Preliminary Discussion about the 2022 Forecast Process

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Contents

1 Objective

To determine the process for the 2022 Southeast Alaska (SEAK) preseason pink salmon forecast using data through 2020.

2 Executive Summary

Forecasts were developed using an approach originally described in Wertheimer et al. (2006), and modified in Orsi et al. (2016) and Murphy et al. (2019). We used a similar approach to Murphy et al. (2019), but assumed a log-normal error. This approach is based on a multiple regression model with juvenile pink salmon catch-per-unit-effort (CPUE) and temperature data from the Southeast Alaska Coastal Monitoring Survey (SECM; Murphy et al. 2020) or satellite sea surface temperature data (SST and SST Anomaly, NOAA Global Coral Bleaching Monitoring, 5km, V.3.1, Monthly, 1985-Present' time series (https://coastwatch.pfeg.noaa.gov/erddap/griddap/NOAA_DHW_monthly.html). See the document satellite_SST_process_4_June_2021 for details about the temperature variables. Based on prior discussions, the index of juvenile abundance (i.e., CPUE) was based on the pooled-species vessel calibration coefficient.

Leave-one-out cross validation (hindcast) and model performance metrics were used to evaluate the forecast accuracy of models. These metrics included Akaike Information Criterion corrected for small sample sizes

(AICc values; Burnham and Anderson 2004), the mean absolute scaled error (*MASE* metric; Hyndman and Kohler 2006), the weighted mean absolute percentage error (*wMAPE*; based on the last 5 years), leave one out cross validation *MAPE* (*MAPE_LOOCV*), one step ahead forecasts (*MAPE_one_step_ahead*) for the last five years (juvenile years 2015 through 2019), and significant coefficients (i.e., covariates) in the model. A sensitivity analysis was also done to determine if the juvenile years 1998 and 2016 were influential in the models.

Conclusions:

- Overall, the performance metrics recommended models m10 (Chatham_SST_May), m14 (Icy_Strait_SST_May), m18 (NSEAK_SST_May), m20 (NSEAK_SST_AMJ), and m21 (NSEAK_SST_AMJJ). These five models were additive models with CPUE and a temperature variable.
- With the exclusion of juvenile years 1998 and 2016, the performance metrics recommended models m10s (Chatham_SST_May), m14s (Icy_Strait_SST_May), m16s (Icy_Strait_SST_AMJ), m18s (NSEAK_SST_May), m20s (NSEAK_SST_AMJ), and m21s (NSEAK_SST_AMJJ) are recommended.
- The model averaged forecast prediction for 2021, weighting based of AICc weights (Akaike 1973; Burnham and Anderson 2002) of all 25 additive models, is 18.80 million fish (prediction interval: 11.81-29.94 million fish).

3 Analysis

3.1 Hierarchical models

Forty nine hierarchical models were investigated. The full model was:

$$E(y) = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_1 X_2,$$

where X_1 is the average CPUE for catches in either the June or July survey, whichever month had the highest average catches in a given year, and was based on the pooled-species vessel calibration coefficient, X_2 is a temperature index, and β_3 is the interaction term between CPUE and the temperature index. The CPUE data were log-transformed in the model, but temperature data was not. The simplest model did not contain a temperature variable (model m1). None of the interactions were significant at $alpha <= 0.05$ (see Appendix Table 6 for detailed output); therefore only additive models (25 models; Table 1 and Figure 1) were considered further.

Table 1: Parameter estimates for the 25 potential models.

model	term	estimate	std.error	statistic	p.value
m1	(Intercept)	2.2891818	0.208	11.019	0.000
m1	CPUE	0.4379654	0.071	6.157	0.000
m2	(Intercept)	4.4699466	0.545	8.196	0.000
m2	CPUE	0.4595498	0.054	8.582	0.000
m2	ISTI3_May	-0.2774746	0.067	-4.172	0.000
m3	(Intercept)	4.7958758	0.582	8.244	0.000
m3	CPUE	0.4650143	0.052	8.950	0.000
m3	ISTI10_May	-0.3320310	0.074	-4.461	0.000
m4	(Intercept)	5.0332354	0.613	8.204	0.000
m4	CPUE	0.4668849	0.051	9.129	0.000
m4	ISTI15_May	-0.3761665	0.082	-4.609	0.000

model	term	estimate	std.error	statistic	p.value
m5	(Intercept)	5.1986918	0.628	8.275	0.000
m5	CPUE	0.4692675	0.050	9.323	0.000
m5	ISTI20_May	-0.4111851	0.086	-4.761	0.000
m6	(Intercept)	6.1885346	1.089	5.681	0.000
m6	CPUE	0.4879450	0.058	8.369	0.000
m6	ISTI3_MJJ	-0.3785836	0.105	-3.621	0.002
m7	(Intercept)	6.7120995	1.035	6.487	0.000
m7	CPUE	0.4962538	0.054	9.170	0.000
m7	ISTI10_MJJ	-0.4555927	0.105	-4.322	0.000
m8	(Intercept)	6.9551755	0.965	7.209	0.000
m8	CPUE	0.4990322	0.051	9.833	0.000
m8	ISTI15_MJJ	-0.5075099	0.104	-4.891	0.000
m9	(Intercept)	7.0782279	0.909	7.783	0.000
m9	CPUE	0.5015600	0.048	10.371	0.000
m9	ISTI20_MJJ	-0.5456648	0.102	-5.327	0.000
m10	(Intercept)	5.9088166	0.565	10.465	0.000
m10	CPUE	0.5078547	0.042	11.973	0.000
m10	Chatham_SST_May	-0.5047298	0.077	-6.560	0.000
m11	(Intercept)	6.8811758	1.087	6.328	0.000
m11	CPUE	0.4762879	0.054	8.902	0.000
m11	Chatham_SST_MJJ	-0.4796449	0.112	-4.266	0.000
m12	(Intercept)	6.4363593	0.746	8.631	0.000
m12	CPUE	0.4908457	0.046	10.626	0.000
m12	Chatham_SST_AMJ	-0.5591776	0.099	-5.650	0.000
m13	(Intercept)	6.8961291	0.948	7.273	0.000
m13	CPUE	0.4835189	0.050	9.686	0.000
m13	Chatham_SST_AMJJ	-0.5428793	0.110	-4.915	0.000
m14	(Intercept)	5.5619011	0.540	10.290	0.000
m14	CPUE	0.5262189	0.045	11.734	0.000
m14	Icy_Strait_SST_May	-0.4879391	0.078	-6.222	0.000
m15	(Intercept)	6.5012488	1.016	6.397	0.000
m15	CPUE	0.4822883	0.054	8.897	0.000
m15	Icy_Strait_SST_MJJ	-0.4318923	0.103	-4.194	0.000
m16	(Intercept)	6.2004053	0.747	8.296	0.000
m16	CPUE	0.5075410	0.049	10.428	0.000
m16	Icy_Strait_SST_AMJ	-0.5491897	0.103	-5.323	0.000
m17	(Intercept)	6.5077323	0.917	7.094	0.000
m17	CPUE	0.4932834	0.052	9.514	0.000
m17	Icy_Strait_SST_AMJJ	-0.4995336	0.107	-4.659	0.000
m18	(Intercept)	5.6755303	0.525	10.810	0.000
m18	CPUE	0.4852638	0.041	11.718	0.000
m18	NSEAK_SST_May	-0.4697650	0.071	-6.623	0.000
m19	(Intercept)	6.8011220	0.976	6.967	0.000
m19	CPUE	0.4604035	0.051	9.097	0.000
m19	NSEAK_SST_MJJ	-0.4648662	0.099	-4.675	0.000
m20	(Intercept)	6.2974300	0.701	8.982	0.000
m20	CPUE	0.4753863	0.045	10.591	0.000
m20	NSEAK_SST_AMJ	-0.5444161	0.094	-5.818	0.000
m21	(Intercept)	6.7569868	0.887	7.617	0.000
m21	CPUE	0.4701853	0.048	9.701	0.000
m21	NSEAK_SST_AMJJ	-0.5257282	0.103	-5.101	0.000
m22	(Intercept)	5.7091930	0.591	9.652	0.000

model	term	estimate	std.error	statistic	p.value
m22	CPUE	0.4853470	0.045	10.872	0.000
m22	SEAK_SST_May	-0.4395554	0.074	-5.923	0.000
m23	(Intercept)	6.5160237	1.007	6.468	0.000
m23	CPUE	0.4524101	0.053	8.541	0.000
m23	SEAK_SST_MJJ	-0.4131161	0.097	-4.246	0.000
m24	(Intercept)	6.2716380	0.755	8.302	0.000
m24	CPUE	0.4743136	0.047	10.052	0.000
m24	SEAK_SST_AMJ	-0.5025653	0.094	-5.360	0.000
m25	(Intercept)	6.5577162	0.929	7.062	0.000
m25	CPUE	0.4634645	0.051	9.125	0.000
m25	SEAK_SST_AMJJ	-0.4719916	0.101	-4.656	0.000

3.2 Performance metrics

The model summary results (Tables 2 and 3) using the performance metrics AICc, *MASE*, *wMAPE*, *MAPE_LOOCV*, and *MAPE_one_step_ahead* are shown in Table 2. For all of these metrics, the smallest value is the preferred model. Models with Δ_iAICc ≤ 2 have substantial support, those in which $4 \leq \Delta_i$AICc ≤ 7 have considerably less support, and models with Δ_iAICc > 10 have essentially no support (Burnham and Anderson 2004). The performance metric *MAPE* was calculated as:

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}|\frac{A_t - F_t}{A_t}|$$

where A_t is the observed value and F_t is the predicted value. The performance metric *wMAPE* was calculated as:

$$wMAPE = \sum_{t=1}^{n}\frac{1}{w_t}\sum_{t=1}^{n}|\frac{A_t - F_t}{A_t}|w_t.$$

where w_t is the weight for each year. For the *wMAPE* metric, the last 5 years (juvenile years 2015-2019) were given a weight of 1 and all other years, a weight of 0.001. Therefore, compared to the performance metric *MAPE_LOOCV*, the performance of the model in the last 5 years was given more weight in the *wMAPE* metric.

The performance metric *MAPE_LOOCV* uses five steps.

1. The dataset is split into a training set. The training set uses all but one observation of the full dataset.
2. Run the regression model based on the training set.
3. Use the regression model based on the training set to predict F_t for the one observation left out of the model.
4. Repeat the process n times based on the number of observations in the dataset, leaving out a different observation from the training set each time.
5. Calculate MAPE, based on the average of all the training datasets (i.e., one MAPE is calculated for each training set and then these are averaged.)

The performance metric *MAPE_one_step_ahead* involves three steps:

1. Estimate the regression parameters at time t from data up to time $t-1$.

2. Make a prediction of F_t at time t based on the predictor variables at time t and the estimate of the regression parameters at time t.

3. Calculate the MAPE based on the prediction of F_t at time t and the observed value of A_t at time t.

4. The *MAPE_one_step_ahead* will then be an average of the MAPE calculated from data up through juvenile year 2014 (e.g., juvenile year 2014 is $t-1$ and the forecast is for juvenile year 2015; t), data up through juvenile year 2015 (e.g., juvenile year 2015 is $t-1$ and the forecast is for juvenile year 2016; t), data up through juvenile year 2016, data up through juvenile year 2017, data up through juvenile year 2018, and data up through juvenile year 2019.

The AICc in Table 2 is the AICc value and not the Δ_iAICc. The performance metric AICc suggests that models m10, m14, and m18 are the recommended models (Table 2). The performance metrics *MASE* and *MAPE_LOOCV* suggest that models m10, m14, and m18 are the recommended models (Table 2). The performance metric *wMAPE* suggests that models m14, m20, and m21 are the recommended models (Table 2). The performance metric *MAPE_one_step_ahead* suggests that models m14 and m21 are the recommended models (Table 2). Detailed outputs for recommended models m10, m14, m18, m20, and m21, are in the appendix (Tables 7 to 11, and Figures 2 through 11).

Table 2: Summary of model outputs and forecast error measures. These metrics included Akaike Information Criterion corrected for small sample sizes (AICc values), the mean absolute scaled error (MASE metric), the weighted mean absolute percentage error (wMAPE; based on the last 5 years), leave one out cross validation MAPE (MAPE_LOOCV), and one step ahead forecasts (MAPE_one_step_ahead).

model	AdjR2	AICc	MASE	wMAPE	MAPE_LOOCV	MAPE_one_step_ahead
m1	0.627	30.21	0.399	0.184	0.116	NA
m2	0.790	18.77	0.284	0.134	0.087	NA
m3	0.803	17.28	0.276	0.128	0.084	NA
m4	0.810	16.52	0.278	0.119	0.084	NA
m5	0.816	15.74	0.274	0.111	0.082	NA
m6	0.763	21.57	0.308	0.130	0.094	NA
m7	0.797	17.99	0.286	0.119	0.087	NA
m8	0.821	15.08	0.263	0.105	0.079	NA
m9	0.838	12.85	0.246	0.092	0.073	NA
m10	0.876	6.76	0.234	0.074	0.069	NA
m11	0.795	18.29	0.300	0.093	0.089	NA
m12	0.849	11.22	0.261	0.072	0.076	NA
m13	0.822	14.95	0.274	0.069	0.079	NA
m14	0.866	8.40	0.212	0.064	0.062	NA
m15	0.791	18.66	0.305	0.093	0.090	NA
m16	0.838	12.87	0.255	0.071	0.075	NA
m17	0.812	16.26	0.292	0.079	0.085	NA
m18	0.877	6.47	0.224	0.070	0.066	NA
m19	0.813	16.18	0.286	0.078	0.084	NA
m20	0.854	10.39	0.250	0.066	0.073	NA
m21	0.830	14.00	0.270	0.063	0.078	NA
m22	0.858	9.87	0.246	0.083	0.074	NA
m23	0.794	18.39	0.297	0.088	0.088	NA
m24	0.839	12.68	0.262	0.073	0.077	NA
m25	0.812	16.28	0.281	0.073	0.082	NA

Table 3: Summary of model forecasts including the 80 percent prediction intervals (corrected for log transformation bias in a linear-model).

model	terms	fit	fit_LPI	fit_UPI
m1	CPUE	27.568	15.659	48.536
m2	CPUE + ISTI3_May	23.986	15.670	36.716
m3	CPUE + ISTI10_May	23.592	15.619	35.635
m4	CPUE + ISTI15_May	23.599	15.731	35.403
m5	CPUE + ISTI20_May	23.994	16.111	35.736
m6	CPUE + ISTI3_MJJ	31.465	19.960	49.603
m7	CPUE + ISTI10_MJJ	30.411	19.990	46.264
m8	CPUE + ISTI15_MJJ	29.191	19.709	43.234
m9	CPUE + ISTI20_MJJ	28.281	19.461	41.097
m10	CPUE + Chatham_SST_May	19.015	13.628	26.531
m11	CPUE + Chatham_SST_MJJ	23.573	15.463	35.937
m12	CPUE + Chatham_SST_AMJ	22.884	15.939	32.855
m13	CPUE + Chatham_SST_AMJJ	23.972	16.206	35.461
m14	CPUE + Icy_Strait_SST_May	18.218	12.872	25.783
m15	CPUE + Icy_Strait_SST_MJJ	22.064	14.389	33.833
m16	CPUE + Icy_Strait_SST_AMJ	20.319	13.911	29.677
m17	CPUE + Icy_Strait_SST_AMJJ	21.979	14.654	32.966
m18	CPUE + NSEAK_SST_May	17.566	12.575	24.537
m19	CPUE + NSEAK_SST_MJJ	21.710	14.479	32.553
m20	CPUE + NSEAK_SST_AMJ	20.686	14.464	29.585
m21	CPUE + NSEAK_SST_AMJJ	21.877	14.876	32.173
m22	CPUE + SEAK_SST_May	17.680	12.328	25.356
m23	CPUE + SEAK_SST_MJJ	22.540	14.750	34.445
m24	CPUE + SEAK_SST_AMJ	20.924	14.365	30.478
m25	CPUE + SEAK_SST_AMJJ	22.275	14.856	33.399

3.3 Sensitivity analysis

A sensitivity analysis was done to determine if the juvenile years 1998 and 2016 were influential in the models. For the sensitivity analysis, juvenile years 1998 and 2016 (high leverage values in a majority of the five preferred models) were removed, the models rerun, and the performance metrics recalculated (Tables 4 and 5).The performance metric AICc suggests that model m14s is the recommended model. The performance metrics *MASE* and *MAPE_LOOCV* suggest that models m10s, m14s, and m18s are the recommended models. The performance metric *wMAPE* suggests that models m14s, m16s, and m20s are the recommended models. The performance metric *MAPE_one_step_ahead* suggests that models m16s, and m21s are the recommended models. Therefore, based on the performance metrics, models m10s, m14s, m16s, m18s, m20s, and m21s are recommended.

Table 4: Summary of model outputs and forecast error measures for the sensitivity analysis (exclusion of juvenile years 1998 and 2016). These metrics included Akaike Information Criterion corrected for small sample sizes (AICc values), the mean absolute scaled error (MASE metric), the weighted mean absolute percentage error (wMAPE; based on the last 5 years), leave one out cross validation MAPE (MAPE_LOOCV), and one step ahead forecasts (MAPE_one_step_ahead).

model	AdjR2	AICc	MASE	wMAPE	MAPE_LOOCV	MAPE_one_step_ahead
m1s	0.693	24.16	0.378	0.162	0.106	0.195
m2s	0.847	11.48	0.249	0.126	0.074	0.137
m3s	0.850	11.10	0.245	0.124	0.073	0.136
m4s	0.844	11.94	0.249	0.121	0.073	0.142
m5s	0.841	12.33	0.249	0.121	0.073	0.150
m6s	0.820	14.96	0.276	0.115	0.083	0.148
m7s	0.835	13.09	0.264	0.115	0.079	0.148
m8s	0.844	11.87	0.252	0.109	0.075	0.140
m9s	0.854	10.50	0.240	0.100	0.071	0.127
m10s	0.904	1.71	0.207	0.068	0.059	0.085
m11s	0.822	14.74	0.287	0.096	0.083	0.118
m12s	0.866	8.69	0.249	0.070	0.070	0.081
m13s	0.837	12.85	0.274	0.074	0.077	0.089
m14s	0.914	-0.70	0.184	0.061	0.052	0.079
m15s	0.826	14.26	0.286	0.097	0.083	0.120
m16s	0.873	7.59	0.223	0.057	0.063	0.072
m17s	0.836	12.92	0.276	0.077	0.078	0.091
m18s	0.904	1.64	0.203	0.066	0.059	0.102
m19s	0.831	13.59	0.280	0.082	0.081	0.092
m20s	0.869	8.25	0.241	0.062	0.068	0.084
m21s	0.839	12.54	0.267	0.064	0.075	0.068
m22s	0.875	7.26	0.239	0.082	0.069	0.105
m23s	0.812	15.81	0.288	0.092	0.083	0.104
m24s	0.848	11.43	0.260	0.074	0.074	0.088
m25s	0.821	14.87	0.278	0.077	0.079	0.082

Table 5: Summary of model forecasts including the 80 percent prediction intervals (corrected for log transformation bias in a linear-model) for the sensitivity analysis (exclusion of juvenile years 1998 and 2016).

model	terms	fit	fit_LPI	fit_UPI
m1s	CPUE	27.618	16.486	46.269
m2s	CPUE + ISTI3_May	24.012	16.648	34.633
m3s	CPUE + ISTI10_May	23.686	16.471	34.062
m4s	CPUE + ISTI15_May	23.770	16.409	34.433
m5s	CPUE + ISTI20_May	24.180	16.642	35.132
m6s	CPUE + ISTI3_MJJ	31.123	20.864	46.428
m7s	CPUE + ISTI10_MJJ	30.082	20.549	44.039
m8s	CPUE + ISTI15_MJJ	28.985	20.037	41.929
m9s	CPUE + ISTI20_MJJ	28.165	19.712	40.244
m10s	CPUE + Chatham_SST_May	19.248	14.316	25.879
m11s	CPUE + Chatham_SST_MJJ	23.764	15.984	35.330
m12s	CPUE + Chatham_SST_AMJ	22.907	16.244	32.302
m13s	CPUE + Chatham_SST_AMJJ	24.095	16.504	35.178
m14s	CPUE + Icy_Strait_SST_May	17.953	13.539	23.806
m15s	CPUE + Icy_Strait_SST_MJJ	21.973	14.794	32.637
m16s	CPUE + Icy_Strait_SST_AMJ	19.658	13.978	27.647
m17s	CPUE + Icy_Strait_SST_AMJJ	21.808	14.868	31.987
m18s	CPUE + NSEAK_SST_May	17.816	13.208	24.033
m19s	CPUE + NSEAK_SST_MJJ	22.016	14.921	32.485
m20s	CPUE + NSEAK_SST_AMJ	20.687	14.667	29.178
m21s	CPUE + NSEAK_SST_AMJJ	22.064	15.105	32.229
m22s	CPUE + SEAK_SST_May	18.104	12.843	25.520
m23s	CPUE + SEAK_SST_MJJ	22.937	15.241	34.519
m24s	CPUE + SEAK_SST_AMJ	21.144	14.592	30.638
m25s	CPUE + SEAK_SST_AMJJ	22.618	15.160	33.743

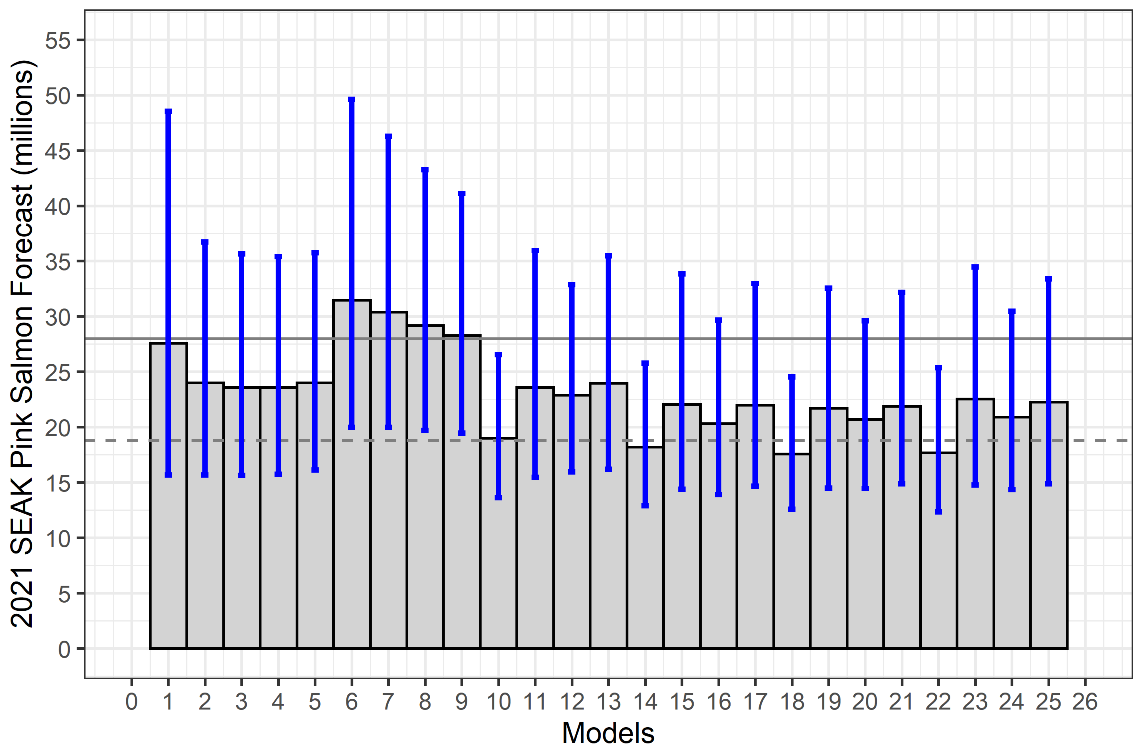

Figure 1: The 2021 SEAK pink salmon harvest (millions) forecast by model. The 80% prediction intervals (corrected for log transformation bias in a linear-model) around each forecast were calculated using the car package (Fox and Weisberg 2019) in program R (R Core Team 2020). The dotted horizontal line is the model average forecast across all models. The SEAK pink salmon harvest in 2021 (based on the November 18, 2020 advisory announcement) was a point estimate of 28 million fish (80% prediction interval: 19–42 million fish; grey horizontal line).

3.4 Model averaging (multi-model inference)

The model averaged forecast prediction for 2021, weighting based of AICc weights (Akaike 1973; Burnham and Anderson 2002) of all 25 additive models, is 18.80 million fish (prediction interval: 11.81-29.94 million fish). The prediction interval is based on equation 9 in Buckland et al. 1997 (derivation in Burnham and Anderson 2002:159-162).

4 References

Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle. In B. N. Pet rov & F. Caski (Eds.), Proceedings of the Second International Symposium on Information Theory (pp. 267-281). Budapest: Akademiai Kiado.

Buckland, S.T., K. P. Burnham, and N. H. Augustin. 1997. Model selection: an integral part of inference. Biometrics: 603-618.

Burnham, K. P., and D. R. Anderson, D. R. 2002. Model selection and multimodel inference: A practical information-theoretic approach. Second Edition. New York: Springer-Verlag

Burnham, K. P., and D. R. Anderson. 2004. Multimodel inference: Understanding AIC and BIC in model selection. Sociological Methods and Research 33: 261-304.

Fox, J. and S. Weisburg. 2019. An R Companion to Applied Regression, Third Edition. Thousand Oaks CA: Sage Publications, Inc.

Hyndman, R. J. and A. B. Koehler. 2006. Another look at measures of forecast accuracy. International Journal of Forecasting 22: 679-688.

Murphy, J. M., E. A. Fergusson, A. Piston, A. Gray, and E. Farley. 2019. Southeast Alaska pink salmon growth and harvest forecast models. North Pacific Anadromous Fish Commission Technical Report No. 15: 75-81.

NOAA Coral Reef Watch. 2021, updated daily. NOAA Coral Reef Watch Version 3.1 Monthly 5km SST and SST Anomaly, NOAA Global Coral Bleaching Monitoring Time Series Data, May 1997-July 2020. College Park, Maryland, USA: NOAA/NESDIS/STAR Coral Reef Watch program. Data set accessed 2021-04-09 at https://coastwatch.pfeg.noaa.gov/erddap/griddap/NOAA_DHW_monthly.html.

Orsi, J. A., E. A. Fergusson, A. C. Wertheimer, E. V. Farley, and P. R. Mundy. 2016. Forecasting pink salmon production in Southeast Alaska using ecosystem indicators in times of climate change. N. Pac. Anadr. Fish Comm. Bull. 6: 483–499. (Available at https://npafc.org)

R Core Team. 2020. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: http://www.r-project.org/index.html

Wertheimer A. C., J. A. Orsi, M. V. Sturdevant, and E. A. Fergusson. 2006. Forecasting pink salmon harvest in Southeast Alaska from juvenile salmon abundance and associated environmental parameters. In Proceedings of the 22nd Northeast Pacific Pink and Chum Workshop. Edited by H. Geiger (Rapporteur). Pac. Salmon Comm. Vancouver, British Columbia. pp. 65–72.

5 Appendix

Table 6: Parameter estimates for the 24 interaction models. None of the interactions were significant.

model	term	estimate	std.error	statistic	p.value
m2i	(Intercept)	5.5000607	1.678	3.277	0.004
m2i	CPUE	0.1034146	0.550	0.188	0.853
m2i	ISTI3_May	-0.4028292	0.204	-1.972	0.063
m2i	CPUE:ISTI3_May	0.0430304	0.066	0.650	0.523
m3i	(Intercept)	5.3476073	1.787	2.992	0.007
m3i	CPUE	0.2701309	0.598	0.452	0.656
m3i	ISTI10_May	-0.4017039	0.226	-1.777	0.092
m3i	CPUE:ISTI10_May	0.0244329	0.075	0.327	0.747
m4i	(Intercept)	5.0806682	1.871	2.715	0.014
m4i	CPUE	0.4499176	0.633	0.711	0.486
m4i	ISTI15_May	-0.3823424	0.244	-1.565	0.134
m4i	CPUE:ISTI15_May	0.0021937	0.081	0.027	0.979
m5i	(Intercept)	4.7960554	1.886	2.543	0.020
m5i	CPUE	0.6149077	0.643	0.956	0.351
m5i	ISTI20_May	-0.3574078	0.253	-1.414	0.174
m5i	CPUE:ISTI20_May	-0.0193146	0.085	-0.227	0.823
m6i	(Intercept)	1.9591583	2.592	0.756	0.459
m6i	CPUE	2.4143936	1.084	2.227	0.038
m6i	ISTI3_MJJ	0.0165585	0.243	0.068	0.946
m6i	CPUE:ISTI3_MJJ	-0.1788905	0.101	-1.780	0.091
m7i	(Intercept)	2.2233006	2.370	0.938	0.360
m7i	CPUE	2.4377236	0.939	2.596	0.018

model	term	estimate	std.error	statistic	p.value
m7i	ISTI10_MJJ	-0.0114003	0.236	-0.048	0.962
m7i	CPUE:ISTI10_MJJ	-0.1908928	0.092	-2.071	0.052
m8i	(Intercept)	3.1474179	2.310	1.363	0.189
m8i	CPUE	2.0406049	0.860	2.373	0.028
m8i	ISTI15_MJJ	-0.1099114	0.242	-0.454	0.655
m8i	CPUE:ISTI15_MJJ	-0.1599028	0.089	-1.796	0.088
m9i	(Intercept)	3.9888764	2.279	1.750	0.096
m9i	CPUE	1.7040630	0.819	2.081	0.051
m9i	ISTI20_MJJ	-0.2082355	0.250	-0.833	0.415
m9i	CPUE:ISTI20_MJJ	-0.1304306	0.089	-1.471	0.158
m10i	(Intercept)	4.4405370	1.900	2.337	0.031
m10i	CPUE	1.0539326	0.676	1.560	0.135
m10i	Chatham_SST_May	-0.3136577	0.248	-1.263	0.222
m10i	CPUE:Chatham_SST_May	-0.0703165	0.087	-0.810	0.428
m11i	(Intercept)	5.3710247	3.294	1.630	0.119
m11i	CPUE	1.0297877	1.138	0.905	0.377
m11i	Chatham_SST_MJJ	-0.3262826	0.335	-0.973	0.343
m11i	CPUE:Chatham_SST_MJJ	-0.0559429	0.115	-0.487	0.632
m12i	(Intercept)	6.1007263	2.422	2.519	0.021
m12i	CPUE	0.6108159	0.823	0.743	0.467
m12i	Chatham_SST_AMJ	-0.5161014	0.312	-1.655	0.114
m12i	CPUE:Chatham_SST_AMJ	-0.0152776	0.105	-0.146	0.885
m13i	(Intercept)	6.1632533	2.915	2.114	0.048
m13i	CPUE	0.7478154	0.992	0.754	0.460
m13i	Chatham_SST_AMJJ	-0.4597799	0.332	-1.387	0.182
m13i	CPUE:Chatham_SST_AMJJ	-0.0297891	0.112	-0.267	0.793
m14i	(Intercept)	4.5422061	1.626	2.794	0.012
m14i	CPUE	0.9072136	0.574	1.581	0.130
m14i	Icy_Strait_SST_May	-0.3474022	0.225	-1.541	0.140
m14i	CPUE:Icy_Strait_SST_May	-0.0517711	0.078	-0.666	0.513
m15i	(Intercept)	5.9919048	2.888	2.075	0.052
m15i	CPUE	0.6617433	0.951	0.696	0.495
m15i	Icy_Strait_SST_MJJ	-0.3810858	0.289	-1.320	0.202
m15i	CPUE:Icy_Strait_SST_MJJ	-0.0177978	0.094	-0.189	0.852
m16i	(Intercept)	6.4970988	2.204	2.948	0.008
m16i	CPUE	0.4055630	0.712	0.570	0.576
m16i	Icy_Strait_SST_AMJ	-0.5886572	0.295	-1.999	0.060
m16i	CPUE:Icy_Strait_SST_AMJ	0.0134266	0.094	0.144	0.887
m17i	(Intercept)	6.2525831	2.601	2.404	0.027
m17i	CPUE	0.5824195	0.849	0.686	0.501
m17i	Icy_Strait_SST_AMJJ	-0.4705053	0.297	-1.584	0.130
m17i	CPUE:Icy_Strait_SST_AMJJ	-0.0100645	0.096	-0.105	0.917
m18i	(Intercept)	4.4982267	1.664	2.703	0.014
m18i	CPUE	0.9336459	0.602	1.551	0.137
m18i	NSEAK_SST_May	-0.3162165	0.218	-1.452	0.163
m18i	CPUE:NSEAK_SST_May	-0.0580543	0.078	-0.747	0.464
m19i	(Intercept)	5.3567440	2.736	1.958	0.065
m19i	CPUE	1.0065245	0.965	1.043	0.310
m19i	NSEAK_SST_MJJ	-0.3198518	0.275	-1.162	0.260
m19i	CPUE:NSEAK_SST_MJJ	-0.0546809	0.097	-0.567	0.578
m20i	(Intercept)	5.8370985	2.080	2.806	0.011
m20i	CPUE	0.6449750	0.721	0.895	0.382

model	term	estimate	std.error	statistic	p.value
m20i	NSEAK_SST_AMJ	-0.4847596	0.271	-1.792	0.089
m20i	CPUE:NSEAK_SST_AMJ	-0.0218539	0.093	-0.236	0.816
m21i	(Intercept)	5.8500460	2.514	2.327	0.031
m21i	CPUE	0.8068581	0.872	0.925	0.366
m21i	NSEAK_SST_AMJJ	-0.4229203	0.286	-1.479	0.156
m21i	CPUE:NSEAK_SST_AMJJ	-0.0380016	0.098	-0.387	0.703
m22i	(Intercept)	4.1684624	1.897	2.198	0.041
m22i	CPUE	1.0582224	0.671	1.577	0.131
m22i	SEAK_SST_May	-0.2531580	0.230	-1.099	0.285
m22i	CPUE:SEAK_SST_May	-0.0687647	0.080	-0.856	0.403
m23i	(Intercept)	4.7177981	2.797	1.687	0.108
m23i	CPUE	1.1410860	0.999	1.142	0.267
m23i	SEAK_SST_MJJ	-0.2413948	0.268	-0.902	0.378
m23i	CPUE:SEAK_SST_MJJ	-0.0656543	0.095	-0.691	0.498
m24i	(Intercept)	5.3671292	2.283	2.351	0.030
m24i	CPUE	0.8056182	0.789	1.021	0.320
m24i	SEAK_SST_AMJ	-0.3935877	0.276	-1.426	0.170
m24i	CPUE:SEAK_SST_AMJ	-0.0396907	0.094	-0.421	0.679
m25i	(Intercept)	5.2125548	2.638	1.976	0.063
m25i	CPUE	0.9662559	0.922	1.048	0.308
m25i	SEAK_SST_AMJJ	-0.3283874	0.282	-1.162	0.259
m25i	CPUE:SEAK_SST_AMJJ	-0.0534897	0.098	-0.546	0.591

Table 7: Detailed output for model m10. Fitted values are log-transformed.

model	year	juvenile_year	resid	hat_values	Cooks_distance	std_resid	fitted
m10	1998	1997	0.358	0.044	0.036	1.520	3.392
m10	1999	1998	-0.458	0.302	0.746	-2.277	4.812
m10	2000	1999	-0.257	0.107	0.051	-1.131	3.268
m10	2001	2000	0.106	0.090	0.007	0.463	4.098
m10	2002	2001	-0.151	0.115	0.019	-0.665	3.964
m10	2003	2002	-0.137	0.183	0.030	-0.630	4.098
m10	2004	2003	0.233	0.050	0.017	0.993	3.580
m10	2005	2004	0.198	0.094	0.026	0.863	3.882
m10	2006	2005	-0.199	0.168	0.055	-0.906	2.650
m10	2007	2006	0.201	0.057	0.015	0.859	3.602
m10	2008	2007	-0.182	0.116	0.028	-0.805	2.949
m10	2009	2008	-0.034	0.100	0.001	-0.150	3.672
m10	2010	2009	-0.231	0.050	0.017	-0.985	3.409
m10	2011	2010	0.103	0.111	0.009	0.455	3.973
m10	2012	2011	0.101	0.086	0.006	0.437	2.958
m10	2013	2012	0.422	0.101	0.128	1.849	4.129
m10	2014	2013	0.021	0.105	0.000	0.093	3.595
m10	2015	2014	-0.166	0.106	0.021	-0.728	3.724
m10	2016	2015	0.235	0.233	0.126	1.115	2.677
m10	2017	2016	-0.070	0.262	0.013	-0.337	3.616
m10	2018	2017	-0.131	0.217	0.035	-0.617	2.223
m10	2019	2018	0.280	0.108	0.061	1.234	2.769
m10	2020	2019	-0.242	0.195	0.101	-1.120	2.330

Table 8: Detailed output for model m14. Fitted values are log-transformed.

model	year	juvenile_year	resid	hat_values	Cooks_distance	std_resid	fitted
m14	1998	1997	0.304	0.046	0.025	1.249	3.445
m14	1999	1998	-0.585	0.315	1.229	-2.833	4.939
m14	2000	1999	-0.381	0.143	0.152	-1.652	3.392
m14	2001	2000	0.105	0.090	0.006	0.443	4.099
m14	2002	2001	-0.096	0.100	0.006	-0.407	3.910
m14	2003	2002	-0.012	0.133	0.000	-0.051	3.973
m14	2004	2003	0.189	0.049	0.010	0.777	3.624
m14	2005	2004	0.140	0.090	0.011	0.587	3.940
m14	2006	2005	-0.086	0.228	0.015	-0.392	2.537
m14	2007	2006	0.224	0.055	0.016	0.924	3.578
m14	2008	2007	-0.214	0.121	0.038	-0.915	2.980
m14	2009	2008	-0.010	0.095	0.000	-0.040	3.647
m14	2010	2009	-0.103	0.047	0.003	-0.424	3.281
m14	2011	2010	0.114	0.112	0.010	0.485	3.962
m14	2012	2011	0.054	0.088	0.002	0.227	3.005
m14	2013	2012	0.512	0.083	0.139	2.145	4.038
m14	2014	2013	0.035	0.103	0.001	0.148	3.581
m14	2015	2014	-0.158	0.108	0.018	-0.670	3.716
m14	2016	2015	0.129	0.184	0.025	0.574	2.783
m14	2017	2016	-0.006	0.299	0.000	-0.029	3.553
m14	2018	2017	-0.129	0.218	0.032	-0.585	2.221
m14	2019	2018	0.247	0.107	0.044	1.050	2.802
m14	2020	2019	-0.274	0.186	0.113	-1.217	2.362

Table 9: Detailed output for model m18. Fitted values are log-transformed.

model	year	juvenile_year	resid	hat_values	Cooks_distance	std_resid	fitted
m18	1998	1997	0.324	0.045	0.031	1.388	3.425
m18	1999	1998	-0.456	0.302	0.749	-2.282	4.810
m18	2000	1999	-0.293	0.115	0.074	-1.302	3.303
m18	2001	2000	0.116	0.088	0.008	0.506	4.089
m18	2002	2001	-0.126	0.107	0.012	-0.556	3.939
m18	2003	2002	-0.064	0.150	0.005	-0.291	4.025
m18	2004	2003	0.200	0.049	0.013	0.859	3.613
m18	2005	2004	0.218	0.096	0.033	0.958	3.861
m18	2006	2005	-0.259	0.143	0.077	-1.171	2.710
m18	2007	2006	0.157	0.065	0.011	0.680	3.645
m18	2008	2007	-0.234	0.124	0.052	-1.047	3.001
m18	2009	2008	-0.046	0.103	0.002	-0.204	3.684
m18	2010	2009	-0.191	0.048	0.011	-0.818	3.369
m18	2011	2010	0.052	0.107	0.002	0.230	4.024
m18	2012	2011	0.083	0.086	0.004	0.363	2.976
m18	2013	2012	0.431	0.099	0.131	1.899	4.120
m18	2014	2013	-0.003	0.112	0.000	-0.015	3.620
m18	2015	2014	-0.141	0.110	0.016	-0.626	3.699
m18	2016	2015	0.237	0.233	0.130	1.132	2.675
m18	2017	2016	-0.050	0.270	0.007	-0.244	3.597
m18	2018	2017	-0.111	0.221	0.026	-0.525	2.203
m18	2019	2018	0.343	0.111	0.096	1.519	2.707
m18	2020	2019	-0.186	0.216	0.071	-0.880	2.274

Table 10: Detailed output for model m20. Fitted values are log-transformed.

model	year	juvenile_year	resid	hat_values	Cooks_distance	std_resid	fitted
m20	1998	1997	0.303	0.047	0.023	1.191	3.447
m20	1999	1998	-0.419	0.300	0.529	-1.922	4.773
m20	2000	1999	-0.263	0.111	0.048	-1.070	3.273
m20	2001	2000	0.157	0.084	0.012	0.631	4.047
m20	2002	2001	-0.032	0.084	0.000	-0.127	3.845
m20	2003	2002	-0.062	0.159	0.004	-0.259	4.023
m20	2004	2003	0.190	0.049	0.010	0.749	3.623
m20	2005	2004	0.169	0.092	0.016	0.681	3.910
m20	2006	2005	-0.320	0.128	0.085	-1.314	2.771
m20	2007	2006	0.289	0.048	0.022	1.136	3.514
m20	2008	2007	-0.259	0.130	0.056	-1.066	3.025
m20	2009	2008	-0.095	0.126	0.007	-0.390	3.733
m20	2010	2009	-0.287	0.057	0.026	-1.134	3.465
m20	2011	2010	0.028	0.106	0.001	0.115	4.048
m20	2012	2011	0.120	0.085	0.007	0.482	2.939
m20	2013	2012	0.445	0.098	0.117	1.798	4.106
m20	2014	2013	0.133	0.080	0.008	0.532	3.483
m20	2015	2014	-0.395	0.083	0.076	-1.582	3.953
m20	2016	2015	0.158	0.206	0.040	0.682	2.754
m20	2017	2016	0.081	0.359	0.028	0.387	3.466
m20	2018	2017	-0.134	0.218	0.032	-0.584	2.226
m20	2019	2018	0.349	0.112	0.085	1.421	2.700
m20	2020	2019	-0.158	0.239	0.050	-0.693	2.245

Table 11: Detailed output for model m21. Fitted values are log-transformed.

model	year	juvenile_year	resid	hat_values	Cooks_distance	std_resid	fitted
m21	1998	1997	0.407	0.045	0.034	1.477	3.343
m21	1999	1998	-0.394	0.300	0.399	-1.671	4.748
m21	2000	1999	-0.302	0.127	0.064	-1.148	3.313
m21	2001	2000	0.199	0.081	0.016	0.738	4.005
m21	2002	2001	0.003	0.079	0.000	0.010	3.811
m21	2003	2002	0.037	0.127	0.001	0.142	3.924
m21	2004	2003	0.215	0.049	0.011	0.781	3.599
m21	2005	2004	0.268	0.105	0.040	1.005	3.812
m21	2006	2005	-0.350	0.125	0.084	-1.327	2.801
m21	2007	2006	0.331	0.045	0.023	1.201	3.472
m21	2008	2007	-0.208	0.122	0.029	-0.787	2.974
m21	2009	2008	-0.201	0.183	0.046	-0.788	3.838
m21	2010	2009	-0.260	0.054	0.017	-0.948	3.438
m21	2011	2010	-0.123	0.111	0.009	-0.463	4.199
m21	2012	2011	0.055	0.088	0.001	0.204	3.004
m21	2013	2012	0.391	0.118	0.097	1.478	4.160
m21	2014	2013	0.247	0.061	0.018	0.904	3.369
m21	2015	2014	-0.420	0.083	0.073	-1.556	3.978
m21	2016	2015	0.028	0.156	0.001	0.109	2.884
m21	2017	2016	0.028	0.348	0.003	0.121	3.519
m21	2018	2017	-0.217	0.207	0.065	-0.865	2.309
m21	2019	2018	0.399	0.119	0.102	1.510	2.650
m21	2020	2019	-0.133	0.266	0.037	-0.550	2.221

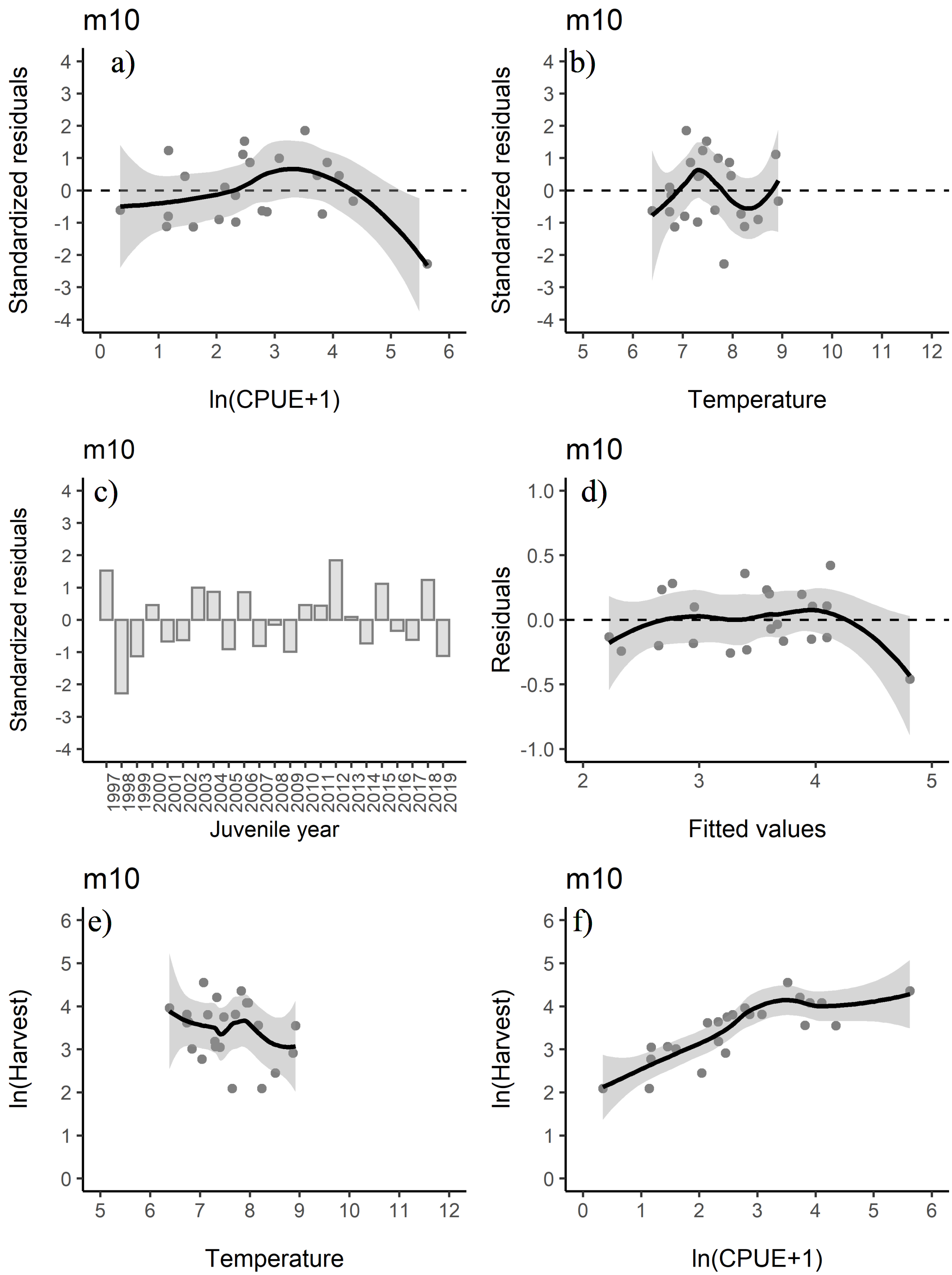

Figure 2: Standardized residuals versus the predicted plots for a) CPUE and b) temperature. c) Standardized residuals versus juvenile year and d) residuals versus fitted values for model m10. Relationship between e) temperature and harvest and f) CPUE and harvest. The line in figures a, b, d, e, and f is a smoothing function applied to the relationship with a 95% confidence interval.

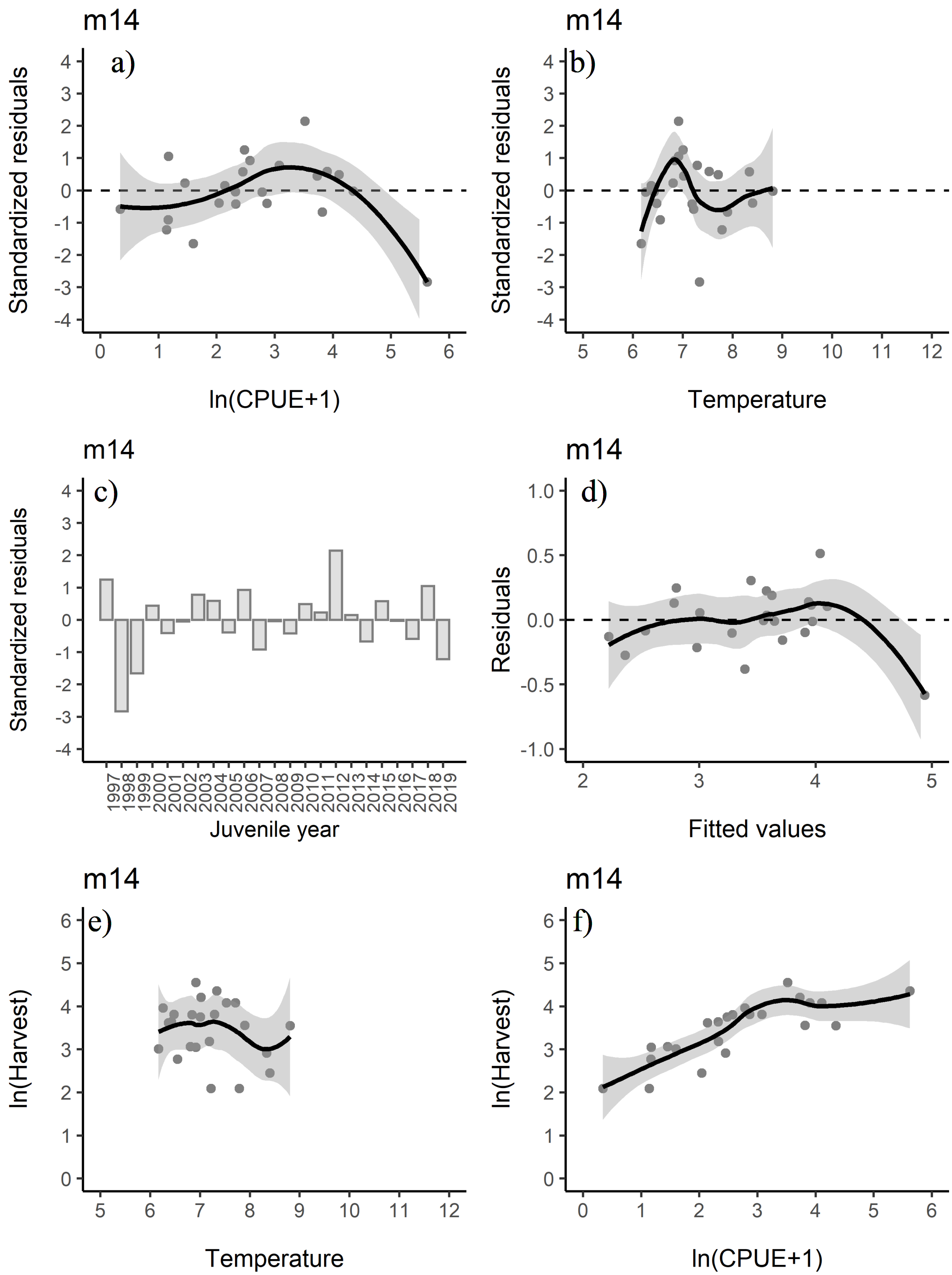

Figure 3: Standardized residuals versus the predicted plots for a) CPUE and b) temperature. c) Standardized residuals versus juvenile year and d) residuals versus fitted values for model m14. Relationship between e) temperature and harvest and f) CPUE and harvest. The line in figures a, b, d, e, and f is a smoothing function applied to the relationship with a 95% confidence interval.

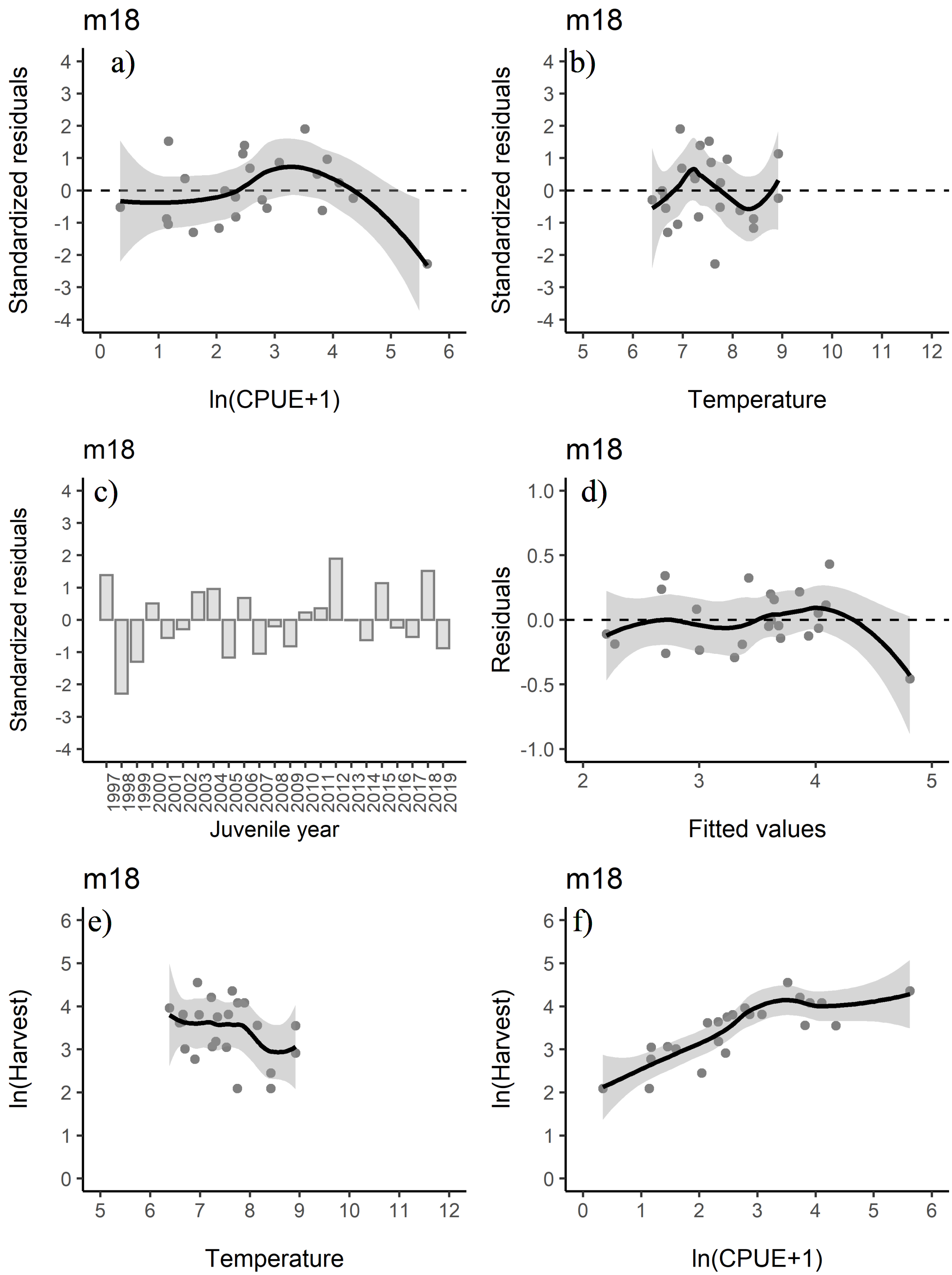

Figure 4: Standardized residuals versus the predicted plots for a) CPUE and b) temperature. c) Standardized residuals versus juvenile year and d) residuals versus fitted values for model m18. Relationship between e) temperature and harvest and f) CPUE and harvest. The line in figures a, b, d, e, and f is a smoothing function applied to the relationship with a 95% confidence interval.

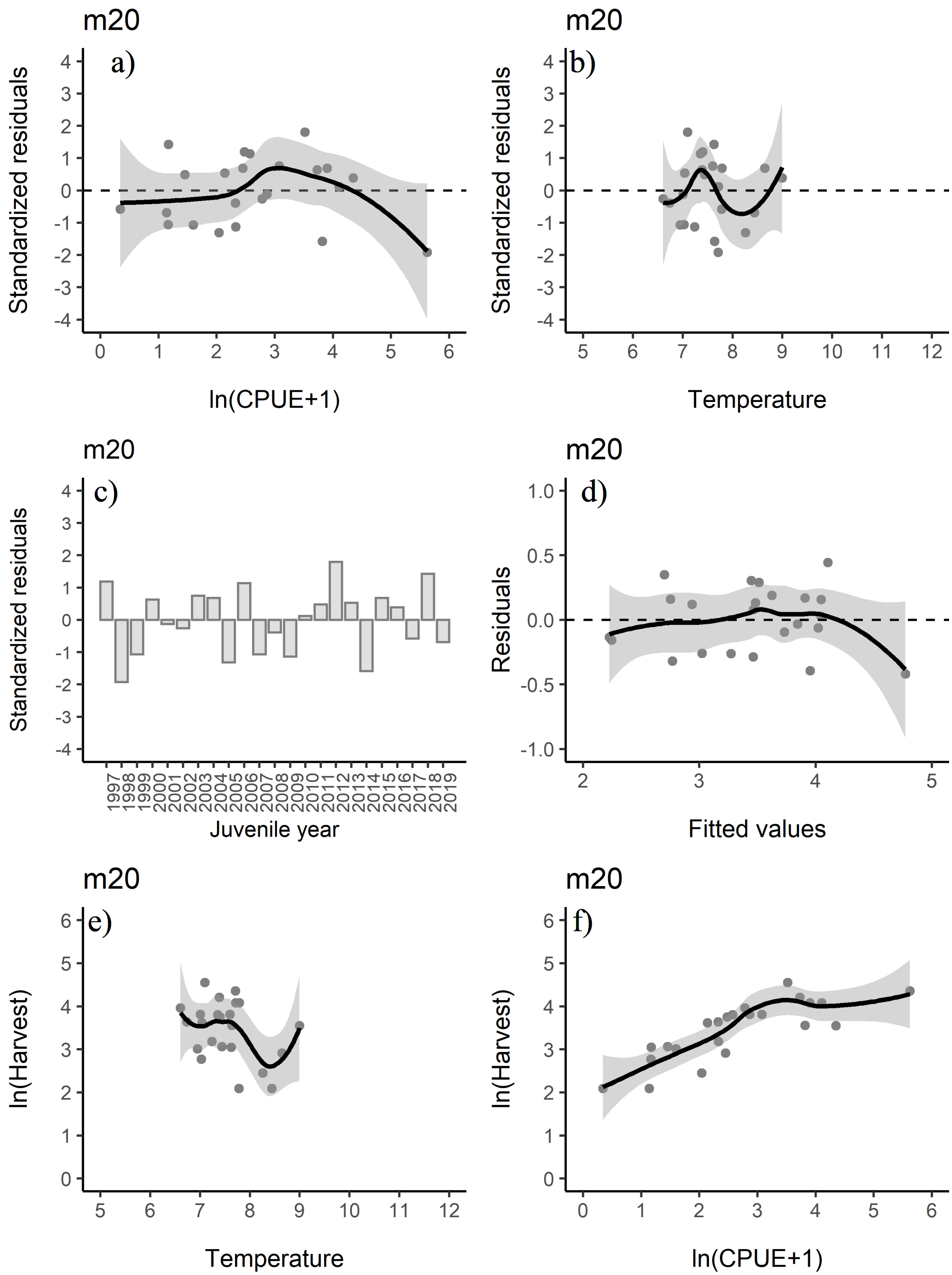

Figure 5: Standardized residuals versus the predicted plots for a) CPUE and b) temperature. c) Standardized residuals versus juvenile year and d) residuals versus fitted values for model m20. Relationship between e) temperature and harvest and f) CPUE and harvest. The line in figures a, b, d, e, and f is a smoothing function applied to the relationship with a 95% confidence interval.

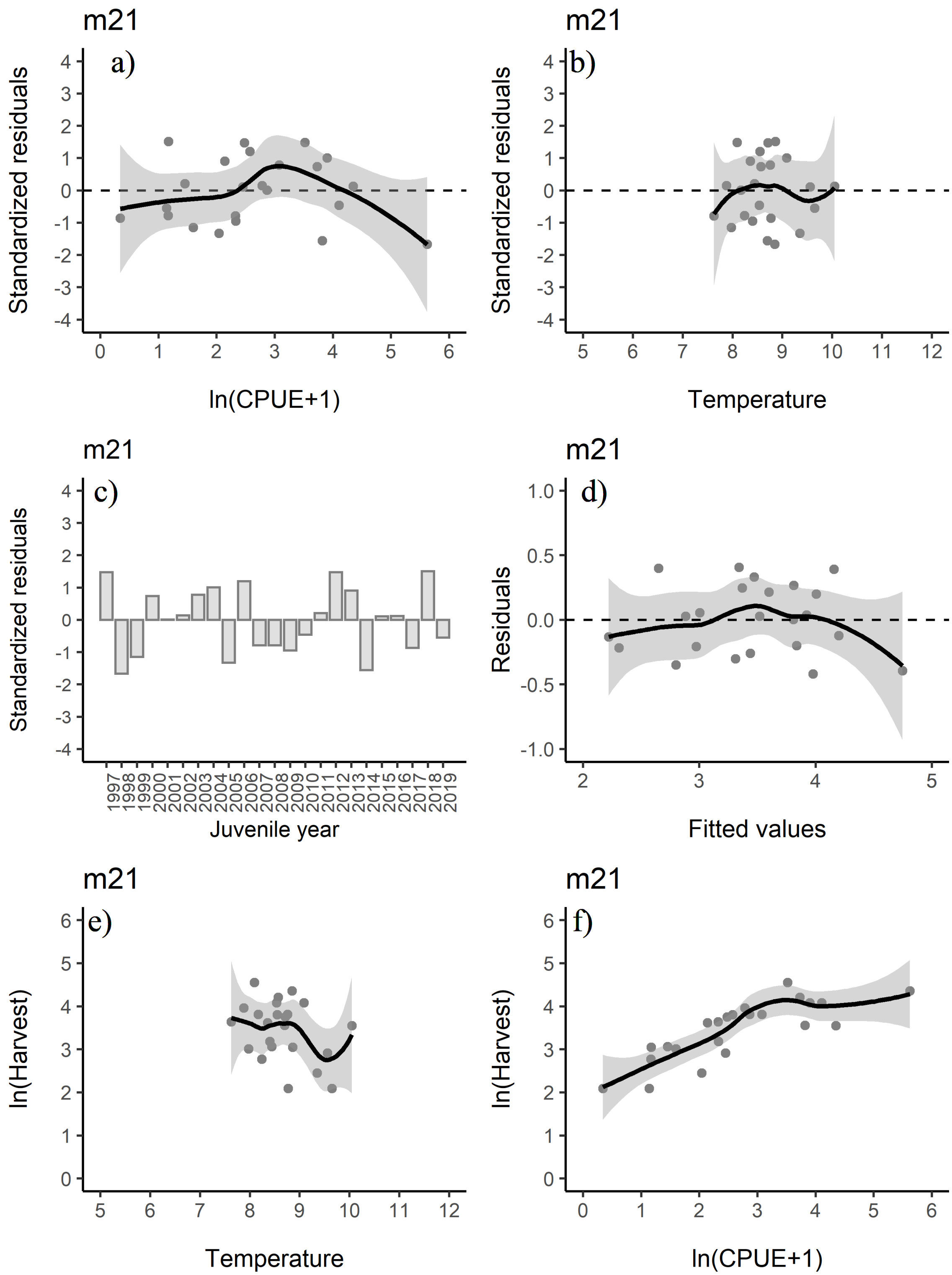

Figure 6: Standardized residuals versus the predicted plots for a) CPUE and b) temperature. c) Standardized residuals versus juvenile year and d) residuals versus fitted values for model m21. Relationship between e) temperature and harvest and f) CPUE and harvest. The line in figures a, b, d, e, and f is a smoothing function applied to the relationship with a 95% confidence interval.

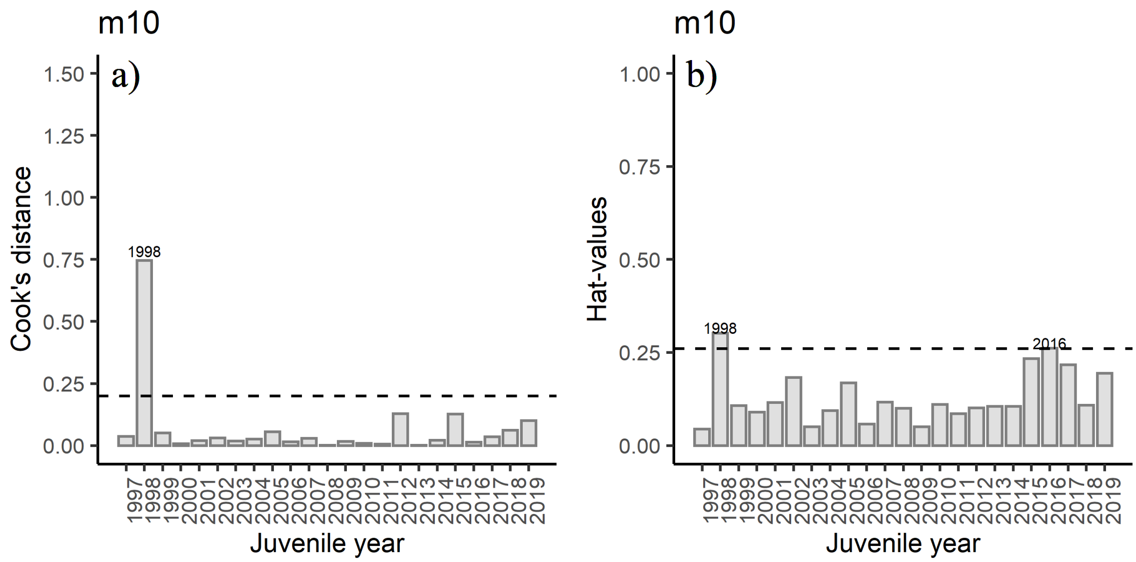

Figure 7: Diagnostics plots of influential observations including a) Cook's Distance (with a cut-off value of 0.20), and b) leverage values (with a cut-off value of 0.26) from model m10.

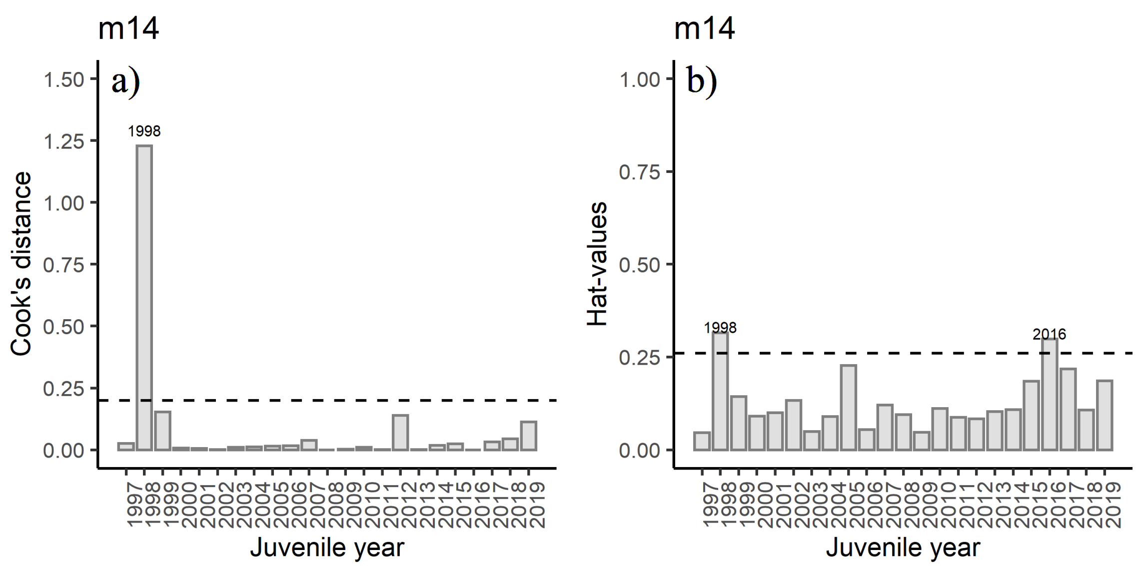

Figure 8: Diagnostics plots of influential observations including a) Cook's Distance (with a cut-off value of 0.20), and b) leverage values (with a cut-off value of 0.26) from model m14.

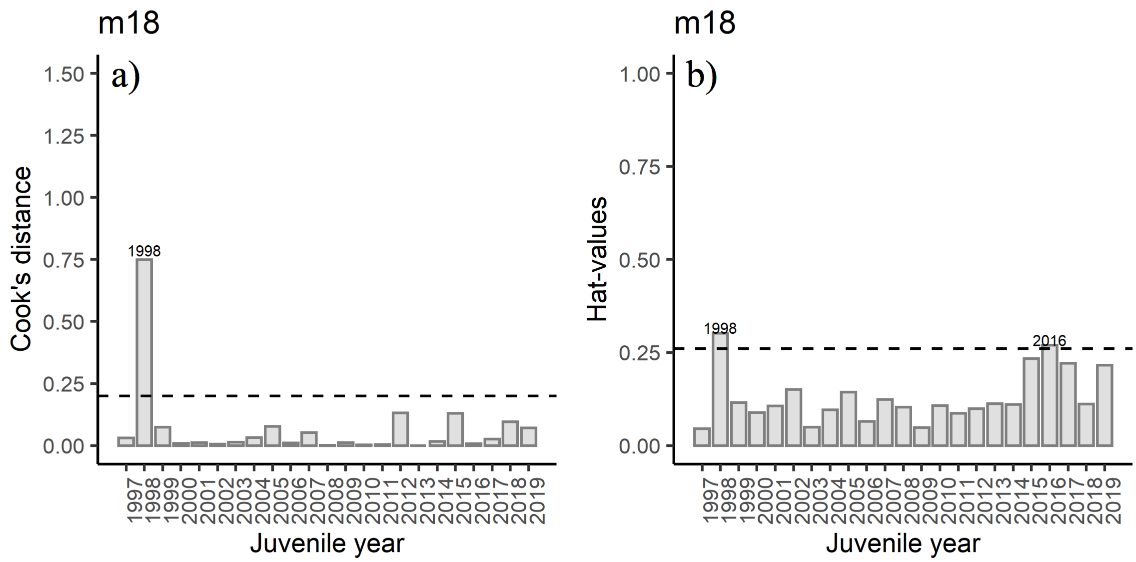

Figure 9: Diagnostics plots of influential observations including a) Cook's Distance (with a cut-off value of 0.20), and b) leverage values (with a cut-off value of 0.26) from model m18.

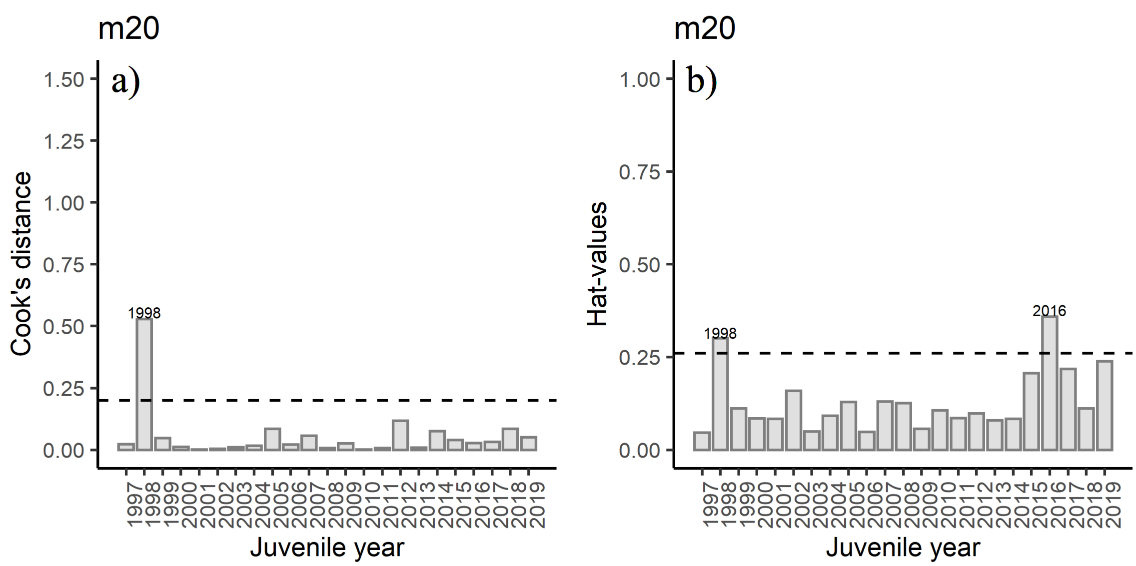

Figure 10: Diagnostics plots of influential observations including a) Cook's Distance (with a cut-off value of 0.20), and b) leverage values (with a cut-off value of 0.26) from model m20.

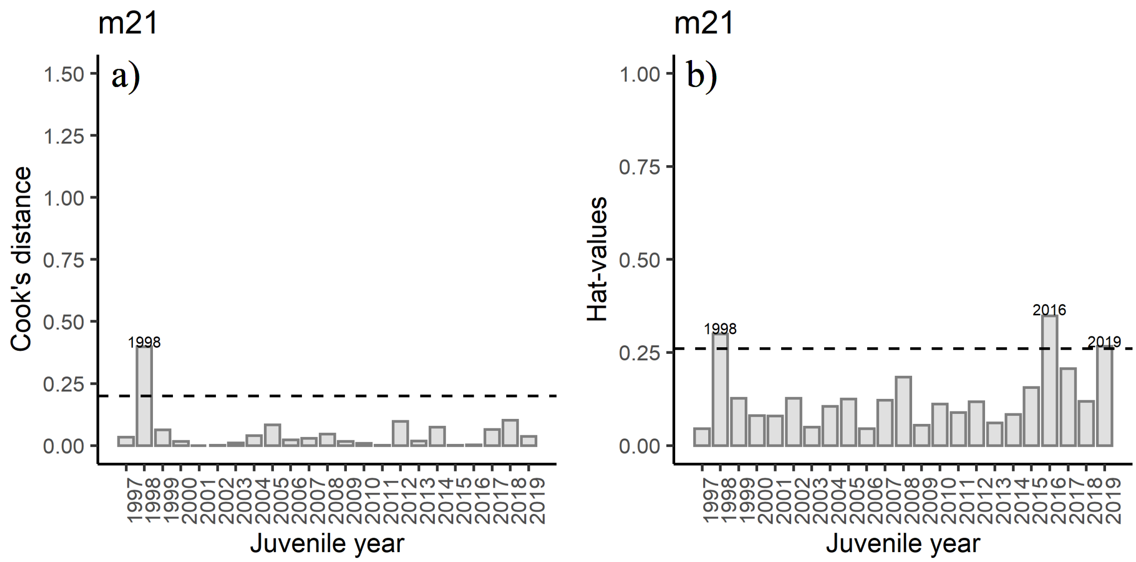

Figure 11: Diagnostics plots of influential observations including a) Cook's Distance (with a cut-off value of 0.20), and b) leverage values (with a cut-off value of 0.26) from model m21.