Assessing the Impacts of Environmental and Ecological variables on the Performance of Fraser Sockeye Salmon Forecast

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Supplementary materials

Table S1. Naïve models and their model descriptions.

LLY	Return from the previous year; $Ret_t = Ret_{t-1} + \varepsilon_t$, where Ret_{t-1} is the observed return during the previous year (t-1)
R1C	Return from 4 years before the forecast year; $Ret_t = Ret_{t-4} + \varepsilon_t$, where Ret_{t-4} is the observed return four years prior to the forecasted return
R2C	Geometric mean return from 4 and 8 years before the forecast year; $Ret_t = \exp\left[\frac{log_e(Ret_{t-4})+log_e(Ret_{t-8})}{2} + \varepsilon_t\right]$, where Ret_{t-4} and Ret_{t-8} are the observed returns four and eight years prior to the forecasted return
RAC	Geometric mean return on the forecast cycle line for all years; $Ret_t = \exp\left[\frac{log_e(Ret_{t-4})+log_e(Ret_{t-8})...+log_e(Ret_{t-x})}{n} + \varepsilon_t\right]$, where *t-x* is the first cycle-line year with return data, and n is the number of cycle-line years with return data
TSA	Geometric mean return across all years; $Ret_t = \exp[\frac{log_e(Ret_{t-1})+log_e(Ret_{t-2})...+log_e(Ret_{t-N})}{N} + \varepsilon_t]$, where *N* is the number of years with return data
RS1	Product of average survival from 4 years before the forecast year and the forecast brood year EFS; $R_t = \left(\frac{R_{t-4}}{eff_{t-4}}\right) \times (eff_t) + \varepsilon_t$, where R_{t-4} is the recruits resulting from the EFS(eff_{t-4}) in the brood year four years prior to most recent brood year
RS2	Product of average survival from 4 and 8 years before the forecast year and the forecast brood year EFS; $R_t = \exp\left[\frac{log_e\left(\frac{R_{t-4}}{eff_{t-4}}\right)+log_e\left(\frac{R_{t-8}}{eff_{t-8}}\right)}{2} + log_e(eff_t) + \varepsilon_t\right]$, where R_{t-4} and R_{t-8} are the recruits resulting from the previous two cycle-line brood years (4 & 8 years prior to most recent brood year), and eff_{t-4} and eff_{t-8} are the number of EFS in the previous two cycle-line brood years
RS4yr	Product of average survival from the last 4 consecutive years and the forecast brood year EFS; $R_t = \exp\left[\frac{log_e\left(\frac{R_{t-1}}{eff_{t-1}}\right)+log_e\left(\frac{R_{t-2}}{eff_{t-2}}\right)+log_e\left(\frac{R_{t-3}}{eff_{t-3}}\right)+log_e\left(\frac{R_{t-4}}{eff_{t-4}}\right)}{4} + log_e(eff_t) + \varepsilon_t\right]$, where R_t are the recruits (3, 4, and 5 year old fish) resulting from spawners in the brood year
RS8yr	Product of average survival from the last consecutive 8 years and the forecast brood year EFS; $R_t = \exp\left[\frac{log_e\left(\frac{R_{t-1}}{eff_{t-1}}\right)+log_e\left(\frac{R_{t-2}}{eff_{t-2}}\right)+log_e\left(\frac{R_{t-3}}{eff_{t-3}}\right)...+log_e\left(\frac{R_{t-8}}{eff_{t-8}}\right)}{4} + log_e(eff_t) + \varepsilon_t\right]$, where R_t are the recruits (3, 4, and 5 year old fish) resulting from spawners in the brood year
MRS	Product of average survival for all years and the forecast brood year EFS; $R_t = \exp\left[\frac{log_e\left(\frac{R_{t-1}}{eff_{t-1}}\right)+log_e\left(\frac{R_{t-2}}{eff_{t-2}}\right)...+log_e\left(\frac{R_{t-N}}{eff_{t-N}}\right)}{4} + log_e(eff_t) + \varepsilon_t\right]$, where R_t are the recruits (3, 4, and 5 year old fish) resulting from spawners in the brood year and *N* is the number of years with data
RSC	Product of average cycle-line survival (entire time series) and the forecast brood year EFS; $R_t = \exp\left[\frac{log_e\left(\frac{R_{t-4}}{eff_{t-4}}\right)+log_e\left(\frac{R_{t-8}}{eff_{t-8}}\right)...+log_e\left(\frac{R_{t-x}}{eff_{t-x}}\right)}{4} + log_e(eff_t) + \varepsilon_t\right]$, where *t-x* is the first cycle-line year with data, and *n* is the number of cycle-line years with data.

Table S2. Summary of 2021 and 2022 sockeye runs

	2021			2022		
	Forecast Return	Observed Return	(Observed-Forecast)/Forecast	Forecast Return	Observed Return	(Observed-Forecast)/Forecast
Bristol Bay[1]	51,000,000	65,860,000	+29%	75,270,000	79,000,000	+5%
Nass[2]	318,000	417,000	+31%	471,000	487,000	+3%
Skeena[3]	1,690,000	1,030,000	-39%	2,054,000	4,333,344	+111%
Somass[4]	350,000	365,000	+4%	400,000	910,513	+128%
Fraser River	**1,330,000**	**2,549,000**	**+92%**	**9,775,000**	**6,836,789**	**-30%**
Baker Lake[5]	11,400	20,800	+82%	27,081	25,738	-5%
Lake Washington[6]	24,800	38,600	+56%	10,165	43,289	+326%
Columbia River[7]	155,600	151,800	-2%	198,700	663,253	+234%

Source: PSC 2021; PSC 2022

[1]https://www.adfg.alaska.gov/index.cfm?adfg=commercialbyareabristolbay.harvestsummary
[2]https://www.nisgaanation.ca/stock-assessments

[3]http://www.pac.dfo-mpo.gc.ca/fm-gp/northcoast-cotenord/skeenatyee-eng.html

[4]https://www.roundtables.westcoastaquatic.ca/area-23-barkley-harvest

[5]https://wdfw.wa.gov/fishing/reports/counts/baker-river#returns

[6]https://wdfw.wa.gov/fishing/reports/counts/lake-washington#sockeye

[7]https://www.fpc.org/webapps/adultsalmon/Q_adultcounts_dataquery.php

Figure S1. Area (red polygon) where tagged Sockeye salmon were captured. Numbers are months when captured Sockeye salmon were tagged. Sea surface temperature was averaged over the polygon and used as a predictor for Sockeye salmon dynamics.

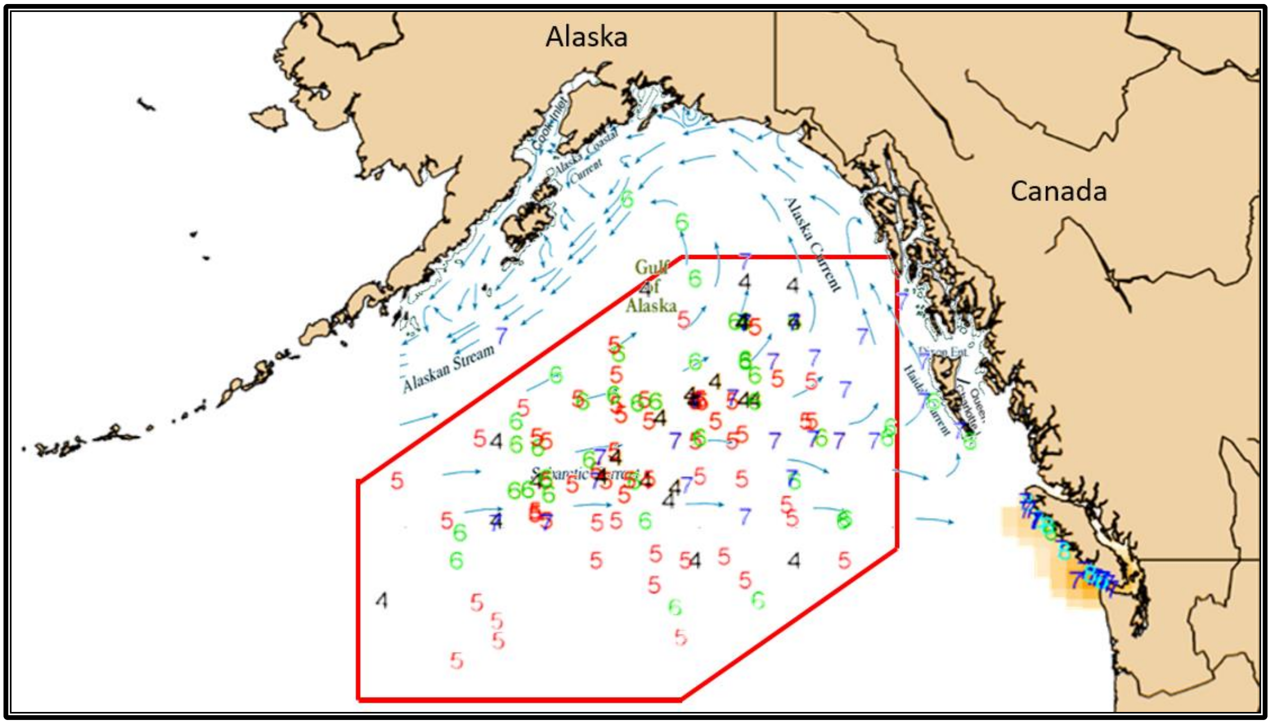


Figure S2. Observed and previously forecast Fraser sockeye adult returns for the 18 major stocks from 2009 to 2020.

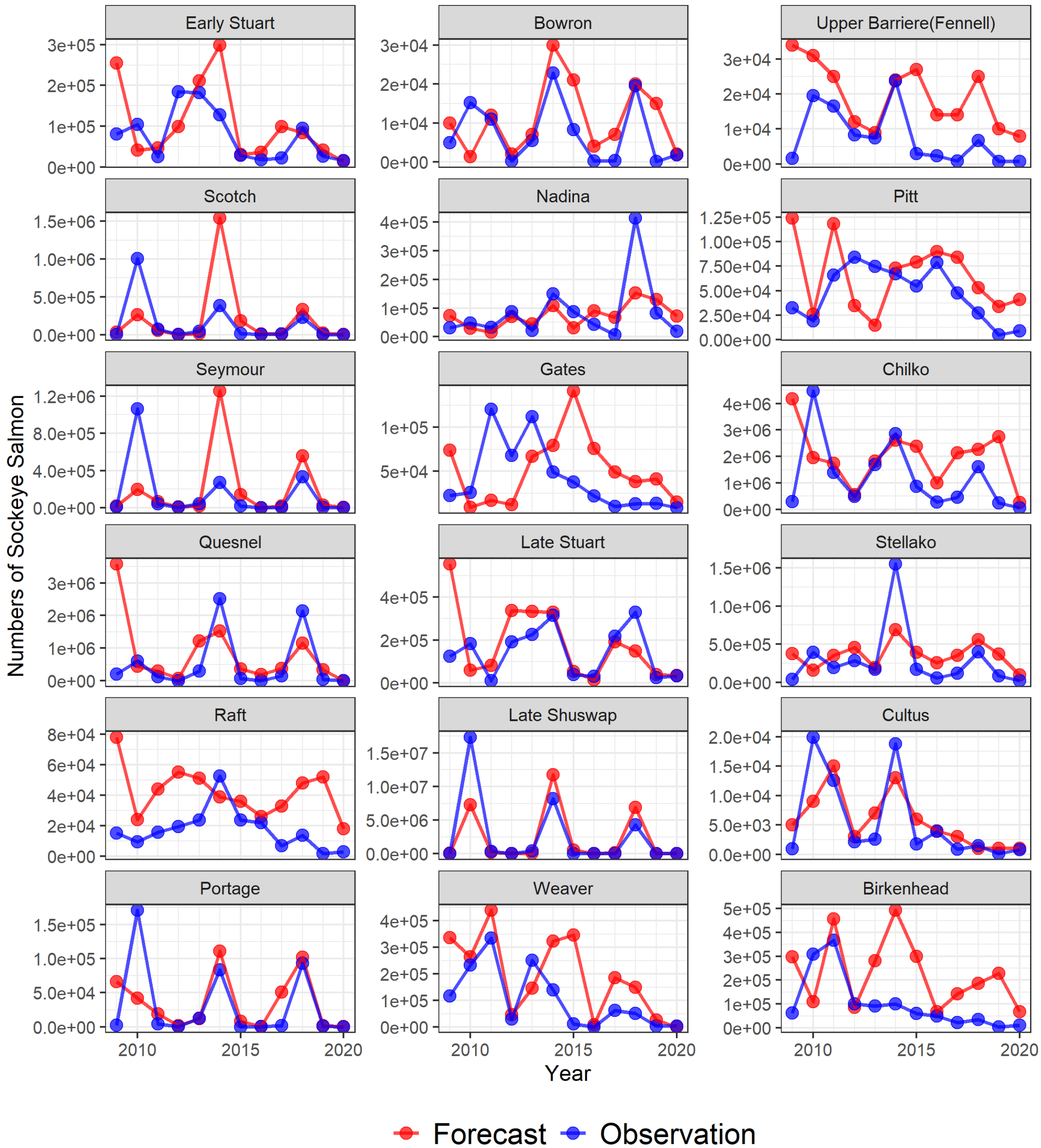
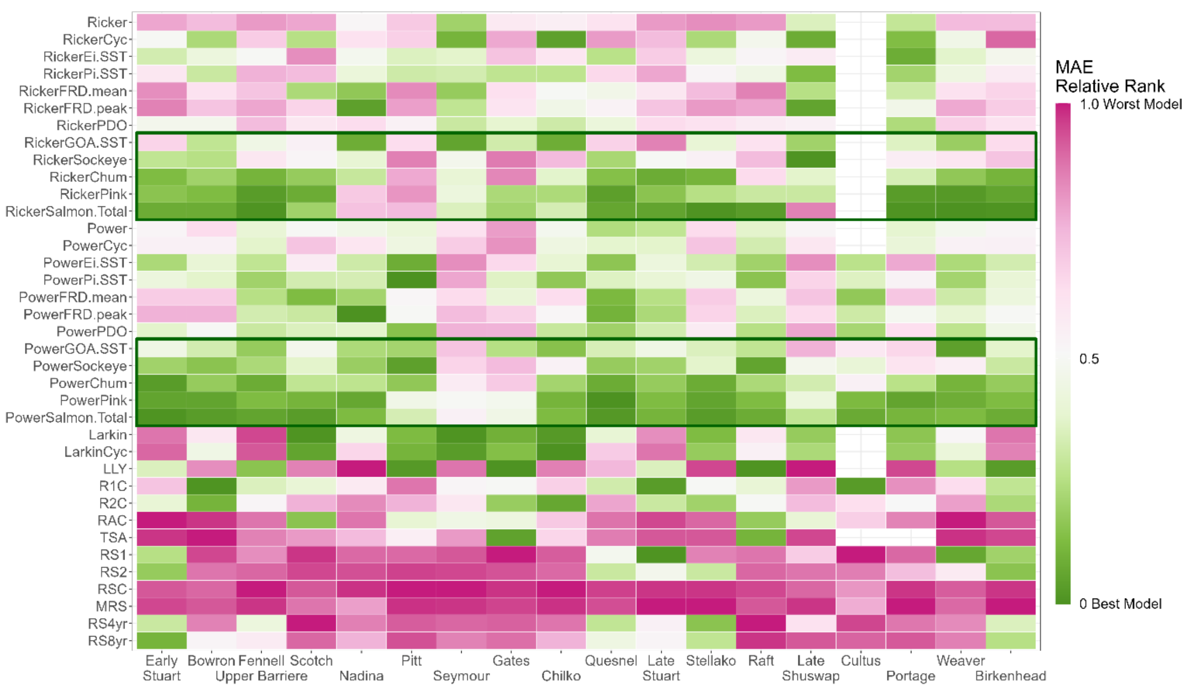


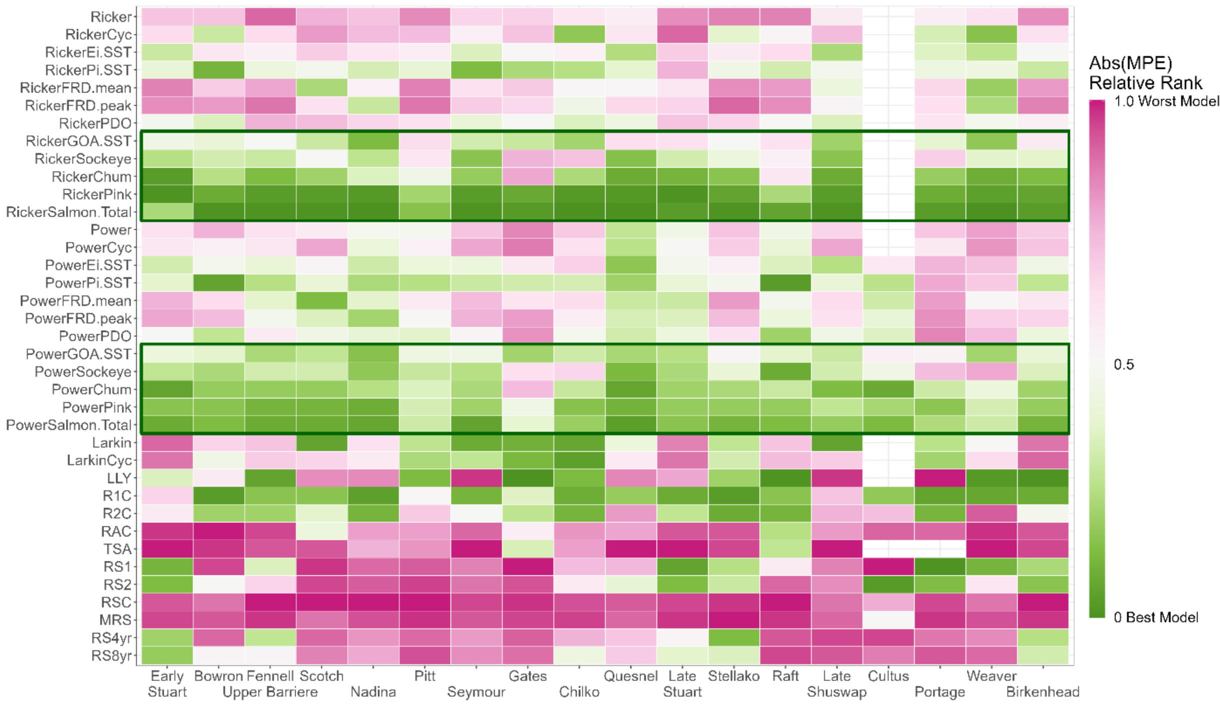
Figure S3. Relative ranking for all 37 models and all 18 Fraser Sockeye stocks of a) absolute value of mean raw error Abs(MRE) b) mean absolute error (MAE) c) absolute value of mean percent error Abs(MPE), d) root-mean-square error (RMSE), and e) normalized forecast metric (NFM) that measures bias with small biases between -2.0 and 2.0 shown numerically.

a.

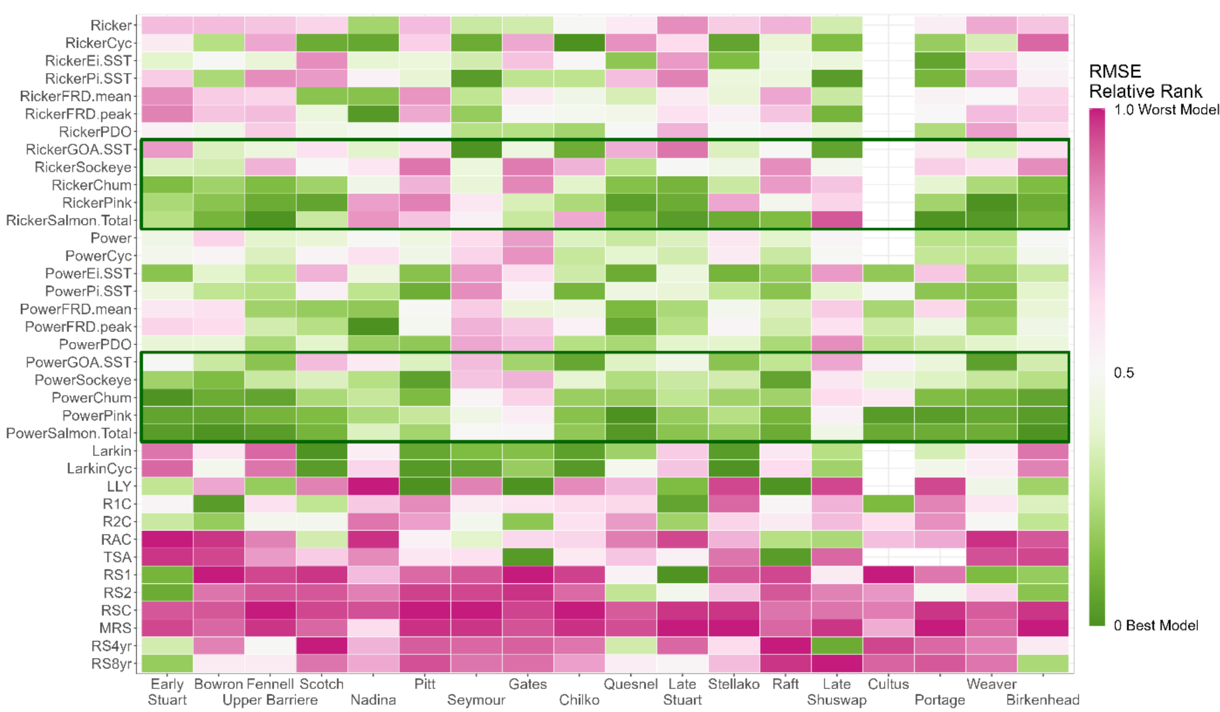
b.



c.


Ricker
RickerCyc
RickerEi.SST
RickerPi.SST
RickerFRD.mean
RickerFRD.peak
RickerPDO
RickerGOA.SST
RickerSockeye
RickerChum
RickerPink
RickerSalmon.Total
Power
PowerCyc
PowerEi.SST
PowerPi.SST
PowerFRD.mean
PowerFRD.peak
PowerPDO
PowerGOA.SST
PowerSockeye
PowerChum
PowerPink
PowerSalmon.Total
Larkin
LarkinCyc
LLY
R1C
R2C
RAC
TSA
RS1
RS2
RSC
MRS
RS4yr
RS8yr
Early Stuart
Bowron
Fennell
Upper Barriere
Scotch
Nadina
Pitt
Seymour
Gates
Chilko
Quesnel
Late Stuart
Stellako
Raft
Late Shuswap
Cultus
Portage
Weaver
Birkenhead
Abs(MPE) Relative Rank
1.0 Worst Model
0.5
0 Best Model

d.


Ricker
RickerCyc
RickerEi.SST
RickerPi.SST
RickerFRD.mean
RickerFRD.peak
RickerPDO
RickerGOA.SST
RickerSockeye
RickerChum
RickerPink
RickerSalmon.Total
Power
PowerCyc
PowerEi.SST
PowerPi.SST
PowerFRD.mean
PowerFRD.peak
PowerPDO
PowerGOA.SST
PowerSockeye
PowerChum
PowerPink
PowerSalmon.Total
Larkin
LarkinCyc
LLY
R1C
R2C
RAC
TSA
RS1
RS2
RSC
MRS
RS4yr
RS8yr
Early Stuart
Bowron
Fennell
Upper Barriere
Scotch
Nadina
Pitt
Seymour
Gates
Chilko
Quesnel
Late Stuart
Stellako
Raft
Late Shuswap
Cultus
Portage
Weaver
Birkenhead
RMSE Relative Rank
1.0 Worst Model
0.5
0 Best Model

e.

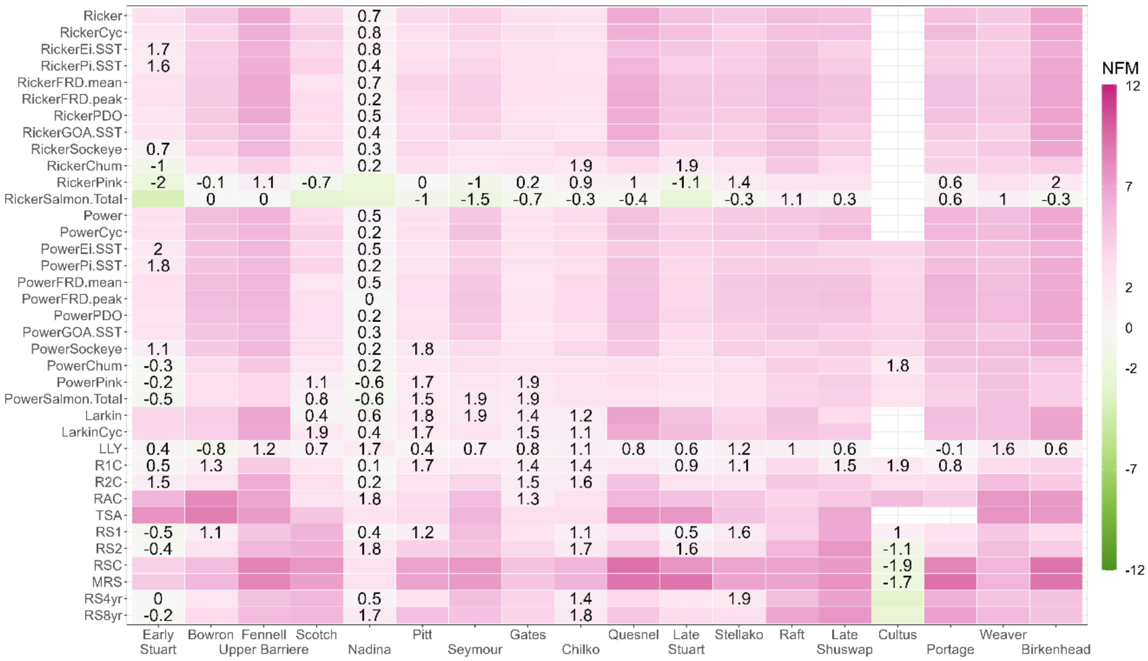


Figure S4. Normalized standard deviation of forecasts from all 37 models along with that from the historically selected model (named Forecast for simplicity) for all 18 Fraser Sockeye stocks during the period of 2009 to 2020.

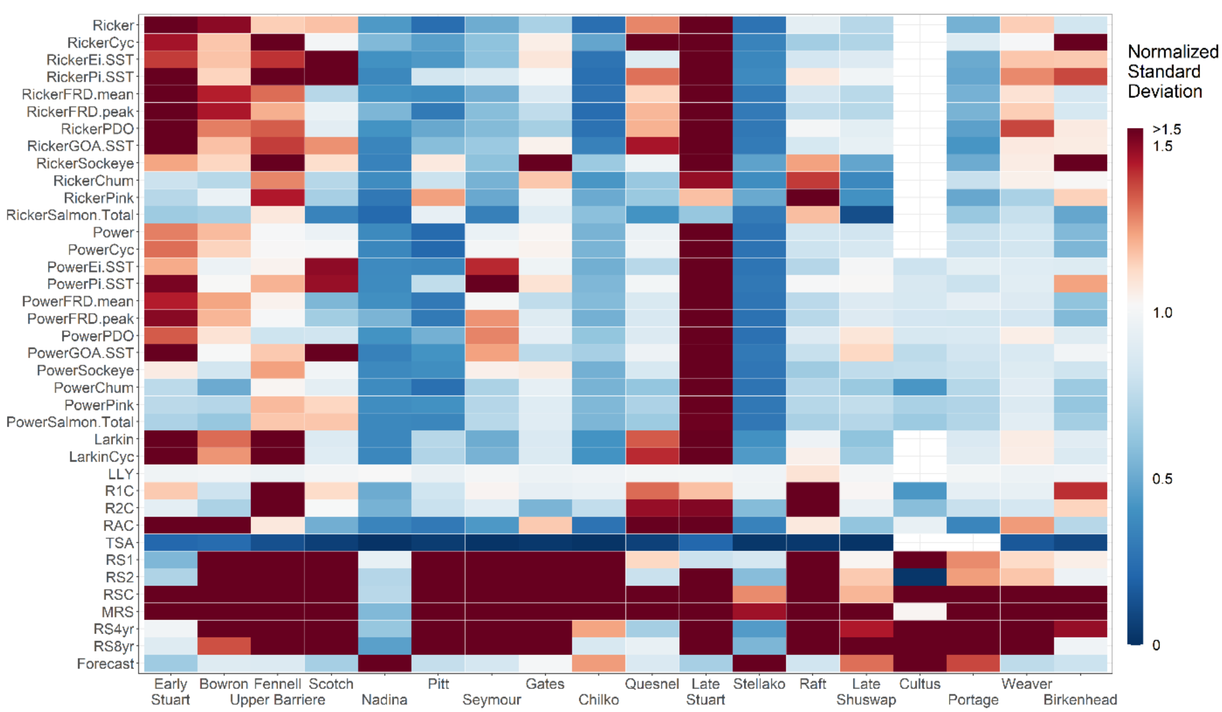
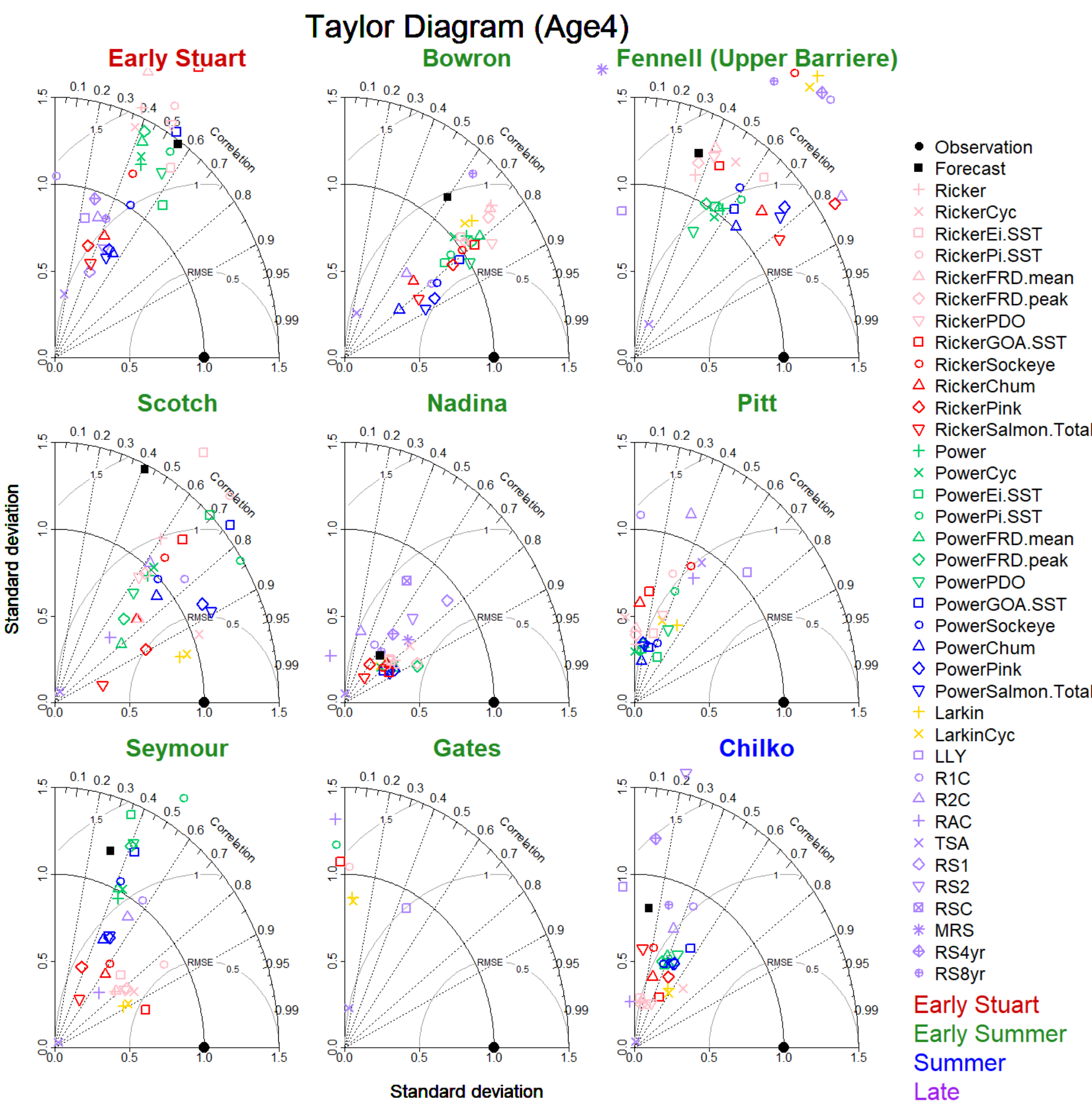


Figure S5. (a) Age 4 Taylor diagrams for Early Stuart sockeye stock, 7 Early Summer run stocks (Bowron, Fennel (Upper Barriere), Scotch, Nadina, Pitt, Seymour, and Gates), and 1 Summer run stock (Chilko). (b) Age 4 Taylor diagrams for 4 Summer run stocks (Quesnel, Late Stuart, Stellako, Raft) and 5 Late run stocks (Late Shuswap, Cultus, Portage, Weaver, and Birkenhead). Each Taylor diagram compares 37 model forecasts and the historical Forecast (black solid square) against the Observation (black solid circle on the x-axis). The distance from the origin is the normalized standard deviation with the normalized value for observations being 1. The angle describes the correlation between model forecasts and observations. The dashed arcs around the Observation illustrate the root-mean-square error (RMSE). Models with negative correlations are not shown. The closer the model is to the Observation, the better predictive power the model has.

a.



b.

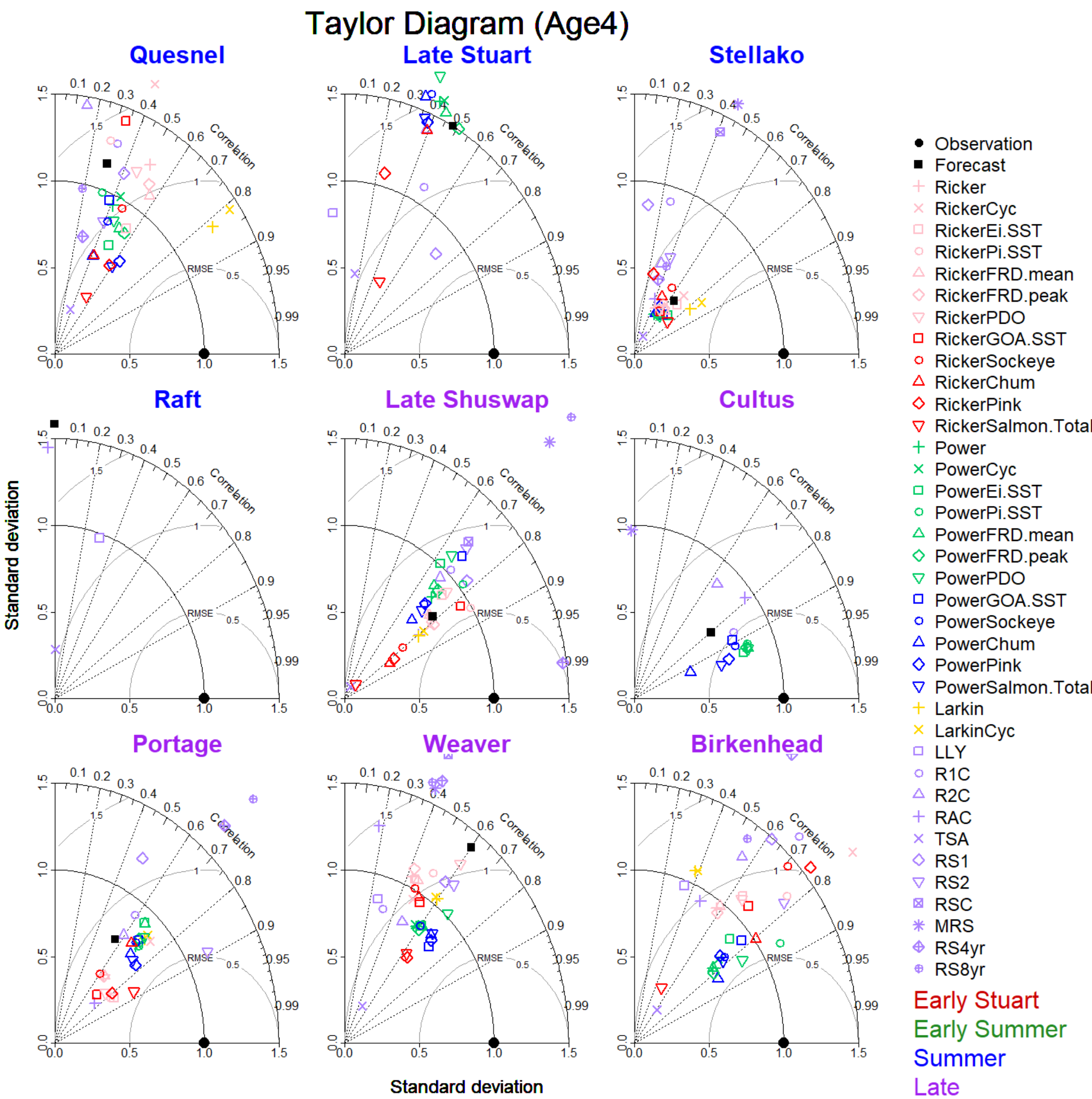
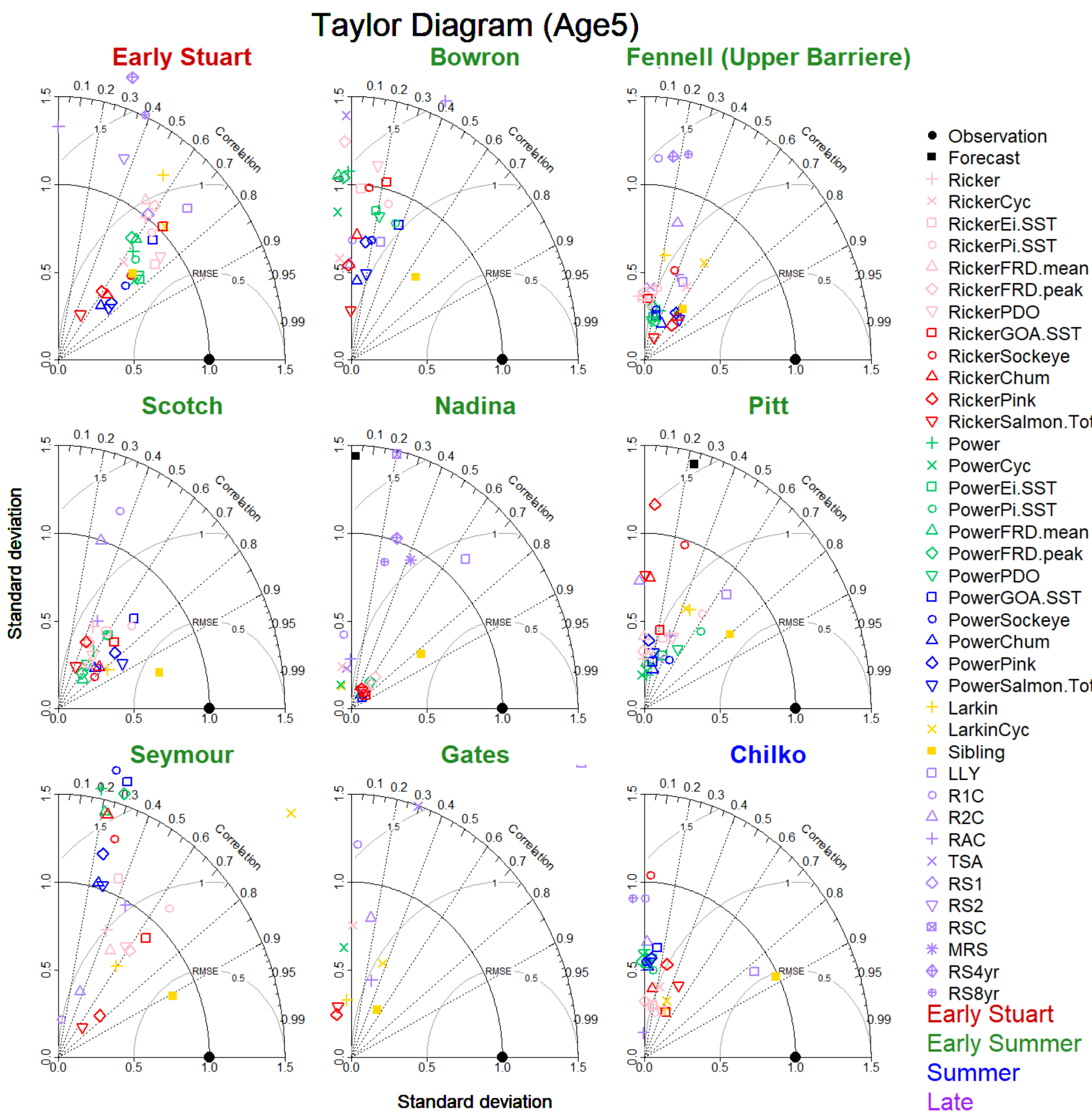
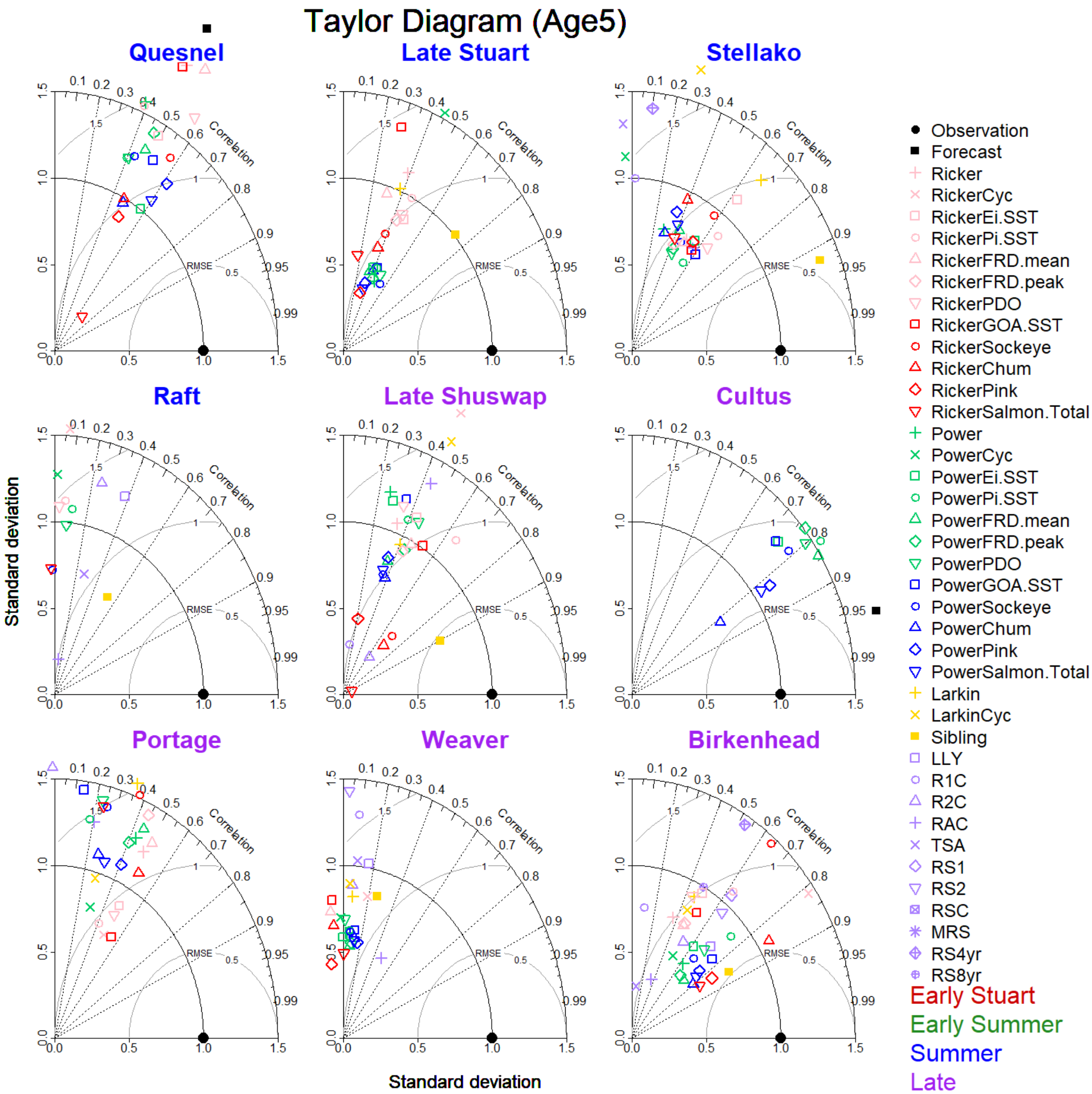

Taylor Diagram (Age4)
Quesnel
Late Stuart
Stellako
Raft
Late Shuswap
Cultus
Portage
Weaver
Birkenhead
Standard deviation
Standard deviation
Correlation
RMSE
Observation
Forecast
Ricker
RickerCyc
RickerEi.SST
RickerPi.SST
RickerFRD.mean
RickerFRD.peak
RickerPDO
RickerGOA.SST
RickerSockeye
RickerChum
RickerPink
RickerSalmon.Total
Power
PowerCyc
PowerEi.SST
PowerPi.SST
PowerFRD.mean
PowerFRD.peak
PowerPDO
PowerGOA.SST
PowerSockeye
PowerChum
PowerPink
PowerSalmon.Total
Larkin
LarkinCyc
LLY
R1C
R2C
RAC
TSA
RS1
RS2
RSC
MRS
RS4yr
RS8yr
Early Stuart
Early Summer
Summer
Late

Figure S6. (a) Age 5 Taylor diagrams for Early Stuart Sockeye stock, 7 Early Summer run stocks (Bowron, Fennel (Upper Barriere), Scotch, Nadina, Pitt, Seymour, and Gates), and 1 Summer run stock (Chilko). (b) Age 5 Taylor diagrams for 4 Summer run stocks (Quesnel, Late Stuart, Stellako, Raft) and 5 Late run stocks (Late Shuswap, Cultus, Portage, Weaver, and Birkenhead). Each Taylor diagram compares 38 model forecasts and the historical Forecast (black solid square) against the Observation (black solid circle on the x-axis). The distance from the origin is the normalized standard deviation with the normalized value for observations being 1. The angle describes the correlation between model forecasts and observations. The dashed arcs around the Observation illustrate the root-mean-square error (RMSE). Models with negative correlations are not shown. The closer the model is to the Observation, the better predictive power the model has.

a.



b.



Taylor Diagram (Age5)
Quesnel
Late Stuart
Stellako
Raft
Late Shuswap
Cultus
Portage
Weaver
Birkenhead
Standard deviation
Standard deviation
Correlation
RMSE
Observation
Forecast
Ricker
RickerCyc
RickerEi.SST
RickerPi.SST
RickerFRD.mean
RickerFRD.peak
RickerPDO
RickerGOA.SST
RickerSockeye
RickerChum
RickerPink
RickerSalmon.Total
Power
PowerCyc
PowerEi.SST
PowerPi.SST
PowerFRD.mean
PowerFRD.peak
PowerPDO
PowerGOA.SST
PowerSockeye
PowerChum
PowerPink
PowerSalmon.Total
Larkin
LarkinCyc
Sibling
LLY
R1C
R2C
RAC
TSA
RS1
RS2
RSC
MRS
RS4yr
RS8yr
Early Stuart
Early Summer
Summer
Late