012 on a limited number of MR-EV models found that the MR-EV model that minimized the MSE was a 5YA MR and a 1Y EV (TCChinook 14-1 V1). In updating the analysis, the AWG confirmed that use of various other models resulted in smaller discrepancies between the preseason and postseason AIs generated by the Chinook Model, across calibrations, compared to the LTA and 5YA MRs. According to the composite MSE metric, the MR-EV model that minimized the preseason to postseason AI discrepancy across the three AABM fisheries was the 9YA MR and 1Y EV (Table 5.1; see Appendix I for details). Though a different estimation model produced the smallest discrepancy between the preseason and first post-season AI for each AABM fishery across Model calibrations 2004-2014 based on the fishery-specific MSE.

The CTC recommends that the 9YA MR and 1Y EV is used for the annual Chinook Model calibration. Given this departure from the MR average used in previous Chinook Model calibrations, it may be advisable to periodically reassess whether the 9YA MRs continue to provide the best overall approach to minimizing the discrepancy between the preseason and postseason AIs generated by the Chinook Model across calibrations.

The investigation of the ETS method did demonstrate that it was possible and feasible to employ a time series modelling approach. While the 9YA emerged as the overall recommended approach to estimate age-specific MRs for stocks in the Chinook Model's MATAEQ input file, the ETS method also showed promise. This method, in fact, generated the best overall results in terms of precision (MSE) for WCVI (Table 5.1) and in terms of accuracy (MPE) for NBC (Table 3.3). Future investigation of time series approaches for the projection of MRS can include applications of the ETS model to brood year-based MRs and the exploration of ARIMA models. One challenge that was encountered was the need to infill gaps in the MR time series which can occur due to missing or invalid broods; these are brood years that were tagged, but had such low survivals that CWT recoveries were either absent or produced nonsensical MRs, and the LTA was used. The infilling can be achieved but the best approach to do so could not be determined in the time frame of this investigation.

Stock aggregate MRs are different than CWT indicator stock MRs. Results using data from the North Oregon Coast show that there is a large discrepancy between naturally-produced stock aggregate MRs and hatchery CWT indicator stock MRs, which could result in errors in both preseason and postseason AIs because the model will fit to the inputted CWT indicator stock MRs. The results also indicate that CWT MRs may be biased high for any age given the earlier maturation of the hatchery stock versus the natural stock. Given that nearly all driver stocks use a hatchery indicator (e.g., Fraser Lates), this approach to adjust the maturation rates for the natural stocks has potential to improve abundance predictions.

As noted above, other factors and inputs undoubtedly contribute to errors in forecasting AIs. These include, but are not limited to, preseason forecasts, delays in obtaining CWT data and some terminal run and catch data, escapement estimation, etc. A future examination of forecasting relative abundance should examine issues like these with the same rigor applied in this investigation.

Table 5.1. Mean squared error between the preseason and first postseason AI assuming a 1-year EV. The scenario that minimized the MSE is highlighted in darker shading and the second best scenario is lighter shading.

Model	SEAK	NBC	WCVI	Composite
3YA	0.0289	0.0233	0.0161	0.0683
5YA	0.0309	0.0238	0.0157	0.0704
7YA	0.0300	0.0246	0.0132	0.0678
8YA	0.0299	0.0248	0.0134	0.0681
9YA	0.0268	0.0234	0.0125	0.0627
10YA	0.0320	0.0252	0.0125	0.0696
11YA	0.0357	0.0277	0.0131	0.0765
LTA	0.0374	0.0283	0.0180	0.0836
ETS	0.0333	0.0239	0.0122	0.0695

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APPENDICES

Appendix A. Estimated and Observed MRs at Three Ages from Completed Broods for Each of the 12 Model Stocks in the MATAEQ Input File for the 2004-2014 Chinook Model Calibrations.

The estimated values were constructed using three models: 1) an average of the three most recently completed and valid broods (3YA); 2) an average of the nine most recently completed and valid broods (9YA), and 3) a projection using a time series exponential smoothing model (ETS). Estimates from the 3YA, 9YA and ETS models were included because each produced the lowest fishery-specific MSE for one of the AABM fisheries. For the average models, invalid broods were not replaced with other values in the computation of averages (see Section 2.2). The first, second and third age is 3, 4 and 5 respectively for the two spring stocks (AKS and WSH). The first, second and third age is 2, 3 and 4 respectively for the other (fall) stocks. All observed values are from the cohort analysis procedure completed by the CTC-AWG in March 2015 for CWT indicator stocks associated to the Chinook Model stocks in the MATAEQ file. The most recent year with CWT recovery data in this analysis was 2014 for Chinook Model stocks AKS, GSH, RBH and RBT and 2013 for all others. An observed MR is given for only those stock-brood-age combinations where the brood was complete in the 2015 cohort analysis results.

Table A.1. The name of the Chinook Model stocks in the MATAEQ file and the associated CWT indicator stock is provided at the end of this appendix.

			First Age				Second Age				Third Age			
CLB YR	Stock	Stock #	3YA	9YA	ETS	Observed	3YA	9YA	ETS	Observed	3YA	9YA	ETS	Observed
2004	AKS	1	0.0187	0.0151	0.0193	0.0078	0.1448	0.0892	0.1049	0.3152	0.6862	0.5747	0.6129	0.7049
	BON	2	0.0236	0.0392	0.0263	0.0215	0.4988	0.5320	0.5972	0.2230	0.9792	0.9833	0.9561	0.8869
	CWF	3	0.0153	0.0359	0.0075	0.0135	0.2705	0.2635	0.2278	0.1414	0.7773	0.7887	0.7560	0.4718
	GSH	4	0.0374	0.0505	0.0420	0.1171	0.2578	0.3473	0.2838	0.2595	0.7305	0.8065	0.7677	0.8000
	LRW	5	0.0472	0.0895	0.0680	0.0412	0.1092	0.1027	0.1115	0.1230	0.6600	0.3505	0.4187	0.6034
	ORC	6	0.0461	0.0414	0.0678	0.0241	0.1516	0.1407	0.1155	0.1243	0.5058	0.4405	0.4443	0.4064
	RBH	7	0.0189	0.0188	0.0192	0.0127	0.1574	0.1619	0.1573	0.3015	0.7028	0.6662	0.6318	0.7170
	RBT	8	0.0189	0.0188	0.0192	0.0127	0.1574	0.1619	0.1573	0.3015	0.7028	0.6662	0.6318	0.7170
	SPR	9	0.0710	0.0586	0.0746	0.1059	0.6282	0.6716	0.6491	0.5962	0.9771	0.9851	0.9686	0.9680
	URB	10	0.0225	0.0270	0.0294	0.0369	0.1731	0.1661	0.1641	0.2160	0.7197	0.5992	0.5926	0.4709
	WSH	11	0.0036	0.0134	0.0114	0.0241	0.3955	0.4454	0.4464	0.6229	0.9763	0.9725	0.9677	0.9730
	FRL	12	0.0792	0.0767	0.0779	0.1100	0.2554	0.2591	0.2106	0.3191	0.8907	0.9056	0.8417	0.7992

2005	AKS	1	0.0162	0.0142	0.0099	0.0107	0.1621	0.0956	0.1056	0.1853	0.7454	0.5992	0.6206	0.7472
	BON	2	0.0148	0.0220	0.0202	0.0306	0.4955	0.5214	0.6034	0.6032	0.9749	0.9832	0.9578	0.9657
	CWF	3	0.0124	0.0336	0.0048	0.0340	0.3078	0.2916	0.3062	0.2377	0.7035	0.7884	0.7414	0.8211
	GSH	4	0.0405	0.0508	0.0418	0.0494	0.3140	0.3501	0.3109	0.3928	0.7858	0.8039	0.8240	0.7110
	LRW	5	0.0180	0.0503	0.0539	0.0544	0.0237	0.0881	0.1066	0.0297	0.4153	0.3699	0.4176	0.2050
	ORC	6	0.0442	0.0397	0.0401	0.0524	0.1521	0.1449	0.1171	0.1459	0.5920	0.4984	0.4873	0.5520
	RBH	7	0.0236	0.0165	0.0120	0.0058	0.2182	0.1825	0.1622	0.1146	0.7148	0.6800	0.6348	0.7402
	RBT	8	0.0236	0.0165	0.0120	0.0058	0.2182	0.1825	0.1622	0.1146	0.7148	0.6800	0.6348	0.7402
	SPR	9	0.0829	0.0619	0.0721	0.0833	0.6572	0.6851	0.6522	0.7911	0.9845	0.9858	0.9697	0.9612
	URB	10	0.0206	0.0235	0.0254	0.0296	0.2013	0.1757	0.1675	0.2050	0.7030	0.6172	0.5900	0.5451
	WSH	11	0.0048	0.0121	0.0112	0.0425	0.4768	0.4309	0.4554	0.4948	0.9828	0.9777	0.9688	0.9684
	FRL	12	0.1088	0.0851	0.0801	0.1583	0.2746	0.2296	0.3627	0.2857	0.8644	0.8858	0.8639	0.9461
2006	AKS	1	0.0140	0.0143	0.0154	0.0212	0.1502	0.1036	0.1084	0.1795	0.7367	0.6279	0.6235	0.7627
	BON	2	0.0164	0.0214	0.0166	0.0427	0.4678	0.4942	0.5052	0.4867	0.9790	0.9843	0.9318	0.7649
	CWF	3	0.0282	0.0360	0.0099	0.1535	0.2174	0.2577	0.2211	0.3674	0.7125	0.7847	0.7386	0.7576
	GSH	4	0.0415	0.0540	0.0430	0.0102	0.2902	0.3488	0.3042	0.3937	0.8056	0.7949	0.7703	0.9606
	LRW	5	0.0104	0.0327	0.0429	0.0132	0.0179	0.0801	0.1016	0.0668	0.2304	0.3257	0.3192	0.4535
	ORC	6	0.0371	0.0392	0.0499	0.0027	0.1437	0.1567	0.1387	0.1481	0.5248	0.5081	0.4696	0.4271
	RBH	7	0.0123	0.0171	0.0091	0.0170	0.1639	0.1748	0.1586	0.2159	0.5287	0.6512	0.6232	0.7640
	RBT	8	0.0123	0.0171	0.0091	0.0170	0.1639	0.1748	0.1586	0.2159	0.5287	0.6512	0.6232	0.7640
	SPR	9	0.0364	0.0585	0.0759	0.0912	0.5338	0.6688	0.6450	0.6985	0.9794	0.9865	0.9697	1.0000
	URB	10	0.0148	0.0241	0.0254	0.0800	0.1496	0.1829	0.1669	0.2723	0.6358	0.6266	0.5900	0.8041
	WSH	11	0.0069	0.0105	0.0111	0.0117	0.5000	0.4634	0.4592	0.6696	0.9881	0.9785	0.9691	0.9436
	FRL	12	0.0652	0.0590	0.0593	0.4047	0.1821	0.2227	0.1433	0.4917	0.8707	0.8837	0.8080	0.9603
2007	AKS	1	0.0161	0.0148	0.0166	0.0282	0.1453	0.1178	0.1159	0.2133	0.7293	0.6446	0.6352	0.7134
	BON	2	0.0143	0.0182	0.0157	0.0533	0.4242	0.4540	0.4495	0.8686	0.9512	0.9624	0.9556	1.0000
	CWF	3	0.0243	0.0181	0.0270	0.0632	0.2519	0.2633	0.2839	0.5152	0.7012	0.7571	0.7486	0.9183
	GSH	4	0.0435	0.0485	0.0428	0.1260	0.3303	0.3362	0.3036	0.5315	0.8016	0.7850	0.7771	0.7950
	LRW	5	0.0138	0.0285	0.0389	0.0000	0.0208	0.0745	0.0609	0.0554	0.3755	0.3754	0.4780	0.2653
	ORC	6	0.0348	0.0375	0.0351	0.0147	0.1568	0.1650	0.1468	0.0548	0.4762	0.5151	0.4628	0.6102
	RBH	7	0.0115	0.0130	0.0096	0.0242	0.1764	0.1819	0.1592	0.1374	0.6404	0.6720	0.6326	0.6653
	RBT	8	0.0115	0.0130	0.0096	0.0242	0.1764	0.1819	0.1592	0.1374	0.6404	0.6720	0.6326	0.6653
	SPR	9	0.0417	0.0585	0.0473	0.1511	0.5937	0.6552	0.6412	0.9712	0.9770	0.9826	0.9692	1.0000

	URB	10	0.0161	0.0225	0.0243	0.0708	0.1605	0.1883	0.1638	0.1921	0.5521	0.6407	0.5869	0.7480
	WSH	11	0.0117	0.0107	0.0114	0.0113	0.5287	0.4740	0.4574	0.5869	0.9819	0.9804	0.9692	0.9712
	FRL	12	0.0804	0.0608	0.0608	0.1355	0.1601	0.2174	0.1976	0.4360	0.8290	0.8691	0.8666	0.9492
2008	AKS	1	0.0177	0.0155	0.0198	0.0118	0.1887	0.1226	0.1574	0.2442	0.6344	0.6600	0.6307	0.8238
	BON	2	0.0094	0.0158	0.0158	0.0303	0.3011	0.4106	0.4001	0.5878	0.9439	0.9636	0.9562	1.0000
	CWF	3	0.0187	0.0174	0.0078	0.0831	0.1836	0.2577	0.2016	0.2840	0.7006	0.7523	0.7503	1.0000
	GSH	4	0.0366	0.0448	0.0416	0.0551	0.2957	0.3290	0.2946	0.3908	0.7543	0.7788	0.7548	0.9497
	LRW	5	0.0101	0.0283	0.0339	0.0217	0.0532	0.0742	0.0803	0.0382	0.3283	0.3669	0.3498	0.6246
	ORC	6	0.0120	0.0268	0.0030	0.0126	0.1402	0.1445	0.1358	0.1665	0.4709	0.5244	0.4715	0.4545
	RBH	7	0.0123	0.0133	0.0093	0.0316	0.1994	0.1981	0.1654	0.3185	0.6382	0.6827	0.6377	0.6602
	RBT	8	0.0123	0.0133	0.0093	0.0316	0.1994	0.1981	0.1654	0.3185	0.6382	0.6827	0.6377	0.6602
	SPR	9	0.0499	0.0573	0.0480	0.0187	0.5219	0.6251	0.6395	0.7372	0.9637	0.9777	0.9688	1.0000
	URB	10	0.0188	0.0208	0.0228	0.1131	0.1517	0.1858	0.1660	0.2882	0.5300	0.6227	0.5855	0.7410
	WSH	11	0.0153	0.0090	0.0125	0.0206	0.5300	0.4681	0.4737	0.6190	0.9740	0.9788	0.9704	1.0000
	FRL	12	0.0654	0.0613	0.0606	0.1021	0.1623	0.2185	0.3627	0.4279	0.8677	0.8748	0.9427	0.8981
2009	AKS	1	0.0163	0.0154	0.0393	0.0441	0.2060	0.1447	0.1669	0.3028	0.7268	0.6730	0.6936	0.8232
	BON	2	0.0089	0.0163	0.0136	0.0192	0.3572	0.4398	0.4654	0.7700	0.8661	0.9336	0.9488	0.9600
	CWF	3	0.0101	0.0168	0.0114	0.0326	0.2280	0.2397	0.2253	0.3676	0.7137	0.7476	0.7516	0.9076
	GSH	4	0.0624	0.0474	0.0622	0.0833	0.3182	0.3134	0.3106	0.3995	0.8320	0.7855	0.8202	0.9322
	LRW	5	0.0224	0.0239	0.0416	0.0000	0.0581	0.0761	0.0696	0.0478	0.4470	0.3517	0.3530	0.3440
	ORC	6	0.0262	0.0268	0.0359	0.0144	0.1141	0.1434	0.1308	0.1060	0.4436	0.5209	0.4491	0.5606
	RBH	7	0.0123	0.0125	0.0114	0.0103	0.2076	0.1773	0.1640	0.1327	0.7488	0.6872	0.6423	0.8615
	RBT	8	0.0123	0.0125	0.0114	0.0103	0.2076	0.1773	0.1640	0.1327	0.7488	0.6872	0.6423	0.8615
	SPR	9	0.0671	0.0633	0.0783	0.2126	0.6339	0.6330	0.6435	0.8142	0.9641	0.9751	0.9669	0.9874
	URB	10	0.0265	0.0222	0.0296	0.0429	0.1884	0.1866	0.1693	0.1485	0.6112	0.6331	0.5926	0.7705
	WSH	11	0.0193	0.0105	0.0140	0.0479	0.5141	0.4772	0.4733	0.6193	0.9615	0.9766	0.9686	0.9938
	FRL	12	0.0684	0.0603	0.0618	0.1390	0.2156	0.2159	0.2313	0.1799	0.9041	0.8852	0.9466	0.8408
2010	AKS	1	0.0119	0.0167	0.0099	0.0100	0.2181	0.1598	0.1698	0.2345	0.7356	0.6885	0.6994	0.8464
	BON	2	0.0176	0.0176	0.0201	0.0787	0.4389	0.4449	0.4659	0.7692	0.9021	0.9406	0.9509	1.0000
	CWF	3	0.0160	0.0189	0.0148	0.0469	0.2505	0.2551	0.2529	0.1576	0.8338	0.7640	0.7563	0.7000
	GSH	4	0.0612	0.0497	0.0636	0.0471	0.3451	0.3170	0.3272	0.4588	0.8288	0.7903	0.7916	0.8820
	LRW	5	0.0342	0.0237	0.0427	0.0191	0.0767	0.0484	0.0717	0.0328	0.3245	0.3396	0.3455	0.4559
	ORC	6	0.0252	0.0257	0.0628	0.0341	0.1215	0.1506	0.1289	0.2841	0.4399	0.5051	0.4306	0.6027

	RBH	7	0.0134	0.0141	0.0110	0.0294	0.2141	0.1873	0.1667	0.1706	0.7322	0.6883	0.6437	0.7480
	RBT	8	0.0134	0.0141	0.0110	0.0294	0.2141	0.1873	0.1667	0.1706	0.7322	0.6883	0.6437	0.7480
	SPR	9	0.0822	0.0650	0.0815	0.0898	0.6955	0.6310	0.6451	0.9138	0.9871	0.9792	0.9693	1.0000
	URB	10	0.0239	0.0212	0.0267	0.0973	0.2356	0.1907	0.1721	0.2741	0.6960	0.6506	0.5993	0.5599
	WSH	11	0.0263	0.0120	0.0152	0.0539	0.6007	0.4921	0.4785	0.7821	0.9606	0.9731	0.9683	0.9844
	FRL	12	0.0980	0.0738	0.0655	0.1097	0.2513	0.2225	0.2820	0.4333	0.9554	0.8905	0.9254	0.9493
2011	AKS	1	0.0130	0.0173	0.0260	0.0210	0.1860	0.1742	0.1563	0.3668	0.7651	0.7195	0.7004	0.9038
	BON	2	0.0314	0.0194	0.0208	--	0.6475	0.4786	0.4749	0.7617	0.9158	0.9406	0.9557	1.0000
	CWF	3	0.0647	0.0188	0.0314	--	0.3746	0.2553	0.3174	0.4520	0.8921	0.7674	0.7675	0.9197
	GSH	4	0.0591	0.0483	0.0439	0.0984	0.4348	0.3506	0.4022	0.4587	0.8999	0.8126	0.8731	1.0000
	LRW	5	0.0309	0.0213	0.0403	--	0.0448	0.0450	0.0756	0.0218	0.4607	0.3218	0.5010	0.3543
	ORC	6	0.0317	0.0257	0.1417	--	0.1083	0.1425	0.1320	0.3564	0.5650	0.5535	0.5021	0.6595
	RBH	7	0.0097	0.0144	0.0275	0.0089	0.1611	0.1892	0.1658	0.1859	0.6940	0.6845	0.6442	0.6453
	RBT	8	0.0097	0.0144	0.0275	0.0089	0.1611	0.1892	0.1658	0.1859	0.6940	0.6845	0.6442	0.6453
	SPR	9	0.0880	0.0711	0.0532	--	0.8199	0.6684	0.6491	0.7927	1.0000	0.9821	0.9694	1.0000
	URB	10	0.0452	0.0282	0.0362	--	0.2261	0.1958	0.1685	0.4015	0.7613	0.6680	0.6009	0.7889
	WSH	11	0.0240	0.0153	0.0143	--	0.5850	0.5231	0.4825	0.6786	0.9715	0.9724	0.9685	0.9949
	FRL	12	0.2257	0.1160	0.1309	0.0974	0.2830	0.2418	0.2037	0.4510	0.9347	0.8908	0.8821	0.9579
2012	AKS	1	0.0194	0.0180	0.0171	--	0.2051	0.1870	0.1821	0.1352	0.7862	0.7418	0.7380	0.8215
	BON	2	0.0447	0.0244	0.0243	--	0.6451	0.4926	0.4892	--	0.9845	0.9420	0.9547	1.0000
	CWF	3	0.0827	0.0426	0.0353	--	0.3910	0.2874	0.3337	--	0.9422	0.8086	0.8446	0.8669
	GSH	4	0.0618	0.0551	0.0704	--	0.4387	0.3506	0.3654	0.3814	0.8938	0.8440	0.8637	0.8542
	LRW	5	0.0227	0.0225	0.0320	--	0.0546	0.0483	0.0628	--	0.4258	0.3746	0.3594	0.3187
	ORC	6	0.0252	0.0203	0.0223	--	0.0933	0.1280	0.1167	--	0.6116	0.5346	0.5123	0.6990
	RBH	7	0.0134	0.0132	0.0116	--	0.2207	0.2031	0.1676	0.1743	0.7280	0.6996	0.6512	0.7453
	RBT	8	0.0134	0.0132	0.0116	--	0.2207	0.2031	0.1676	0.1743	0.7280	0.6996	0.6512	0.7453
	SPR	9	0.1084	0.0717	0.0970	--	0.8017	0.6557	0.6586	--	0.9959	0.9844	0.9709	1.0000
	URB	10	0.0606	0.0340	0.0515	--	0.2496	0.1961	0.1757	--	0.7496	0.6680	0.6094	0.8392
	WSH	11	0.0215	0.0154	0.0146	--	0.6265	0.5255	0.5502	--	0.9904	0.9755	0.9708	0.9821
	FRL	12	0.2343	0.1236	0.1466	--	0.4123	0.2962	0.3362	0.2565	0.8956	0.8880	0.8852	0.9670
2013	AKS	1	0.0195	0.0184	0.0279	--	0.2043	0.1893	0.2284	--	0.7864	0.7517	0.8001	0.8448
	BON	2	0.0429	0.0254	0.0242	--	0.7436	0.5348	0.7130	--	0.9855	0.9498	0.9585	--
	CWF	3	0.0991	0.0472	0.0380	--	0.3890	0.2958	0.3467	--	0.8742	0.7986	0.8495	--

	GSH	4	0.0889	0.0620	0.0759	--	0.4109	0.3798	0.4322	--	0.9444	0.8632	0.9156	1.0000
	LRW	5	0.0116	0.0199	0.0152	--	0.0471	0.0471	0.0408	--	0.4748	0.3805	0.4356	--
	ORC	6	0.0214	0.0193	0.0127	--	0.1063	0.1191	0.1213	--	0.5255	0.5303	0.5636	--
	RBH	7	0.0217	0.0150	0.0125	--	0.2084	0.1888	0.1681	--	0.7357	0.6885	0.6545	0.7940
	RBT	8	0.0217	0.0150	0.0125	--	0.2084	0.1888	0.1681	--	0.7357	0.6885	0.6545	0.7940
	SPR	9	0.0869	0.0710	0.1131	--	0.8401	0.7078	0.6769	--	0.9959	0.9864	0.9733	--
	URB	10	0.0877	0.0438	0.0671	--	0.2128	0.2018	0.1789	--	0.7126	0.6442	0.6139	--
	WSH	11	0.0215	0.0163	0.0295	--	0.6299	0.5446	0.7575	--	0.9892	0.9795	0.9726	--
	FRL	12	0.1252	0.1360	0.1645	--	0.3478	0.3052	0.3789	--	0.9186	0.9070	0.9232	0.9378
2014	AKS	1	0.0282	0.0220	0.0343	--	0.2620	0.2245	0.2878	--	0.8597	0.7811	0.8345	--
	BON	2	0.0342	0.0253	0.0426	--	0.7087	0.5576	0.7537	--	0.9867	0.9520	0.9628	--
	CWF	3	0.0609	0.0494	0.0387	--	0.2704	0.2760	0.3600	--	0.8490	0.8133	0.8758	--
	GSH	4	0.0618	0.0638	0.0789	--	0.4391	0.3993	0.4563	--	0.9128	0.8775	0.9003	--
	LRW	5	0.0116	0.0198	0.0149	--	0.0471	0.0470	0.0402	--	0.4748	0.3799	0.4173	--
	ORC	6	0.0138	0.0174	0.0198	--	0.1831	0.1450	0.2050	--	0.6064	0.5242	0.5612	--
	RBH	7	0.0214	0.0155	0.0216	--	0.1490	0.1821	0.1546	--	0.6914	0.7078	0.6399	--
	RBT	8	0.0214	0.0155	0.0216	--	0.1490	0.1821	0.1546	--	0.6914	0.7078	0.6399	--
	SPR	9	0.1274	0.0886	0.1199	--	0.8217	0.7190	0.7306	--	0.9958	0.9869	0.9746	--
	URB	10	0.0756	0.0483	0.0776	--	0.2401	0.2099	0.2461	--	0.7251	0.6725	0.6884	--
	WSH	11	0.0147	0.0183	0.0347	--	0.6086	0.5734	0.6650	--	0.9927	0.9787	0.9835	--
	FRL	12	0.1165	0.1430	0.1511	--	0.3542	0.3509	0.4945	--	0.9579	0.9163	0.9274	--

Table A.2 The following table provides the name for each Chinook Model stock in the MATAEQ files and the associated CWT indicator stock:

Sequence in MATAEQ file	Model Stock Acronym	Model Stock Name	CWT Indicator Acronym
1	AKS	Alaska Spring	AKS
2	BON	Lower Bonneville Hatchery	LRH
3	CWF	Cowlitz Fall Hatchery	CWF
4	GSH	Lower Georgia Strait Hatchery	BQR
5	LRW	Lewis River Wild	LRW
6	ORC	Oregon Coastal	SRH
7	RBH	WCVI Hatchery	RBT
8	RBT	WCVI Wild	RBT
9	SPR	Spring Creek Hatchery	SPR
10	URB	Columbia River Upriver Bright	URB
11	WSH	Willamette Spring Hatchery	WSH
12	FRL	Fraser Late	CHI*

* Note: The MRs for the Fraser Late aggregate stock, consisting of the Harrison River natural stock and the Chilliwack River Hatchery stock, are calculated external to the MATAEQ program using a method that relies on the observed MRs for CHI CWT indicator stock.

Appendix B. Graphical Presentation of the Time Series of Brood-Specific MRs at Age, the Stock-Specific Cohort-Based Survival Rate for the Youngest Mature Age and the Mean Age of Maturation for the Suite of Individual and Composite Chinook CWT Indicators.

Data used to generate all figures presented in this appendix originated from or were based on results of the annual CWT-based exploitation rate analysis (ERA) carried out by the CTC-AWG in March 2015.

Two side-by-side panels are presented for each CWT indicator stock. The three-letter acronym used for each CWT indicator appears at the top of each panel. The stock name for each indicator and other information such as geographical location is given in a table which follows after the series of graphs. Each panel displays the following time series by brood:

Left panel: This panel shows the rate of maturation on a scale from 0 to 1 for each age with recovery data. The commonly used acronym for the CWT indicator appears above the panel as well as the oldest age with recovery data used in the cohort analysis procedure for the stock. The range and number of ages of maturing fish varies among stocks but the youngest age included in the cohort analysis procedure is 2 and the oldest is 6. The range of ages is typically 3 – 6 for spring stocks and is either 2 - 5 or 2 - 6 for summer and fall stocks. The same line color indicates the same numerical age for every stock (red = 2, blue = 3, green = 4, purple = 5 and grey = 6). The time series for each stock includes all broods for which the analysis was completed. A gap in the time series at all ages in a brood indicates that no CWTs were released. A gap in the time series for the oldest age only indicates that the no CWTs were observed at the oldest age and thus the brood was complete (MR = 1) at the next-to-oldest age. Age-specific estimates for incomplete broods are shown as colored dots. The estimates for incomplete broods were calculated by assuming a MR equal to the average of the five most recently completed broods for the oldest available age of mature fish. All MR values were extracted from the calendar year (‘CYR’) version of the brood-specific ‘OUT’ files which are generated as a standard output by the cohort analysis program.

Right panel: Two time series are displayed in the right panel. One time series is the mean age of maturation (indicated by the line in a lighter blue color) and it is associated with the left-hand Y-axis scale ranging from 2 – 6 years. The second is the cohort-based survival rate for tagged smolts to the first age vulnerable in fisheries (indicated by the line in a darker blue color) and it is associated with the right-hand Y-axis scale. The youngest age is 2 for summer and fall stocks and age 3 for most spring stocks, though 2 in a few cases. This survival rate, expressed as a percentage out of 100, is a statistic automatically produced by the cohort analysis procedure used by the CTC-AWG in the analysis of CWT recoveries and it was extracted from the stock-specific ‘SVRC.csv’ output file.

The mean age of maturation, equivalent to generation time in semelparous species (Wootton and Smith 2015), is a brood-specific composite value in years which incorporates the rate of maturation across all ages included in the cohort analysis. It can be calculated using the following two approaches:

1) Mean Age of Maturation (with fishing effects) = $\frac{(\prod_{a=min}^{a=max}(a * Esc_{BY,a}))}{TotEsc_{BY}}$

Where a = age, with possible values ranging from 2 - 6 depending on the stock, $Esc_{BY,a}$ = estimated CWT escapement at age for a brood year, and $TotEsc_{BY}$ = total escapement for the brood. Values will lie between the observed minimum and maximum ages with mature fish for a given stock.

This formulation uses the estimated CWT escapement as determined from the CWT sampling programs and population estimation method employed for each CWT indicator stock. It also reflects size- (and therefore, age-) selective effects of pre-terminal and terminal fisheries which influence the population 'escaping' to spawning locations. These effects are likely to have stock, age and calendar year dependencies due to the particular set of fisheries impacting a stock and the magnitude and regulations characterizing each fishery in a given year. A second formulation of the mean age of maturation metric was developed to remove the potential influence of fishing effects on the mean age of maturation. It was used in the figures presented in this appendix.

2) Mean Age of Maturation (fishing effects removed) = $\frac{(\prod_{a=min}^{a=max}(a * EscNF_{BY,a}))}{TotEscNF_{BY}}$

Where a = age with possible values from 2 - 6 depending on the stock. The total brood escapement with fishing effect removed, $TotEscNF_{BY}$, is obtained in an analogous fashion to the total of the conventional estimated CWT escapement for a brood:

$$TotEscNF_{BY} = \left(\sum_{a=min}^{a=max} EscNF_{BY,a}\right)$$

The escapement at age with fishing effects removed, starting with the youngest and proceeding to the oldest in sequence,$EscNF_a$, is obtained with the following set of equations:

1) $EscNF_{a1} = (CohANM_{a1} * MR_{a1})$

2) $EscNF_{a2} = \big((CohANM_{a1} * MR_{a1}) * SR_{a2}\big) * MR_{a2}$

3) $EscNF_{a3} = \big(((CohANM_{a1} * MR_{a1}) * SR_{a2}\big) - EscNF_{a2}) * SR_{a3}) * MR_{a3}$

4) $EscNF_{a4} = (((((CohANM_{a1} * MR_{a1}) * SR_{a2}) - EscNF_{a2}) * SR_{a3}) - EscNF_{a3}) * SR_4) * MR_{a4}$

5) $EscNF_{a5} = (((((((CohANM_{a1} * MR_{a1}) * SR_{a2}) - EscNF_{a2}) * SR_{a3}) - EscNF_{a3}) * SR_4) - EscNF_4) * SR_5) * MR_{a5}$

Terms in the above equations are brood-specific. Values are obtained from the cohort analysis procedure used by the CTC-AWG to conduct the annual ERA, and they are defined as follows:

$CohANM_{a1}$ = cohort size, after over-wintering natural mortality has occurred, for the youngest age of maturing fish for a stock (and brood)

$MR_{a1}$to MR_{a5} = MR at age, from the youngest to oldest age, for a stock (and brood)

SR_{a2} to SR_{a5} = survival rate at age, from the second youngest to oldest age

The age subscript (*a*) of 1 - 5 refers to the five (though typically four) possible ages of maturation starting with the youngest (*a1*) to the oldest (*a4* or *a5*, depending on the stock). For fall and summer stocks the span of actual ages is 2 – 5 (*a1 - a4*), though there are a few cases of 2 – 6 (*a1 - a5*). For these stocks the second actual age is 3. For spring stocks, the span of actual ages is 3 - 6 and for this adult life history pattern, the second actual age is 4.

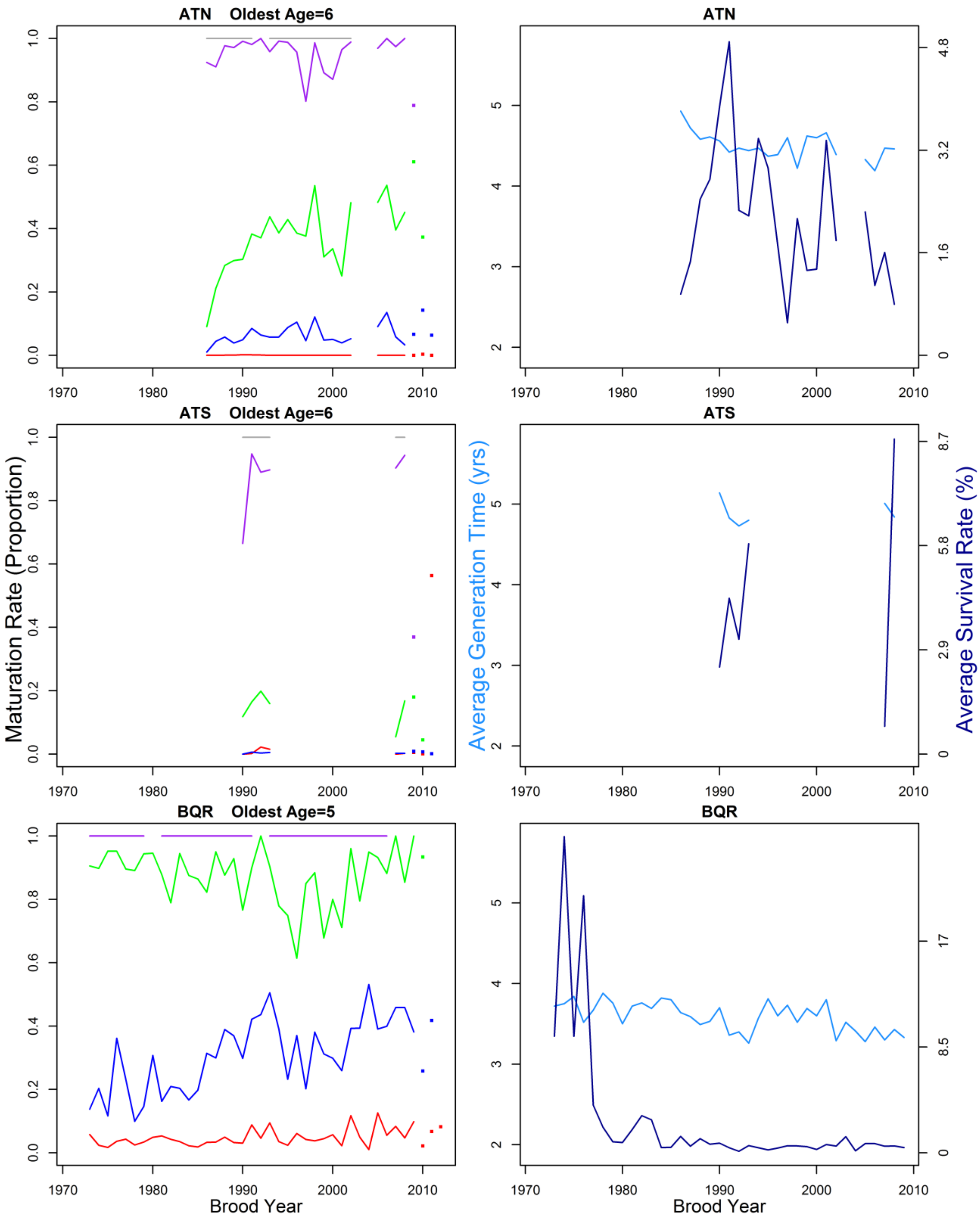
The survival rates (*SR*) are age-specific constants employed by the CTC in the cohort analysis procedure and expressed as proportions. They are 0.7, 0.8 and 0.9 for the second through fourth ages of maturation. For stocks with an additional fifth age, 0.9 is also used.

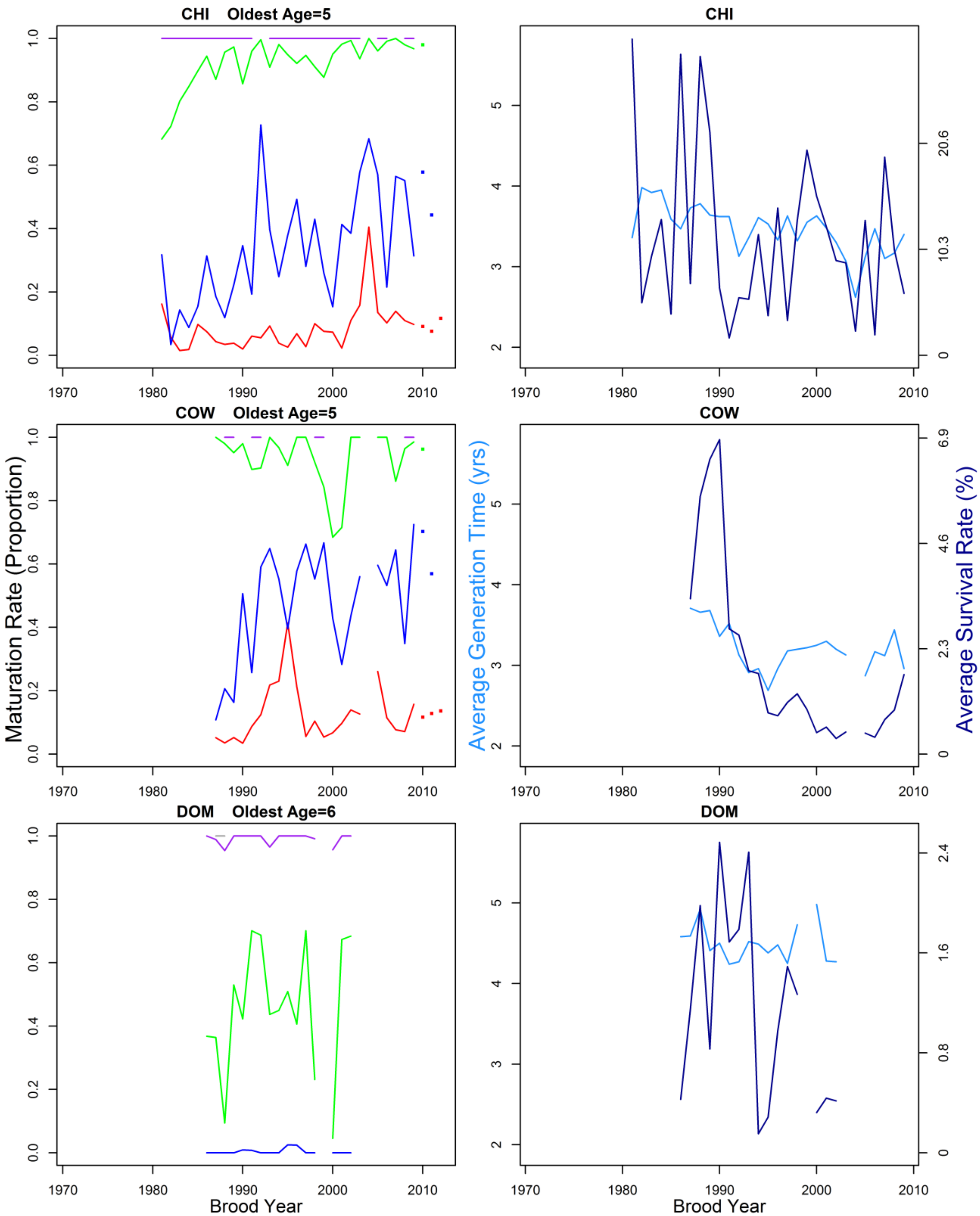
The mean age of MR metric is an integration of the age-specific MRs which can change in opposite direction from one brood to the next. The overall effect of these changes at age within a brood can be difficult to determine and the mean age of maturation metric captures the overall effect in a single value. It's useful for revealing trends in the maturation pattern across successive broods. A pattern of an increase in the MRs at age across broods (i.e., an increaing proportion of fish are maturing at younger ages) will tend to correpond with a declining trend in the mean age of maturation, and vice versa.

Trends exist in the age-specific MRs for a number of the CWT indicator stocks (e.g., QUI, GAD, LYY and SPS), including some of the CWT indicators which contribute MR data for Model stocks in the calibration of the Chinook Model (e.g., AKS, BQR, SPR and WSH). The most common pattern is a trend toward increaing rate of maturation and an overall effect of earlier maturation schedule is supported by a corresponding declining trend in the mean age of maturation. As an indication of a directional tendency, the slope of a line of simple linear regression was obtained from the complete data set for each CWT indicator associated to a Chinook Model stock with the following results:

CWT Indicator	Model Stock	Slope from Linear Regression
BQR	GSH	-0.0099
RBT	RBT, RBH	+0.0006
CHI	FRL	-0.0230
HAR	FRL	-0.0170
AKS	AKS	-0.0080
CWF	CWF	-0.0140
LRW	LRW	+0.0200
LRH	BON	-0.0094
SRH	ORC	-0.0076
SPR	SPR	-0.0089
URB	URB	-0.0047
WSH	WSH	-0.0060

This review across stocks indicates that a pattern of increasing rates at one or more ages and a declining trend in the mean age of maturation has occurred in all regions. The direction of trend in mean age of maturation was downward for all but two of the stocks (RBT and LRW). It has also occurred in stocks considered predominantly natural (e.g., transboundary stocks STI and TAK and the northern BC stock KLM) as well as those considered dominated by releases of hatchery-origin Chinook salmon (e.g., BQR and LRH).


ATN Oldest Age=6
ATN
ATS Oldest Age=6
ATS
BQR Oldest Age=5
BQR
Maturation Rate (Proportion)
Average Generation Time (yrs)
Average Survival Rate (%)
Brood Year
Brood Year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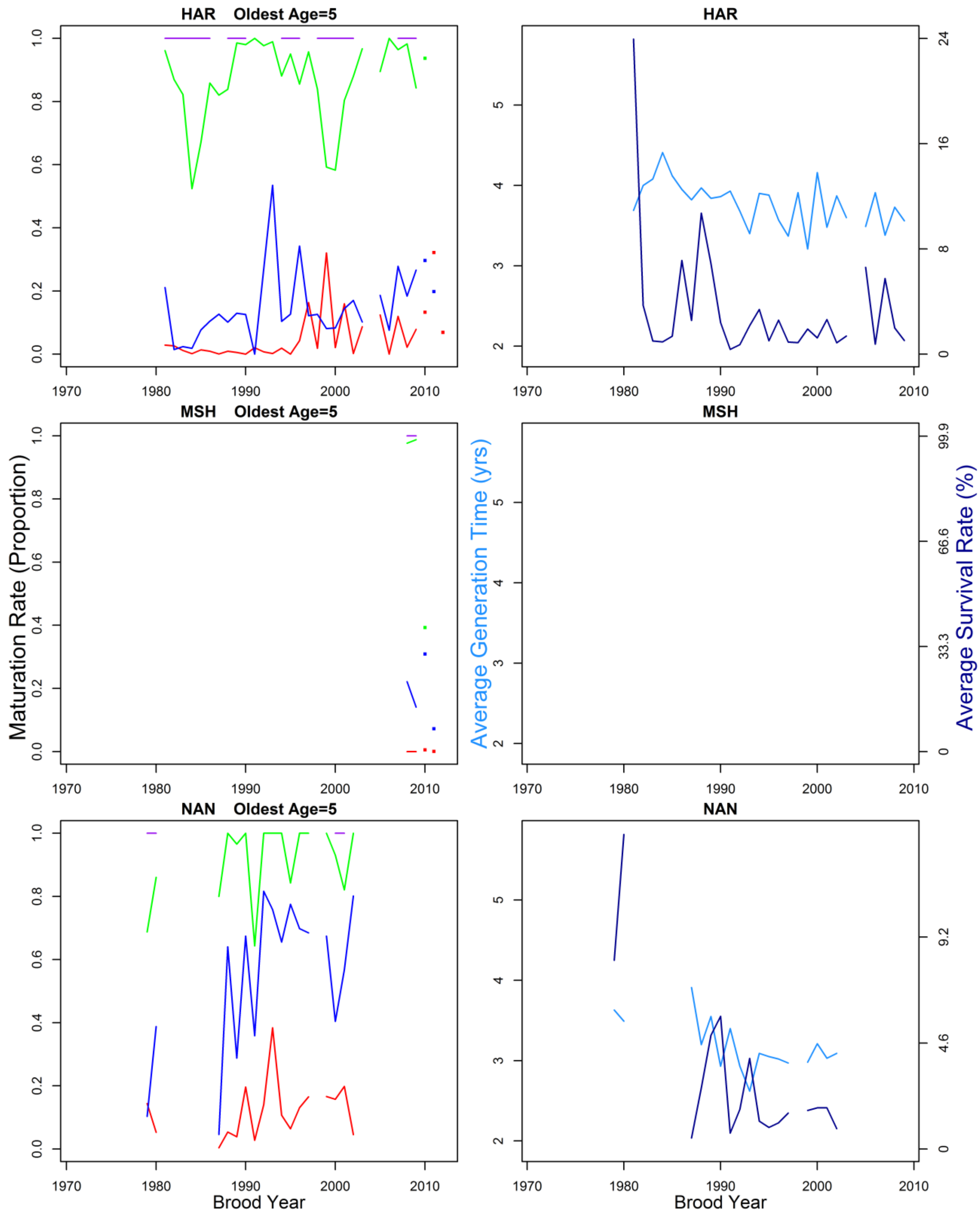
CHI
COW Oldest Age=5
COW
DOM Oldest Age=6
DOM
Maturation Rate (Proportion)
Average Generation Time (yrs)
Average Survival Rate (%)
Brood Year
Brood Year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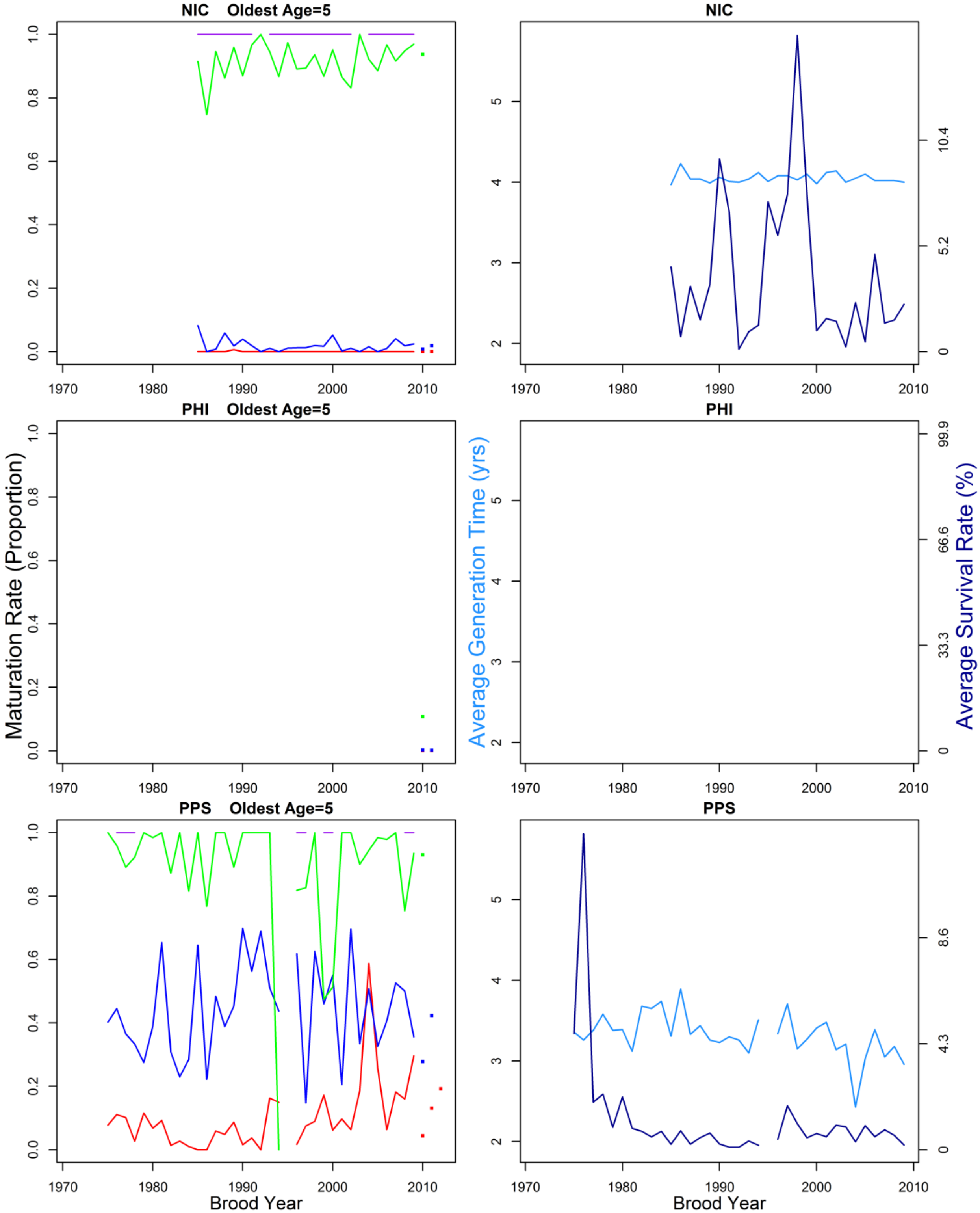
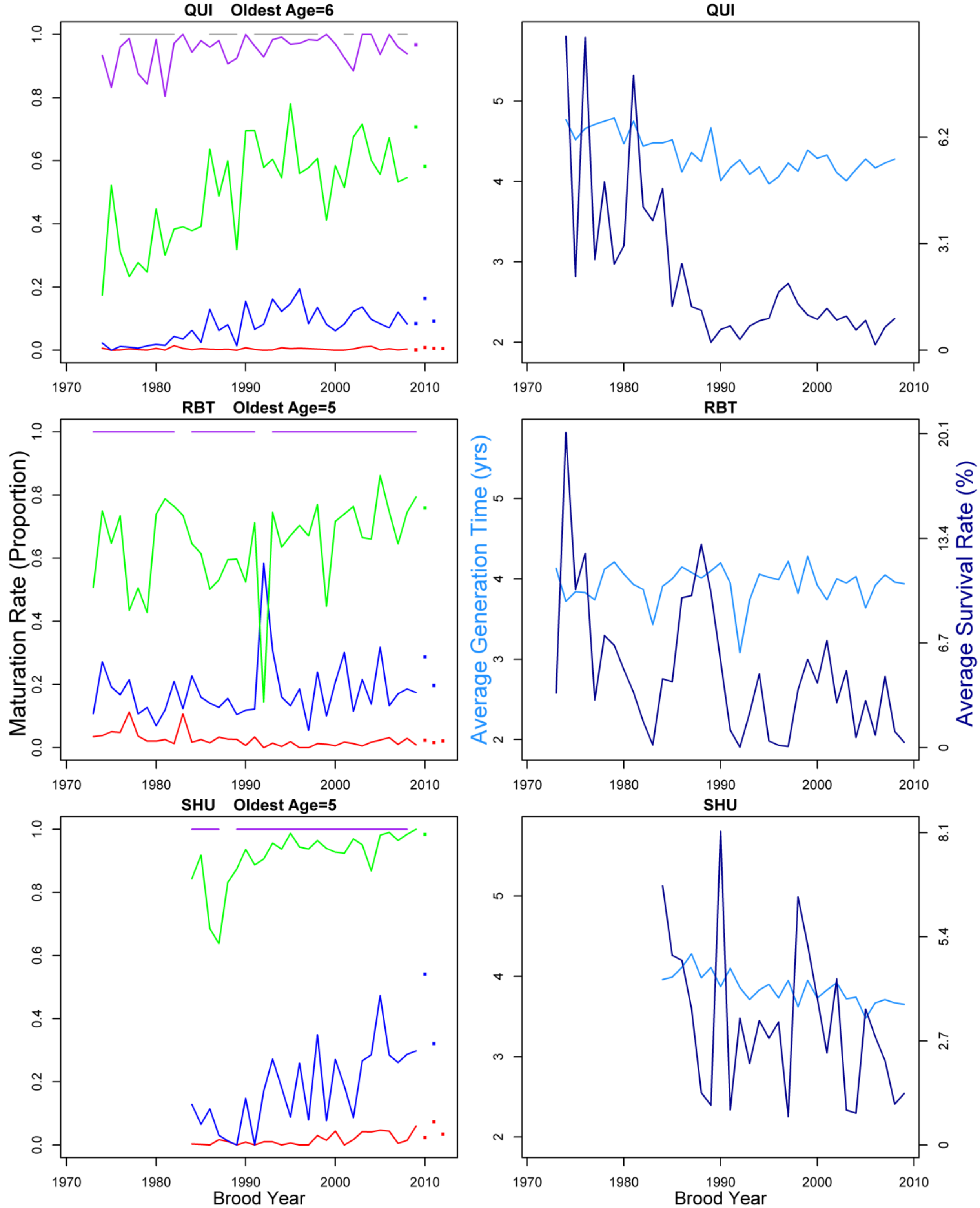
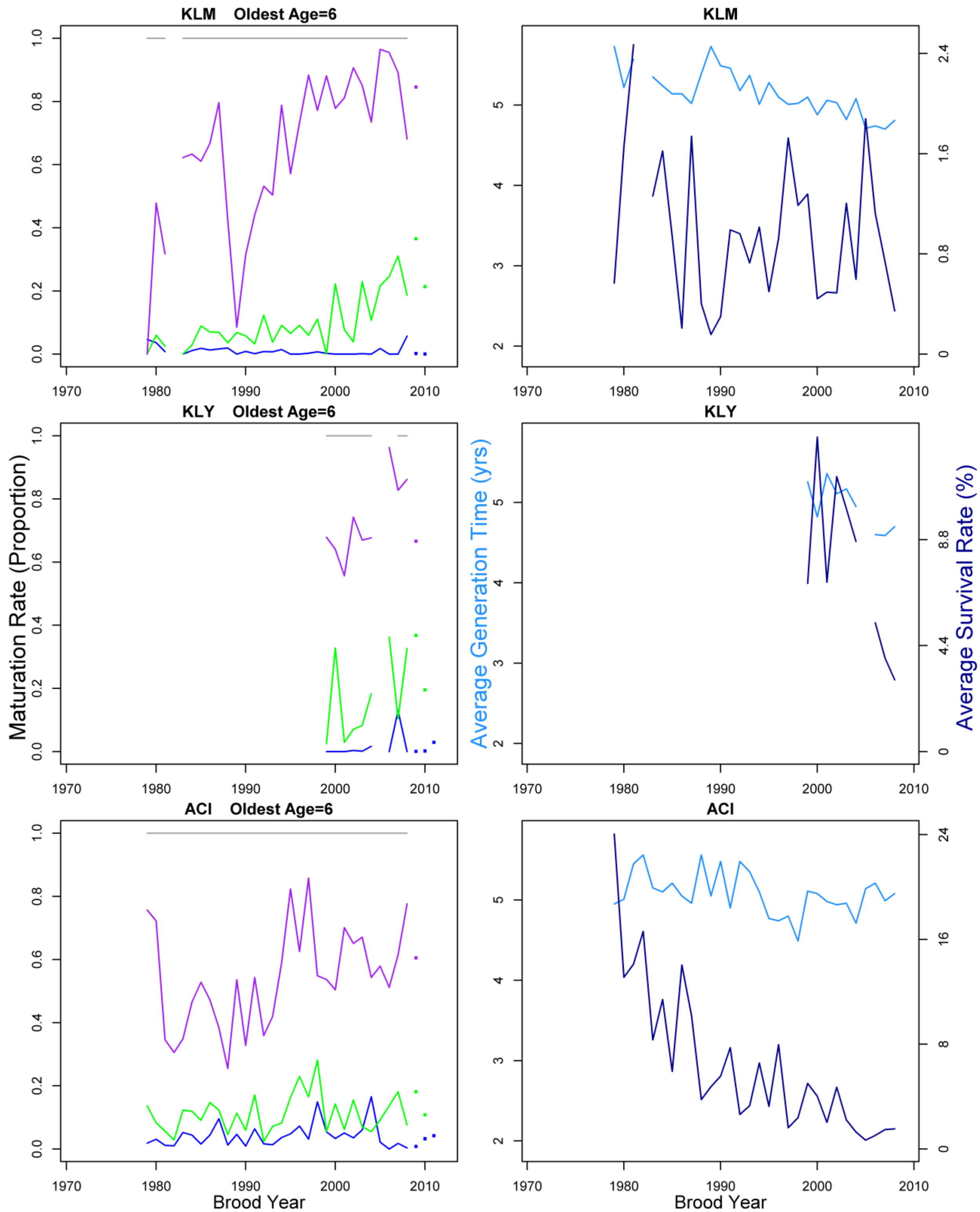
HAR
MSH Oldest Age=5
MSH
NAN Oldest Age=5
NAN
Maturation Rate (Proportion)
Average Generation Time (yrs)
Average Survival Rate (%)
Brood Year
Brood Year



NIC Oldest Age=5
NIC
PHI Oldest Age=5
PHI
PPS Oldest Age=5
PPS
Maturation Rate (Proportion)
Average Generation Time (yrs)
Average Survival Rate (%)
Brood Year
Brood Year
0.0
0.2
0.4
0.6
0.8
1.0
2
3
4
5
0
5.2
10.4
0
33.3
66.6
99.9
0
4.3
8.6
1970
1980
1990
2000
2010



QUI Oldest Age=6
QUI
RBT Oldest Age=5
RBT
SHU Oldest Age=5
SHU
Maturation Rate (Proportion)
Average Generation Time (yrs)
Average Survival Rate (%)
Brood Year
Brood Year


KLM Oldest Age=6
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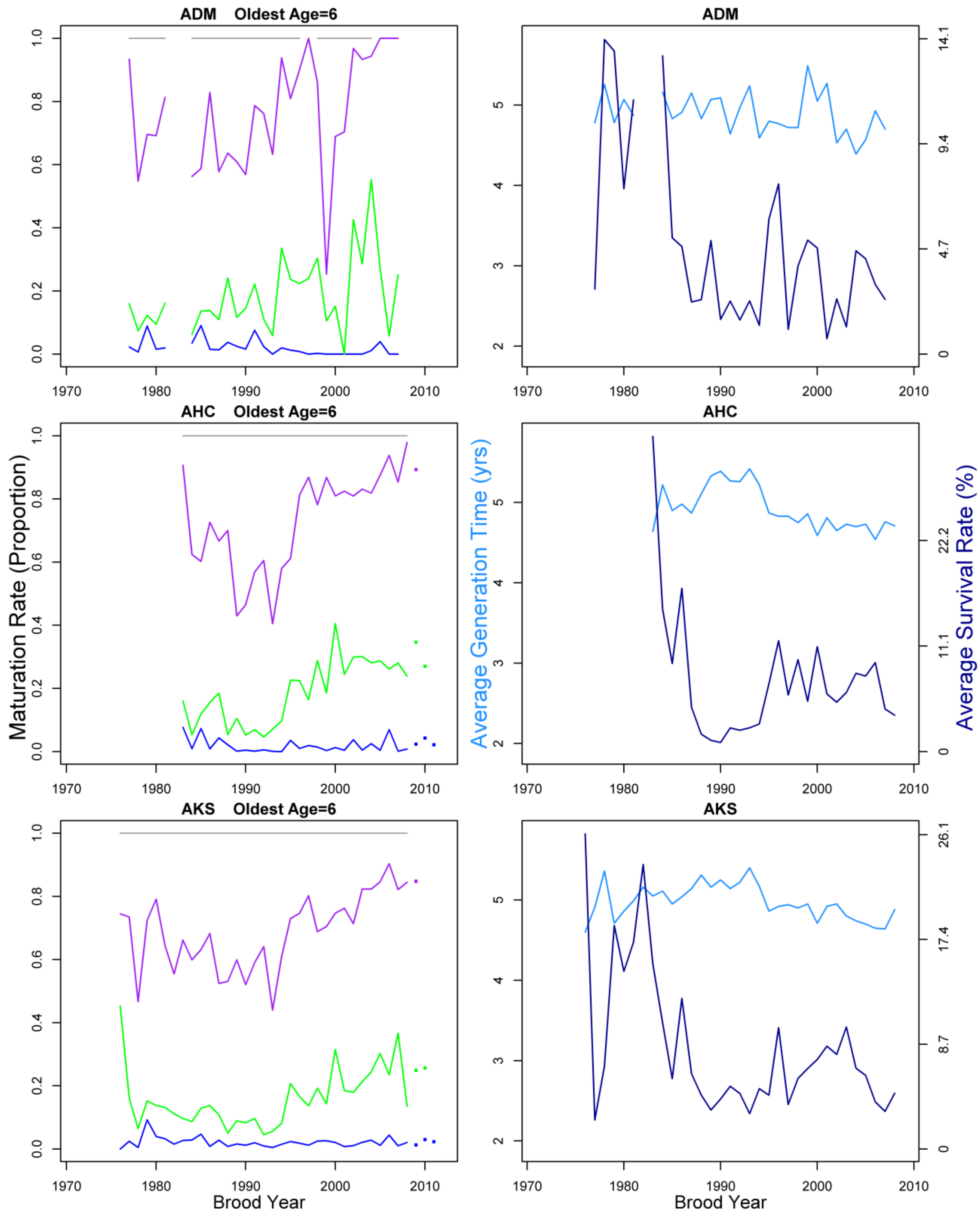
KLY Oldest Age=6
KLY
ACI Oldest Age=6
ACI
Maturation Rate (Proportion)
Average Generation Time (yrs)
Average Survival Rate (%)
Brood Year
Brood Year
0.0
0.2
0.4
0.6
0.8
1.0
2
3
4
5
0
0.8
1.6
2.4
4.4
8.8
8
16
24
1970
1980
1990
2000
2010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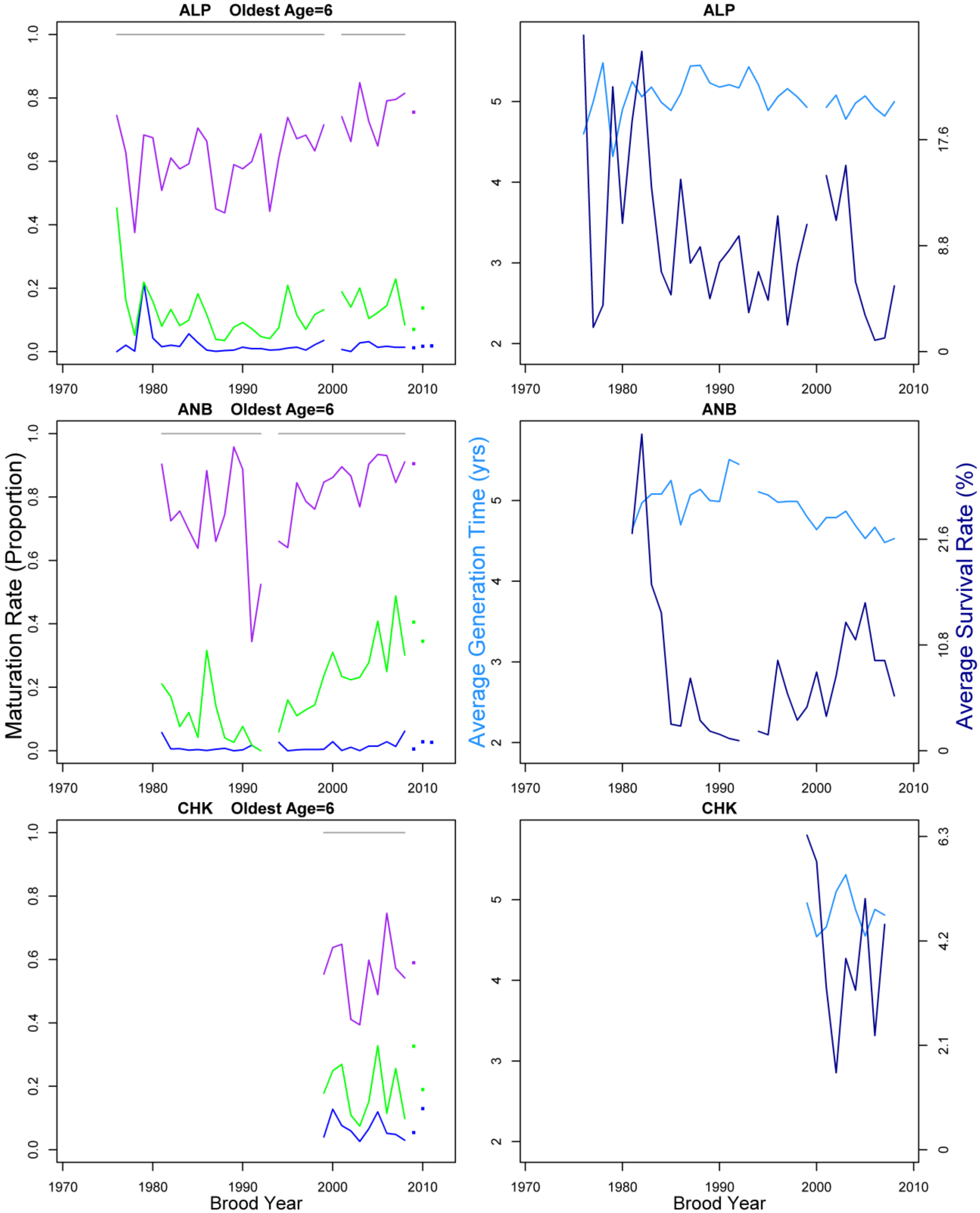
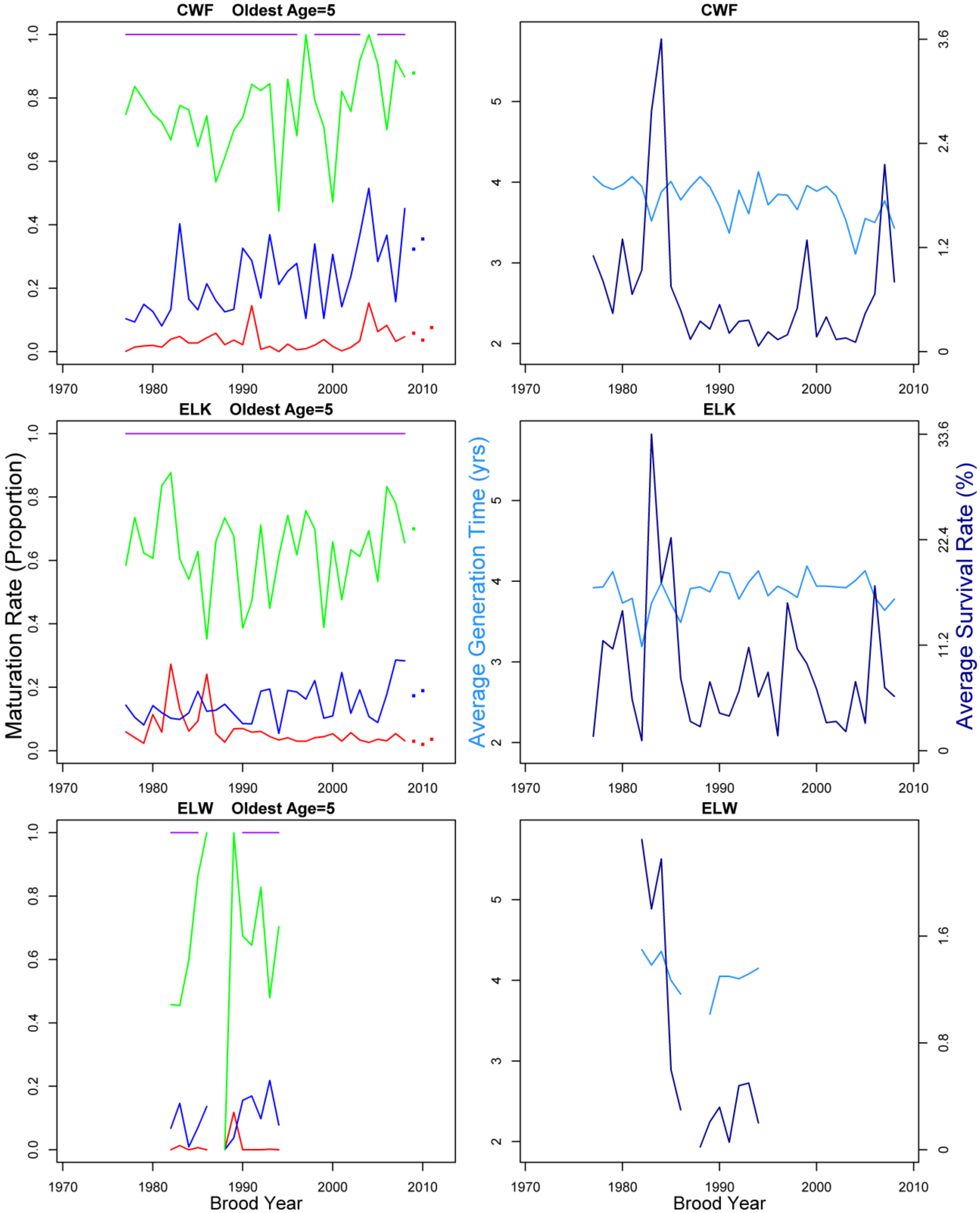
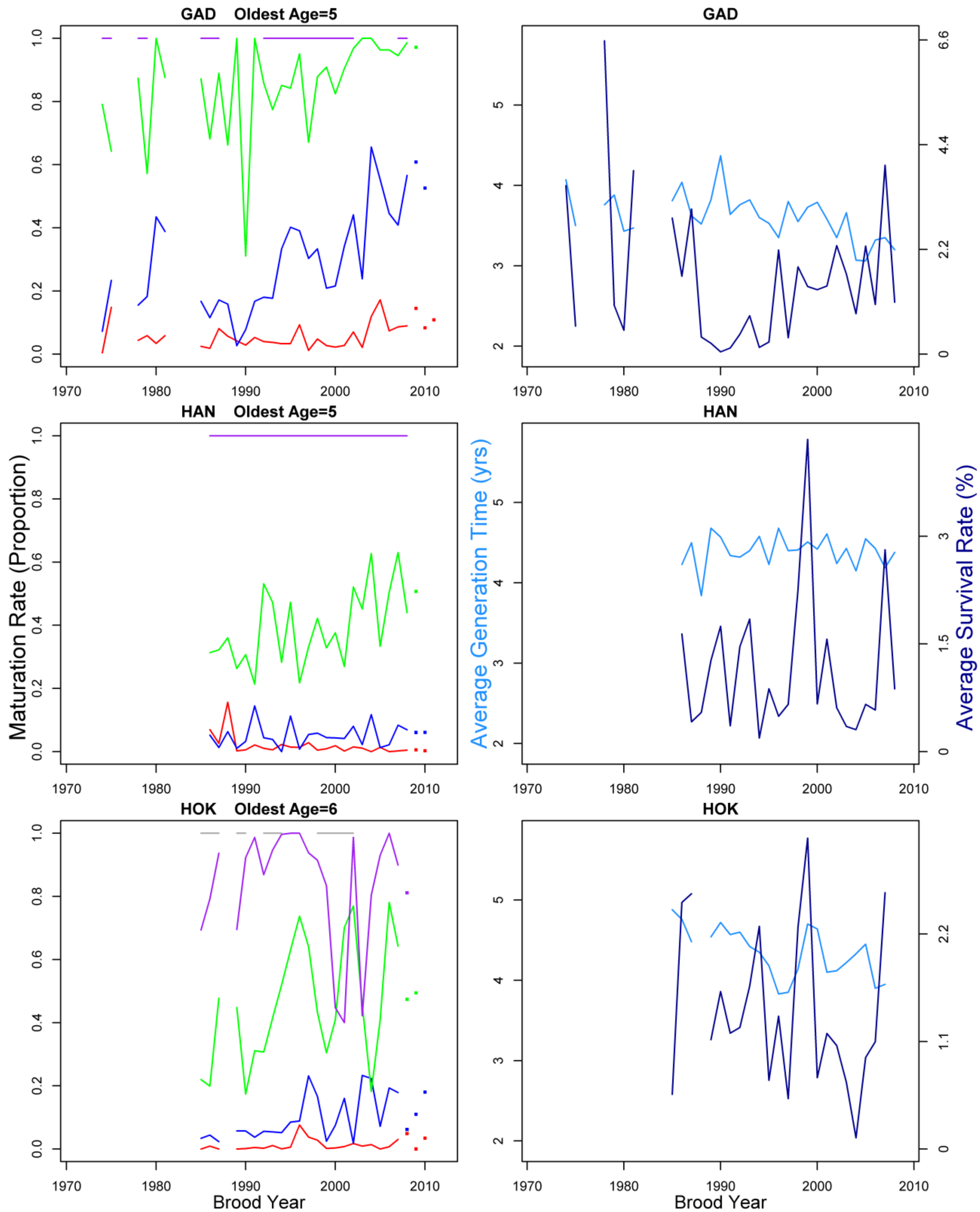
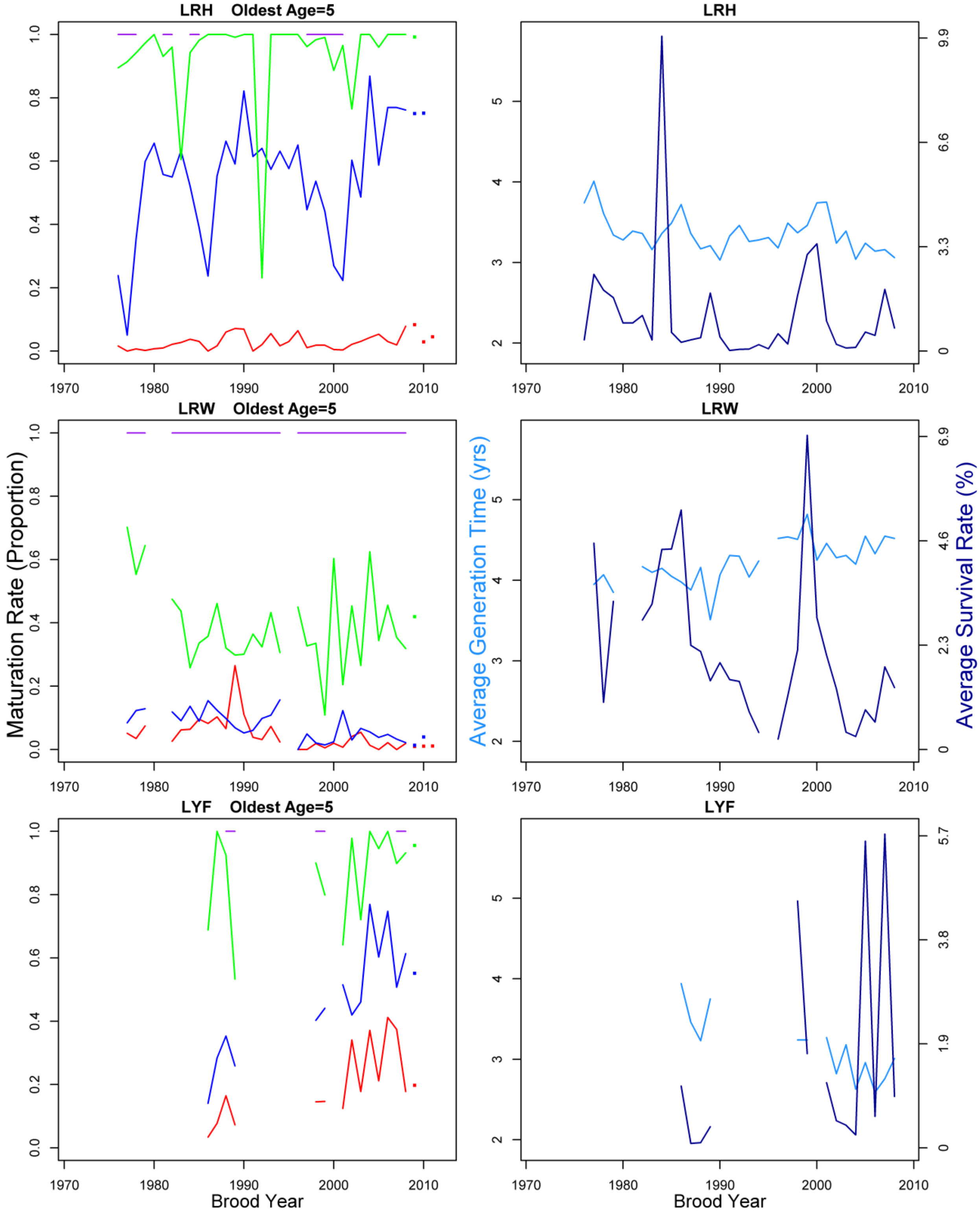
AHC Oldest Age=6
AHC
AKS Oldest Age=6
AKS
Maturation Rate (Proportion)
Average Generation Time (yrs)
Average Survival Rate (%)
Brood Year
Brood Year



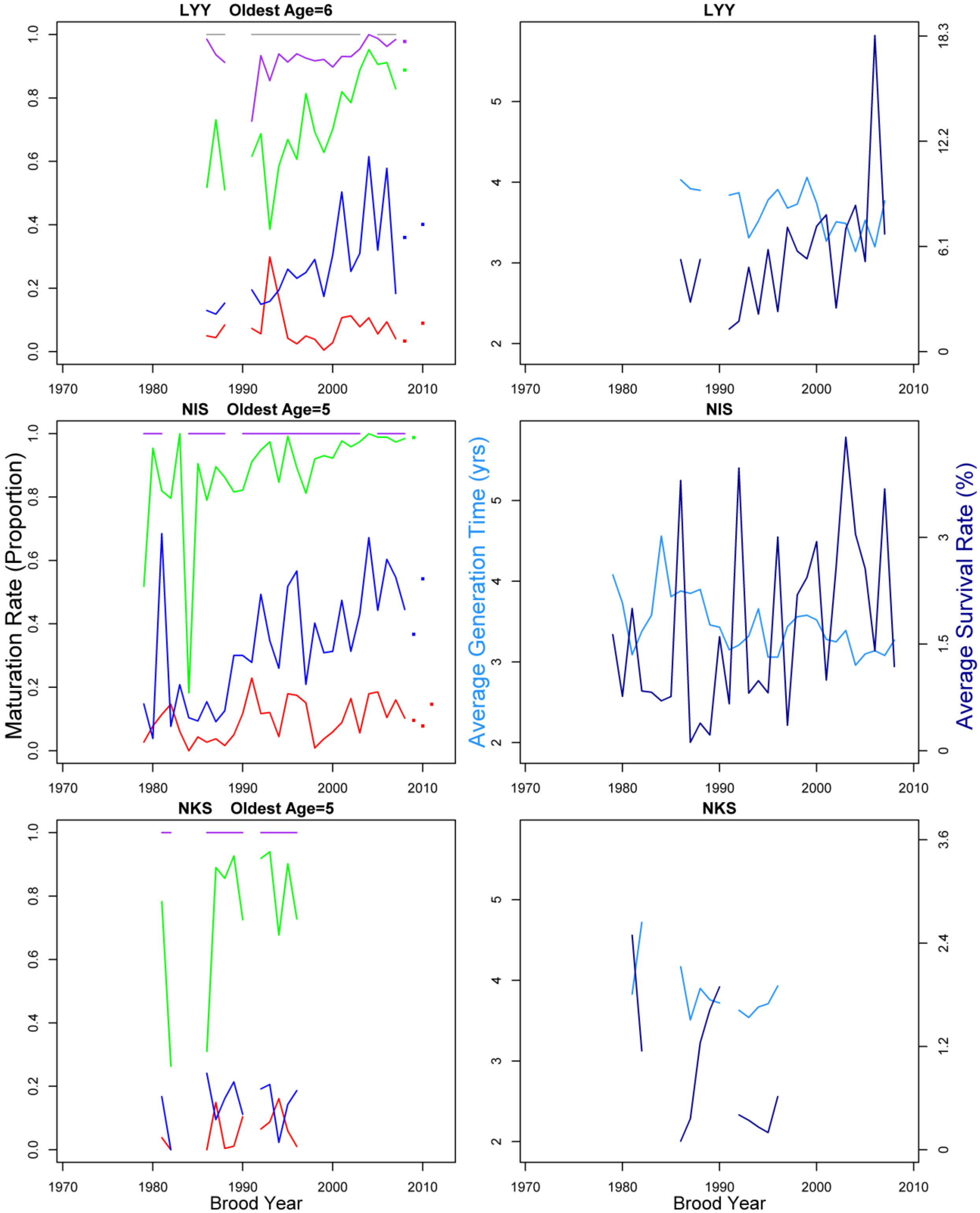
ALP Oldest Age=6
ALP
ANB Oldest Age=6
ANB
CHK Oldest Age=6
CHK
Maturation Rate (Proportion)
Average Generation Time (yrs)
Average Survival Rate (%)
Brood Year
Brood Year

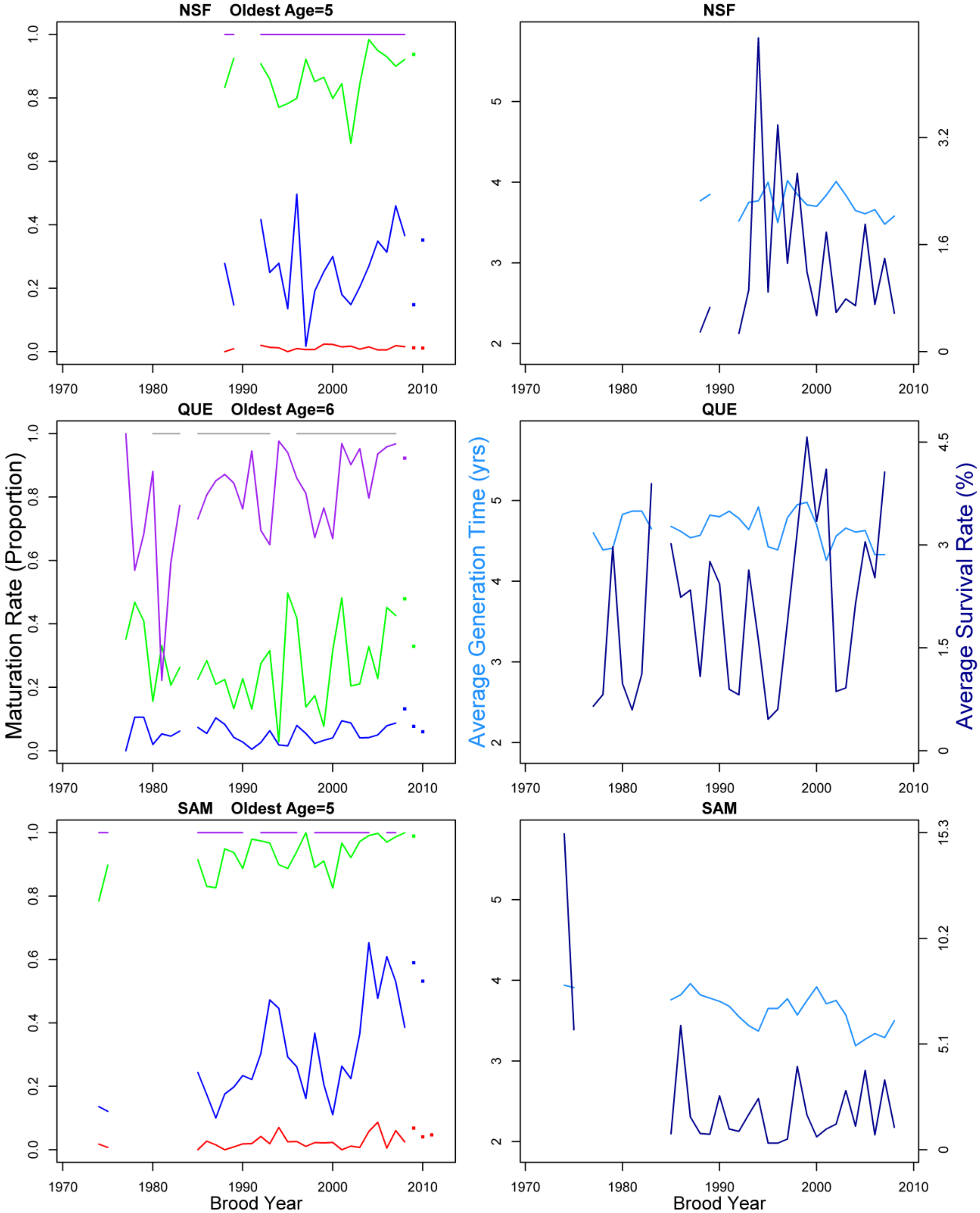

CWF Oldest Age=5
CWF
ELK Oldest Age=5
ELK
ELW Oldest Age=5
ELW
Maturation Rate (Proportion)
Average Generation Time (yrs)
Average Survival Rate (%)
Brood Year
Brood Year


GAD Oldest Age=5
GAD
HAN Oldest Age=5
HAN
HOK Oldest Age=6
HOK
Maturation Rate (Proportion)
Average Generation Time (yrs)
Average Survival Rate (%)
Brood Year
Brood Year
1970
1980
1990
2000
2010
0.0
0.2
0.4
0.6
0.8
1.0
2
3
4
5
0
2.2
4.4
6.6
1.5
3
1.1



LRH Oldest Age=5
LRH
LRW Oldest Age=5
LRW
LYF Oldest Age=5
LYF
Maturation Rate (Proportion)
Average Generation Time (yrs)
Average Survival Rate (%)
Brood Year
Brood Year


LYY Oldest Age=6
LYY
NIS Oldest Age=5
NIS
NKS Oldest Age=5
NKS
Maturation Rate (Proportion)
Average Generation Time (yrs)
Average Survival Rate (%)
Brood Year
Brood Year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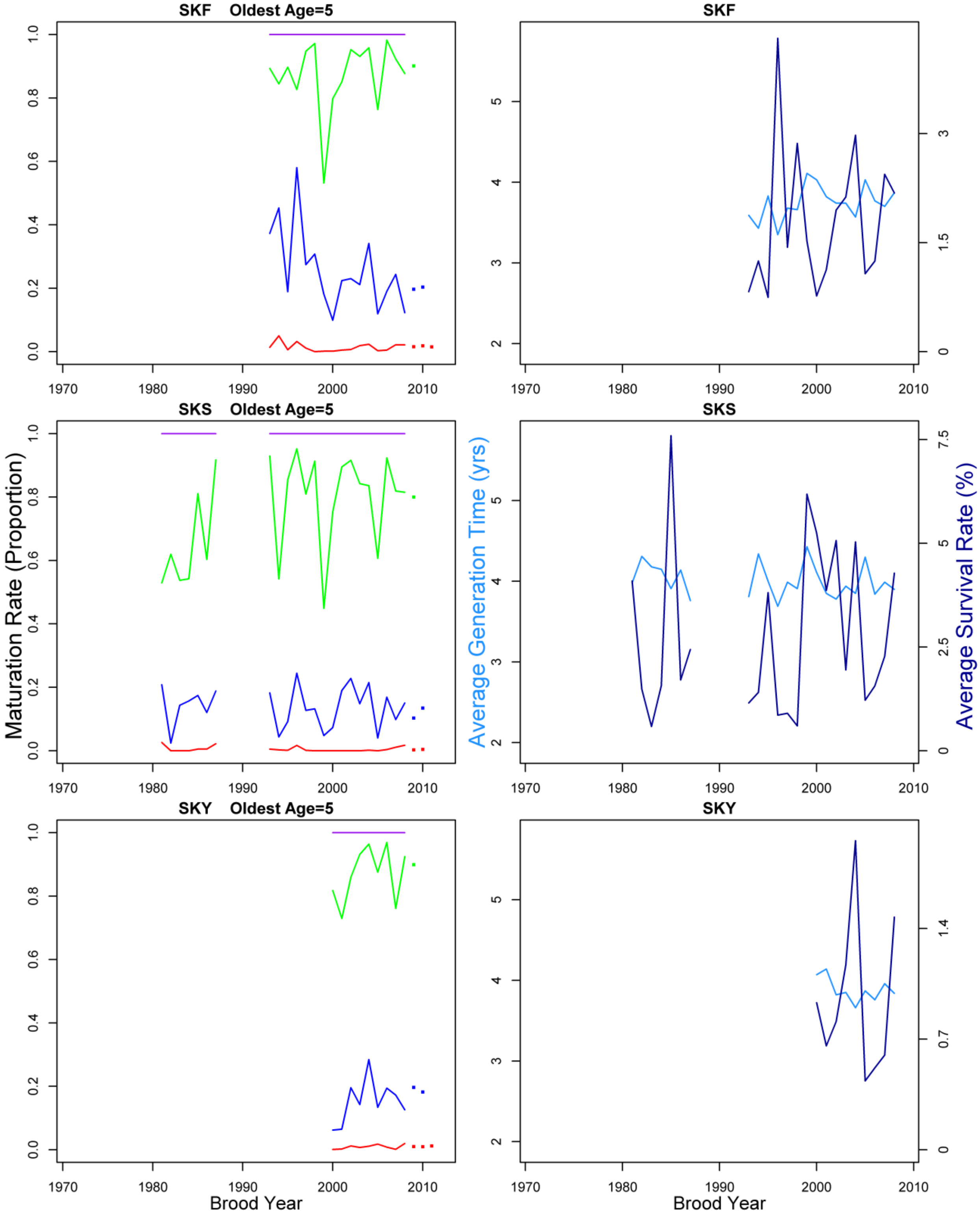
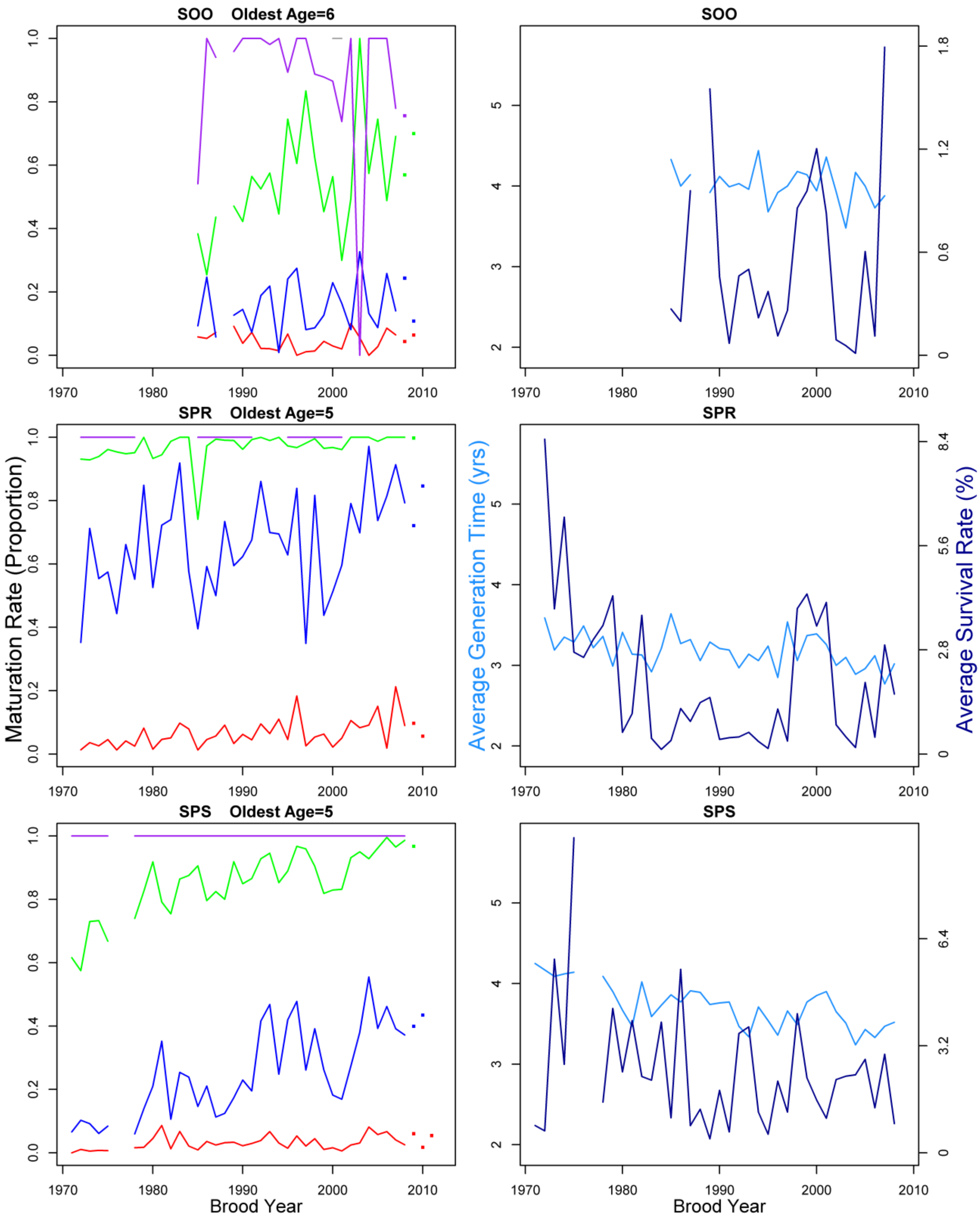
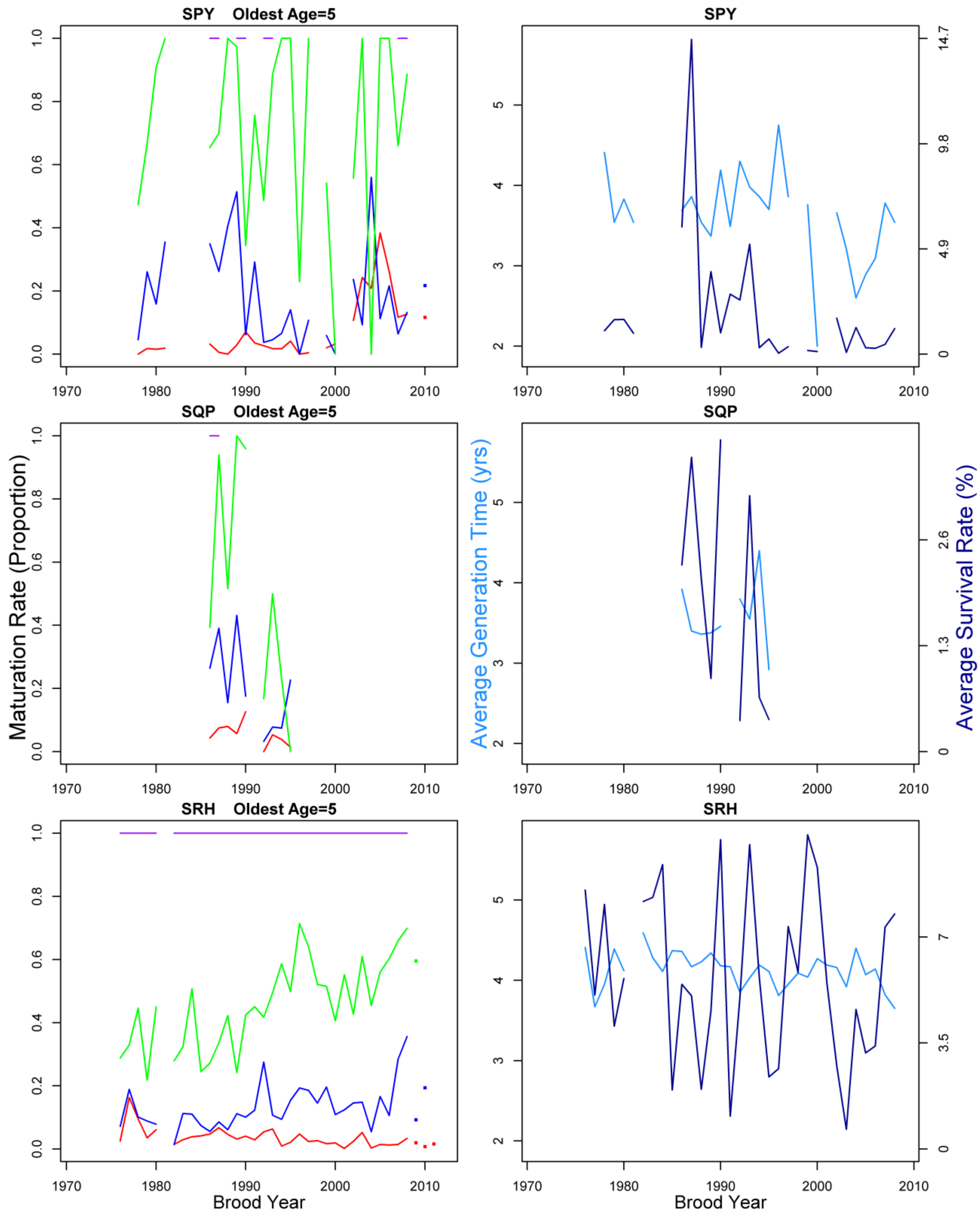
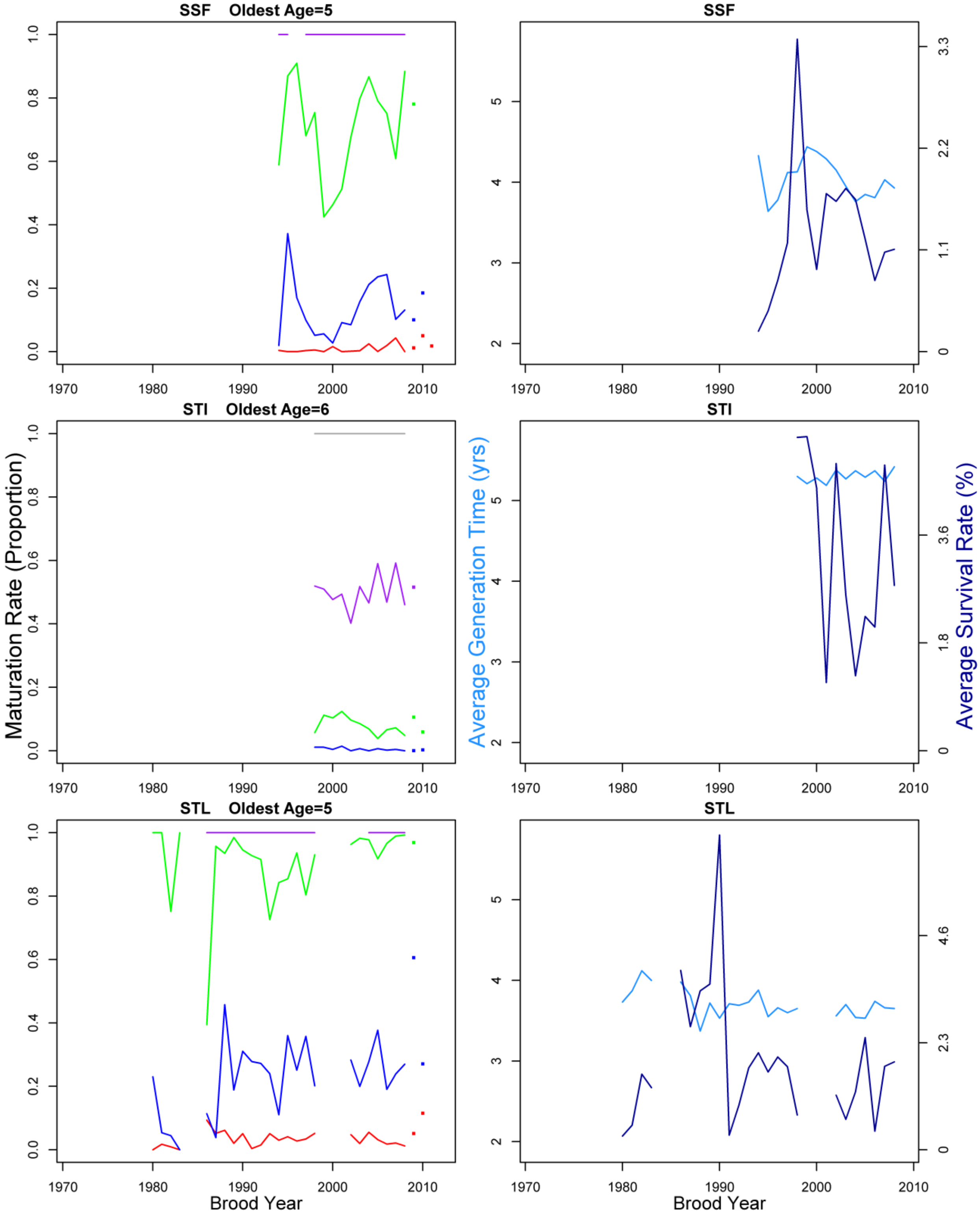
NSF
QUE Oldest Age=6
QUE
SAM Oldest Age=5
SAM
Maturation Rate (Proportion)
Average Generation Time (yrs)
Average Survival Rate (%)
Brood Year
Brood Year

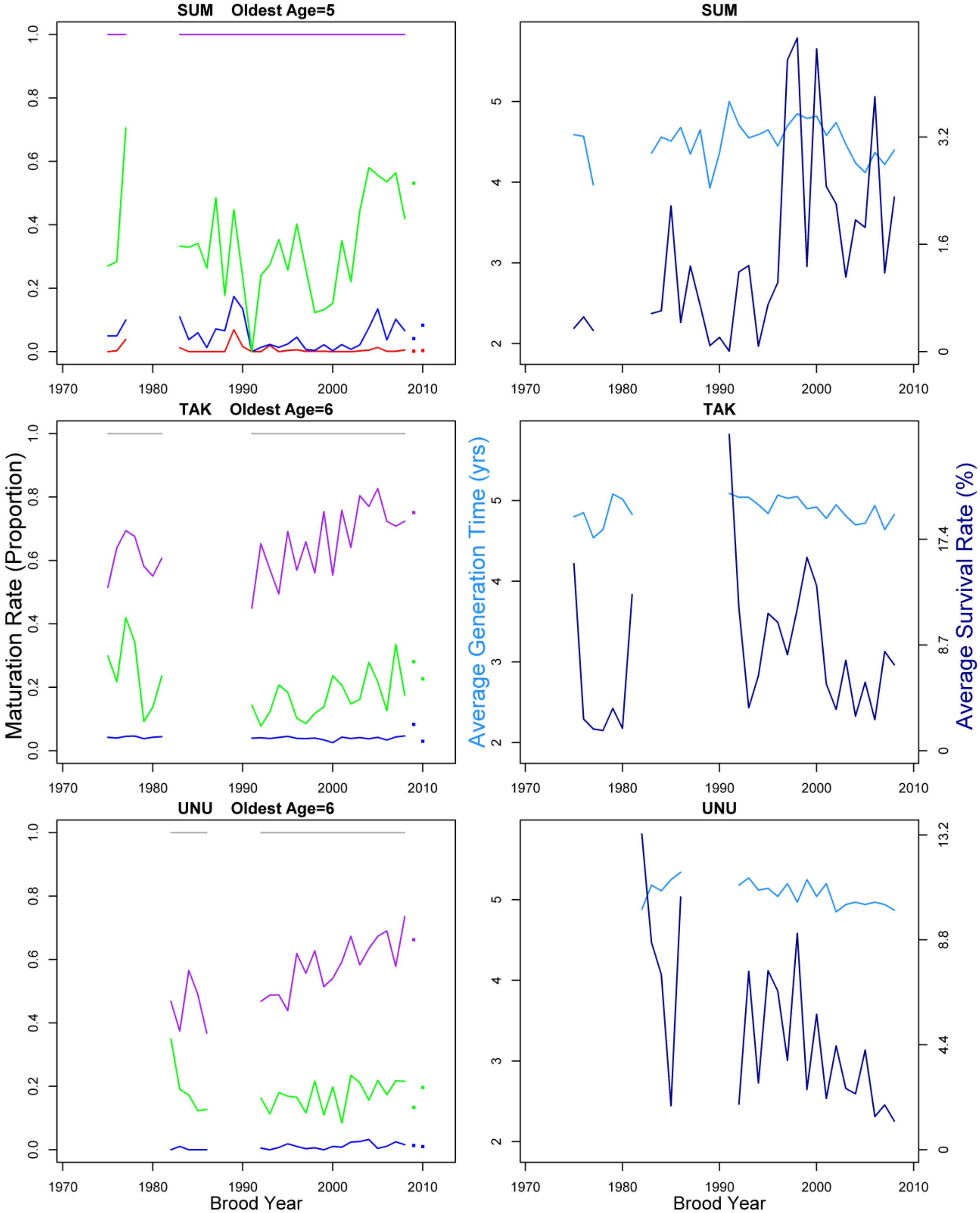

SKF Oldest Age=5
SKF
SKS Oldest Age=5
SKS
SKY Oldest Age=5
SKY
Maturation Rate (Proportion)
Average Generation Time (yrs)
Average Survival Rate (%)
Brood Year
Brood Year


SOO Oldest Age=6
SOO
SPR Oldest Age=5
SPR
SPS Oldest Age=5
SPS
Maturation Rate (Proportion)
Average Generation Time (yrs)
Average Survival Rate (%)
Brood Year
Brood Year
0.0
0.2
0.4
0.6
0.8
1.0
2
3
4
5
0
0.6
1.2
1.8
2.8
5.6
8.4
3.2
6.4
1970
1980
1990
2000
2010

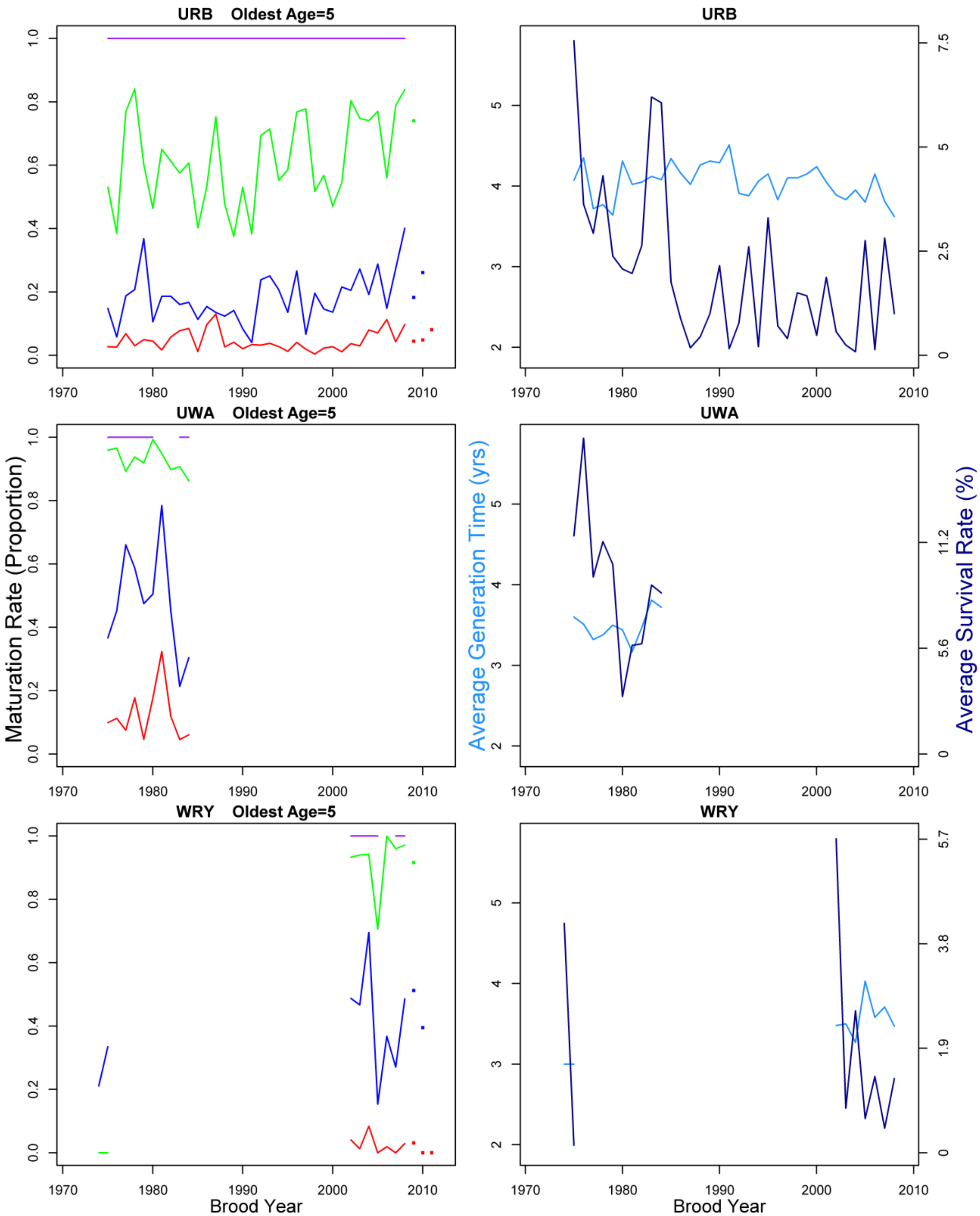

SPY Oldest Age=5
SPY
SQP Oldest Age=5
SQP
SRH Oldest Age=5
SRH
Maturation Rate (Proportion)
Average Generation Time (yrs)
Average Survival Rate (%)
Brood Year
Brood Year



SSF Oldest Age=5
SSF
STI Oldest Age=6
STI
STL Oldest Age=5
STL
Maturation Rate (Proportion)
Average Generation Time (yrs)
Average Survival Rate (%)
Brood Year
Brood Year



SUM Oldest Age=5
SUM
TAK Oldest Age=6
TAK
UNU Oldest Age=6
UNU
Maturation Rate (Proportion)
Average Generation Time (yrs)
Average Survival Rate (%)
Brood Year
Brood Year


URB Oldest Age=5
URB
UWA Oldest Age=5
UWA
WRY Oldest Age=5
WRY
Maturation Rate (Proportion)
Average Generation Time (yrs)
Average Survival Rate (%)
Brood Year
Brood Year

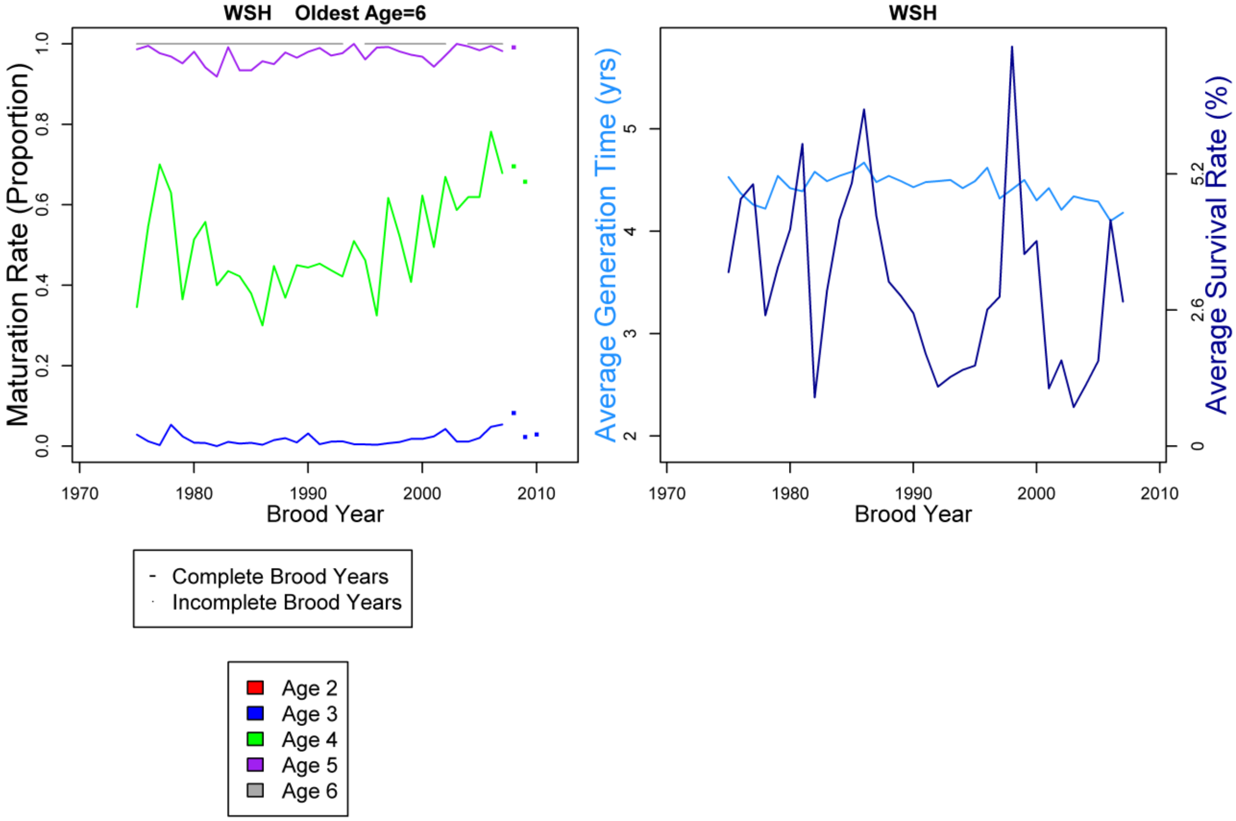

WSH Oldest Age=6
Maturation Rate (Proportion)
Brood Year
Complete Brood Years
Incomplete Brood Years
Age 2
Age 3
Age 4
Age 5
Age 6
WSH
Average Generation Time (yrs)
Average Survival Rate (%)
Brood Year

Table B.1. The table below provides a stock name and other information for each CWT indicator stock identified using its three-letter acronym in the graphs above. The stock acronym is highlighted in bold type for those stocks which currently annually provide MR data for Chinook Model stocks included in the MATAEQ file.

CWT Indicator	Stock Name	Jurisdiction	Region	First Age	Final Age
ACI	Alaska Central Inside	AK	SEAK	3	6
ADM	Alaska Deer Mountain	AK	SEAK	3	6
AHC	Alaska Herring Cove	AK	SEAK	3	6
AKS	Alaska Spring	AK	SEAK	3	6
ALP	Little Port Walter	AK	SEAK	3	6
ANB	Alaska Neets Bay	AK	SEAK	3	6
ATN	Atnarko River Summer	BC	CBC	2	6
ATS	Atnarko River Spring	BC	CBC	2	6
BQR	Big Qualicum River Fall	BC	ECVI	2	5
CHI	Chilliwack River Fall	BC	LFR	2	5
CHK	Chilkat Spring	AK	SEAK	3	6
COW	Cowichan River Fall	BC	ECVI	2	5
CWF	Cowlitz Fall Tule	CR	LCOLR	2	5
DOM	Dome Creek Spring	BC	UFR	3	6
ELK	Elk River	OR	ORCST	2	5
ELW	Elwha Fall Fingerling	WA	JFUCA	2	5
GAD	George Adams Fall Fingerling	WA	HOODC	2	5
HAN	Hanford Wild	CR	UCOLR	2	5
HAR	Harrison River Fall	BC	LFR	2	5
HOK	Hoko Fall Fingerling	WA	JFUCA	2	6
KLM	Kitsumkalum River Summer	BC	NBC	3	6
KLY	Kitsumkalum River Yearling	BC	NBC	3	6
LRH	Columbia Lower River Hatchery	CR	LCOLR	2	5
LRW	Lewis River Wild	CR	LCOLR	2	5
LYF	Lyons Ferry	CR	UCOLR	2	5
LYY	Lyons Ferry Yearling	CR	UCOLR	3	6
NAN	Nanaimo River Fall	BC	ECVI	2	5
NIC	Nicola River Spring	BC	MFR	2	5
NIS	Nisqually Fall Fingerling	WA	SPGSD	2	5
NKS	Nooksack Spring Yearling	WA	NPGSD	2	5
NSF	Nooksack Spring Fingerling	WA	NPGSD	2	5
PPS	Puntledge River Summer	BC	ECVI	2	5
QUE	Queets Fall Fingerling	WA	WACST	2	6
QUI	Quinsam River Fall	BC	ECVI	2	6
RBT	Robertson Creek Fall	BC	WCVI	2	5
SAM	Samish Fall Fingerling	WA	NPGSD	2	5
SHU	Lower Shuswap River Summer	BC	MFR	2	5
SKF	Skagit Spring Fingerling	WA	NPGSD	2	5
SKS	Skagit Spring Yearling	WA	NPGSD	2	5
SKY	Skykomish Fall Fingerling	WA	NPGSD	2	5

SOO	Sooes Fall Fingerling	WA	WACST	2	6
SPR	Spring Creek Tule	CR	MCOLR	2	5
SPS	South Puget Sound Fall Fingerling	WA	SPGSD	2	5
SPY	South Puget Sound Fall Yearling	WA	SPGSD	2	5
SQP	Squaxin Pens Fall Yearling	WA	SPGSD	2	5
SRH	Salmon River	OR	ORCST	2	6
SSF	Skagit Summer Fingerling	WA	NPGSD	2	5
STI	Stikine Spring	TBR	TBR	3	6
STL	Stillaguamish Summer Fingerling	WA	NPGSD	2	5
SUM	Columbia Summers	CR	UCOLR	2	5
TAK	Taku Spring	TBR	TBR	3	6
UNU	Unuk Spring	SEAK	SEAK	3	6
URB	Upriver Brights	CR	UCOLR	2	5
UWA	University of Washington Accelerated	WA	SPGSD	2	5
WRY	White River Spring Yearling	WA	SPGSD	2	5
WSH	Willamette Spring	CR	LCOLR	3	6

Appendix C. Description of the MATAEQ Program

In order to produce the MATAEQ file that contains the yearly MR values for the twelve stocks with adequate CWT information and the MR averages computed from these values, a Microsoft VB.NET program (MATAEQVB_xxx.EXE) is used to extract the MR and Adult Equivalent (AEQ) values from the ERA output (OUT) files of the twelve stocks. The VB.NET program also reads the base period MR and AEQ values from the STK file (containing base period stock and age specific cohort sizes, MRs, AEQs, and exploitation rates by fishery) of the Chinook Model. The VB.NET program then calculates the average MR and AEQ values to be used for the years being projected.

Occasionally, MR and AEQ values are missing for certain stocks and broods due to lack of CWT releases and/or recoveries for those broods. In addition, some broods have CWT data but due to inadequate CWT recoveries the MR and AEQ values cannot be reliably estimated. Typically these values are readily detected as outliers relative to MRs calculated by the cohort analysis procedure. In these situations where the CWT recovery data are inadequate, the MR and AEQ values that are read from the OUT files are excluded and treated as though they were missing. The stocks and broods where the MR and AEQ values exist but are set to missing are identified in the table below:

Table C.1. The stocks and broods where the MR and AEQ values exist but are set to missing.

Model Stock	**Acronym**	**ERA Indicator**	**Excluded Broods**[1]
Alaska Spring	AKS	AKS	1976
Lower Bonneville Hatchery	BON	LRH	1977, 1980, 1983, 1986, 1988, 1990-1994, 1996
Cowlitz Fall Hatchery	CWF	CWF	1994, 1997
Lower Georgia Strait Hatchery	GSH	BQR	1992
Lewis River Wild	LRW	LRW	1996, 1997
Oregon Coastal	ORC	SRH	1976
WCVI Hatchery	RBH	RBH	1992, 1997
WCVI Wild	RBT	RBH	1992, 1997
Willamette Spring Hatchery	WSH	WSH	1982, 1994

[1] Excluded broods experienced such poor survival that CWT recoveries were so few that MRs were nonsensical, and the long-term average was used.

In addition, the MR values read from the OUT files for the CHI CWT indicator stock (associated with the Fraser Late Model stock) are replaced with values supplied by Canadian Department of Fisheries and Oceans staff. The replacement values have been adjusted to take into account the differing maturation schedules between the hatchery and wild components of the Fraser Late stock. The resulting AEQ values are then calculated from the user supplied MR values.

The VB.NET program then produces a year, stock and age specific MATAEQ_xxx.DAT file containing the MR and AEQ values that are read into the PSC Chinook Model during the calibration and projection runs. The base period years in the MATAEQ_xxx.DAT file contain the base period MR and AEQ values from the STK file. Years after the base period but prior to the projection years that have valid (non-missing) MR and AEQ values contain data from the ERA OUT files (with the exception of Fraser Late). Years that have missing CWT data (or have been set to missing) contain LTA MR and AEQ values calculated for each stock and age. The projection years contain the average MR and AEQ values calculated for each stock and age based on a specified number of completed broods. For all Chinook Model calibrations prior to 2013, the MRs are based on the average of all available completed broods (except missing or excluded broods). Starting in 2013, the MRs are based on the average of the five most recent complete broods. The average could consist of less than five broods if the five-brood ‘window ’also included missing or excluded broods.

Appendix D. Details of Model Evaluation Criteria

D.1 Mean Squared Error (MSE):

MSE provides a measure of the variability of the retrospective forecast errors. It is the average of each of the individual squared errors, i.e., the difference between the model estimated AI and some measure of the true AI, calculated as,

$$MSE = \frac{\sum_{i=1}^{n}(\widehat{AI}_i - AI_i)^2}{n},$$

where $\widehat{AI}_i$ is the estimated AI for year *i* using a particular MR estimate and AI_i is the "true" value of the abundance index for year *i*. It is a measure that includes both the variability of errors, and the bias in AI estimates.

Each of the individual square errors, i.e., $\left(\widehat{AI}_i - AI_i\right)^2$, contributes a proportion of the error to the total. Because the errors are squared, large errors can contribute more to the proportion than smaller errors. Hence large errors can unduly influence the overall MSE and will grow as the total error is concentrated within a decreasing number of increasingly large individual errors. The effect of different MRs on the MSE of model estimates of the AI are shown graphically.

D.2 Median Error

The median error is calculated as,

$$Med.Error = median\left(\widehat{AI}_i - AI_i\right), \forall\ i.$$

Medians, like means, are a measure of central tendency. However, unlike averages, or means, it is not influenced by large values. Positive values of the median error will result when AIs tend to be overestimated, negative when AIs are underestimated. Thus, it provides a little more information on overall model behavior than the MSE. Median errors for different estimates of the MR based on different metrics of the true AI are shown graphically.

D.3 Mean Absolute Scaled Error (MASE)

MASE was proposed by Hyndman and Koehler (2006) as a generally applicable, scale-free measure of forecast accuracy. This measure never gives infinite or undefined values. MASE is computed as the average of the absolute values of the scaled retrospective estimation errors. The scaling of the errors involves dividing the errors by the Mean Absolute Error (MAE) computed from the retrospective estimation errors associated with the naïve model based on the MRs for the previous year. A value of MASE less than 1 suggests that the retrospective estimation accuracy of MRs is better than the retrospective estimation accuracy of the benchmark naïve model based on the MRs for the previous year. A value of MASE greater than 1 suggests that the retrospective estimation accuracy is worse than the retrospective estimation accuracy of the benchmark naïve model based on MRs for the previous year.

MASE measures the magnitude of the error compared to the magnitude of the error of a naive one-step ahead forecast as a ratio. A naïve estimate assumes that whatever the MR value was last year it will be the same value this current year. Ideally, the value of MASE will be significantly less than 1. For example, a MASE of 0.5 means that the MR estimate is likely to have half as much error as a naïve estimate. Since MASE is a normalized statistic that is defined for all data values and weighs errors evenly, it is an excellent metric for comparing the quality of different estimation methods.

The advantage of MASE over the more common Mean Absolute Percent Error (MAPE) metric is that MASE is defined for time series that contain zero, whereas MAPE is not. Also, MASE weights errors equally, whereas MAPE weights positive and/or extreme errors more heavily.

D.4 Mean Percent Error

The Mean Percent Error (MPE) takes into account values of the AI, and scales the error accordingly. MPE is calculated as,

$$MPE = \frac{\sum_{i=1}^{n} \frac{(\widehat{AI}_i - AI_i)}{AI_i}}{n}.$$

Because the MPE is not calculated from absolute errors, values indicated by what percentage the AI will be over or under estimated.

Appendix E. Percent Error for Three MR Estimates (3YA, 9YA and ETS) Relative to the Observed MR at Age for Model Stocks in the MATAEQ File for the 2004-2010 Chinook Model Calibrations.

All contributing broods were complete through to the 2010 calibration for each of the Chinook Model stocks based on using observed MRs from the CTC-AWG's exploitation rate analysis in March 2015. Positive values indicate that the forecasted MR exceeded the observed MR at age. Negative values indicate the forecasted MR was below the observed MR. Cases where the observed MR was 0 and percent error could not be calculated are indicated with a horizontal bar ('—'). The first, second and third age are stock-dependent and are defined in the caption for Appendix A.

			First Age			Second Age			Third Age		
CLB Year	Stock #	Stock	3YA	9YA	ETS	3YA	9YA	ETS	3YA	9YA	ETS
2004	1	AKS	139.7	93.6	147.4	-54.1	-71.7	-66.7	-2.7	-18.5	-13.1
2005	1		51.4	32.7	-7.5	-12.5	-48.4	-43.0	-0.2	-19.8	-16.9
2006	1		-34.0	-32.5	-27.4	-16.3	-42.3	-39.6	-3.4	-17.7	-18.3
2007	1		-42.9	-47.5	-41.1	-31.9	-44.8	-45.7	2.2	-9.6	-11.0
2008	1		50.0	31.4	67.8	-22.7	-49.8	-35.5	-23.0	-19.9	-23.4
2009	1		-63.0	-65.1	-10.9	-32.0	-52.2	-44.9	-11.7	-18.2	-15.7
2010	1		19.0	67.0	-1.0	-7.0	-31.9	-27.6	-13.1	-18.7	-17.4
2004	2	BON	9.8	82.3	22.3	123.7	138.6	167.8	10.4	10.9	7.8
2005	2		-51.6	-28.1	-34.0	-17.9	-13.6	0.0	1.0	1.8	-0.8
2006	2		-61.6	-49.9	-61.1	-3.9	1.5	3.8	28.0	28.7	21.8
2007	2		-73.2	-65.9	-70.5	-51.2	-47.7	-48.3	-4.9	-3.8	-4.4
2008	2		-69.0	-47.9	-47.9	-48.8	-30.1	-31.9	-5.6	-3.6	-4.4
2009	2		-53.6	-15.1	-29.2	-53.6	-42.9	-39.6	-9.8	-2.8	-1.2
2010	2		-77.6	-77.6	-74.5	-42.9	-42.2	-39.4	-9.8	-5.9	-4.9
2004	3	CWF	13.3	165.9	-44.4	91.3	86.4	61.1	64.8	67.2	60.2
2005	3		-63.5	-1.2	-85.9	29.5	22.7	28.8	-14.3	-4.0	-9.7
2006	3		-81.6	-76.5	-93.6	-40.8	-29.9	-39.8	-6.0	3.6	-2.5
2007	3		-61.6	-71.4	-57.3	-51.1	-48.9	-44.9	-23.6	-17.6	-18.5
2008	3		-77.5	-79.1	-90.6	-35.4	-9.3	-29.0	-29.9	-24.8	-25.0
2009	3		-69.0	-48.5	-65.0	-38.0	-34.8	-38.7	-21.4	-17.6	-17.2
2010	3		-65.9	-59.7	-68.4	58.9	61.9	60.5	19.1	9.1	8.0
2004	4	GSH	-68.1	-56.9	-64.1	-0.7	33.8	9.4	-8.7	0.8	-4.0
2005	4		-18.0	2.8	-15.4	-20.1	-10.9	-20.9	10.5	13.1	15.9
2006	4		306.9	429.4	321.6	-26.3	-11.4	-22.7	-16.1	-17.2	-19.8
2007	4		-65.5	-61.5	-66.0	-37.9	-36.7	-42.9	0.8	-1.3	-2.3
2008	4		-33.6	-18.7	-24.5	-24.3	-15.8	-24.6	-20.6	-18.0	-20.5

2009	4		-25.1	-43.1	-25.3	-20.4	-21.6	-22.3	-10.7	-15.7	-12.0
2010	4		29.9	5.5	35.0	-24.8	-30.9	-28.7	-6.0	-10.4	-10.2
2004	5	LRW	14.6	117.2	65.0	-11.2	-16.5	-9.3	9.4	-41.9	-30.6
2005	5		-66.9	-7.5	-0.9	-20.2	196.6	258.9	102.6	80.4	103.7
2006	5		-21.2	147.7	225.0	-73.2	19.9	52.1	-49.2	-28.2	-29.6
2007	5		--	--	--	-62.5	34.5	9.9	41.5	41.5	80.2
2008	5		-53.5	30.4	56.2	39.3	94.2	110.2	-47.4	-41.3	-44.0
2009	5		--	--	--	21.5	59.2	45.6	29.9	2.2	2.6
2010	5		79.1	24.1	123.6	133.8	47.6	118.6	-28.8	-25.5	-24.2
2004	6	ORC	91.3	71.8	181.3	22.0	13.2	-7.1	24.5	8.4	9.3
2005	6		-15.6	-24.2	-23.5	4.2	-0.7	-19.7	7.2	-9.7	-11.7
2006	6		1274.1	1351.9	1748.1	-3.0	5.8	-6.3	22.9	19.0	10.0
2007	6		136.7	155.1	138.8	186.1	201.1	167.9	-22.0	-15.6	-24.2
2008	6		-4.8	112.7	-76.2	-15.8	-13.2	-18.4	3.6	15.4	3.7
2009	6		81.9	86.1	149.3	7.6	35.3	23.4	-20.9	-7.1	-19.9
2010	6		-26.1	-24.6	84.2	-57.2	-47.0	-54.6	-27.0	-16.2	-28.6
2004	7	RBH	48.8	48.0	51.2	-47.8	-46.3	-47.8	-2.0	-7.1	-11.9
2005	7		306.9	184.5	106.9	90.4	59.2	41.5	-3.4	-8.1	-14.2
2006	7		-27.6	0.6	-46.5	-24.1	-19.0	-26.5	-30.8	-14.8	-18.4
2007	7		-52.5	-46.3	-60.3	28.4	32.4	15.9	-3.7	1.0	-4.9
2008	7		-61.1	-57.9	-70.6	-37.4	-37.8	-48.1	-3.3	3.4	-3.4
2009	7		19.4	21.4	10.7	56.4	33.6	23.6	-13.1	-20.2	-25.4
2010	7		-54.4	-52.0	-62.6	25.5	9.8	-2.3	-2.1	-8.0	-13.9
2004	8	RBT	48.8	48.0	51.2	-47.8	-46.3	-47.8	-2.0	-7.1	-11.9
2005	8		306.9	184.5	106.9	90.4	59.2	41.5	-3.4	-8.1	-14.2
2006	8		-27.6	0.6	-46.5	-24.1	-19.0	-26.5	-30.8	-14.8	-18.4
2007	8		-52.5	-46.3	-60.3	28.4	32.4	15.9	-3.7	1.0	-4.9
2008	8		-61.1	-57.9	-70.6	-37.4	-37.8	-48.1	-3.3	3.4	-3.4
2009	8		19.4	21.4	10.7	56.4	33.6	23.6	-13.1	-20.2	-25.4
2010	8		-54.4	-52.0	-62.6	25.5	9.8	-2.3	-2.1	-8.0	-13.9
2004	9	SPR	-33.0	-44.7	-29.6	5.4	12.6	8.9	0.9	1.8	0.1
2005	9		-0.5	-25.7	-13.4	-16.9	-13.4	-17.6	2.4	2.6	0.9
2006	9		-60.1	-35.9	-16.8	-23.6	-4.3	-7.7	-2.1	-1.4	-3.0
2007	9		-72.4	-61.3	-68.7	-38.9	-32.5	-34.0	-2.3	-1.7	-3.1
2008	9		166.8	206.4	156.7	-29.2	-15.2	-13.3	-3.6	-2.2	-3.1
2009	9		-68.4	-70.2	-63.2	-22.1	-22.3	-21.0	-2.4	-1.2	-2.1
2010	9		-8.5	-27.6	-9.2	-23.9	-30.9	-29.4	-1.3	-2.1	-3.1
2004	10	URB	-39.0	-26.8	-20.3	-19.9	-23.1	-24.0	52.8	27.2	25.8
2005	10		-30.4	-20.6	-14.2	-1.8	-14.3	-18.3	29.0	13.2	8.2
2006	10		-81.5	-69.9	-68.3	-45.1	-32.8	-38.7	-20.9	-22.1	-26.6

2007	10		-77.3	-68.2	-65.7	-16.4	-2.0	-14.7	-26.2	-14.3	-21.5
2008	10		-83.4	-81.6	-79.8	-47.4	-35.5	-42.4	-28.5	-16.0	-21.0
2009	10		-38.2	-48.3	-31.0	26.9	25.7	14.0	-20.7	-17.8	-23.1
2010	10		-75.4	-78.2	-72.6	-14.0	-30.4	-37.2	24.3	16.2	7.0
2004	11	WSH	-85.1	-44.4	-52.7	-36.5	-28.5	-28.3	0.3	-0.1	-0.5
2005	11		-88.7	-71.5	-73.6	-3.6	-12.9	-8.0	1.5	1.0	0.0
2006	11		-41.0	-10.3	-5.1	-25.3	-30.8	-31.4	4.7	3.7	2.7
2007	11		3.5	-5.3	0.9	-9.9	-19.2	-22.1	1.1	0.9	-0.2
2008	11		-25.7	-56.3	-39.3	-14.4	-24.4	-23.5	-2.6	-2.1	-3.0
2009	11		-59.7	-78.1	-70.8	-17.0	-22.9	-23.6	-3.3	-1.7	-2.5
2010	11		-51.2	-77.7	-71.8	-23.2	-37.1	-38.8	-2.4	-1.1	-1.6
2004	12	FRL	-28.0	-30.3	-29.2	-20.0	-18.8	-34.0	11.4	13.3	5.3
2005	12		-31.3	-46.2	-49.4	-3.9	-19.6	27.0	-8.6	-6.4	-8.7
2006	12		-83.9	-85.4	-85.3	-63.0	-54.7	-70.9	-9.3	-8.0	-15.9
2007	12		-40.7	-55.1	-55.1	-63.3	-50.1	-54.7	-12.7	-8.4	-8.7
2008	12		-35.9	-40.0	-40.6	-62.1	-48.9	-15.2	-3.4	-2.6	5.0
2009	12		-50.8	-56.6	-55.5	19.8	20.0	28.6	7.5	5.3	12.6
2010	12		-10.7	-32.7	-40.3	-42.0	-48.6	-34.9	0.6	-6.2	-2.5

Note that Percent Error (PE) for a stock, age, calibration year and estimate type is calculated as:

$$PE = \left(\frac{(Estimate - Observed)}{Observed}\right) * 100\%$$

Appendix F. Mean Percent Error (MPE) of Three MR Estimates (3YA, 9YA and ETS) Relative to the Observed MR at Each of Three Ages for Chinook Model Stocks in the MATAEQ File.

Means are based on percent errors calculated by stock and age for calibration years 2004-2010 and are based directly on data in Appendix E. The statistical summary was limited to this set of calibrations because all observed MRs are from completed broods. Observed values were obtained from the results of the CTC-AWG's March 2015 cohort analysis procedure applied to CWT indicator stocks associated to the Chinook Model stocks in the MATAEQ file. Positive values indicate that the MPEs exceeded the actual MR at age. Negative values indicate the MPEs were below the actual MR at age. The first, second and third age are stock-dependent and are defined in the caption for Appendix A.

		First Age			Second Age			Third Age		
Stock #	Stock	3YA	9YA	ETS	3YA	9YA	ETS	3YA	9YA	ETS
1	AKS	17.2	11.4	18.2	-25.2	-48.7	-43.3	-7.4	-17.5	-16.5
2	BON	-53.8	-28.9	-42.1	-13.5	-5.2	1.8	1.3	3.6	2.0
3	CWF	-58.0	-24.3	-72.2	2.1	6.9	-0.3	-1.6	2.3	-0.7
4	GSH	18.1	36.8	23.0	-22.0	-13.4	-21.8	-7.3	-7.0	-7.6
5	LRW	-9.6	62.4	93.8	3.9	62.2	83.7	8.3	-1.8	8.3
6	ORC	219.6	247.0	314.6	20.6	27.8	12.1	-1.7	-0.8	-8.8
7	RBH	25.6	14.0	-10.2	13.1	4.6	-6.2	-8.4	-7.7	-13.2
8	RBT	25.6	14.0	-10.2	13.1	4.6	-6.2	-8.4	-7.7	-13.2
9	SPR	-10.9	-8.4	-6.3	-21.3	-15.1	-16.3	-1.2	-0.6	-1.9
10	URB	-60.7	-56.2	-50.3	-16.8	-16.1	-23.1	1.4	-1.9	-7.3
11	WSH	-49.7	-49.1	-44.6	-18.6	-25.1	-25.1	-0.1	0.1	-0.7
12	FRL	-40.2	-49.5	-50.8	-33.5	-31.6	-22.0	-2.1	-1.9	-1.8
Grand MPE		2.2	12.9	11.6	-8.2	-4.1	-5.6	-2.2	-3.4	-5.1

Note that Mean Percent Error for a stock at age and forecast method is calculated as:

$$MPE = \frac{\sum_{clb=2004}^{clb=2010}\left(\frac{(Estimate-Observed)}{Observed}\right)}{NumCalibrations} * 100\%$$

NumCalibrations in the above formula equals 7 at each age for all stocks except the first age for LRW. The observed value for the first age was zero in two years (2007 and 2009, see Appendix E) and thus MPE could not be calculated.

The sample size and denominator for the Grand MPE = 7 calibrations x 12 stocks = 84.

Appendix G. Squared Error for Three MR Estimates (3YA, 9YA and ETS) Relative to the Observed MR at Age for Model Stocks in the MATAEQ File for the 2004-2010 Chinook Model calibrations.

All contributing broods were complete through to the 2010 Chinook Model calibration for each of the Model stocks based on using observed MRs from the exploitation rate analysis conducted by the CTC-AWG in March 2015. The first, second and third age are stock-dependent and are defined in the caption for Appendix A.

			First Age			Second Age			Third Age		
CLB Year	Stock #	Stock	3YA	9YA	ETS	3YA	9YA	ETS	3YA	9YA	ETS
2004	1	AKS	0.00012	0.00005	0.00013	0.02904	0.05108	0.04423	0.00035	0.01695	0.00846
2005	1		0.00003	0.00001	0.00000	0.00054	0.00805	0.00635	0.00000	0.02190	0.01603
2006	1		0.00005	0.00005	0.00003	0.00086	0.00576	0.00506	0.00068	0.01817	0.01938
2007	1		0.00015	0.00018	0.00013	0.00462	0.00912	0.00949	0.00025	0.00473	0.00612
2008	1		0.00003	0.00001	0.00006	0.00308	0.01479	0.00753	0.03587	0.02683	0.03729
2009	1		0.00077	0.00082	0.00002	0.00937	0.02500	0.01847	0.00929	0.02256	0.01680
2010	1		0.00000	0.00004	0.00000	0.00027	0.00558	0.00419	0.01228	0.02493	0.02161
2004	2	BON	0.00000	0.00031	0.00002	0.07607	0.09548	0.14003	0.00852	0.00929	0.00479
2005	2		0.00025	0.00007	0.00011	0.01160	0.00669	0.00000	0.00008	0.00031	0.00006
2006	2		0.00069	0.00045	0.00068	0.00036	0.00006	0.00034	0.04584	0.04814	0.02786
2007	2		0.00152	0.00123	0.00141	0.19749	0.17189	0.17564	0.00238	0.00141	0.00197
2008	2		0.00044	0.00021	0.00021	0.08220	0.03140	0.03523	0.00315	0.00132	0.00192
2009	2		0.00011	0.00001	0.00003	0.17040	0.10903	0.09278	0.00882	0.00070	0.00013
2010	2		0.00373	0.00373	0.00343	0.10910	0.10517	0.09199	0.00958	0.00353	0.00241
2004	3	CWF	0.00000	0.00050	0.00004	0.01667	0.01491	0.00746	0.09333	0.10043	0.08077
2005	3		0.00047	0.00000	0.00085	0.00491	0.00291	0.00469	0.01383	0.00107	0.00635
2006	3		0.01570	0.01381	0.02062	0.02250	0.01203	0.02140	0.00203	0.00073	0.00036
2007	3		0.00151	0.00203	0.00131	0.06933	0.06345	0.05350	0.04713	0.02599	0.02880
2008	3		0.00415	0.00432	0.00567	0.01008	0.00069	0.00679	0.08964	0.06136	0.06235
2009	3		0.00051	0.00025	0.00045	0.01949	0.01636	0.02025	0.03760	0.02560	0.02434
2010	3		0.00095	0.00078	0.00103	0.00863	0.00951	0.00908	0.01790	0.00410	0.00317
2004	4	GSH	0.00635	0.00444	0.00564	0.00000	0.00771	0.00059	0.00483	0.00004	0.00104
2005	4		0.00008	0.00000	0.00006	0.00621	0.00182	0.00671	0.00560	0.00863	0.01277
2006	4		0.00098	0.00192	0.00108	0.01071	0.00202	0.00801	0.02403	0.02746	0.03621
2007	4		0.00681	0.00601	0.00692	0.04048	0.03814	0.05194	0.00004	0.00010	0.00032
2008	4		0.00034	0.00011	0.00018	0.00904	0.00382	0.00925	0.03818	0.02921	0.03799
2009	4		0.00044	0.00129	0.00045	0.00661	0.00741	0.00790	0.01004	0.02152	0.01254
2010	4		0.00020	0.00001	0.00027	0.01293	0.02011	0.01732	0.00283	0.00841	0.00817

2004	5	LRW	0.00004	0.00233	0.00072	0.00019	0.00041	0.00013	0.00320	0.06396	0.03411
2005	5		0.00132	0.00002	0.00000	0.00004	0.00341	0.00591	0.04423	0.02719	0.04520
2006	5		0.00001	0.00038	0.00088	0.00239	0.00018	0.00121	0.04977	0.01633	0.01804
2007	5		0.00019	0.00081	0.00151	0.00120	0.00036	0.00003	0.01214	0.01212	0.04524
2008	5		0.00013	0.00004	0.00015	0.00023	0.00130	0.00177	0.08779	0.06641	0.07552
2009	5		0.00050	0.00057	0.00173	0.00011	0.00080	0.00048	0.01061	0.00006	0.00008
2010	5		0.00023	0.00002	0.00056	0.00193	0.00024	0.00151	0.01727	0.01353	0.01219
2004	6	ORC	0.00048	0.00030	0.00191	0.00075	0.00027	0.00008	0.00988	0.00116	0.00144
2005	6		0.00007	0.00016	0.00015	0.00004	0.00000	0.00083	0.00160	0.00287	0.00419
2006	6		0.00118	0.00133	0.00223	0.00002	0.00007	0.00009	0.00955	0.00656	0.00181
2007	6		0.00040	0.00052	0.00042	0.01040	0.01214	0.00846	0.01796	0.00904	0.02173
2008	6		0.00000	0.00020	0.00009	0.00069	0.00048	0.00094	0.00027	0.00489	0.00029
2009	6		0.00014	0.00015	0.00046	0.00007	0.00140	0.00062	0.01369	0.00158	0.01243
2010	6		0.00008	0.00007	0.00082	0.02644	0.01782	0.02409	0.02650	0.00953	0.02962
2004	7	RBH	0.00004	0.00004	0.00004	0.02076	0.01949	0.02079	0.00020	0.00258	0.00726
2005	7		0.00032	0.00011	0.00004	0.01073	0.00461	0.00227	0.00065	0.00362	0.01111
2006	7		0.00002	0.00000	0.00006	0.00270	0.00169	0.00328	0.05537	0.01272	0.01982
2007	7		0.00016	0.00013	0.00021	0.00152	0.00198	0.00048	0.00062	0.00004	0.00107
2008	7		0.00037	0.00033	0.00050	0.01418	0.01450	0.02344	0.00048	0.00051	0.00051
2009	7		0.00000	0.00000	0.00000	0.00561	0.00199	0.00098	0.01270	0.03038	0.04805
2010	7		0.00026	0.00023	0.00034	0.00189	0.00028	0.00002	0.00025	0.00356	0.01088
2004	8	RBT	0.00004	0.00004	0.00004	0.02076	0.01949	0.02079	0.00020	0.00258	0.00726
2005	8		0.00032	0.00011	0.00004	0.01073	0.00461	0.00227	0.00065	0.00362	0.01111
2006	8		0.00002	0.00000	0.00006	0.00270	0.00169	0.00328	0.05537	0.01272	0.01982
2007	8		0.00016	0.00013	0.00021	0.00152	0.00198	0.00048	0.00062	0.00004	0.00107
2008	8		0.00037	0.00033	0.00050	0.01418	0.01450	0.02344	0.00048	0.00051	0.00051
2009	8		0.00000	0.00000	0.00000	0.00561	0.00199	0.00098	0.01270	0.03038	0.04805
2010	8		0.00026	0.00023	0.00034	0.00189	0.00028	0.00002	0.00025	0.00356	0.01088
2004	9	SPR	0.00122	0.00224	0.00098	0.00102	0.00569	0.00280	0.00008	0.00029	0.00000
2005	9		0.00000	0.00046	0.00013	0.01793	0.01124	0.01929	0.00054	0.00061	0.00007
2006	9		0.00300	0.00107	0.00023	0.02713	0.00088	0.00286	0.00042	0.00018	0.00092
2007	9		0.01197	0.00857	0.01077	0.14251	0.09986	0.10890	0.00053	0.00030	0.00095
2008	9		0.00097	0.00149	0.00086	0.04635	0.01257	0.00955	0.00132	0.00050	0.00097
2009	9		0.02117	0.02229	0.01804	0.03251	0.03283	0.02914	0.00054	0.00015	0.00042
2010	9		0.00006	0.00062	0.00007	0.04765	0.07998	0.07220	0.00017	0.00043	0.00094
2004	10	URB	0.00021	0.00010	0.00006	0.00184	0.00249	0.00269	0.06190	0.01646	0.01481
2005	10		0.00008	0.00004	0.00002	0.00001	0.00086	0.00141	0.02493	0.00520	0.00202
2006	10		0.00425	0.00312	0.00298	0.01506	0.00799	0.01111	0.02832	0.03151	0.04584
2007	10		0.00299	0.00233	0.00216	0.00100	0.00001	0.00080	0.03838	0.01151	0.02595
2008	10		0.00889	0.00852	0.00815	0.01863	0.01049	0.01493	0.04452	0.01399	0.02418

2009	10		0.00027	0.00043	0.00018	0.00159	0.00145	0.00043	0.02538	0.01888	0.03165
2010	10		0.00539	0.00579	0.00498	0.00148	0.00696	0.01040	0.01852	0.00823	0.00155
2004	11	WSH	0.00042	0.00011	0.00016	0.05171	0.03151	0.03115	0.00001	0.00000	0.00003
2005	11		0.00142	0.00092	0.00098	0.00032	0.00408	0.00155	0.00021	0.00009	0.00000
2006	11		0.00002	0.00000	0.00000	0.02876	0.04252	0.04427	0.00198	0.00122	0.00065
2007	11		0.00000	0.00000	0.00000	0.00339	0.01275	0.01677	0.00011	0.00008	0.00000
2008	11		0.00003	0.00013	0.00007	0.00792	0.02277	0.02111	0.00068	0.00045	0.00088
2009	11		0.00082	0.00140	0.00115	0.01107	0.02019	0.02132	0.00104	0.00030	0.00064
2010	11		0.00076	0.00176	0.00150	0.03291	0.08410	0.09217	0.00057	0.00013	0.00026
2004	12	FRL	0.00095	0.00111	0.00103	0.00406	0.00360	0.01177	0.00837	0.01132	0.00181
2005	12		0.00245	0.00536	0.00612	0.00012	0.00315	0.00593	0.00667	0.00364	0.00676
2006	12		0.11526	0.11951	0.11930	0.09585	0.07236	0.12138	0.00803	0.00587	0.02320
2007	12		0.00304	0.00558	0.00558	0.07612	0.04779	0.05683	0.01445	0.00642	0.00682
2008	12		0.00135	0.00166	0.00172	0.07054	0.04385	0.00425	0.00092	0.00054	0.00199
2009	12		0.00498	0.00619	0.00596	0.00127	0.00130	0.00264	0.00401	0.00197	0.01119
2010	12		0.00014	0.00129	0.00195	0.03312	0.04444	0.02289	0.00004	0.00346	0.00057

Note that Squared Error for a stock, age, calibration year and forecast method is calculated as:

$$SqE = (Estimate - Observed)^2$$

Appendix H. Mean Squared Error (MSE) for Three MR Estimates (3YA, 9YA and ETS) Relative to the Observed MR at Three Ages for the Chinook Model Stocks in the MATAEQ File.

Means are based on squared errors calculated for calibration years 2004-2010 and are based directly on data in Appendix G. All contributing broods for each Chinook Model stock were complete for these calibrations based on results from the exploitation rate analysis conducted by the CTC-AWG in March 2015. A smaller value for MSE indicates less error. The first, second and third age are stock-dependent and are defined in the caption for Appendix A.

	Model	First Age			Second Age			Third Age		
Stock #	Stock	3YA	9YA	ETS	3YA	9YA	ETS	3YA	9YA	ETS
1	AKS	0.0002	0.0002	0.0001	0.0068	0.0270	0.0305	0.0084	0.0278	0.0197
2	BON	0.0010	0.0009	0.0008	0.0925	0.0111	0.0108	0.0112	0.0076	0.0057
3	CWF	0.0033	0.0031	0.0043	0.0217	0.0041	0.0060	0.0431	0.0068	0.0130
4	GSH	0.0022	0.0020	0.0021	0.0123	0.0040	0.0062	0.0122	0.0148	0.0132
5	LRW	0.0003	0.0006	0.0008	0.0009	0.0079	0.0094	0.0321	0.0116	0.0153
6	ORC	0.0003	0.0004	0.0009	0.0055	0.0525	0.0601	0.0113	0.0085	0.0182
7	RBH	0.0002	0.0001	0.0002	0.0082	0.0256	0.0274	0.0100	0.0065	0.0105
8	RBT	0.0002	0.0001	0.0002	0.0082	0.0095	0.0144	0.0100	0.0235	0.0256
9	SPR	0.0055	0.0052	0.0044	0.0450	0.0343	0.0259	0.0005	0.0092	0.0099
10	URB	0.0032	0.0029	0.0026	0.0057	0.0068	0.0058	0.0346	0.0147	0.0219
11	WSH	0.0005	0.0006	0.0006	0.0194	0.0232	0.0211	0.0007	0.0081	0.0085
12	FRL	0.0183	0.0201	0.0202	0.0402	0.0334	0.0317	0.0061	0.0041	0.0078
Grand MSE		0.0029	0.0030	0.0031	0.0222	0.0199	0.0208	0.0150	0.0119	0.0141

Note that Mean Squared Error for a stock at age and forecast method is calculated as:

$$MSE = \frac{\sum_{clb=2004}^{clb=2010}(Estimate - Observed)^2}{7}$$

The sample size and denominator for the Grand MSE = 7 calibrations x 12 stocks = 84.

Appendix I. Preseason (Pre) to First Postseason (Post 1) Squared Error (SQE) and Percent Error (PE) Calculated for Each AABM Fishery and Calibration Years 2004-2013 for All MR Estimation models.

3YA MRs

	SEAK				NBC				WCVI			
Year	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE
2004	1.68	1.81	0.0169	-7.2%	1.57	1.63	0.0036	-3.7%	0.87	0.93	0.0036	-6.5%
2005	1.74	1.86	0.0144	-6.5%	1.46	1.59	0.0169	-8.2%	0.80	0.86	0.0036	-7.0%
2006	1.65	1.68	0.0009	-1.8%	1.45	1.45	0.0000	0.0%	0.75	0.68	0.0049	10.2%
2007	1.56	1.30	0.0676	20.0%	1.30	1.07	0.0529	21.5%	0.67	0.58	0.0081	15.5%
2008	1.04	0.95	0.0081	9.5%	0.93	0.90	0.0009	3.3%	0.82	0.63	0.0360	30.1%
2009	1.22	1.12	0.0100	8.9%	1.04	1.01	0.0009	3.0%	0.69	0.59	0.0093	16.4%
2010	1.16	1.19	0.0009	-2.5%	1.06	1.15	0.0081	-7.8%	0.87	0.88	0.0001	-1.1%
2011	1.46	1.47	0.0001	-0.7%	1.25	1.30	0.0025	-3.8%	0.95	0.82	0.0169	15.9%
2012	1.26	1.22	0.0016	3.3%	1.18	1.13	0.0025	4.4%	0.73	0.71	0.0004	2.8%
2013	1.25	1.66	0.1681	-24.7%	1.15	1.53	0.1444	-24.8%	0.78	1.06	0.0784	-26.4%

5YA MRs

	SEAK				NBC				WCVI			
Year	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE
2004	1.70	1.90	0.0400	-10.5%	1.58	1.70	0.0144	-7.1%	0.85	0.94	0.0081	-9.6%
2005	1.87	1.80	0.0049	3.9%	1.54	1.54	0.0000	0.0%	0.81	0.82	0.0001	-1.2%
2006	1.56	1.61	0.0025	-3.1%	1.38	1.40	0.0004	-1.4%	0.70	0.67	0.0009	4.5%
2007	1.48	1.27	0.0441	16.5%	1.24	1.05	0.0361	18.1%	0.63	0.57	0.0036	10.5%
2008	1.00	0.96	0.0016	4.2%	0.90	0.90	0.0000	0.0%	0.77	0.63	0.0196	22.2%
2009	1.23	1.16	0.0049	6.0%	1.03	1.03	0.0000	0.0%	0.69	0.62	0.0044	10.8%
2010	1.23	1.23	0.0000	0.0%	1.11	1.17	0.0036	-5.1%	0.97	0.91	0.0036	6.6%
2011	1.52	1.50	0.0004	1.3%	1.30	1.32	0.0004	-1.5%	1.04	0.84	0.0400	23.8%
2012	1.30	1.21	0.0081	7.4%	1.20	1.12	0.0064	7.1%	0.77	0.71	0.0036	8.5%
2013	1.22	1.67	0.2025	-26.9%	1.13	1.55	0.1764	-27.1%	0.78	1.05	0.0729	-25.7%

7YA MRs

	SEAK				NBC				WCVI			
Year	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE
2004	1.72	1.88	0.0237	-8.2%	1.57	1.67	0.0114	-6.4%	0.84	0.93	0.0076	-9.4%
2005	1.83	1.79	0.0014	2.1%	1.50	1.55	0.0023	-3.1%	0.79	0.81	0.0003	-2.1%
2006	1.56	1.65	0.0083	-5.5%	1.38	1.43	0.0018	-2.9%	0.68	0.67	0.0001	1.7%
2007	1.53	1.27	0.0713	21.1%	1.27	1.04	0.0541	22.4%	0.63	0.56	0.0052	13.0%
2008	0.99	0.95	0.0018	4.5%	0.88	0.88	0.0000	-0.4%	0.73	0.63	0.0106	16.5%
2009	1.21	1.16	0.0031	4.8%	1.02	1.03	0.0002	-1.4%	0.68	0.62	0.0043	10.6%
2010	1.22	1.24	0.0005	-1.8%	1.10	1.18	0.0065	-6.8%	0.96	0.93	0.0012	3.7%
2011	1.55	1.54	0.0001	0.6%	1.31	1.35	0.0014	-2.7%	1.08	0.90	0.0333	20.4%
2012	1.38	1.24	0.0185	10.9%	1.25	1.14	0.0120	9.6%	0.83	0.73	0.0096	13.4%
2013	1.27	1.69	0.1716	-24.5%	1.17	1.57	0.1560	-25.2%	0.82	1.07	0.0602	-23.0%

8YA MRs

	SEAK				NBC				WCVI			
Year	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE
2004	1.77	1.92	0.0218	-7.7%	1.60	1.70	0.0095	-5.7%	0.86	0.94	0.0068	-8.8%
2005	1.89	1.79	0.0104	5.7%	1.53	1.54	0.0000	0.0%	0.81	0.80	0.0000	0.6%
2006	1.55	1.63	0.0073	-5.2%	1.36	1.41	0.0026	-3.6%	0.67	0.66	0.0001	1.7%
2007	1.51	1.28	0.0553	18.4%	1.26	1.05	0.0450	20.2%	0.62	0.56	0.0034	10.4%
2008	1.00	0.96	0.0019	4.6%	0.89	0.89	0.0000	-0.2%	0.73	0.63	0.0107	16.5%
2009	1.23	1.15	0.0062	6.9%	1.03	1.02	0.0000	0.5%	0.68	0.61	0.0052	11.9%
2010	1.20	1.24	0.0014	-3.0%	1.08	1.18	0.0090	-8.1%	0.93	0.93	0.0000	-0.3%
2011	1.55	1.54	0.0003	1.0%	1.31	1.35	0.0013	-2.6%	1.10	0.89	0.0416	22.9%
2012	1.38	1.25	0.0159	10.1%	1.25	1.14	0.0118	9.5%	0.82	0.74	0.0067	11.1%
2013	1.29	1.71	0.1789	-24.7%	1.18	1.59	0.1690	-25.9%	0.84	1.08	0.0592	-22.5%

9YA MRs

	SEAK				NBC				WCVI			
Year	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE
2004	1.81	1.90	0.0081	-4.7%	1.63	1.70	0.0040	-3.7%	0.87	0.94	0.0057	-8.0%
2005	1.87	1.81	0.0033	3.2%	1.54	1.55	0.0001	-0.7%	0.81	0.81	0.0001	0.9%
2006	1.58	1.62	0.0020	-2.7%	1.39	1.41	0.0003	-1.3%	0.68	0.66	0.0006	3.6%
2007	1.51	1.27	0.0572	18.9%	1.25	1.04	0.0421	19.7%	0.61	0.55	0.0033	10.4%
2008	0.99	0.96	0.0009	3.2%	0.88	0.89	0.0001	-1.3%	0.72	0.63	0.0080	14.3%
2009	1.23	1.16	0.0059	6.6%	1.03	1.03	0.0000	0.2%	0.68	0.61	0.0050	11.5%
2010	1.22	1.23	0.0001	-0.9%	1.09	1.17	0.0056	-6.4%	0.93	0.92	0.0001	1.0%
2011	1.53	1.54	0.0001	-0.5%	1.29	1.35	0.0030	-4.1%	1.07	0.90	0.0301	19.3%
2012	1.38	1.26	0.0135	9.2%	1.25	1.15	0.0104	8.9%	0.84	0.74	0.0088	12.6%
2013	1.30	1.72	0.1774	-24.4%	1.18	1.59	0.1680	-25.7%	0.84	1.10	0.0635	-23.0%

10YA MRs

	SEAK				NBC				WCVI			
Year	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE
2004	1.84	1.99	0.0219	-7.5%	1.66	1.75	0.0083	-5.2%	0.88	0.95	0.0058	-8.0%
2005	1.99	1.83	0.0241	8.5%	1.60	1.57	0.0012	2.2%	0.83	0.81	0.0005	2.8%
2006	1.61	1.64	0.0011	-2.1%	1.41	1.42	0.0001	-0.6%	0.69	0.66	0.0007	4.0%
2007	1.53	1.26	0.0715	21.2%	1.26	1.04	0.0512	21.8%	0.62	0.55	0.0042	11.7%
2008	0.99	0.96	0.0011	3.4%	0.87	0.89	0.0001	-1.4%	0.71	0.62	0.0079	14.3%
2009	1.22	1.16	0.0034	5.0%	1.02	1.03	0.0002	-1.3%	0.67	0.61	0.0037	10.0%
2010	1.23	1.24	0.0001	-0.7%	1.10	1.17	0.0053	-6.2%	0.93	0.92	0.0001	0.9%
2011	1.55	1.53	0.0004	1.2%	1.30	1.34	0.0012	-2.6%	1.08	0.89	0.0343	20.7%
2012	1.36	1.26	0.0108	8.3%	1.23	1.14	0.0082	7.9%	0.83	0.75	0.0069	11.1%
2013	1.30	1.73	0.1856	-24.8%	1.18	1.60	0.1759	-26.1%	0.85	1.10	0.0607	-22.4%

11YA MRs

	SEAK				NBC				WCVI			
Year	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE
2004	1.85	2.00	0.0241	-7.8%	1.67	1.77	0.0086	-5.2%	0.89	0.96	0.0049	-7.3%
2005	2.01	1.86	0.0246	8.4%	1.63	1.59	0.0014	2.4%	0.85	0.82	0.0008	3.5%
2006	1.64	1.67	0.0005	-1.3%	1.44	1.43	0.0000	0.2%	0.69	0.66	0.0010	4.7%
2007	1.56	1.28	0.0786	22.0%	1.28	1.05	0.0551	22.4%	0.62	0.56	0.0044	12.0%
2008	1.00	0.96	0.0022	4.9%	0.88	0.89	0.0000	-0.2%	0.72	0.62	0.0093	15.5%
2009	1.22	1.16	0.0039	5.4%	1.01	1.03	0.0001	-1.1%	0.67	0.61	0.0037	10.0%
2010	1.22	1.25	0.0006	-2.0%	1.09	1.18	0.0074	-7.3%	0.92	0.92	0.0000	-0.5%
2011	1.56	1.54	0.0004	1.3%	1.31	1.34	0.0010	-2.4%	1.08	0.90	0.0333	20.3%
2012	1.38	1.24	0.0171	10.5%	1.24	1.13	0.0123	9.8%	0.83	0.74	0.0078	11.9%
2013	1.29	1.74	0.2048	-26.0%	1.17	1.60	0.1910	-27.2%	0.85	1.11	0.0661	-23.3%

LTA MRs

	SEAK				NBC				WCVI			
Year	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE
2004	1.89	2.06	0.0289	-8.3%	1.72	1.82	0.0100	-5.5%	0.93	0.99	0.0036	-6.1%
2005	2.08	1.90	0.0324	9.5%	1.70	1.64	0.0036	3.7%	0.90	0.84	0.0036	7.1%
2006	1.70	1.73	0.0009	-1.7%	1.51	1.50	0.0001	0.7%	0.74	0.69	0.0025	7.2%
2007	1.64	1.34	0.0900	22.4%	1.36	1.09	0.0729	24.8%	0.67	0.57	0.0100	17.5%
2008	1.06	1.00	0.0036	6.0%	0.94	0.92	0.0004	2.2%	0.76	0.64	0.0144	18.8%
2009	1.30	1.20	0.0100	8.3%	1.07	1.06	0.0001	0.9%	0.71	0.63	0.0064	12.7%
2010	1.31	1.30	0.0001	0.8%	1.16	1.23	0.0049	-5.7%	1.00	0.95	0.0025	5.3%
2011	1.68	1.62	0.0036	3.7%	1.40	1.41	0.0001	-0.7%	1.15	0.90	0.0625	27.8%
2012	1.51	1.32	0.0361	14.4%	1.35	1.20	0.0225	12.5%	0.90	0.77	0.0169	16.9%
2013	1.41	1.82	0.1681	-22.5%	1.27	1.68	0.1681	-24.4%	0.91	1.15	0.0576	-20.9%

ETS MRs

	SEAK				NBC				WCVI			
Year	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE	Pre	Post 1	SQE	PE
2004	1.85	2.05	0.0384	-9.6%	1.69	1.80	0.0133	-6.4%	0.90	0.96	0.0032	-5.9%
2005	2.02	1.89	0.0192	7.3%	1.65	1.62	0.0009	1.8%	0.82	0.84	0.0006	-3.0%
2006	1.66	1.72	0.0038	-3.6%	1.46	1.48	0.0003	-1.1%	0.75	0.67	0.0058	11.4%
2007	1.59	1.33	0.0714	20.1%	1.31	1.08	0.0535	21.3%	0.64	0.55	0.0070	15.2%
2008	1.03	1.00	0.0010	3.2%	0.91	0.92	0.0000	-0.5%	0.67	0.63	0.0020	7.0%
2009	1.28	1.19	0.0069	7.0%	1.06	1.06	0.0000	0.6%	0.69	0.61	0.0052	11.7%
2010	1.29	1.29	0.0000	-0.1%	1.15	1.21	0.0047	-5.6%	0.91	0.94	0.0005	-2.5%
2011	1.62	1.60	0.0004	1.3%	1.36	1.38	0.0006	-1.7%	1.09	0.90	0.0332	20.1%
2012	1.46	1.19	0.0729	22.7%	1.30	1.10	0.0417	18.6%	0.84	0.72	0.0142	16.5%
2013	1.29	1.64	0.1195	-21.1%	1.17	1.52	0.1240	-23.1%	0.83	1.05	0.0506	-21.4%