Oregon Coast Coho Conservation Plan

12-Year Plan Assessment

Appendix II.

Population Persistence Models

Oregon Department of Fish and Wildlife
4034 Fairview Industrial Drive SE
Salem, OR 97302

Disclaimer

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Population Persistence Models

The Oregon Coast Coho Conservation Plan (OCCCP) includes measurable criteria for assessing of the status of Independent Populations of Oregon Coast coho salmon (OC Coho) relative to broad sense goals. The persistence criterion for Independent Populations requires the use of quantitative models to estimate the probability that populations will persist for the next 100 years. To evaluate this criterion, population viability analysis (PVA) models are used to estimate population-scale extinction risk over a 100-year time frame, and the probability of persistence is calculated as one minus the extinction risk. Population viability analysis includes a variety of quantitative analyses to predict the future status of a population or collection of populations, especially to predict the risk of extinction (or quasi-extinction) over time. To assess population persistence for this 12-year assessment of the OCCCP, density-dependent, count-based PVA models were applied to the Oregon Coast coho salmon (OC Coho) Independent Populations.

Modeling the Probability of Persistence

Modeling the probability that a population will persist into the foreseeable future (e.g., 100 years) requires the assumption that future conditions will be consistent with the conditions over the period represented by the stock-recruit data used to parameterize recruitment models. Generally, PVA models do not explicitly account for changes in stock-recruit relationships attributable to changing conditions. Therefore, PVAs may be better considered as a means for assessing current status rather than as absolute predictors of the future. This aspect of PVA modeling is well-addressed in the following excerpt from ODFW's Coastal Multi-Species Conservation and Management Plan (ODFW 2014):

> *"The PVA model uses past abundances to infer extinction risk. Thus, the interpretation of the result is couched in the assumption that the conditions that were present when the data were collected will persist for 100 years. The model is not intended to capture effects of global warming, human population growth, or other anticipated future change. Of course, the future will not be like the past. Future food webs are uncertain, as is the adaptive potential of these fish. The purpose of the PVA is not to forecast the future; rather, the PVA is an assessment of current status."*

A key consideration in PVA modeling is balancing the need for a robust (i.e., long term) stock-recruit dataset for parameterizing recruitment models with the need to ensure that the stock-recruit data represent "current" conditions.

Historical and Contemporary Time Periods

For the current assessment, recruitment models were parameterized with stock-recruit data from each Independent Population over two periods: pre-1990 (historical period) and post-1990 (contemporary period). For most populations, the historical period began in brood year 1958[1], and the contemporary period for all populations ended in brood year 2016 (offspring return year 2019). This is a different approach than was used in the original OCCCP assessment, where recruitment models were fit to a single period (brood years 1958-2004). The reasons for this departure are two-fold:

(1) The survey designs used to estimate population abundance have been much more robust in the contemporary period than historically. The first statistical survey of OC coho was initiated in

[1] Stock-recruit time series for most populations begins in brood year 1958; the stock-recruit time series for the Salmon River and Sixes populations begin in brood year 1990; the time series for the Floras population begins in brood year 1994; the time series for the Siuslaw, Siltcoos, and Tahkenitch populations begin in brood year 1960.

1990, and a spatially balanced statistical design was employed starting in 1998. Prior to this, abundance was estimated from index sites.

(2) Conditions currently experienced by these populations are quite different than they were historically. Hatcheries have been essentially eliminated, harvest rates are much lower, ocean productivity regimes have changed, and climate change is occurring. Recruitment in recent years more accurately reflects conditions that we see currently and expect in the near future.

There is an argument for a later starting time (i.e., 1999 vs. 1990). In the period from 1990 to 1999, the effects of higher harvest rates and larger hatchery influence would still have been affecting recruitment on the coast. In this respect, the period starting in 1999 would more accurately reflect the conditions that OC Coho populations experience now. A later start date would also weight the effects of climate change more strongly and thus would be a more accurate representation of conditions that we see now and expect to see in the future. However, starting the time series in 1999 eliminates the influence of a period of poor ocean conditions that occurred in the 1990s. Cycles of ocean productivity in this region occur on the scale of decades, and starting the analysis in 1999 could indicate a higher recruitment rate than we might see over longer time scales. For this reason, and to increase the number of brood years included in the analysis, we opted to start the contemporary assessment period in 1990.

Given that the post-1990 period best represents contemporary management and environmental conditions, the current assessment is based primarily on the persistence probabilities from models parameterized using stock-recruit data from this period. Assessment of the pre-1990 historical period is provided for context, but given the methodological issues raised above, caution should be exercised when inferring changes in biological performance based on differences in the persistence probabilities estimated for the two periods.

Recruitment Models

Assessment of the OCCCP persistence criterion was originally based on PVA models developed by the Oregon Coast Workgroup of the Oregon and Northern California Coast Technical Recovery Team (Wainwright *et al*. 2008). These PVAs used three recruitment models (a modified Ricker model [Ricker 1954]; a modified Beverton-Holt model [Beverton and Holt 1957]; a Hockey Stick model [Barrowman and Myers 2000]) and a stochastic habitat-based life cycle model (Nickelson and Lawson 1998) with stock-recruit data from 1958-2004. In that assessment, the highest probabilities of persistence were typically obtained from PVAs based on the hockey stick, Beverton-Holt, and the Nickelson-Lawson models; the Ricker models were by far the most sensitive to potential extinction (Wainwright *et al*. 2008). Model details provided in source documents (e.g., Chilcote *et al*. 2005; Wainwright *et al*. 2008) were insufficient to precisely replicate the original PVA models, and model coding for some (Ricker; Nickelson-Lawson) existed only in obsolete computing programs. Therefore, ODFW worked with the U.S. Geological Survey’s Oregon Cooperative Fish and Wildlife Research Unit to develop new PVAs to support the current assessment.

For the current assessment, density-dependent PVAs used Ricker and Beverton-Holt stock-recruitment models to assess the probability of persistence for the Independent Populations of the OC Coho ESU. Because initial efforts to fit hockey stick recruitment models resulted in unrealistic parameterizations for some populations, that recruitment model was not incorporated into the current assessment. The PVAs were run by parameterizing each model using data from the two assessment periods (pre-1990 and post-1990).

The Ricker model assumes compensation (i.e., a decrease in productivity with increasing abundance, resulting in an approach to some maximum level of production). In the most basic form of this recruitment model, the number of spawners is used to predict the number of recruits in the next generation as:

$$R = S \times \exp\,(\alpha + BS) \qquad (1)$$

where R is the total number of adult recruits (pre-harvest) produced from the spawners three years previously, S is the number of spawners that produced those recruits, α is the slope of the recruitment function at the origin, and B provides the rate of curvature of the function as spawner abundance increases.

In contrast to the Ricker model, the Beverton-Holt model provides for an initial linear increase in recruitment before a gradual decrease, approaching an asymptote at peak recruitment. The Beverton-Holt model can be expressed as:

$$R = \frac{rS}{1+\frac{r}{K}S} \qquad (2)$$

where R and S are as previously defined, r is intrinsic productivity, and K is the peak recruitment parameter. Because hatchery-origin spawners have been observed to have lower productivity and reproductive success than wild spawners in some populations (e.g., Buhle *et al*. 2009; Chilcote *et al*. 2011), we included a parameter Ψ to represent differential reproductive success between hatchery and wild fish. Thus, the parameter S can be further defined as:

$$S = W + \Psi H \qquad (3)$$

where W is the number of wild spawners and H is the number of hatchery spawners.

The recruits per spawner ratio (R/S, i.e., productivity) observed for OC Coho populations is typically inversely related to spawner abundance (i.e., as spawner abundance increases, R/S decreases). The Beverton-Holt model may have a positive recruitment bias when spawner abundances are very low. While the Ricker model may be well-suited to describe coho recruitment at low spawner abundances, the model also predicts a reduction in R/S when parental spawner abundance is high. Most OC Coho populations do not show a strong decrease in recruits when the spawner escapement level is high, though there is evidence of a plateau in recruitment at higher spawner abundances (See Appendix I, *Measurable Criteria Assessment*). Compensation at high spawner abundances can also lead to false projections of extinction.

Parameter Estimation

The values for the parameters α and B from Equation 1 and r and K in Equation 2 had to be estimated separately for each population and for the pre- and post-1990 time periods to run the PVAs. The data used to parameterize the recruitment models were derived from spawner and recruit data for OC Coho as presented in this assessment. We calculated the number of recruits corresponding to each brood year by dividing the spawner abundance observed three years later by one minus the fishery mortality rate. For example, the number of recruits produced by the fish that spawned in 1996 was calculated as the spawner abundance observed in 1999 divided by one minus the fishery mortality rate observed for 1999. To estimate *R/S* for each brood year, both naturally produced and hatchery fish that spawned in the wild were counted as spawners (combined for the denominator, S), whereas only naturally produced fish were counted as recruits (the numerator, R).

To estimate model parameters, we used Bayesian model inference in the freely available R (v. 4.0.2; R Core Development Team 2021) and JAGS (v. 4.3.0; Plummer 2003) software. We used Gibbs sampling, a Markov chain Monte Carlo algorithm, with three parallel chains of 250,000 iterations following a burn-in period of 100,000 iterations. We thinned each chain by keeping every 5th sample to eliminate possible autocorrelation. This resulted in 30,000 unique samples from the posterior distributions. We conducted visual inspection of trace plots and posterior density plots to verify that adequate chain mixing and parameter convergence occurred. Models were structured hierarchically such that variance (σ) was calculated for each parameter *a*, *B*, *r*, and *K*. We used a multiplicative (or log-normal) error structure where model error (ε) was autocorrelative over time to represent temporal autocorrelation in the stochastic, environmental drivers that are encompassed by the ε term.

Model Selection for Persistence Assessment

To select the best model (Ricker vs. Beverton-Holt) for each population in each assessment period, we used the Deviance Information Criterion (DIC), a generalization of the Akaike Information Criterion (AIC). Like the AIC, models with the smallest values of the DIC represent the best fitting model; therefore, the model initially selected as the best model was the model with the smallest value of the DIC. If the ΔDIC ($DIC_{model\ 2} - DIC_{min}$) for the remaining candidate model was greater than or equal to 3.0, the model with the smallest value of the DIC was retained as the best model. Where the ΔDIC was less than 3, both candidate models were retained. In these cases, the probability of persistence was estimated as a weighted average probability of persistence from both models, where weights were based on DIC weights, wDIC. DIC weights were calculated as:

$$DICw = \frac{\exp(-0.5 \times \Delta DIC)}{\sum \exp(-0.5 \times \Delta DIC)} \qquad (4)$$

Quasi-Extinction Thresholds

A quasi-extinction threshold (QET) represents a threshold of abundance below which the population is considered functionally extinct after multiple consecutive years. The QET is greater than zero to account for genetic and demographic impacts associated with persistent low abundance. In the original assessment for the OCCCP, persistence probabilities were assessed using two QETs for each population regardless of population size (0 and 50 spawners). For the current assessment, we adjusted the QET thresholds to account for relative population size. Populations were classified as small, medium, or large based on evaluation of spawning distribution kilometers (ODFW Fish Habitat Distribution dataset) and estimates of historical population size (Lawson *et al.* 2007). Small, medium, and large populations were defined by spawning distributions of less than 200 km, 200 to 400 km, and greater than 400 km, respectively (Fig. A-II:1). The eight small populations correspond to those classified by Lawson *et al*. (2007) as potentially independent; medium and large populations correspond to those classified as functionally independent. The QETs were set to 50 (small), 150 (medium), and 250 (large), following the approach in the Coastal Multispecies Conservation and Management Plan (ODFW 2014) and spanning much of the range of QETs typically applied to coastal coho populations from California to Puget Sound (Busch *et al*. 2013). For most populations, this resulted in QETs that were set higher than those used in the PVAs for the original OCCCP assessment.

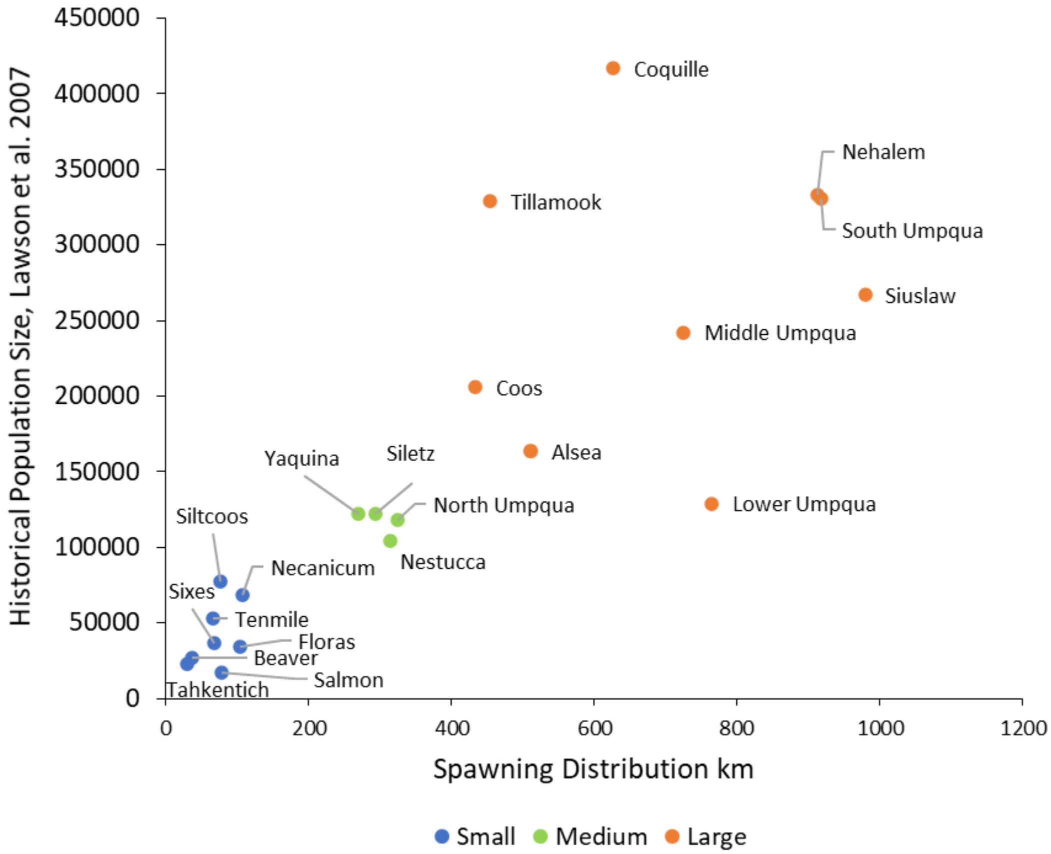

Figure A-II:1. Spawner distributions (kilometers; ODFW Fish Habitat Distribution dataset) and estimates of historical population size from Lawson *et al.* (2007) for the Independent Populations of Oregon Coast Coho Salmon.

Persistence Estimation

The Density Dependent-PVA model is a series of calculations implemented via R analytical software. Recruits are forecast iteratively over multiple generations using the density-dependent stock-recruitment functions (equations 1 and 2), where model parameters are randomly drawn from the posterior distribution of parameter estimates. For the purposes of this analysis, annual harvest rates and the proportion of hatchery-origin spawners were drawn from a beta distribution based on the last ten years of available data for each population and each time period.

To estimate the probability of extinction, 5,000 iterations of a 100-year recruitment simulation were completed for each population using each model in each time period. Quasi-extinction was considered to occur when, at any point in each sequence there was period with a 3-year average spawner abundance less than the QET thresholds (50, 150, or 250 spawners). The probability of extinction was calculated as the number of trials that were classified as extinction events divided by the total number of trials. Persistence probabilities were calculated as one minus the extinction probability.

Results

Recruitment model parameters for the Ricker and Beverton-Holt models for each Independent Population are provided in Tables A-II:1 and A-II:2, respectively. Forecast probabilities of persistence (1 - forecast extinction rate) based on Ricker and Beverton-Holt model parameterizations at the three assessment QETs (50, 150 or 250 spawners) are provided in Table A-II:3 and A-II:4, respectively. In the historical period, probabilities of persistence based on the Ricker recruitment model are similar across the three QETs for most populations. However, the probabilities of persistence for the Nehalem, Beaver Creek and North Umpqua populations were more sensitive to the selected QET. Results are similar in the contemporary period, with the highest sensitivity to the selected QET in the Necanicum, Nestucca, Yaquina, Alsea, Floras and Sixes populations (Table A-II:3). Probabilities of persistence based on the Beverton-Holt model were not particularly sensitive to the selected QET in either the historical or contemporary periods apart from the Necanicum, Salmon, and Sixes populations post-1990 (Table A-II:4).

The Ricker model often fit the data better than the Beverton-Holt model in the historical period (pre-1990), but the Beverton-Holt Model frequently out-performed the Ricker model in the contemporary period (post-1990) (Tables A-II:5 & A-II:6; Fig. A-II:2). For the current 12-year assessment, probabilities of persistence in the historical period were based on the Ricker, Beverton-Holt, or a weighted average of both model results in seven, one, and ten populations, respectively. Where weighted averages were used, weighting favored the Ricker model in most populations (Table A-II:5; Fig. A-II:2, top panel). In the contemporary period, probabilities of persistence were based on the Ricker, Beverton-Holt, or a weighted average of both model results in three, ten, and eight populations, respectively (Table A-II:6; Fig. A-II:2 bottom panel). Probabilities of persistence summarized using the best-fitting recruitment model or weighted average of both models at each population's size-specific QET are provided in Table A-II:6.

The PVA models predict that for most populations the likelihood of extinction is relatively low provided that the environmental conditions of the last ~30 years persist for the next 100 years (Table A-II:7). Eight populations meet the OCCCP's high bar for persistence (≥ 99%), and only four populations have less than a 90% probability of persistence (Table A-II:7). At a coarse scale, the probability of extinction across populations has remained high in both the historical period (n = 18 populations; median = 0.99, interquartile range = 0.95 – 1.00) and the contemporary period (n = 21 populations; median = 0.95, interquartile range = 0.93 – 0.99).

As previously noted, ODFW believes that the post-1990 period best represents current management and environmental conditions. Therefore, persistence probabilities from this period are the primary basis of the current 12-year assessment of the OCCCP. Assessment of the pre-1990 historical period is provided for context, but caution should be exercised when inferring changes in biological performance based on differences in the probabilities of persistence estimated for the historical and contemporary periods. Prior to 1990, estimates of spawner abundance and harvest rates are subject to greater uncertainty and potential biases that are not accounted for in the PVA models. Similarly, persistence probabilities herein are not directly comparable to those in the original OCCCP assessment because the current and original PVAs use different formulations of the recruitment models, were parameterized over different stock-recruit periods, and apply different QETs to most populations. PVA results are sensitive to these changes, as demonstrated in Wainwright et al. (2008). Given this sensitivity to methodology and uncertainty about how well a retrospective analysis reflects future extinction risk in a changing climate, the results presented here should be considered primarily as indicators of relative risk among populations.

Table A-II:1. Ricker recruitment model parameters and standard deviation (sd) for 21 populations of Oregon Coast coho salmon for the historical (pre-1990) and contemporary (post-1990) periods. There are no stock-recruitment data available for the historical period in the Salmon, Floras and Sixes populations.

Population	Pre-1990				Post-1990			
	α	sd	*B*	sd	α	sd	*B*	sd
Necanicum	5.26	1.53	0.00082	0.00025	2.73	0.94	0.00056	0.00013
Nehalem	4.11	2.03	0.00006	0.00004	3.48	1.47	0.00009	0.00002
Tillamook	2.82	0.99	0.00003	0.00006	2.68	0.81	0.00012	0.00003
Nestucca	3.98	1.31	0.00011	0.00006	3.23	1.11	0.00027	0.00007
Salmon	*N/A*	*N/A*	*N/A*	*N/A*	1.42	0.87	0.00071	0.00035
Siletz	5.82	1.68	0.00055	0.00017	2.09	0.68	0.00006	0.00003
Yaquina	4.21	1.49	0.00011	0.00004	3.67	1.39	0.00013	0.00004
Beaver	5.85	1.85	0.00081	0.00023	2.60	0.56	0.00040	0.00008
Alsea	6.04	1.64	0.00032	0.00009	1.98	0.76	0.00007	0.00003
Siuslaw	8.36	1.80	0.00011	0.00002	2.61	1.05	0.00005	0.00002
Siltcoos	6.74	1.64	0.00031	0.00007	4.65	1.19	0.00034	0.00006
Tahkenitch	8.53	1.55	0.00072	0.00010	2.81	0.90	0.00028	0.00008
Tenmile	4.35	1.00	0.00005	0.00002	4.10	1.57	0.00016	0.00004
Lower Umpqua	5.64	1.14	0.00010	0.00003	2.93	0.91	0.00008	0.00002
Middle Umpqua	6.77	1.80	0.00033	0.00012	3.03	1.22	0.00015	0.00005
North Umpqua	3.90	1.58	0.00047	0.00035	1.85	0.67	0.00019	0.00008
South Umpqua	7.98	1.97	0.00053	0.00013	2.25	0.84	0.00007	0.00002
Coos	10.43	3.38	0.00017	0.00005	5.38	1.89	0.00011	0.00002
Coquille	5.12	1.21	0.00007	0.00002	2.39	0.78	0.00004	0.00001
Floras	*N/A*	*N/A*	*N/A*	*N/A*	3.24	1.34	0.00036	0.00010
Sixes	*N/A*	*N/A*	*N/A*	*N/A*	3.71	1.03	0.00603	0.00117

Table A-II:2. Beverton-Holt recruitment model parameters and standard deviation (sd) for 21 populations of Oregon Coast coho salmon for the historical (pre-1990) and contemporary (post-1990) periods. There are no stock-recruitment data available for the historical period in the Salmon, Floras and Sixes populations.

	Pre-1990				*Post-1990*			
Population	*r*	*sd*	*K*	*sd*	*r*	*sd*	*K*	*sd*
Necanicum	6.48	3.02	9770	21668	6.68	2.83	1618	1363
Nehalem	4.85	2.65	55941	37855	5.99	3.06	17044	14359
Tillamook	3.05	1.08	74842	45357	4.04	2.42	12107	12026
Nestucca	4.16	1.94	48326	38920	6.26	2.99	6173	12042
Salmon	*N/A*	*N/A*	*N/A*	*N/A*	2.53	3.03	32799	54173
Siletz	7.63	2.92	8075	15671	2.81	1.69	32710	31844
Yaquina	4.99	2.54	34590	30075	7.63	2.93	8111	8140
Beaver	5.70	2.88	18430	32702	4.56	2.49	4042	8205
Alsea	7.94	2.82	11087	11182	3.15	2.22	27168	31317
Siuslaw	8.88	2.68	45533	15456	5.65	2.98	21339	21603
Siltcoos	7.56	2.94	16514	17629	8.29	2.62	4967	964
Tahkenitch	8.08	2.76	7830	9241	6.73	2.98	4282	4974
Tenmile	5.84	1.69	51195	22845	7.09	2.88	10237	10627
Lower Umpqua	7.34	2.13	33294	16061	6.29	2.80	13998	5509
Middle Umpqua	7.28	2.80	22490	26180	7.73	3.16	6468	5021
North Umpqua	3.20	1.52	42193	52609	4.77	3.14	7886	17559
South Umpqua	8.19	2.85	12322	15259	6.45	3.08	12585	12689
Coos	8.71	2.80	38175	16109	8.51	2.89	14144	4754
Coquille	6.32	2.22	50265	26417	5.09	2.02	21688	12960
Floras	*N/A*	*N/A*	*N/A*	*N/A*	7.97	3.08	2508	2474
Sixes	*N/A*	*N/A*	*N/A*	*N/A*	8.58	2.98	196	44

Table A-II:3. Forecast probability of persistence using Ricker recruitment parameters from for the historical (pre-1990) and contemporary (post-1990) periods. This forecast predicts the probability that the 3-year average wild spawner abundance will fall below QETs (50, 150, 250 spawners) at least once within a simulated 100-year period. Shaded cells indicate the extinction probability with the QET set to the value associated with each population's relative size (small = 50, medium = 150, large = 250). There are no spawner-recruit data available for the Salmon, Floras, and Sixes populations in the pre-1990 period.

Population	Pre-1990			Post-1990		
	QET = 50	QET = 150	QET = 250	QET = 50	QET = 150	QET = 250
Necanicum	1.00	0.99	0.97	0.90	0.71	0.52
Nehalem	0.85	0.78	0.73	0.95	0.91	0.89
Tillamook	0.92	0.89	0.87	0.98	0.96	0.94
Nestucca	0.97	0.95	0.94	0.89	0.75	0.64
Salmon	*N/A*	*N/A*	*N/A*	0.12	0.04	0.03
Siletz	0.99	0.98	0.96	0.96	0.93	0.89
Yaquina	0.96	0.92	0.89	0.88	0.80	0.73
Beaver	0.95	0.87	0.77	1.00	0.98	0.96
Alsea	1.00	0.99	0.99	0.91	0.84	0.79
Siuslaw	1.00	1.00	1.00	0.94	0.90	0.86
Siltcoos	1.00	1.00	0.99	1.00	0.99	0.99
Tahkenitch	1.00	0.99	0.98	0.99	0.98	0.96
Tenmile	1.00	0.99	0.99	0.98	0.96	0.94
Lower Umpqua	1.00	1.00	1.00	0.99	0.99	0.98
Middle Umpqua	1.00	0.99	0.98	0.95	0.91	0.86
North Umpqua	0.86	0.69	0.55	0.95	0.92	0.88
South Umpqua	0.99	0.99	0.97	0.95	0.91	0.87
Coos	1.00	1.00	0.99	0.90	0.84	0.80
Coquille	0.99	0.99	0.99	0.89	0.86	0.84
Floras	*N/A*	*N/A*	*N/A*	0.80	0.61	0.47
Sixes	*N/A*	*N/A*	*N/A*	0.57	0.00	0.00

Table A-II:4. Forecast probability of persistence using Beverton-Holt recruitment parameters from for the historical (pre-1990) and contemporary (post-1990) periods. This forecast predicts the probability that the 3-year average wild spawner abundance will fall below QETs (50, 150, 250 spawners) at least once within a simulated 100-year period. Shaded cells indicate the extinction probability with the QET set to the value associated with each population's relative size (small = 50, medium = 150, large = 250). There are no spawner-recruit data available for the Salmon, Floras, and Sixes populations in the pre-1990 period.

Population	Pre-1990			Post-1990		
	QET = 50	QET = 150	QET = 250	QET = 50	QET = 150	QET = 250
Necanicum	0.99	0.98	0.97	0.99	0.91	0.72
Nehalem	0.92	0.88	0.86	0.99	0.99	0.98
Tillamook	0.95	0.91	0.89	1.00	0.99	0.99
Nestucca	0.97	0.95	0.93	0.99	0.97	0.92
Salmon	*N/A*	*N/A*	*N/A*	0.42	0.19	0.13
Siletz	1.00	1.00	1.00	0.98	0.96	0.94
Yaquina	0.97	0.95	0.94	1.00	1.00	0.99
Beaver	0.96	0.93	0.89	1.00	0.99	0.98
Alsea	1.00	1.00	1.00	0.94	0.91	0.89
Siuslaw	1.00	1.00	1.00	0.99	0.98	0.98
Siltcoos	1.00	1.00	0.99	1.00	1.00	1.00
Tahkenitch	1.00	0.99	0.99	1.00	1.00	1.00
Tenmile	1.00	0.99	0.99	1.00	1.00	1.00
Lower Umpqua	1.00	1.00	1.00	1.00	1.00	1.00
Middle Umpqua	1.00	0.99	0.99	1.00	0.99	0.99
North Umpqua	0.97	0.94	0.91	0.95	0.93	0.92
South Umpqua	1.00	0.99	0.99	1.00	0.99	0.99
Coos	1.00	1.00	1.00	1.00	1.00	1.00
Coquille	1.00	1.00	1.00	1.00	1.00	1.00
Floras	*N/A*	*N/A*	*N/A*	0.99	0.97	0.92
Sixes	*N/A*	*N/A*	*N/A*	0.93	0.03	0.00

Table A-II:5. Deviance Information Criteria (DIC), ΔDIC ($DIC_{model\ 2}$ – $DIC_{minimum}$) and DIC weights for Ricker and Beverton-Holt recruitment models in the pre-1990 period. Shaded cells indicate where both models were retained (ΔDIC < 3). For these populations wDIC values were used to calculate weighted average probabilities of persistence using outputs from both models.

Population	Pre-1990					
	DIC		ΔDIC		wDIC	
	Ricker	B-H	Ricker	B-H	Ricker	B-H
Necanicum	59.81	64.28	0.00	4.47	0.90	0.10
Nehalem	94.99	92.50	2.49	0.00	0.22	0.78
Tillamook	85.39	83.59	1.80	0.00	0.29	0.71
Nestucca	74.15	72.21	1.94	0.00	0.27	0.73
Salmon	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*
Siletz	75.00	75.24	0.00	0.24	0.53	0.47
Yaquina	80.49	79.81	0.68	0.00	0.42	0.58
Beaver	63.73	75.18	0.00	11.45	1.00	0.00
Alsea	72.45	72.21	0.23	0.00	0.47	0.53
Siuslaw	54.04	57.07	0.00	3.03	0.82	0.18
Siltcoos	55.97	59.35	0.00	3.38	0.84	0.16
Tahkenitch	69.20	74.34	0.00	5.14	0.93	0.07
Tenmile	87.55	71.84	15.70	0.00	0.00	1.00
L. Umpqua	59.22	61.72	0.00	2.49	0.78	0.22
M. Umpqua	69.82	71.93	0.00	2.10	0.74	0.26
N. Umpqua	100.66	100.04	0.62	0.00	0.42	0.58
S. Umpqua	68.22	79.65	0.00	11.44	1.00	0.00
Coos	58.04	63.49	0.00	5.45	0.94	0.06
Coquille	74.12	72.58	1.54	0.00	0.32	0.68
Floras	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*
Sixes	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*	*N/A*

Table A-II:5. Deviance Information Criteria (DIC), ΔDIC ($DIC_{model\ 2}$ – $DIC_{minimum}$) and DIC weights for Ricker and Beverton-Holt recruitment models in the post-1990 period. For these populations wDIC values were used to calculate weighted average probabilities of persistence using outputs from both models.

Population	Post-1990					
	DIC		ΔDIC		wDIC	
	Ricker	B-H	Ricker	B-H	Ricker	B-H
Necanicum	77.36	78.61	0.00	1.25	0.65	0.35
Nehalem	80.39	80.04	0.36	0.00	0.46	0.54
Tillamook	89.52	100.24	0.00	10.72	1.00	0.00
Nestucca	87.24	88.23	0.00	1.00	0.62	0.38
Salmon	111.22	114.32	0.00	3.10	0.82	0.18
Siletz	81.28	80.06	1.22	0.00	0.35	0.65
Yaquina	87.61	83.58	4.03	0.00	0.12	0.88
Beaver	91.58	83.33	8.24	0.00	0.02	0.98
Alsea	81.29	79.82	1.47	0.00	0.32	0.68
Siuslaw	88.66	77.94	10.73	0.00	0.00	1.00
Siltcoos	75.78	72.11	3.68	0.00	0.14	0.86
Tahkenitch	66.81	61.83	4.97	0.00	0.08	0.92
Tenmile	72.56	83.63	0.00	11.07	1.00	0.00
L. Umpqua	77.53	72.39	5.14	0.00	0.07	0.93
M. Umpqua	81.51	76.49	5.02	0.00	0.08	0.92
N. Umpqua	54.16	54.67	0.00	0.51	0.56	0.44
S. Umpqua	93.94	78.59	15.35	0.00	0.00	1.00
Coos	82.69	85.43	0.00	2.74	0.80	0.20
Coquille	72.59	70.50	2.09	0.00	0.26	0.74
Floras	76.02	70.24	5.78	0.00	0.05	0.95
Sixes	70.93	67.16	3.77	0.00	0.13	0.87

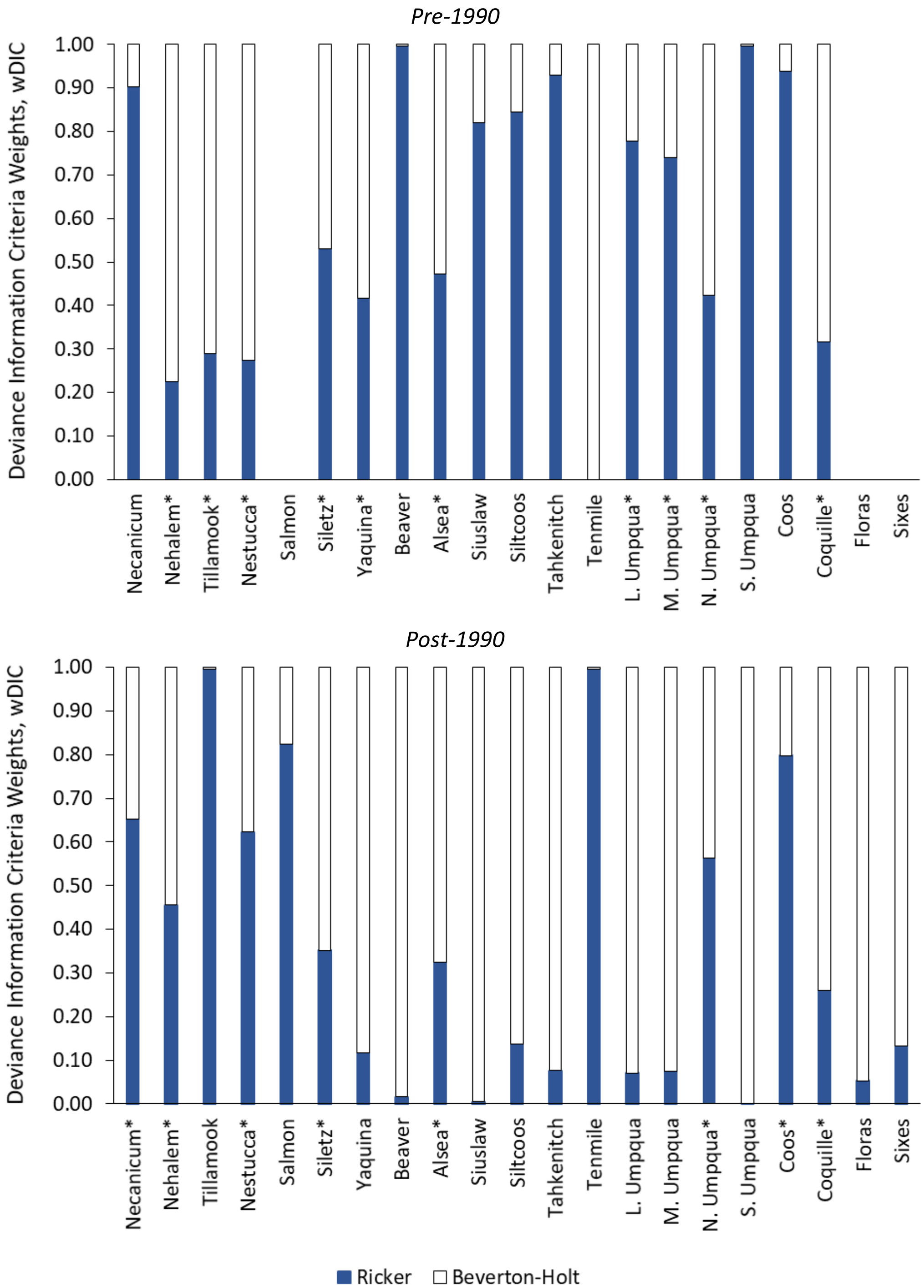

Figure A-II:1. Deviation Information Criteria weights, wDIC, for the Ricker (blue) and Beverton-Holt recruitment models for the historical (pre-1990; top pane) and contemporary (post-1990; bottom pane) periods. Asterisks following population names indicate where both candidate models were retained, and probabilities of persistence were based on a weighted average. For remaining populations where one model was dominant, probabilities of persistence were based on the model with the highest wDIC.

Table A-II:7. Estimates of persistence probabilities for the Independent Populations of the OC Coho ESU indicating the probability that the 3-year average wild spawner abundance will remain above the quasi-extinction threshold within a simulated 100-year period. Quasi-extinction thresholds are 50, 150, and 250 for small, medium, and large populations, respectively. The assessment model indicates the model on which the probability of persistence was based for the current assessment: Ricker, Beverton-Holt (B-H), or a weighted average of both models (W. Avg.). Populations are grouped by stratum.

Population	Population Size	QET	Assessment Model		Probability of Persistence	
			Pre-1990	Post-1990	Pre-1990	Post-1990
Necanicum	Small	50	Ricker	W. Avg	1.00	0.93
Nehalem	Large	250	W. Avg.	W. Avg	0.83	0.94
Tillamook	Large	250	W. Avg	Ricker	0.88	0.94
Nestucca	Medium	150	W. Avg	W. Avg	0.95	0.84
Salmon	Small	50	*N/A*	Ricker	*N/A*	0.13
Siletz	Medium	150	W. Avg	W. Avg	0.99	0.95
Yaquina	Medium	150	W. Avg	B-H	0.94	1.00
Beaver	Small	50	Ricker	B-H	0.95	1.00
Alsea	Large	250	W. Avg	W. Avg	0.99	0.86
Siuslaw	Large	250	Ricker	B-H	1.00	0.98
Siltcoos	Small	50	Ricker	B-H	1.00	1.00
Tahkenitch	Small	50	Ricker	B-H	1.00	1.00
Tenmile	Small	50	B-H	Ricker	0.98	0.98
L. Umpqua	Large	250	W. Avg	B-H	1.00	1.00
M. Umpqua	Large	250	W. Avg	B-H	0.99	0.99
N. Umpqua	Medium	150	W. Avg	W. Avg	0.83	0.92
S. Umpqua	Large	250	Ricker	B-H	0.97	0.99
Coos	Large	250	Ricker	W. Avg	1.00	0.84
Coquille	Large	250	W. Avg	W. Avg	0.99	0.96
Floras	Small	50	*N/A*	B-H	*N/A*	0.99
Sixes	Small	50	*N/A*	B-H	*N/A*	0.93

Table A-II:8. Differences in probabilities of persistence between the historical and contemporary periods for Ricker, Beverton-Holt or Best Models (i.e., Ricker, Beverton-Holt, or Weighted Average). Shaded cells indicate where the direction of difference is generally consistent among comparisons.

Population	Ricker	Beverton-Holt	Best Model or W. Avg.	Direction
Necanicum	-0.10	0.00	-0.07	Unclear
Nehalem	+0.16	+0.13	+0.11	Increase
Tillamook	+0.07	+0.09	+0.05	Increase
Nestucca	-0.20	+0.02	-0.11	Unclear
Salmon	*N/A*	*N/A*	*N/A*	*N/A*
Siletz	-0.05	-0.04	-0.04	Decrease
Yaquina	-0.12	+0.04	0.00	Unclear
Beaver	+0.05	+0.04	+0.05	Increase
Alsea	-0.20	-0.11	-0.13	Decrease
Siuslaw	-0.14	-0.03	-0.03	Decrease
Siltcoos	0.00	0.00	0.00	~Stable
Tahkenitch	0.00	0.00	0.00	~Stable
Tenmile	-0.02	0.00	-0.02	~Stable
Lower Umpqua	-0.02	0.00	0.00	~Stable
Middle Umpqua	-0.13	0.00	0.00	Unclear
North Umpqua	+0.23	-0.01	0.09	Unclear
South Umpqua	-0.10	0.00	0.02	Unclear
Coos	-0.19	0.00	-0.15	Unclear
Coquille	-0.14	0.00	-0.04	Unclear
Floras	*N/A*	*N/A*	*N/A*	*N/A*
Sixes	*N/A*	*N/A*	*N/A*	*N/A*

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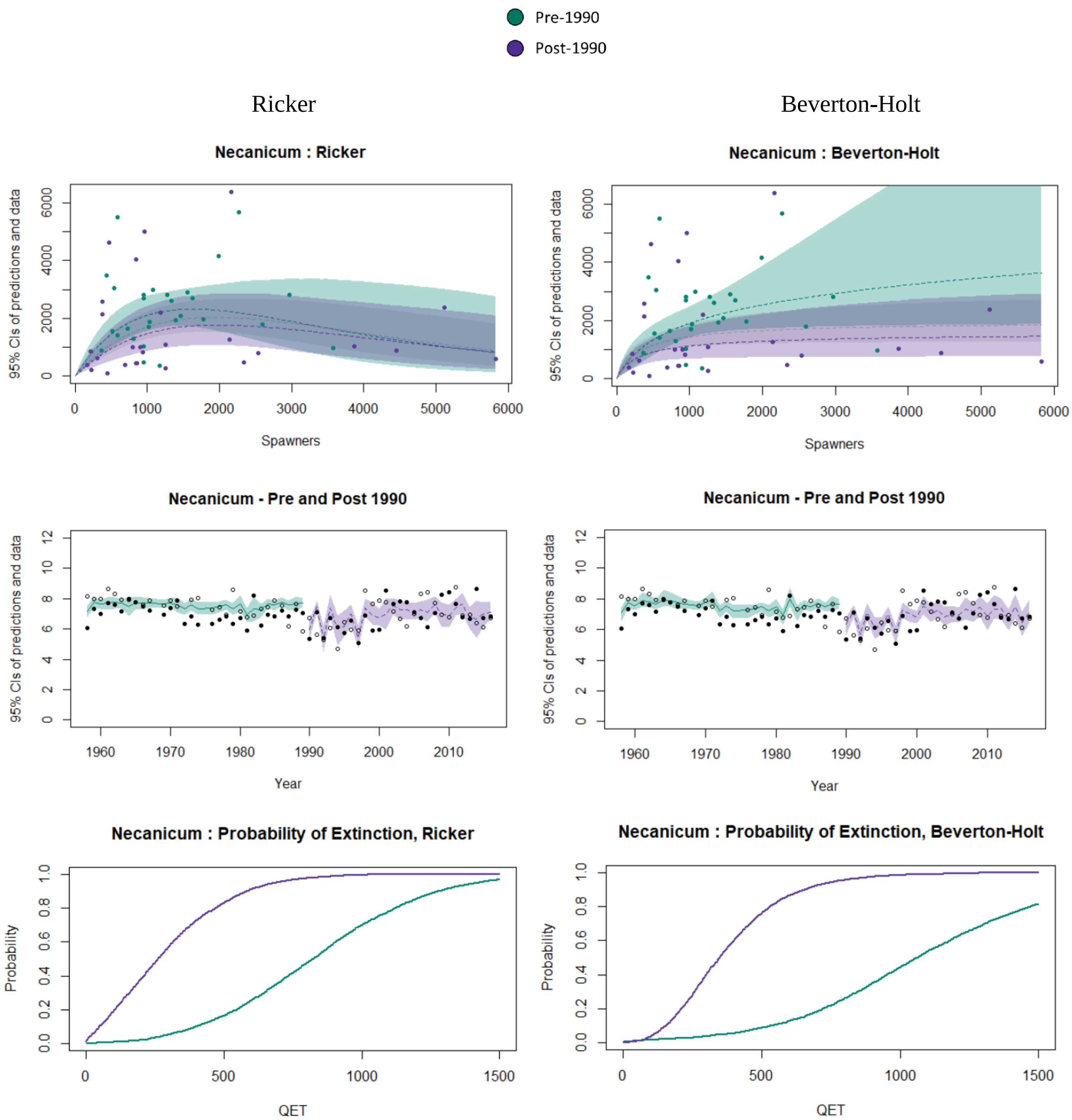
Necanicum Population

Top Panels: Recruitment models (green dashed line = pre-1990; purple dashed line = post-1990; gray dashed line = all data) with 95% confidence intervals relative to data

Middle Panels: Model predictions and 95% confidence intervals for recruits, log-transformed, relative to data

Bottom Panels: Modeled extinction risks across a range of quasi-extinction thresholds (QET)

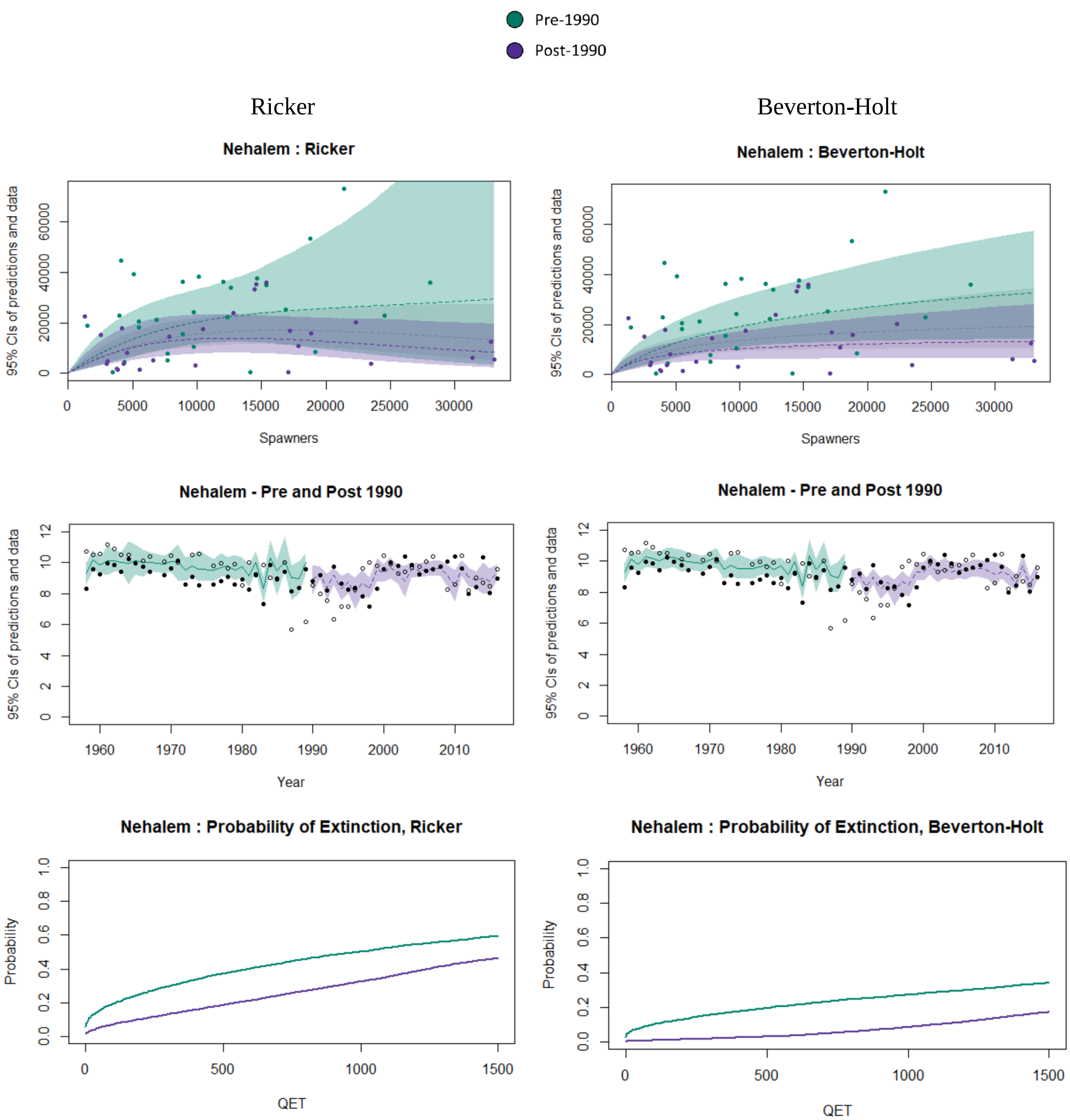


Nehalem Population

Top Panels: Recruitment models (green dashed line = pre-1990; purple dashed line = post-1990; gray dashed line = all data) with 95% confidence intervals relative to data

Middle Panels: Model predictions and 95% confidence intervals for recruits, log-transformed, relative to data

Bottom Panels: Modeled extinction risks across a range of quasi-extinction thresholds (QET)

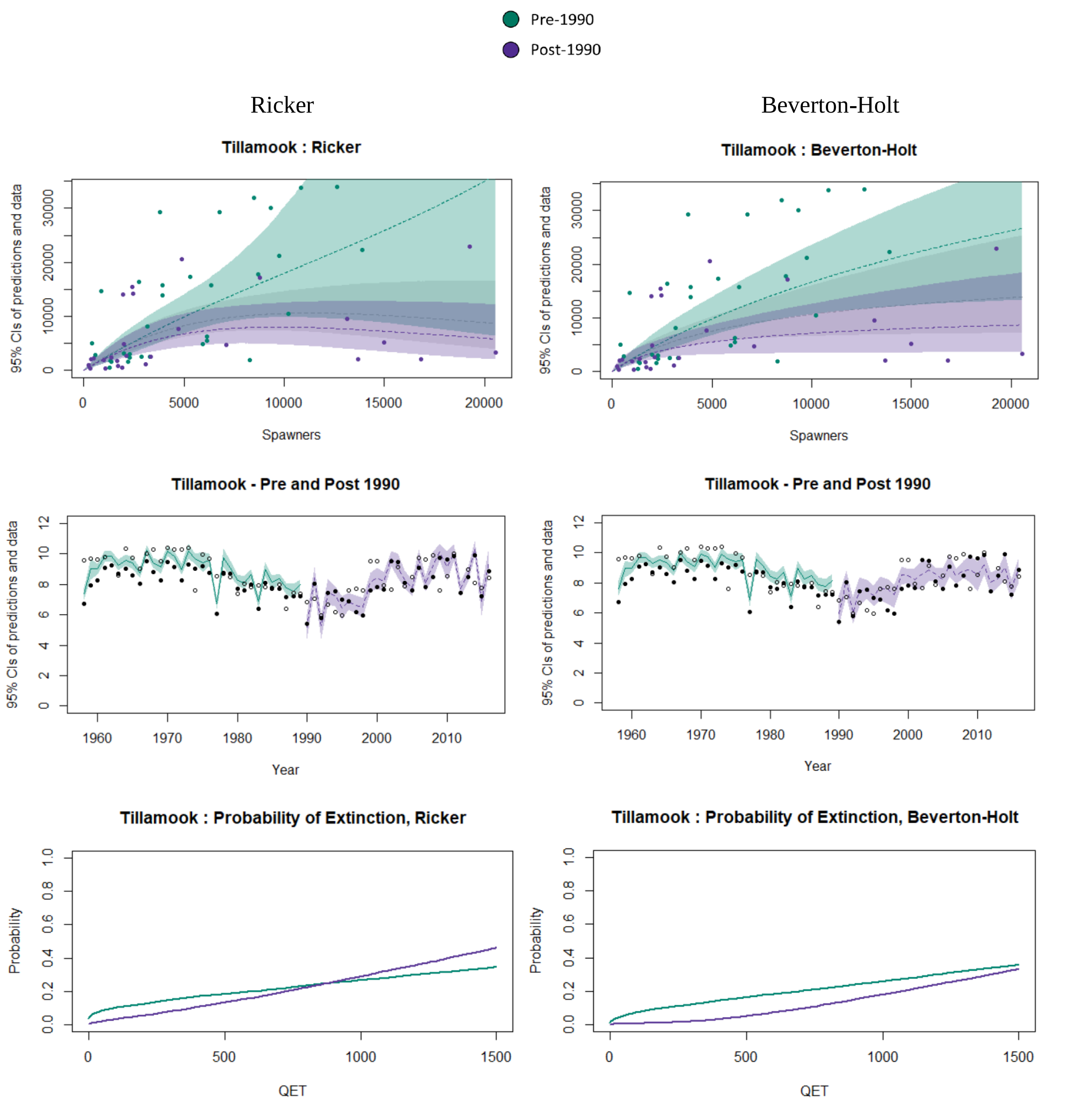


Tillamook Population

Top Panels: Recruitment models (green dashed line = pre-1990; purple dashed line = post-1990; gray dashed line = all data) with 95% confidence intervals relative to data

Middle Panels: Model predictions and 95% confidence intervals for recruits, log-transformed, relative to data

Bottom Panels: Modeled extinction risks across a range of quasi-extinction thresholds (QET)

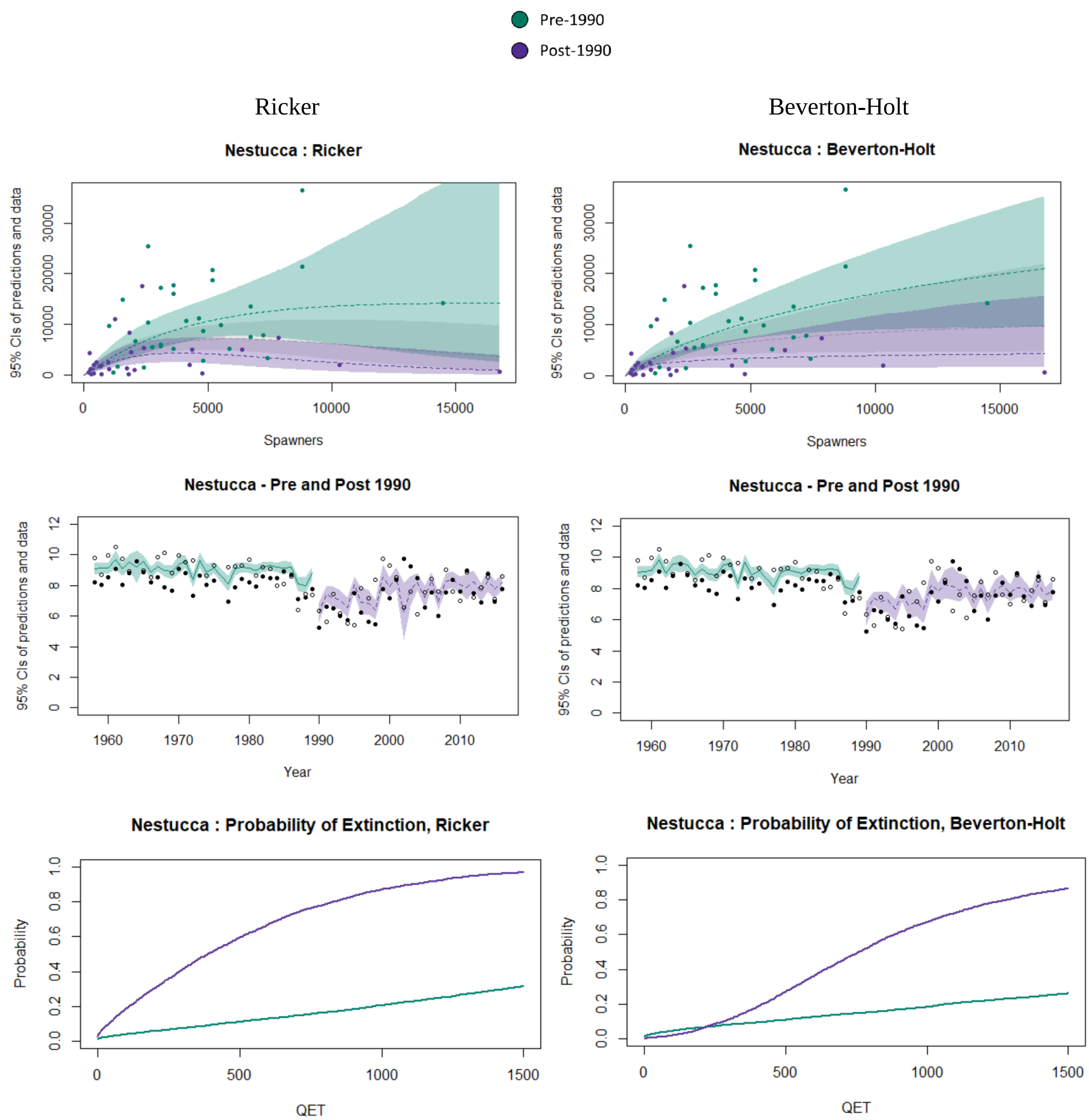


Nestucca Population

Top Panels: Recruitment models (green dashed line = pre-1990; purple dashed line = post-1990; gray dashed line = all data) with 95% confidence intervals relative to data

Middle Panels: Model predictions and 95% confidence intervals for recruits, log-transformed, relative to data

Bottom Panels: Modeled extinction risks across a range of quasi-extinction thresholds (QET)

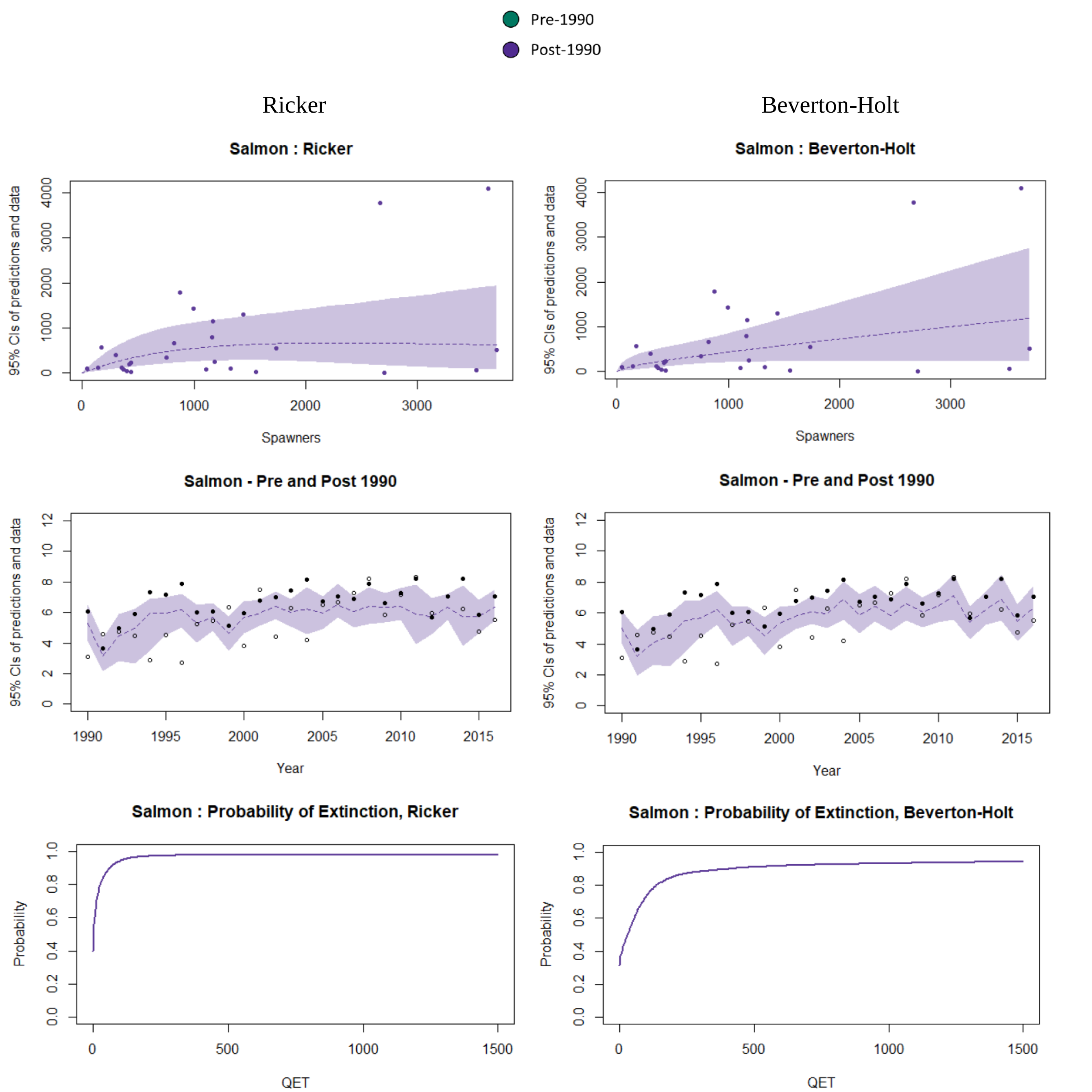


Salmon River Population

Top Panels: Recruitment models (green dashed line = pre-1990; purple dashed line = post-1990; gray dashed line = all data) with 95% confidence intervals relative to data

Middle Panels: Model predictions and 95% confidence intervals for recruits, log-transformed, relative to data

Bottom Panels: Modeled extinction risks across a range of quasi-extinction thresholds (QET)

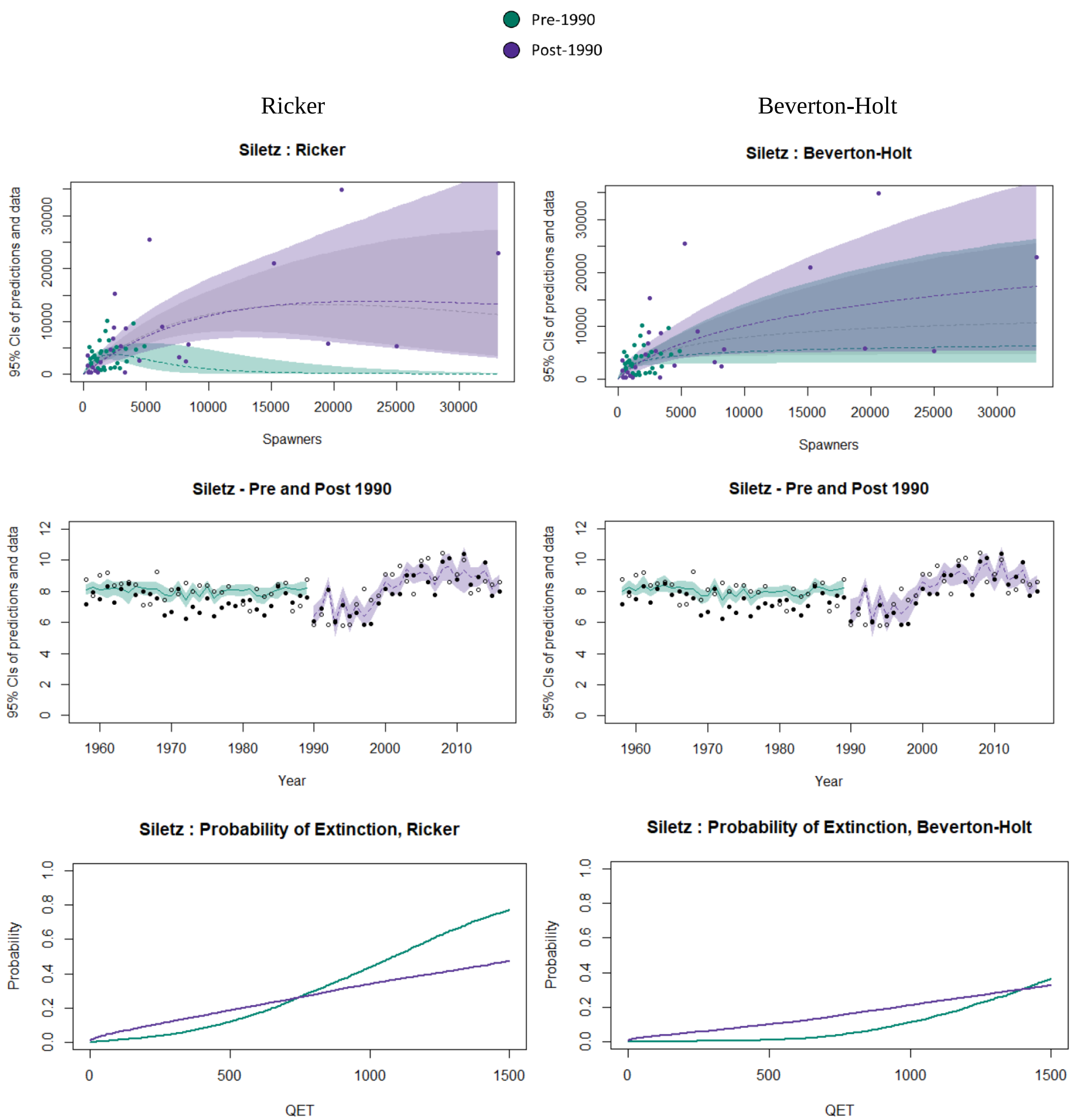


Siletz Population

Top Panels: Recruitment models (green dashed line = pre-1990; purple dashed line = post-1990; gray dashed line = all data) with 95% confidence intervals relative to data

Middle Panels: Model predictions and 95% confidence intervals for recruits, log-transformed, relative to data

Bottom Panels: Modeled extinction risks across a range of quasi-extinction thresholds (QET)

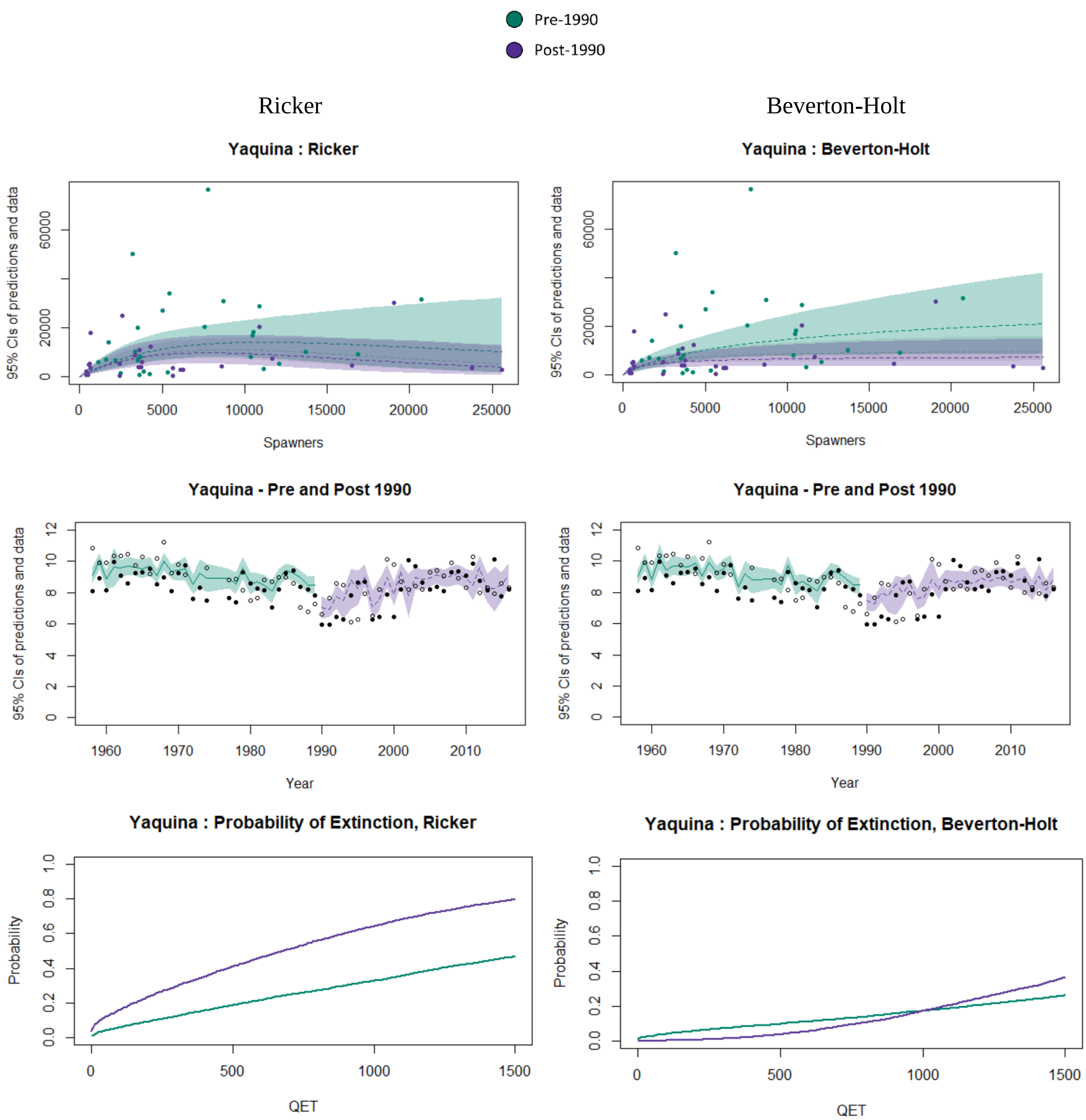


Yaquina Population

Top Panels: Recruitment models (green dashed line = pre-1990; purple dashed line = post-1990; gray dashed line = all data) with 95% confidence intervals relative to data

Middle Panels: Model predictions and 95% confidence intervals for recruits, log-transformed, relative to data

Bottom Panels: Modeled extinction risks across a range of quasi-extinction thresholds (QET)

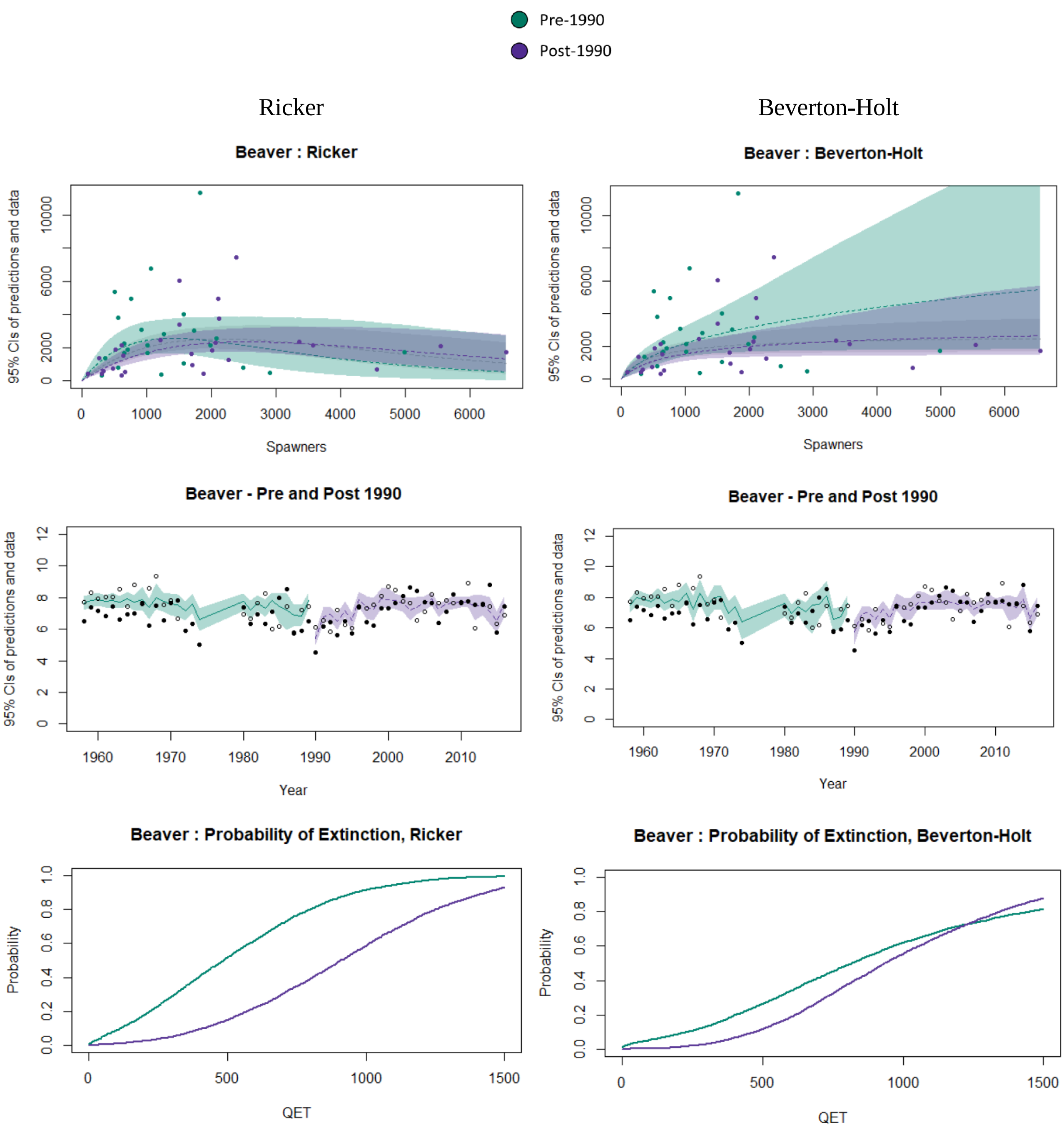


Beaver Creek Population

Top Panels: Recruitment models (green dashed line = pre-1990; purple dashed line = post-1990; gray dashed line = all data) with 95% confidence intervals relative to data

Middle Panels: Model predictions and 95% confidence intervals for recruits, log-transformed, relative to data

Bottom Panels: Modeled extinction risks across a range of quasi-extinction thresholds (QET)

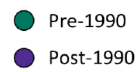


Alsea Population

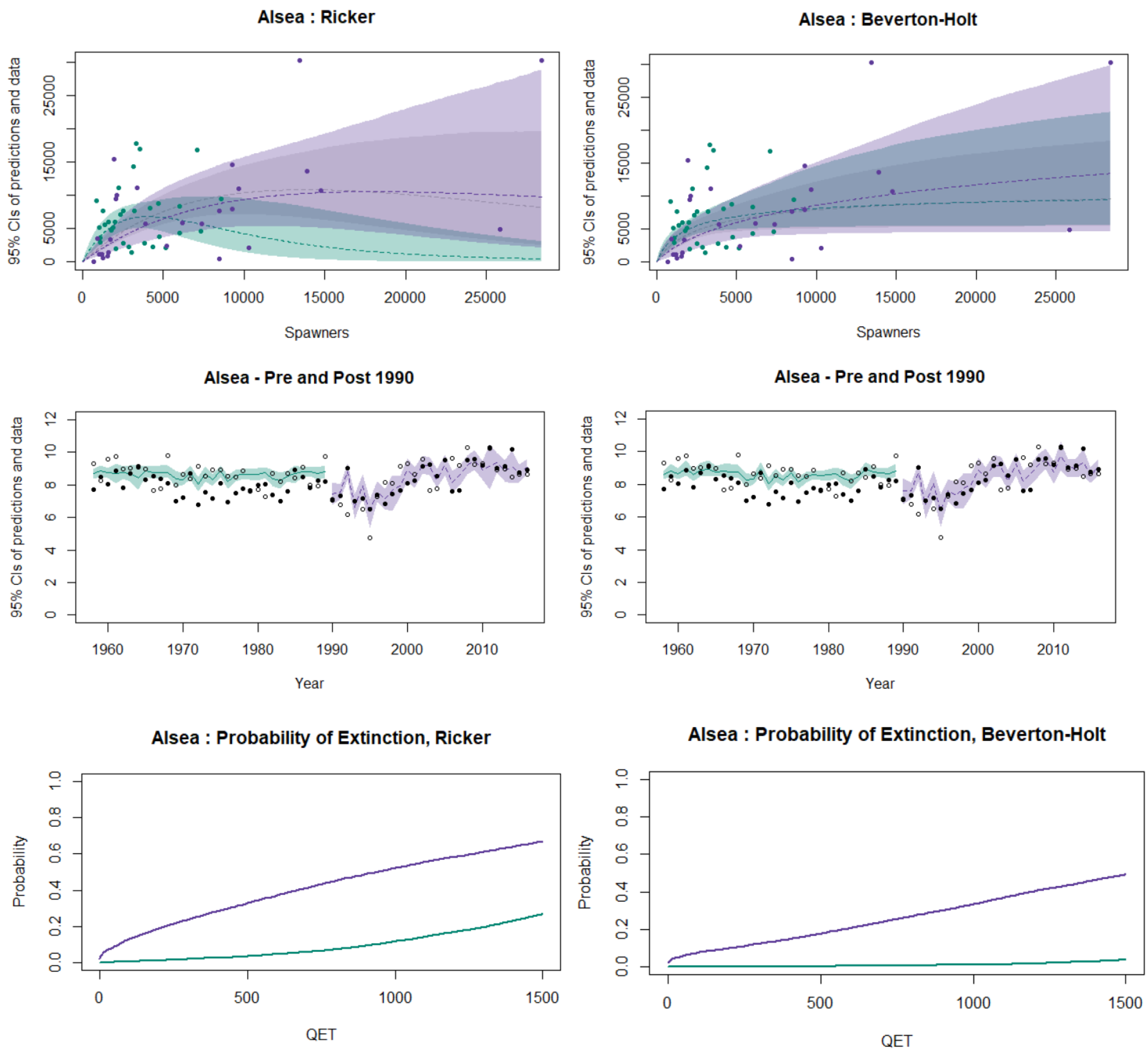
Top Panels: Recruitment models (green dashed line = pre-1990; purple dashed line = post-1990; gray dashed line = all data) with 95% confidence intervals relative to data

Middle Panels: Model predictions and 95% confidence intervals for recruits, log-transformed, relative to data

Bottom Panels: Modeled extinction risks across a range of quasi-extinction thresholds (QET)



Ricker | Beverton-Holt

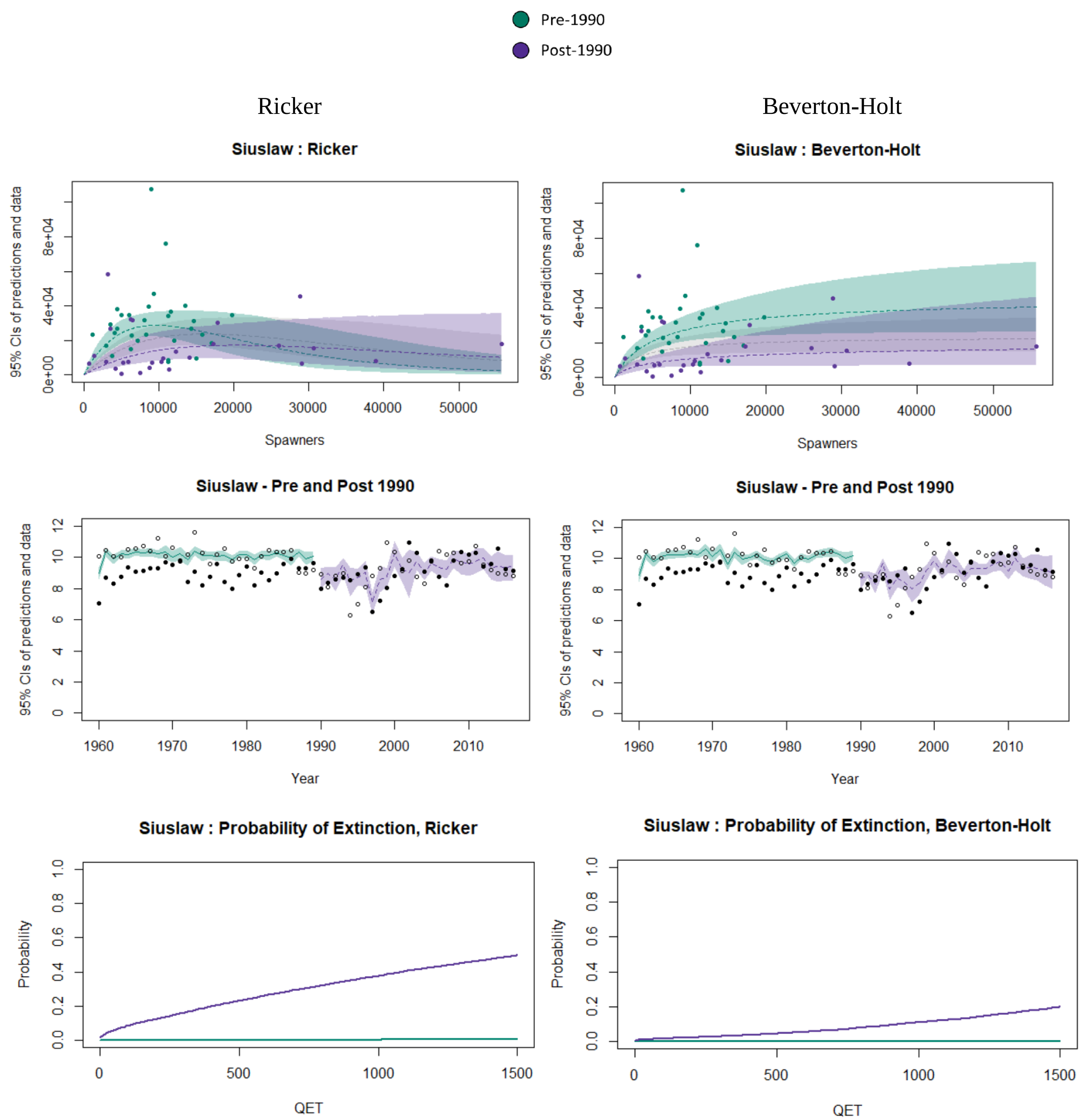


Siuslaw Population

Top Panels: Recruitment models (green dashed line = pre-1990; purple dashed line = post-1990; gray dashed line = all data) with 95% confidence intervals relative to data

Middle Panels: Model predictions and 95% confidence intervals for recruits, log-transformed, relative to data

Bottom Panels: Modeled extinction risks across a range of quasi-extinction thresholds (QET)

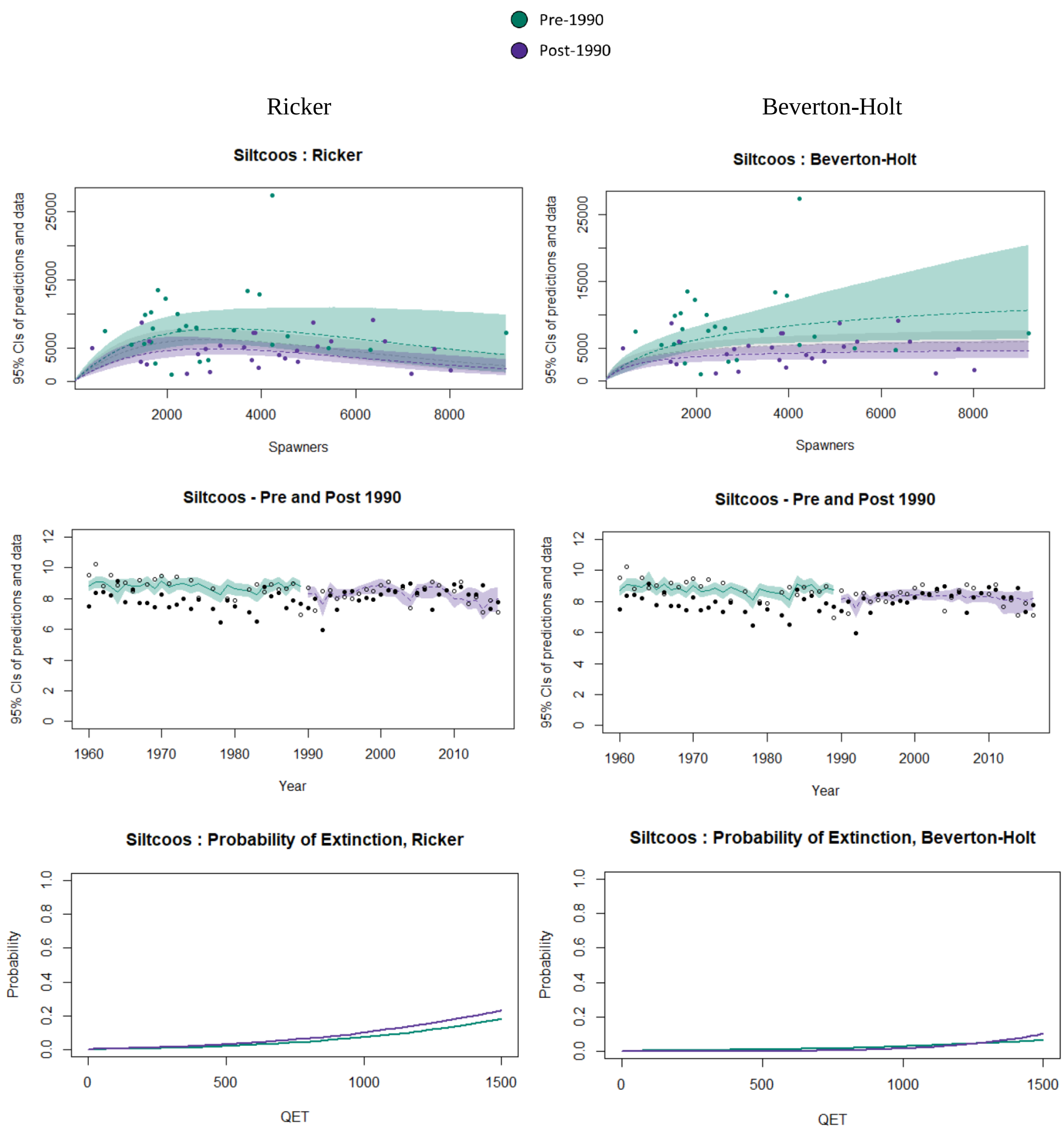


Siltcoos Population

Top Panels: Recruitment models (green dashed line = pre-1990; purple dashed line = post-1990; gray dashed line = all data) with 95% confidence intervals relative to data

Middle Panels: Model predictions and 95% confidence intervals for recruits, log-transformed, relative to data

Bottom Panels: Modeled extinction risks across a range of quasi-extinction thresholds (QET)

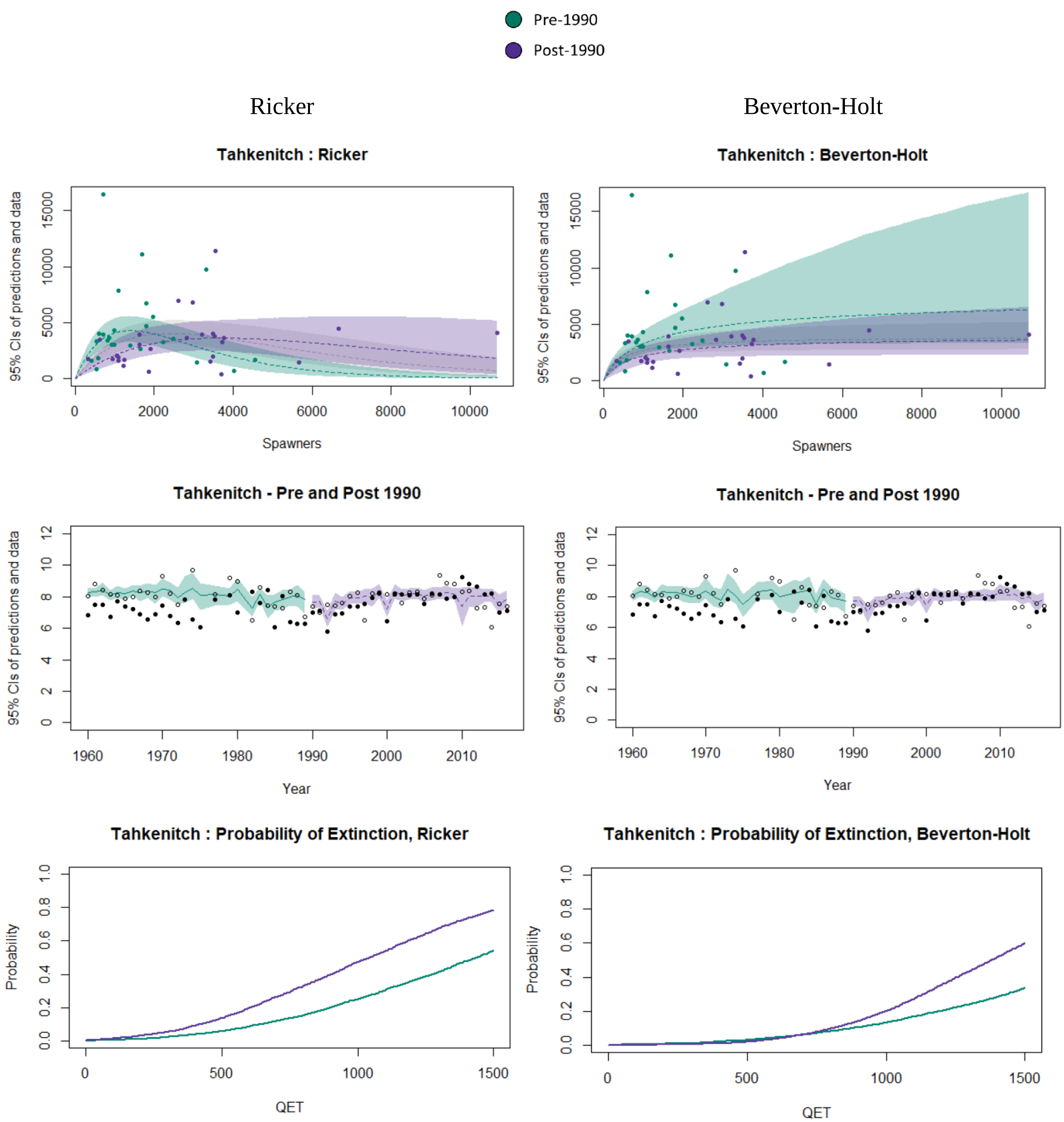


Tahkenitch Population

Top Panels: Recruitment models (green dashed line = pre-1990; purple dashed line = post-1990; gray dashed line = all data) with 95% confidence intervals relative to data

Middle Panels: Model predictions and 95% confidence intervals for recruits, log-transformed, relative to data

Bottom Panels: Modeled extinction risks across a range of quasi-extinction thresholds (QET)

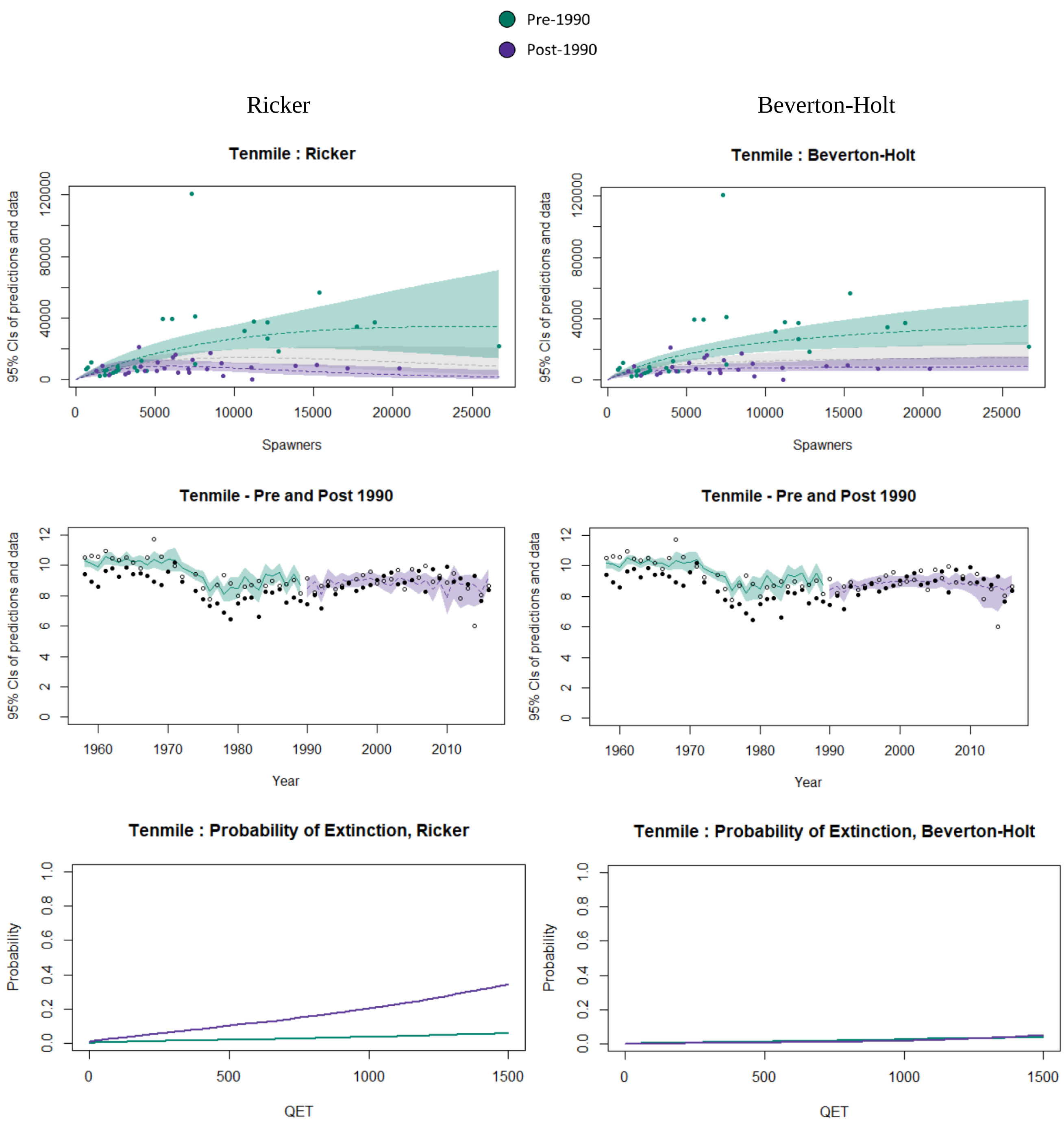


Tenmile Population

Top Panels: Recruitment models (green dashed line = pre-1990; purple dashed line = post-1990; gray dashed line = all data) with 95% confidence intervals relative to data

Middle Panels: Model predictions and 95% confidence intervals for recruits, log-transformed, relative to data

Bottom Panels: Modeled extinction risks across a range of quasi-extinction thresholds (QET)

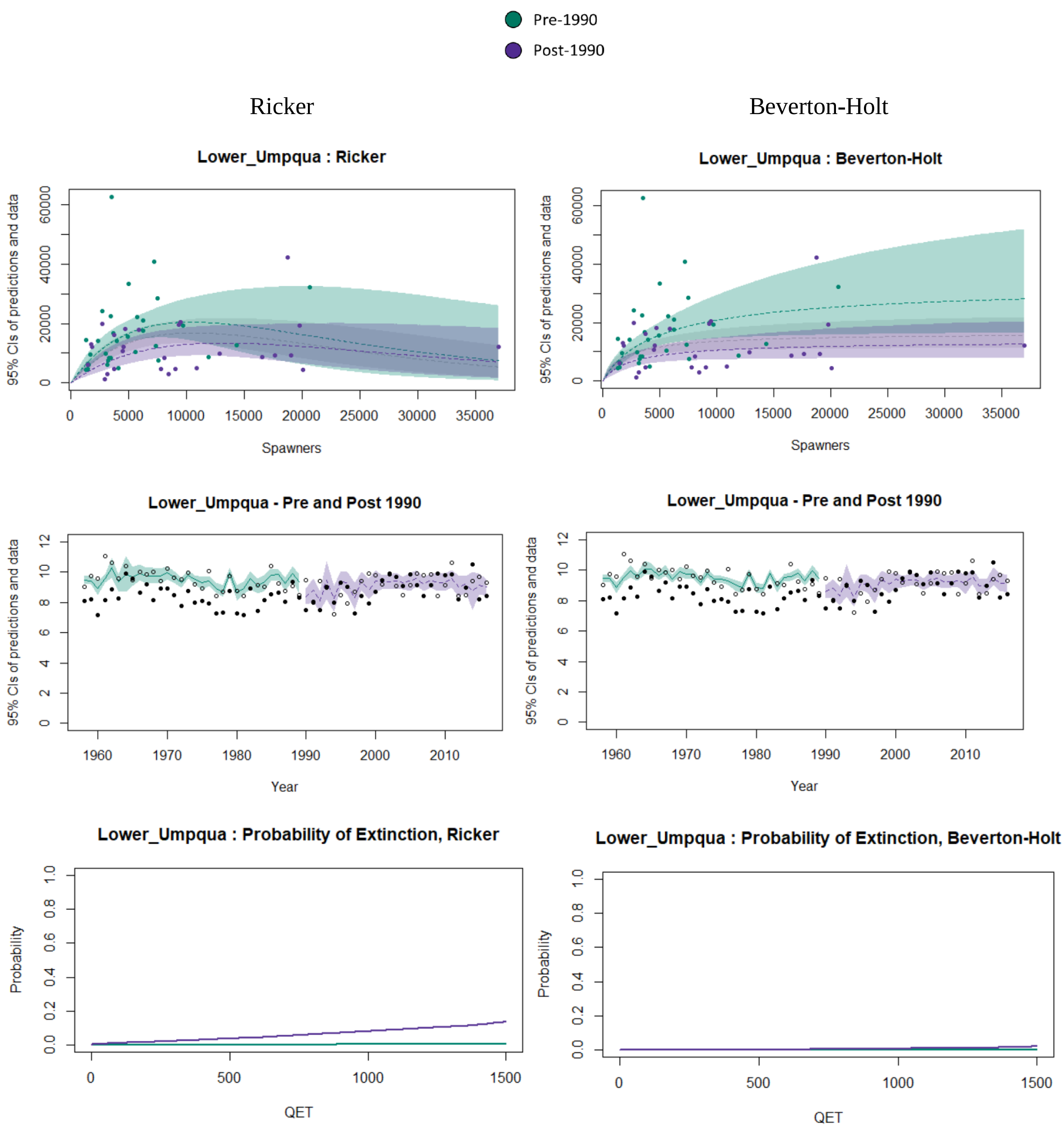


Lower Umpqua Population

Top Panels: Recruitment models (green dashed line = pre-1990; purple dashed line = post-1990; gray dashed line = all data) with 95% confidence intervals relative to data

Middle Panels: Model predictions and 95% confidence intervals for recruits, log-transformed, relative to data

Bottom Panels: Modeled extinction risks across a range of quasi-extinction thresholds (QET)

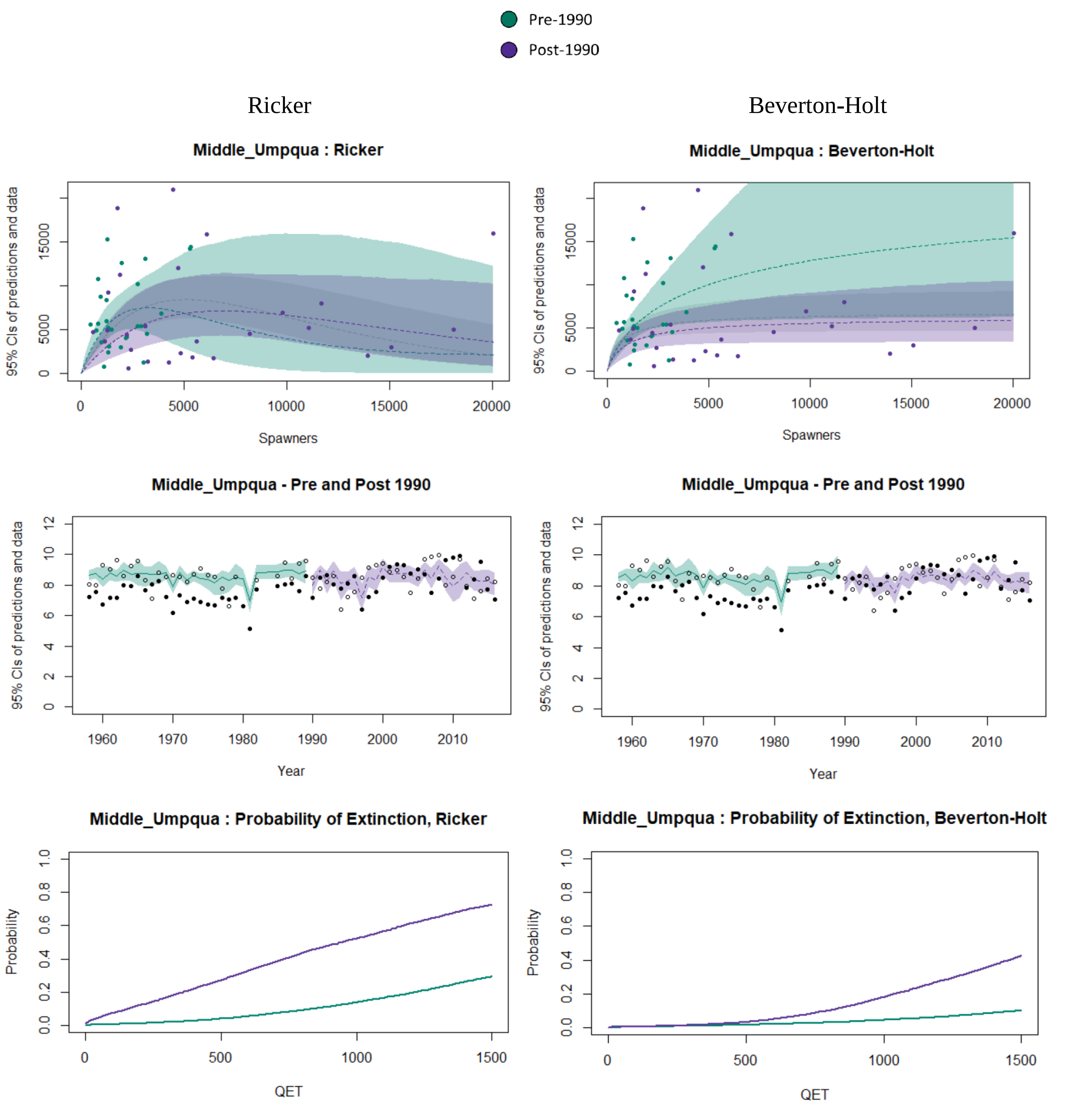


Middle Umpqua Population

Top Panels: Recruitment models (green dashed line = pre-1990; purple dashed line = post-1990; gray dashed line = all data) with 95% confidence intervals relative to data

Middle Panels: Model predictions and 95% confidence intervals for recruits, log-transformed, relative to data

Bottom Panels: Modeled extinction risks across a range of quasi-extinction thresholds (QET)

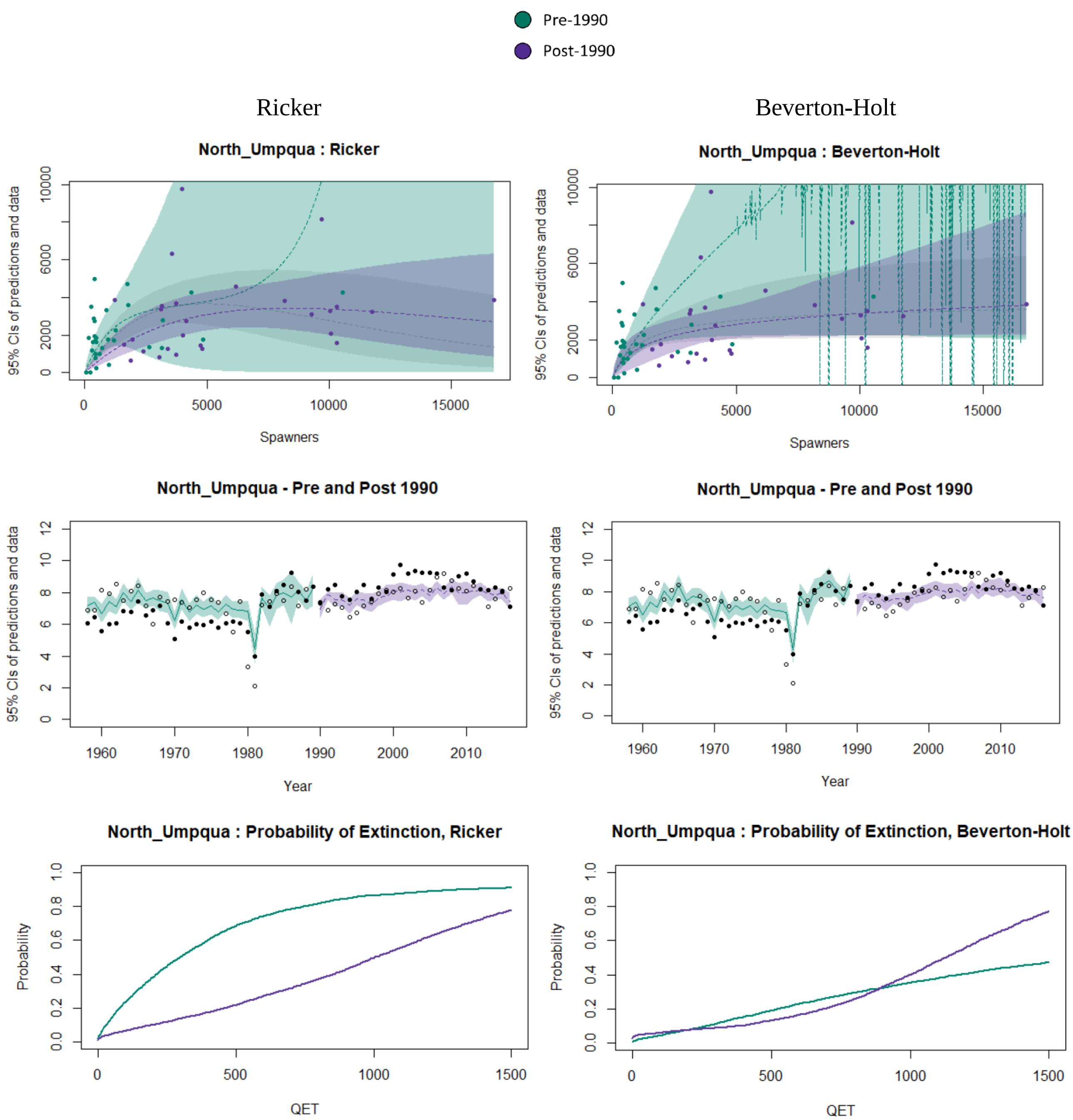


North Umpqua Population

Top Panels: Recruitment models (green dashed line = pre-1990; purple dashed line = post-1990; gray dashed line = all data) with 95% confidence intervals relative to data

Middle Panels: Model predictions and 95% confidence intervals for recruits, log-transformed, relative to data

Bottom Panels: Modeled extinction risks across a range of quasi-extinction thresholds (QET)

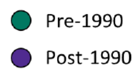


South Umpqua Population

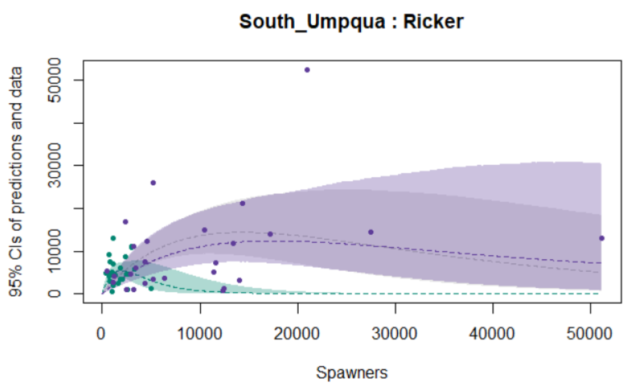
Top Panels: Recruitment models (green dashed line = pre-1990; purple dashed line = post-1990; gray dashed line = all data) with 95% confidence intervals relative to data

Middle Panels: Model predictions and 95% confidence intervals for recruits, log-transformed, relative to data

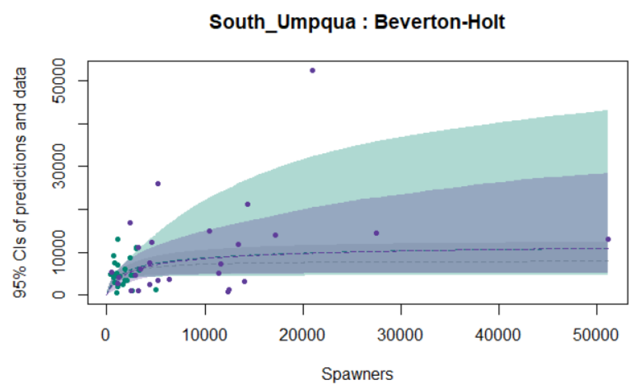
Bottom Panels: Modeled extinction risks across a range of quasi-extinction thresholds (QET)

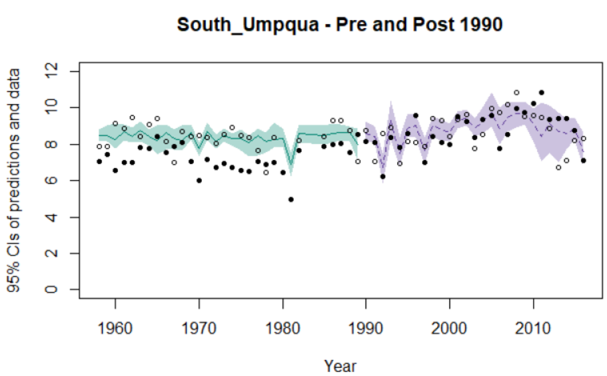


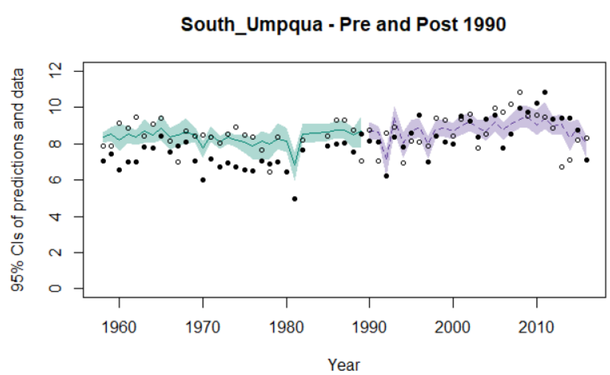
Ricker

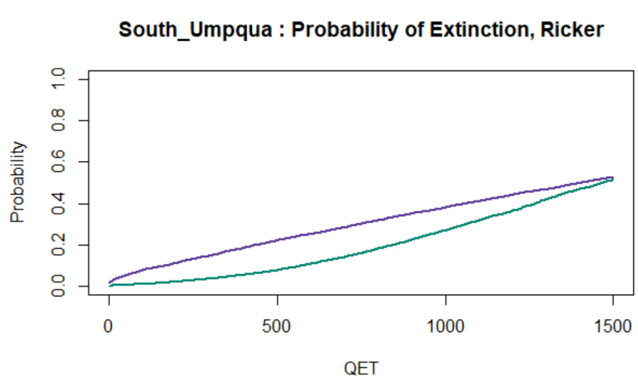


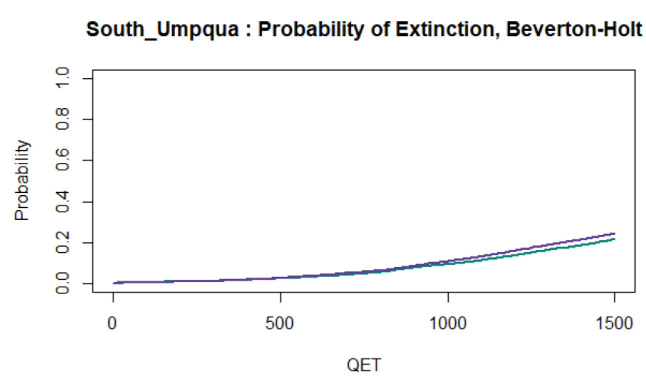
Beverton-Holt









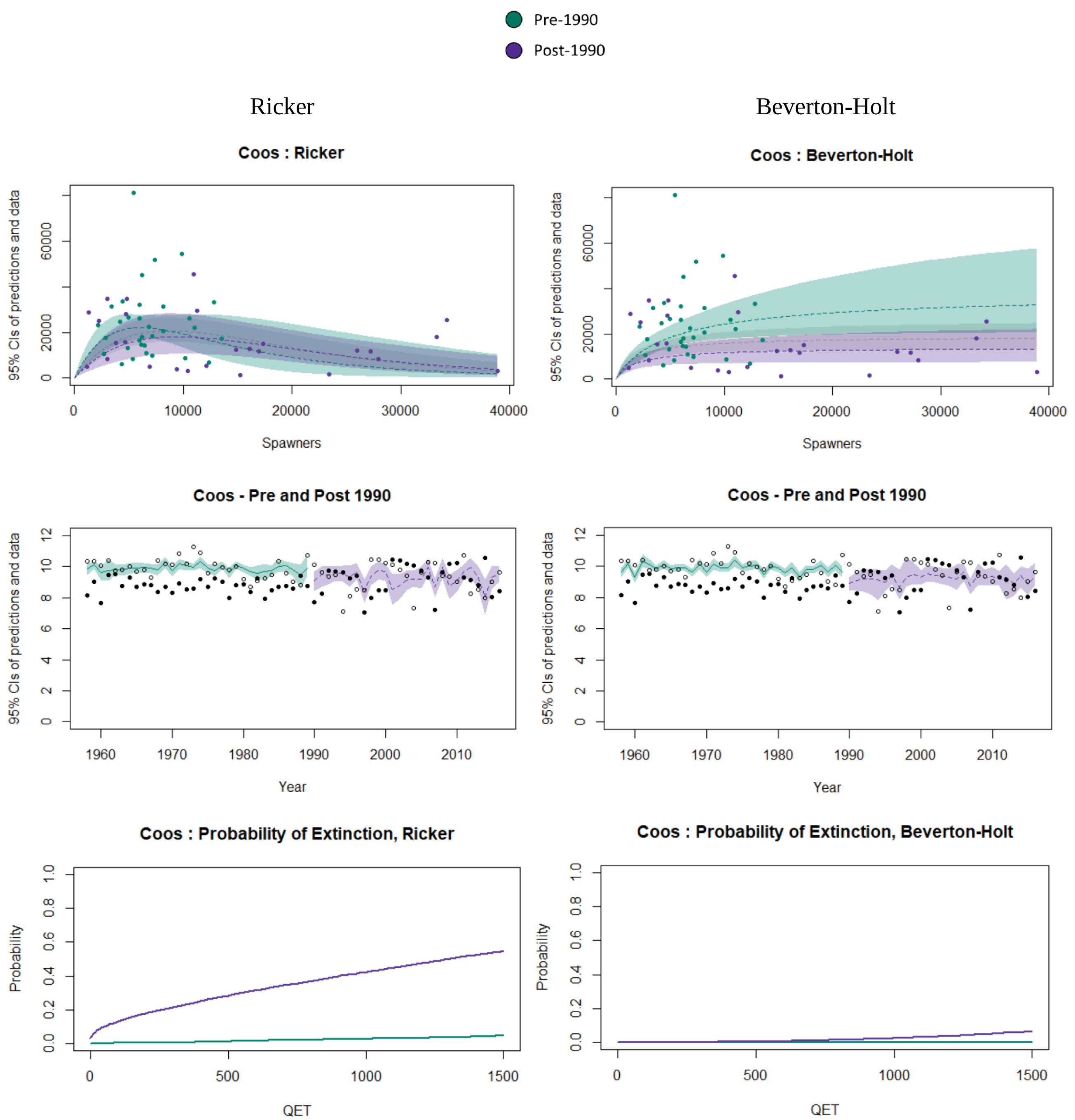


Coos Population

Top Panels: Recruitment models (green dashed line = pre-1990; purple dashed line = post-1990; gray dashed line = all data) with 95% confidence intervals relative to data

Middle Panels: Model predictions and 95% confidence intervals for recruits, log-transformed, relative to data

Bottom Panels: Modeled extinction risks across a range of quasi-extinction thresholds (QET)

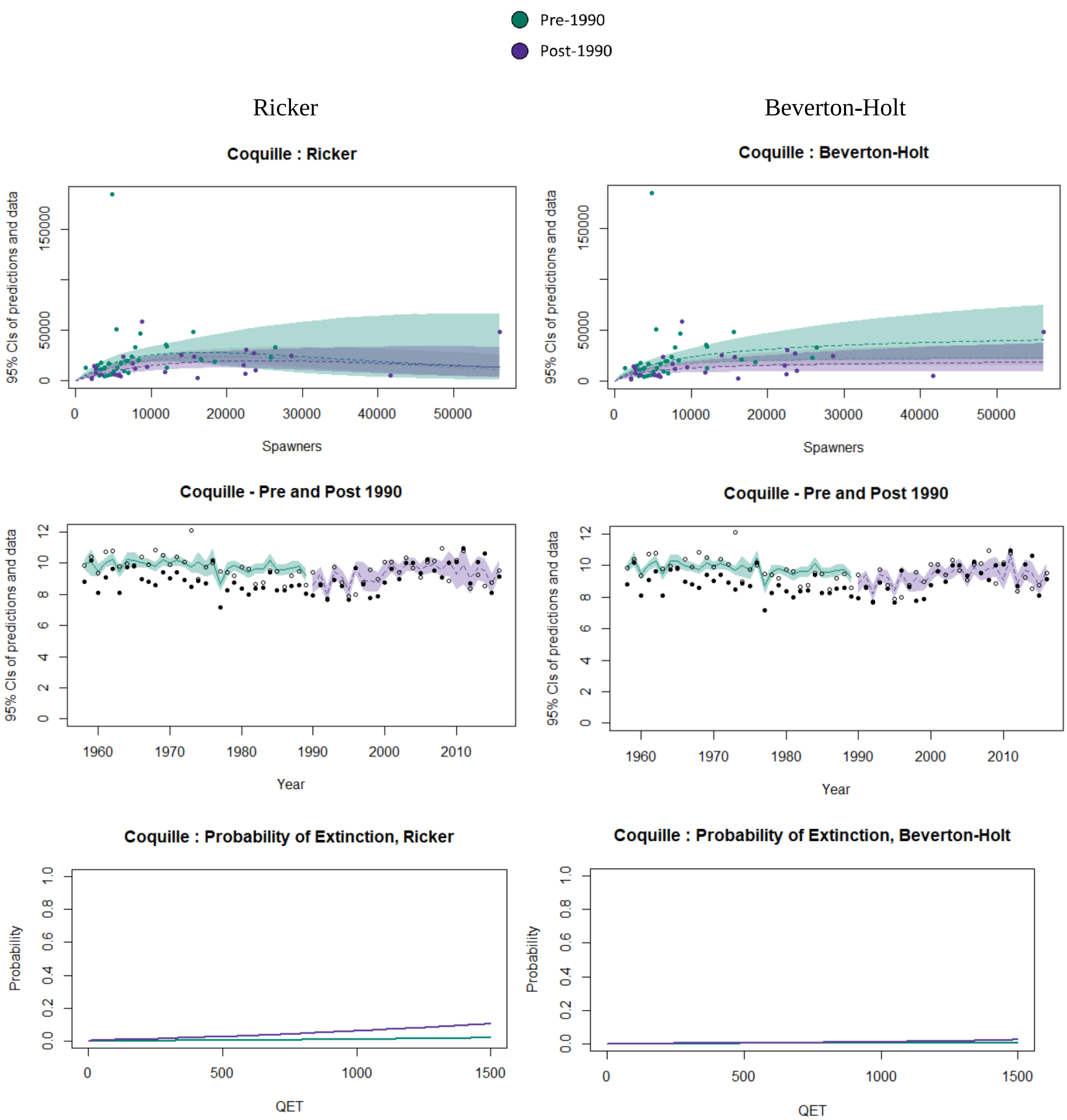


Coquille Population

Top Panels: Recruitment models (green dashed line = pre-1990; purple dashed line = post-1990; gray dashed line = all data) with 95% confidence intervals relative to data

Middle Panels: Model predictions and 95% confidence intervals for recruits, log-transformed, relative to data

Bottom Panels: Modeled extinction risks across a range of quasi-extinction thresholds (QET)

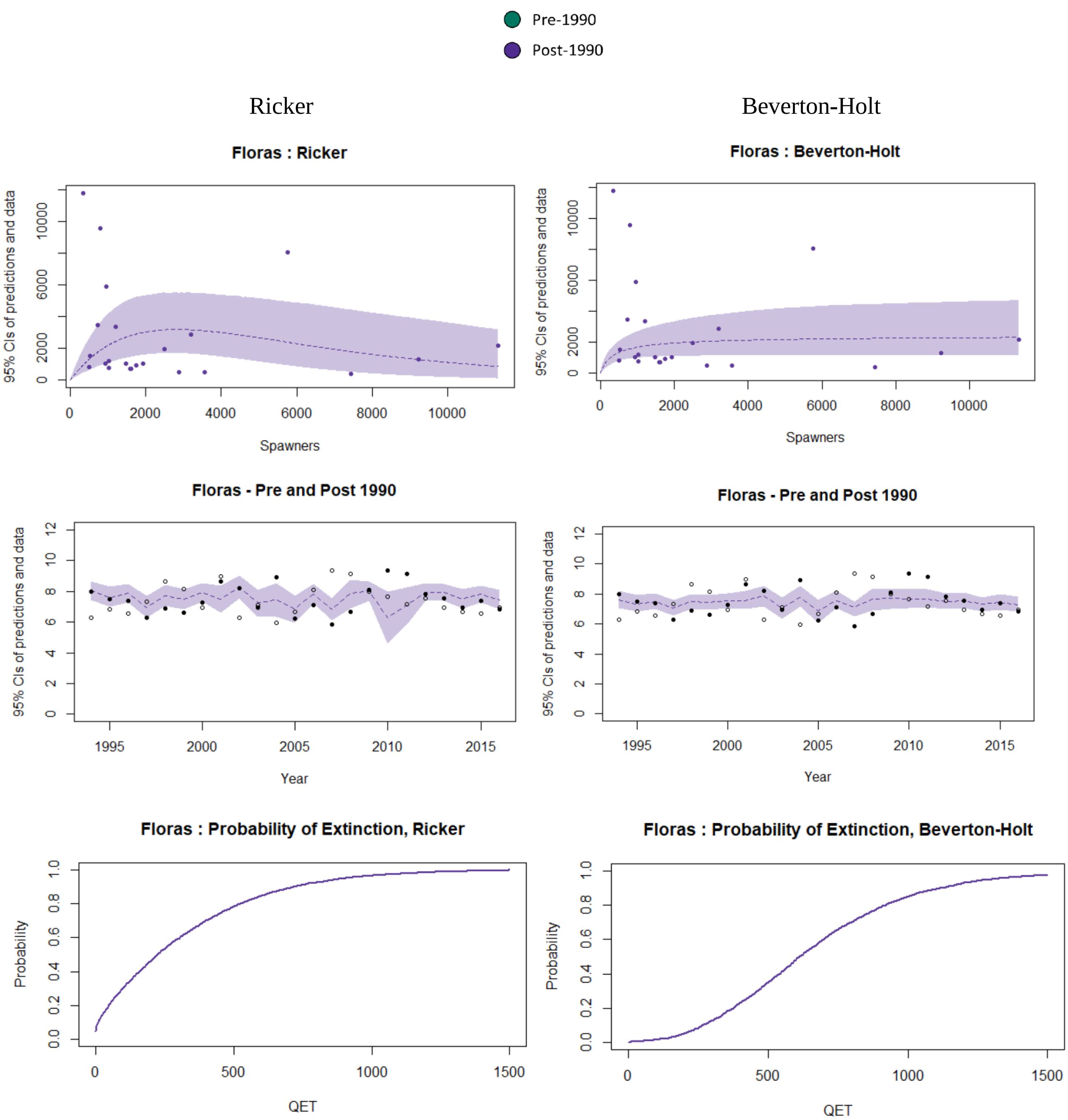


Floras Population

Top Panels: Recruitment models (green dashed line = pre-1990; purple dashed line = post-1990; gray dashed line = all data) with 95% confidence intervals relative to data

Middle Panels: Model predictions and 95% confidence intervals for recruits, log-transformed, relative to data

Bottom Panels: Modeled extinction risks across a range of quasi-extinction thresholds (QET)



Sixes Population

Top Panels: Recruitment models (green dashed line = pre-1990; purple dashed line = post-1990; gray dashed line = all data) with 95% confidence intervals relative to data

Middle Panels: Model predictions and 95% confidence intervals for recruits, log-transformed, relative to data

Bottom Panels: Modeled extinction risks across a range of quasi-extinction thresholds (QET)