Appendix 1. Willapa Bay Chinook Spawner-Recruit Assessment Overview

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Spawner-recruit (SR) relationships for natural origin Chinook salmon returning to Willapa Bay were examined in support of a broader effort to review and evaluate the WDFW policy on Willapa Bay fisheries management.

Willapa region staff have collected and compiled escapement, catch, and age composition data over many years. These data permit the reconstruction of Chinook brood years 2000-2013 for individual sub-basins as well as the bay as a whole. Fitting traditional Ricker spawner-recruit relationships to each of these brood reconstructions offers a data-driven perspective on recent productivity and supports a discussion of biologically meaningful escapement goals.

[Figure 1]

Across brood years, the average numbers of spawners and recruits varied by river system, with the smaller Nemah/Palix diverging from the two larger aggregates. Table 1 shows the arithmetic mean of spawners, recruits and recruits-per-spawner (R/S) over complete brood years (2000-2013). Note the Nemah/Palix average is closer to the other systems after 2003 but is affected by several larger values early in the series, as evident in the third and fourth rows of Figure 1. However, despite the distinct sub-basin parameter estimates associated with these run size differences, the sum of the system-specific reference points was very close to the value calculated for the aggregate Willapa Bay run.

Table 1: Average run size and productivity by system

	Spawners	Recruits	R/S
Willapa Bay aggregate	2719	3902	1.543
Willapa/North/Smith	1442	2041	1.514
Nemah/Palix	149	252	3.339
Naselle/Bear	1128	1608	1.675

The spawners-at-replacement (S_rep) is a reference point at the intersection between the fitted Ricker curve and the 1:1 line of recruits relative to spawners. It may be interpreted as a threshold above which additional spawners would not be expected to produce additional recruits. For the aggregate Willapa Bay run and for each sub-basin, the estimated S_rep values were slightly below the longstanding escapement goals (Table 2).

	Natural spawner estimated capacity	S_rep
Willapa Bay aggregate	4,353	3,967
Willapa/North/Smith	2,172	2,126
Nemah/Palix	328	263
Naselle/Bear	1,853	1,551

[Figure 2a – 2d]

Examining the brood years 2007-2013 underscores the importance of continuing to collect high quality data as the foundation for understanding trends in Willapa Bay productivity. Several consecutive years of increasing spawners in the Willapa/North and Naselle/Bear sub-basins were followed by consecutive declines after 2010. However, since 2013, the number of spawners has rebounded in the Willapa/North system but not in the Naselle/Bear. Understanding the relationship between the number of spawners and the number of fish returning from those broods depends on the ability to continue reconstructing runs and developing brood tables with additional high-quality data.

[Figure 3]

Instream flow is a critical factor affecting the productivity of Chinook salmon (Bergendorf 2002). Specifically, adult salmon are unable to reach spawning areas when low flows create shallow and/or warm water barriers that impede movement. Accordingly, the long-term trends in daily flows at two USGS streamflow gages on the Willapa and Naselle rivers were assessed to understand in-stream flow patterns relative to Willapa Bay Chinook salmon. At both gages, daily flows during August and September, when Willapa Bay Chinook characteristically re-enter freshwater, showed appreciable declines over a period of record from 1962 to 2019. For example, at the Naselle gage, the median daily flow in September decreased 35% from an average of 78 cfs during 1962-1981 to 51 cfs during 2000-2019. Again, maintaining a program of high-quality monitoring is fundamental to our ability to recognize and respond to changes in recruitment that may result from less water in the river when fish have historically returned to spawn.

[Figure 4a &b]

<u>Work Cited</u>

Bergendorf, D. 2002. The Influence of In-stream Habitat Characteristics on Chinook

Salmon (*Oncorhynchus tshawytscha*). Technical Report prepared for NOAA Northwest Fisheries Science Center, Seattle, WA.

Figure 1: Relationships between spawners and recruits for the Willapa Bay aggregate (first column), and the Willapa/North/Smith, Nemah/Palix and Naselle/Bear systems (second to fourth columns respectively). Row (a) illustrates the time series of spawners, row (b) depicts the recruits relative to spawners, row (c) shows the time series of recruits per spawner (rps), and row (d) illustrates recruits per spawner relative to spawners.

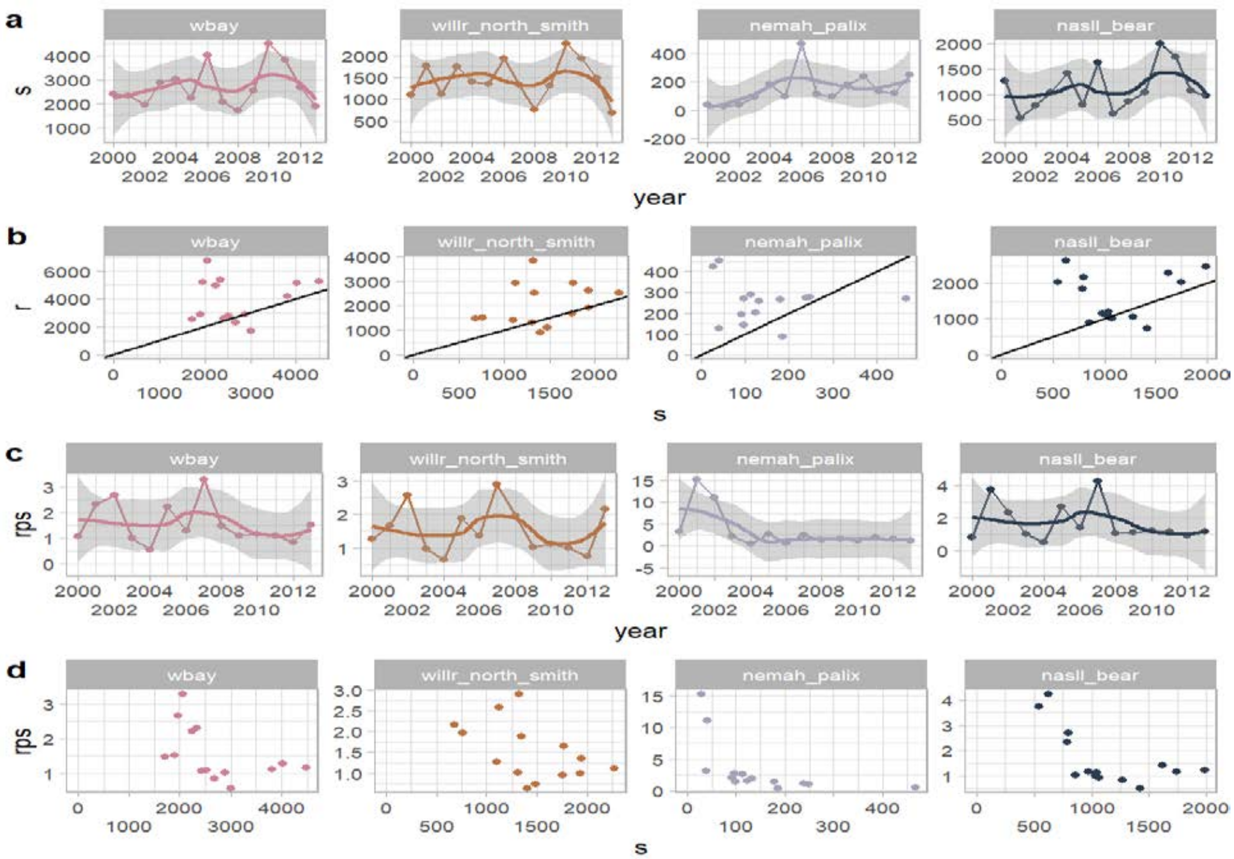

Figure 2a: Spawner time series (upper panel) and estimated Ricker spawner-recruit curves for the aggregate Willapa Bay run. The current natural spawner estimated capacity (solid black line) is shown relative to the fitted S_rep (dashed green line) and S_msy (dotted orange line). In the lower panel, the thick black curve shows the best-fit parameter estimates, with 100 bootstrapped fits illustrated as light grey curves and the full set of bootstrap S_msy estimates shown as short orange lines. These depict some of the uncertainty associated with reference points.

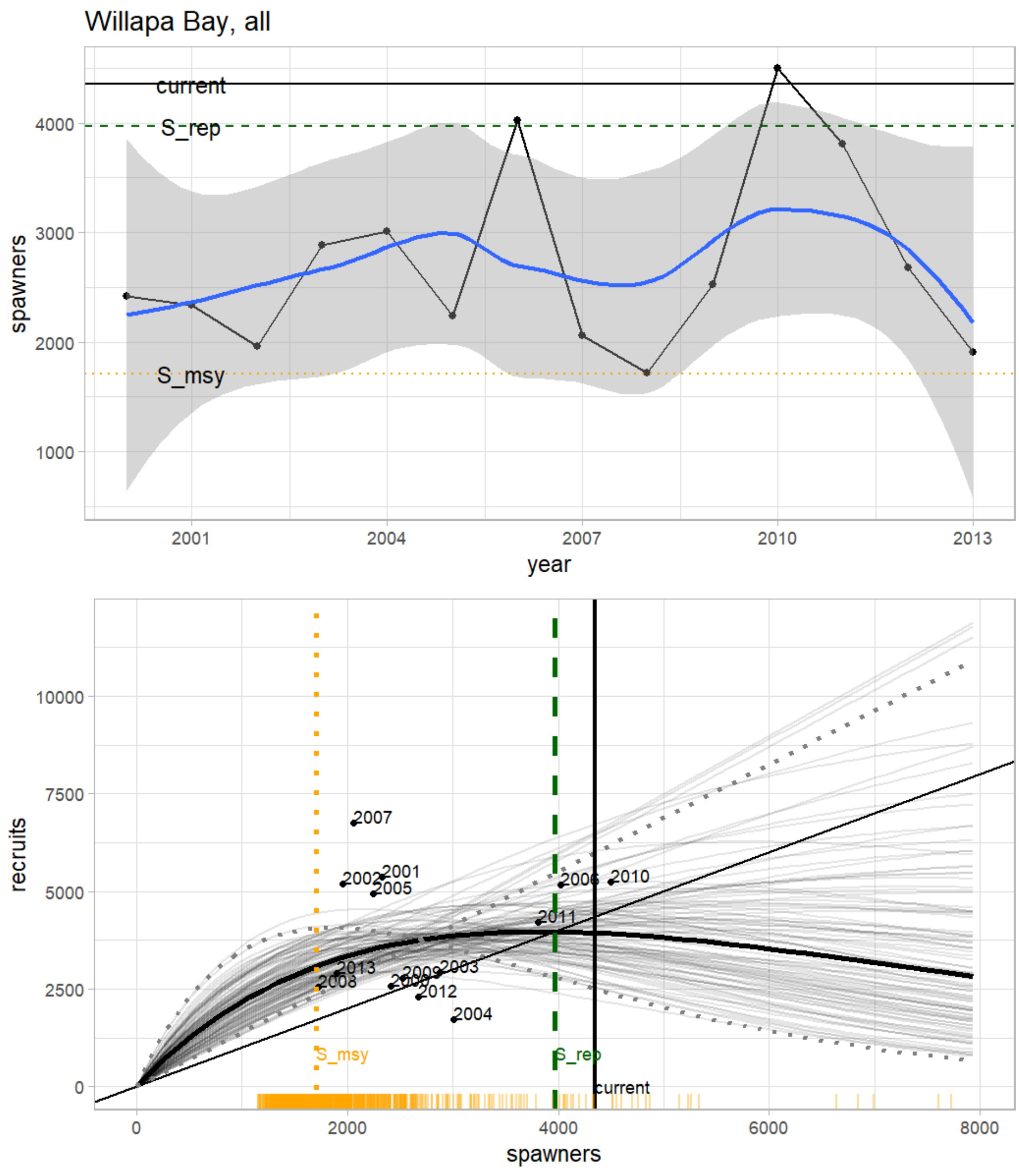

Figure 2b: Willapa & North River spawner time series (upper panel) and estimated Ricker spawner-recruit curves. The current natural spawner estimated capacity (solid black line) is shown relative to the fitted S_rep (dashed green line) and S_msy (dotted orange line). In the lower panel, the thick black curve shows the best-fit parameter estimates, with 100 bootstrapped fits illustrated as light grey curves and the full set of bootstrap S_msy estimates shown as short orange lines. These depict some of the uncertainty associated with reference points.

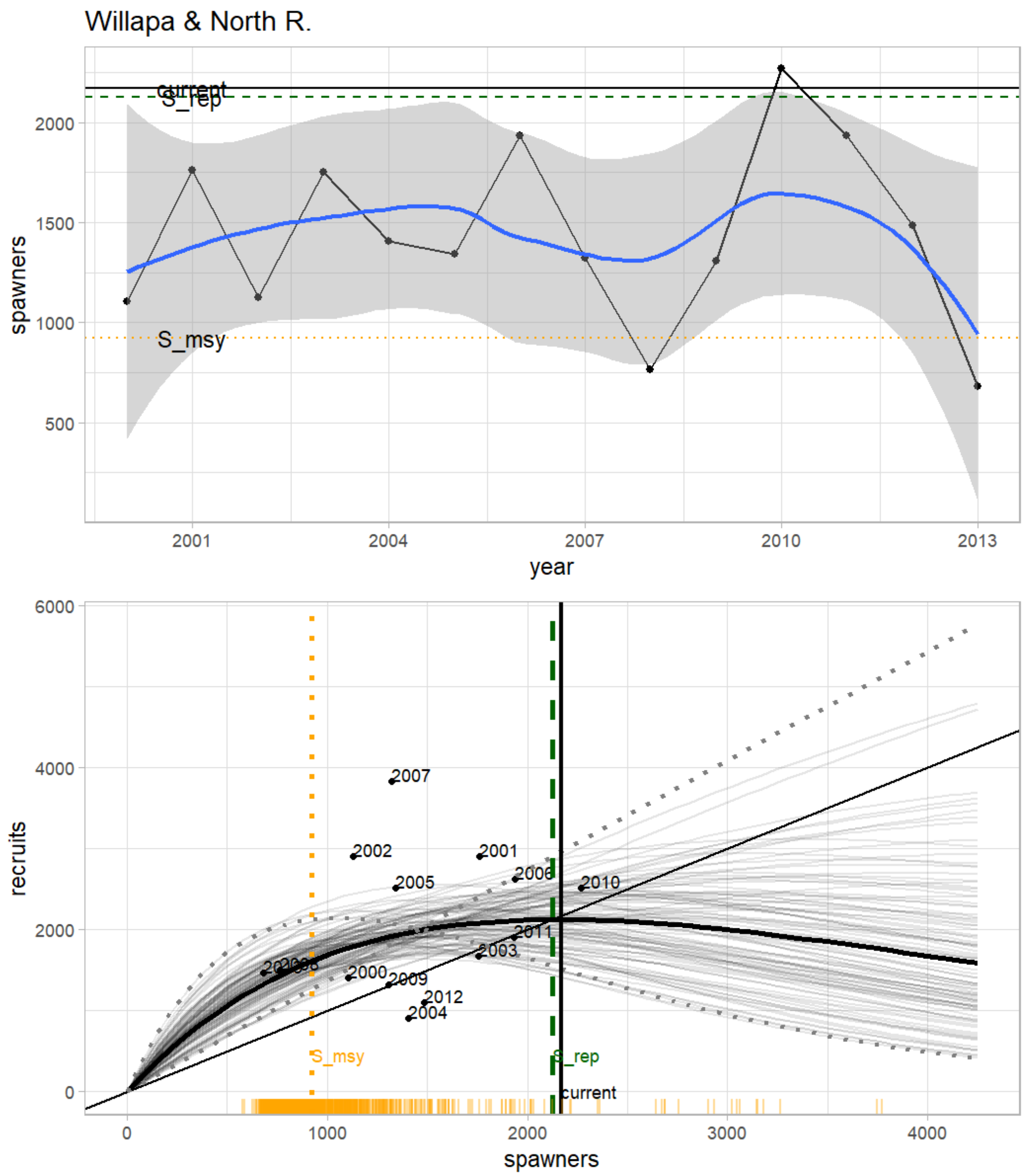

Figure 2c: Naselle and Bear River spawner time series (upper panel) and estimated Ricker spawner-recruit curves. The current natural spawner estimated capacity (solid black line) is shown relative to the fitted S_rep (dashed green line) and S_msy (dotted orange line). In the lower panel, the thick black curve shows the best-fit parameter estimates, with 100 bootstrapped fits illustrated as light grey curves and the full set of bootstrap S_msy estimates shown as short orange lines. These depict some of the uncertainty associated with reference points.

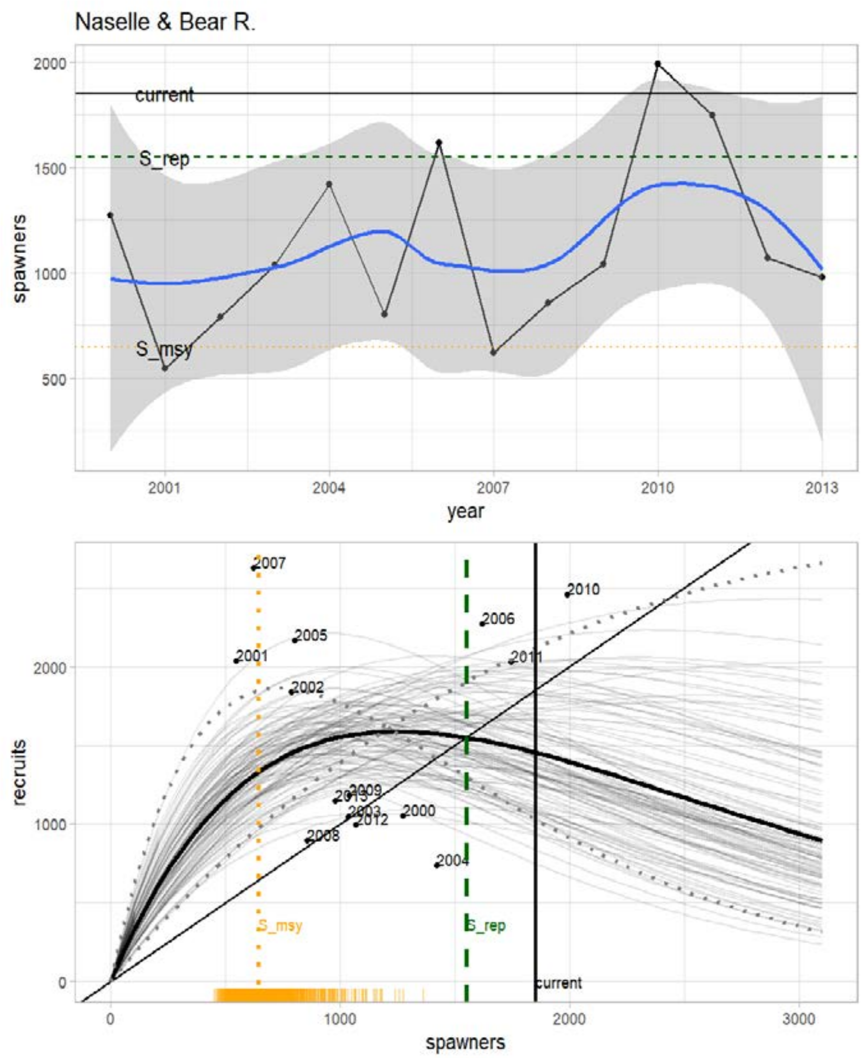

Figure 2d: Nemah and Palix River spawner time series (upper panel) and estimated Ricker spawner-recruit curves. The current natural spawner estimated capacity (solid black line) is shown relative to the fitted S_rep (dashed green line) and S_msy (dotted orange line). In the lower panel, the thick black curve shows the best-fit parameter estimates, with 100 bootstrapped fits illustrated as light grey curves and the full set of bootstrap S_msy estimates shown as short orange lines. These depict some of the uncertainty associated with reference points.

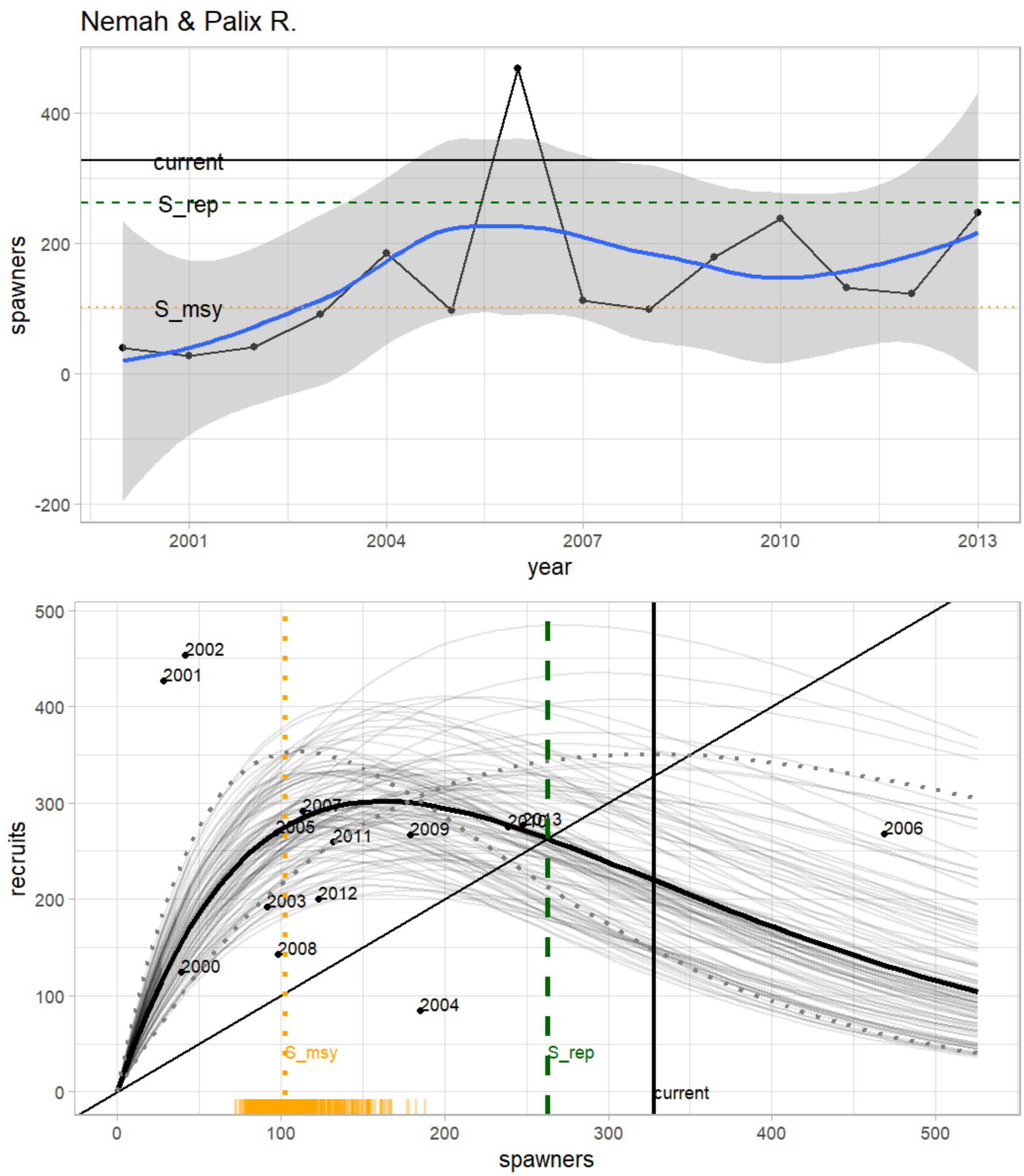

Figure 3: Number of natural origin spawners (escapement) by river, 2000-2019. Observations (solid black line) are shown with a Loess smoother trend (blue lines) and associated confidence interval (shaded colored area).

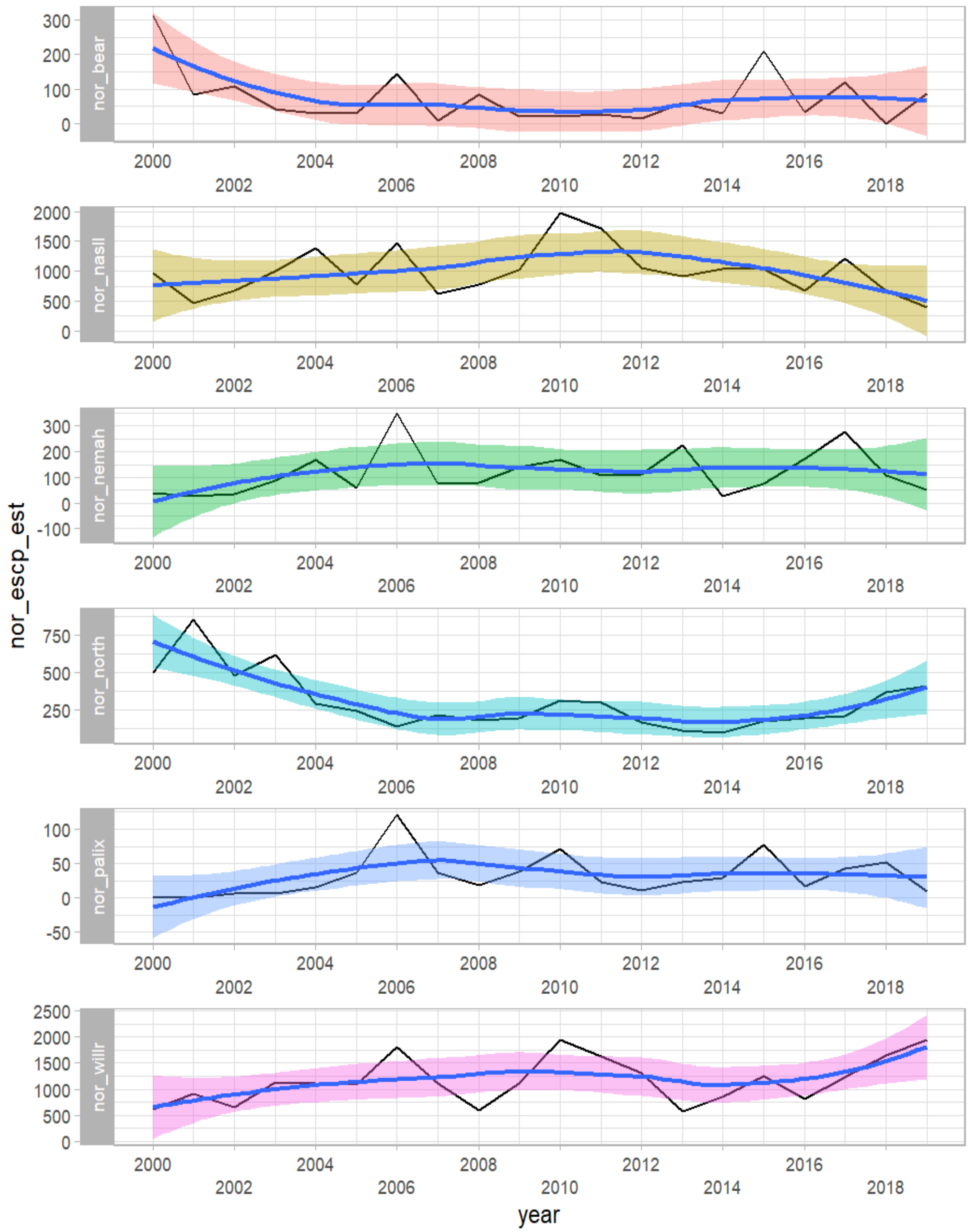

Figure 4a: Per-month low (q10), median (q50) and high (q90) percentiles of daily flow at the Willapa River USGS gage 12013500 from 1962-2019.

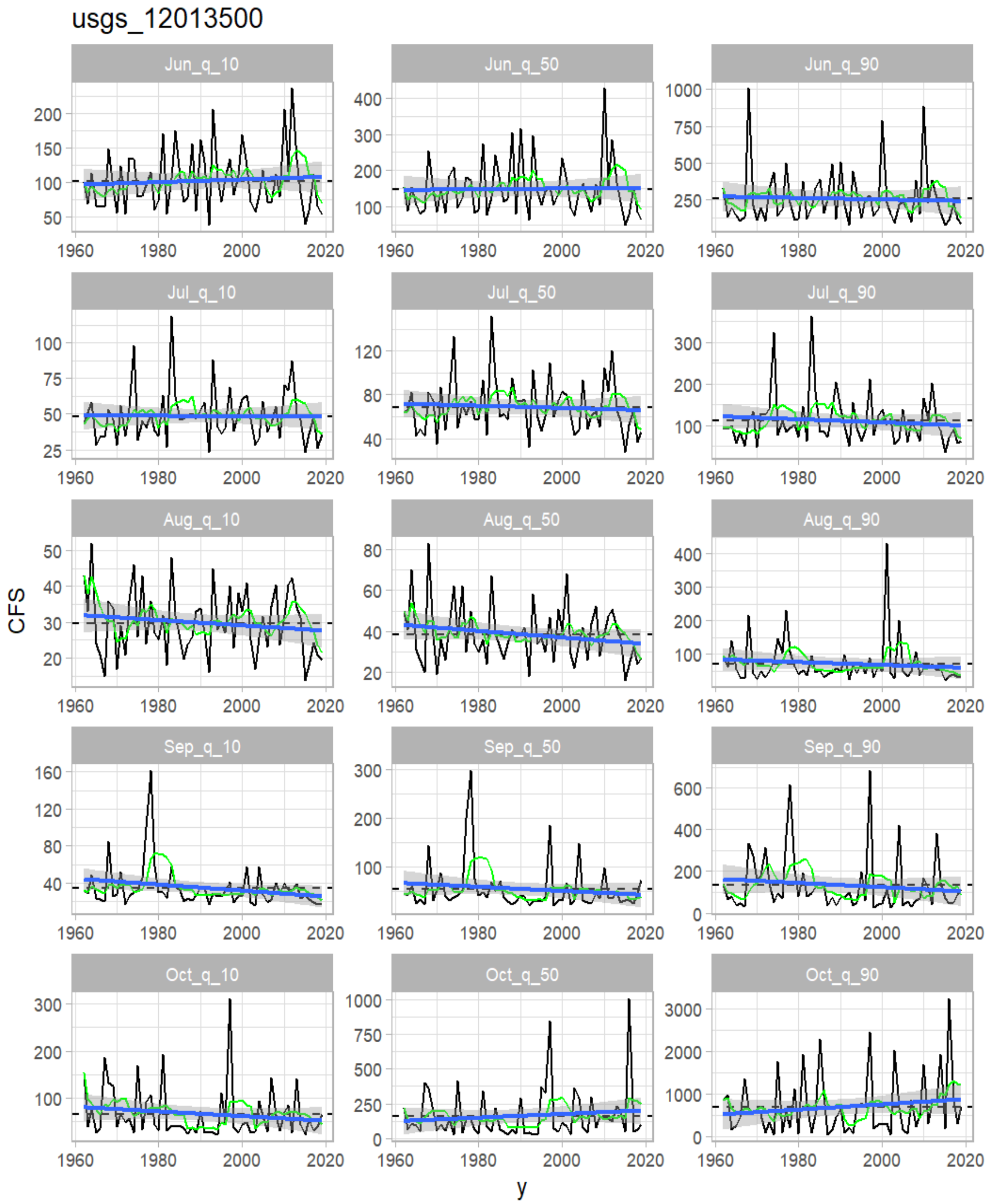

Figure 4b: Per-month low (q10), median (q50) and high (q90) percentiles of daily flow at the Naselle River USGS gage 12010000 from 1962-2019.