MEMORANDUM

TO: Kenai River Sportfishing Association

FROM: Ray Beamesderfer, Fish Science Solutions, Inc.

RE: Analysis of Kenai Late-Run King Escapement Goals

DATE: February 9, 2024

Summary

- Recent low escapements of large Kenai late-run Kenai kings have not sustained high yields as predicted by previous escapement goal analyses.
- Assumptions of the Ricker model used in previous analyses are not supported by current spawner- return data (including 2022 and 2023 which were not available to the latest ADFG escapement goal analysis).
- Escapements of 20,000 or less have been observed to produce little or no yield. The last three completed brood years did not replace themselves.
- The Ricker spawner-recruit model used to derive the Sustainable Escapement Goal (SEG), predicted high yields from low escapements including maximum sustained yield (MSY) from an escapement of 18,400.
- Current analysis found that the Ricker model overestimated yield from low escapements by 800% to 1,000% relative to actual returns.
- The SEG is no longer supported by current data due to the overestimates in model-derived yield probabilities from low escapements.
- A direct analysis of yield data indicates that the current OEG of 15,000 – 30,000 more closely approaches an escapement range likely to sustain high yield.
- Management for the lower SEG bound of 13,500 will risk further decline under current conditions and delay recovery in the event that conditions improve.

Background

This analysis of current escapement and return data was completed to inform consideration of escapement goals and management alternatives for Kenai Late-run King Salmon. This run was designated as a stock of management concern in 2023 after failing to meet established goals for five consecutive years (Figure 1). The 2024 forecast of 13,639 is also below the OEG.

Methods

This analysis included data on large (>75 cm METF) late-run Kenai River Chinook salmon numbers by age class for run years 1986-2023 reported in the 2024 run forecast by Eskelin (2024). Run year returns by age class produced spawner-recruit data for brood years 1986-2017 (Table 1). This includes two additional years of complete brood year data not available to the most recent

ADF&G escapement goal analysis (McKinley et al. 2024). Two additional run years of data fills out age-specific returns for two additional brood years than were included in McKinley et al. (2024).

Two methods were examined for describing productivity relative to escapement at current low levels of stock productivity. The first was the traditional Ricker stock-recruitment model which was the basis for the SEG of 13,500-27,000 (Fleischman & Reimer 2017; McKinley et al. 2024). The second was a Markov table which averages data over a range of escapement values. Markov tables have been used extensively by the Department in establishing SEGs for Kenai sockeye (Erickson et al. 2017) but have not previously been reported for Kenai kings. Hilborn & Walters (1992) in their classical textbook, highly recommend use of a Markov approach when many years of data are available, because it can accommodate any possible form of stock-recruitment curve and explicitly incorporates the type of variation seen in the data.

Results

Little or no potential yield is currently available for Kenai late-run kings (Figure 2). The last three brood years with complete return data have failed to replace themselves.

The Ricker spawner-recruit model substantially overestimated recruitment from escapements under 20,000 based on current data (Figure 3). Every data point in the low range of escapement fell below the curve. The pattern of residuals depicted in Figure 4 highlights the model failure at low escapements. The problem is apparent in both the original model fit by Fleischman & Reimer (2017) to 1986-2015 run year data and the updated fit by McKinley et al. (2024) to 1986-2021 run year data.

The Ricker model also substantially overestimated yield from escapements under 20,000 (Figure 6). Overestimates were 800% to 1,000% relative to actual returns. An MSY of 21,100 was estimated by the current model to be produced by an escapement of 18,400. However, no escapement below 20,000 has produced a yield of more than 10,000 and average yield for these escapements was 1,900. The consistent pattern of low recruitment across multiple brood years indicates that this is not a statistical anomaly.

The SEG is no longer supported by current data due to the overestimates in model-derived yield probabilities for low escapements. An SEG is defined as a level of escapement *"that is known to provide for sustained yield"* in the Policy for the Management of Sustainable Salmon Fisheries [5 AAC 39.222]. The SEG was previously identified based on statistical probabilities of achieving MSY derived from the Ricker model analysis. The lower bound of the SEG (13,500) was estimated in a model-derived optimum yield profile to provide an 86% probability of achieving at least 80% of MSY (McKinley et al. 2024). However, the probability of achieving at least 80% of MSY was zero in data on returns from escapements around the lower bound (Figure 7).

The Markov analysis provides more accurate descriptions of yield than the Ricker model over a wide range of escapements and productivity conditions (Figure 6). Maximum yield of approximately 20,000 big kings is produced at escapements between 20,000 and 35,000 when ocean conditions are favorable

Discussion

Little data were available for returns from low escapements when the Didson-based SEG was established in 2013 and translated to large kings in 2017. Those SEGs were derived from a conventional Ricker spawner-recruit model which inferred returns from low escapement based on higher escapements and levels of productivity prior to 2008. The model projected that MSY would be produced by escapements below the range of most of the available data.

King numbers declined severely after 2008, apparently in response to an extended period of unfavorable environmental conditions and low marine survival. This produced numerous data points on actual returns from low escapements during a period of unfavorable ocean conditions. This data does not support previous model projections of high king productivity from low escapements. In fact, returns per spawner declined along with abundance.

The problem with the SEG modeling is the underlying assumption that the relationship between spawning escapement and returns follows a conventional Ricker spawner-recruit curve or a variation thereof over a broad range of productivity conditions. The Ricker function assumption may hold for a period of relatively stable marine survival conditions, but has proven faulty under shifting productivity patterns. The model analysis is confounded by low contrast in escapement under different productivity regimes. Low escapements are generally only seen during poor production periods and high escapements during high production periods. So, the low escapement periods are representative of one set of Ricker equation parameters. The high escapement periods are representative of an entirely different Ricker equation.

The simple Ricker-type model does not accurately characterize the relationship between spawners and returns over a broad range of escapements under widely varying productivity patterns. The statistical methodology describes the best-fitting Ricker curve to the data even when the fit is not very good. The fit is constrained by the initial assumption that the relationship must follow a Ricker style curve. The problem persists even when more data from low escapements is added to the analysis. More data points shift the curve slightly but do not correct for the faulty assumption up front.

This is not simply a case of competing Ricker and Markov models providing different answers. The Ricker analysis is based on an assumption of a functional relationship which is demonstrably false. The Markov analysis makes no such assumption – it is simply a data averaging methodology that makes no assumptions regarding the form of the underlying function.

The net result is an SEG which does not accurately identify a range of escapements consistent with significant sustained yield. Current data unequivocally shows that managing for the lower end of the SEG will continue to produce low returns and sustain little or no yield under current conditions. Harvest of significant numbers of kings will risk driving the population to even lower levels from which it may be difficult to recover.

References

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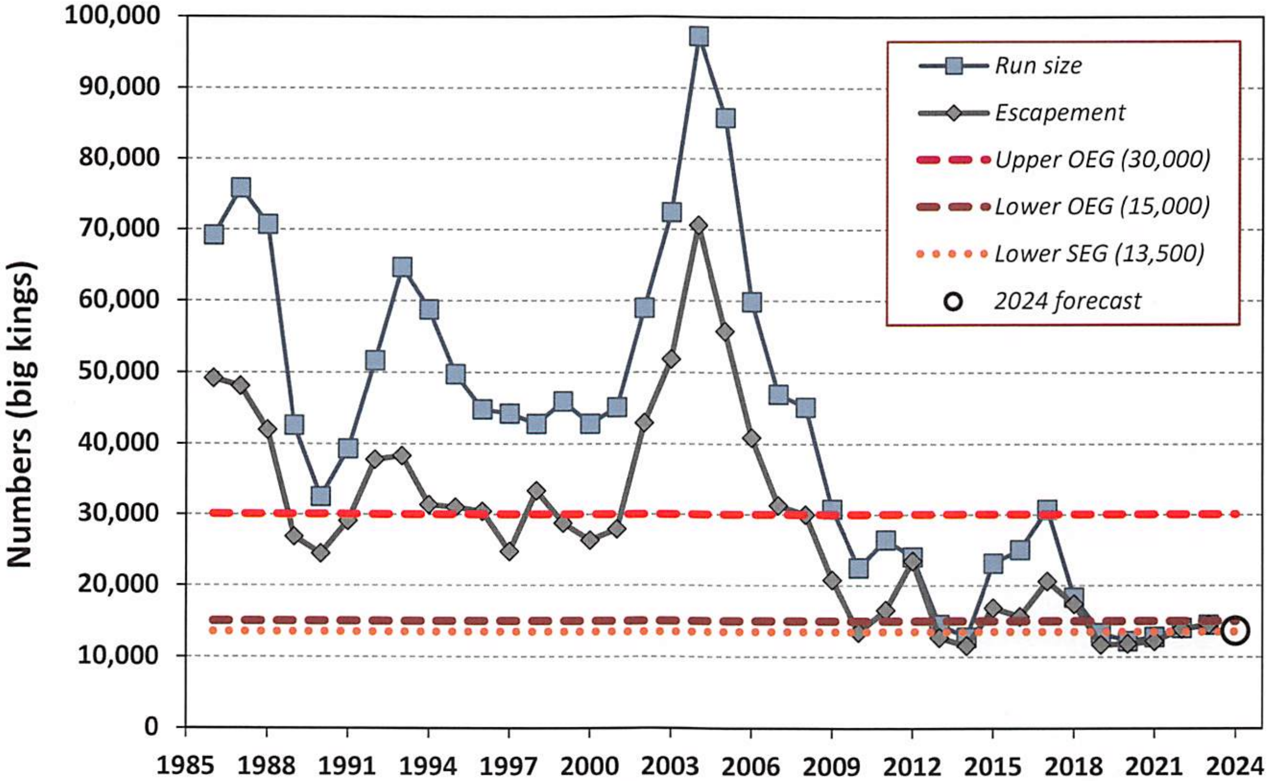

Figure 1. Annual run size and escapement of Kenai River late-run Kings relative to current Sustainable and Optimum Escapement Goals.

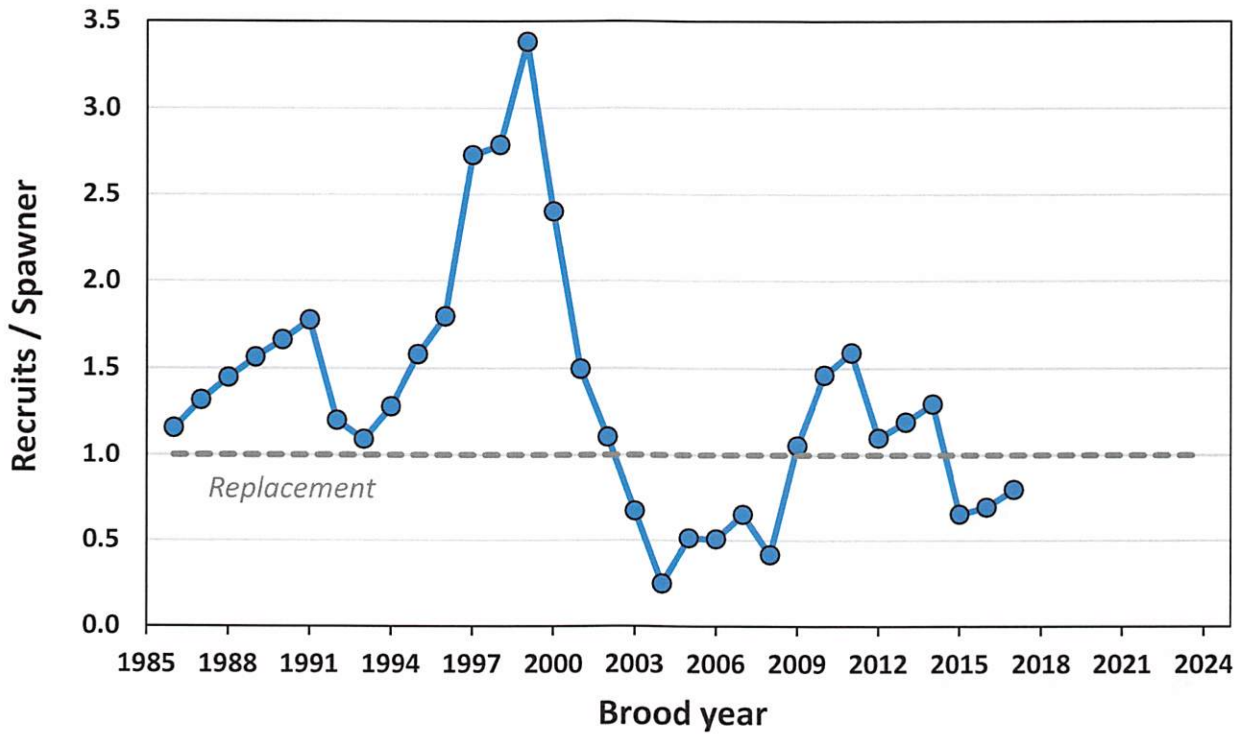

Figure 2. Annual recruits per spawner of large (>75 cm METF) late-run Kenai River Chinook for brood years 1986-2017.

Table 1. **Estimates of run size, escapement, total return, yield, and recruits per spawner of Kenai River Chinook Salmon 75 cm METF and longer by brood year (as reported by Eskelin 2024 by run year).**

Brood year	Total run	Escapement	Brood year return				Yield	Return per spawner
			Age 5	Age 6	Age 7	Total		
1986	69,188	49,197	10,505	42,345	4,096	56,946	7,749	1.2
1987	75,846	48,096	7,883	52,445	3,075	63,403	15,307	1.3
1988	70,691	42,003	7,970	49,284	3,585	60,839	18,836	1.4
1989	42,598	26,852	6,355	35,163	503	42,021	15,169	1.6
1990	32,514	24,496	10,879	28,968	934	40,781	16,285	1.7
1991	39,342	29,076	15,406	34,630	1,644	51,680	22,604	1.8
1992	51,689	37,788	8,582	34,244	2,565	45,391	7,603	1.2
1993	64,711	38,346	6,907	33,714	1,270	41,891	3,545	1.1
1994	58,798	31,400	9,641	29,152	1,465	40,258	8,858	1.3
1995	49,767	31,022	12,269	34,241	2,542	49,052	18,030	1.6
1996	44,874	30,453	9,281	44,847	598	54,726	24,273	1.8
1997	44,260	24,734	11,468	54,445	1,643	67,556	42,822	2.7
1998	42,828	33,381	17,253	71,804	4,058	93,115	59,734	2.8
1999	46,006	28,769	23,730	67,470	6,140	97,340	68,571	3.4
2000	42,826	26,331	14,154	43,687	5,372	63,213	36,882	2.4
2001	45,147	27,895	9,983	27,832	3,937	41,752	13,857	1.5
2002	58,965	42,940	13,685	31,914	1,885	47,484	4,544	1.1
2003	72,422	51,862	9,305	23,848	1,743	34,896	-16,966	0.7
2004	97,329	70,617	5,012	11,689	883	17,584	-53,033	0.2
2005	85,879	55,764	9,006	18,544	1,099	28,649	-27,115	0.5
2006	59,872	40,911	6,944	12,985	846	20,775	-20,136	0.5
2007	46,981	31,276	9,914	10,097	390	20,401	-10,875	0.7
2008	45,202	30,001	3,556	7,574	1,381	12,511	-17,490	0.4
2009	30,785	20,807	4,799	15,924	1,241	21,964	1,157	1.1
2010	22,502	13,425	5,789	12,562	1,271	19,622	6,197	1.5
2011	26,411	16,541	11,202	14,961	146	26,309	9,768	1.6
2012	24,038	23,427	14,483	10,572	711	25,766	2,339	1.1
2013	14,542	12,719	7,597	7,174	401	15,172	2,453	1.2
2014	12,776	11,584	5,435	9,066	504	15,005	3,421	1.3
2015	23,139	16,857	2,716	8,333	0 [a]	11,049	-5,808	0.7
2016	25,023	15,652	3,930	6,952 [a]	0 [a]	10,882	-4,770	0.7
2017	30,734	20,583	7,126 [a]	9,322 [a]	-- [b]	16,448	-4,135	0.8
2018	18,364	17,405	5,214 [a]	--	--	--	--	--
2019	13,360	11,709	--	--	--	--	--	--
2020	12,226	11,854	--	--	--	--	--	--
2021	12,794	12,238	--	--	--	--	--	--
2022	14,078	13,911	--	--	--	--	--	--
2023	14,537	14,502	--	--	--	--	--	--

[a] *Data not available to McKinley et al. 2024.*

[b] *Age 7 return not available for 2017 brood year but likely to be negligible based on recent patterns.*

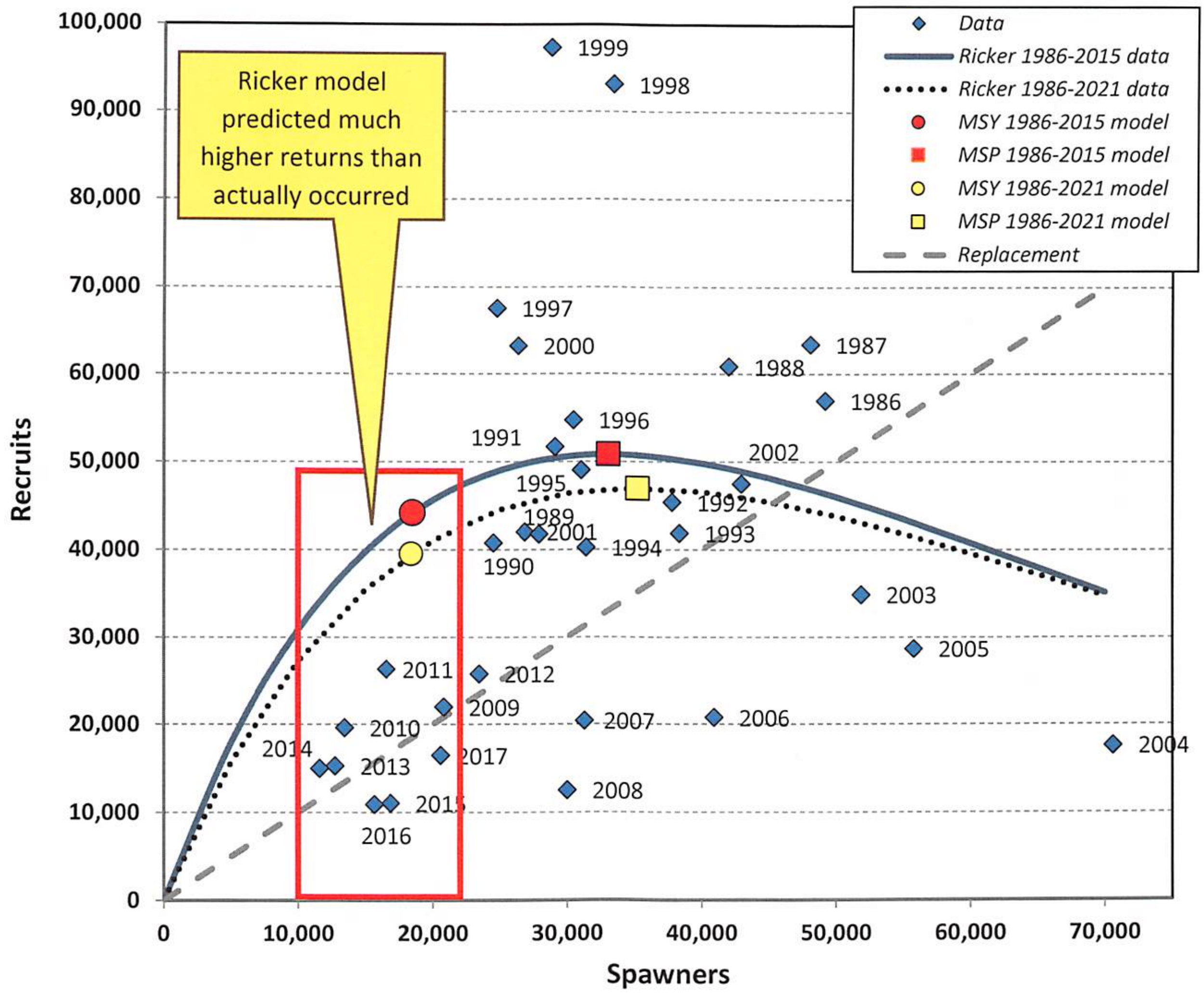

Figure 3. Spawner- recruitment relationships for Kenai late-run Chinook salmon 75 cm METF and longer for 1986-2015 run year data (Fleischman & Reimer (2017) and 1986-2021 run year data (McKinley et al. 2024). The area of model failure is highlighted by a red box.

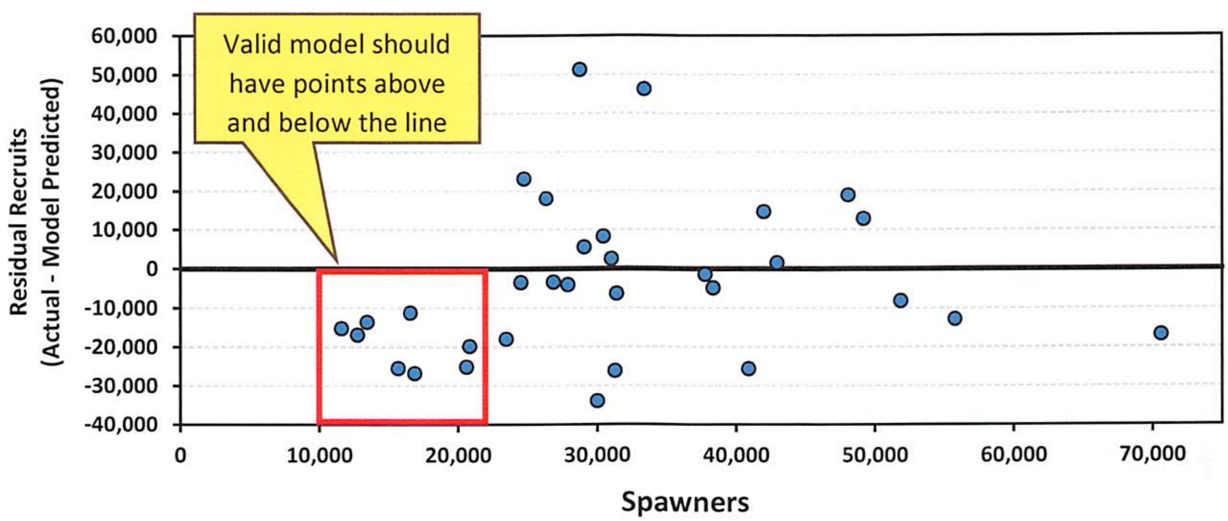

Figure 4. Residual differences between actual and model-predicted recruitment for McKinley et al. (2024) analysis. The area of model failure is highlighted by a red box.

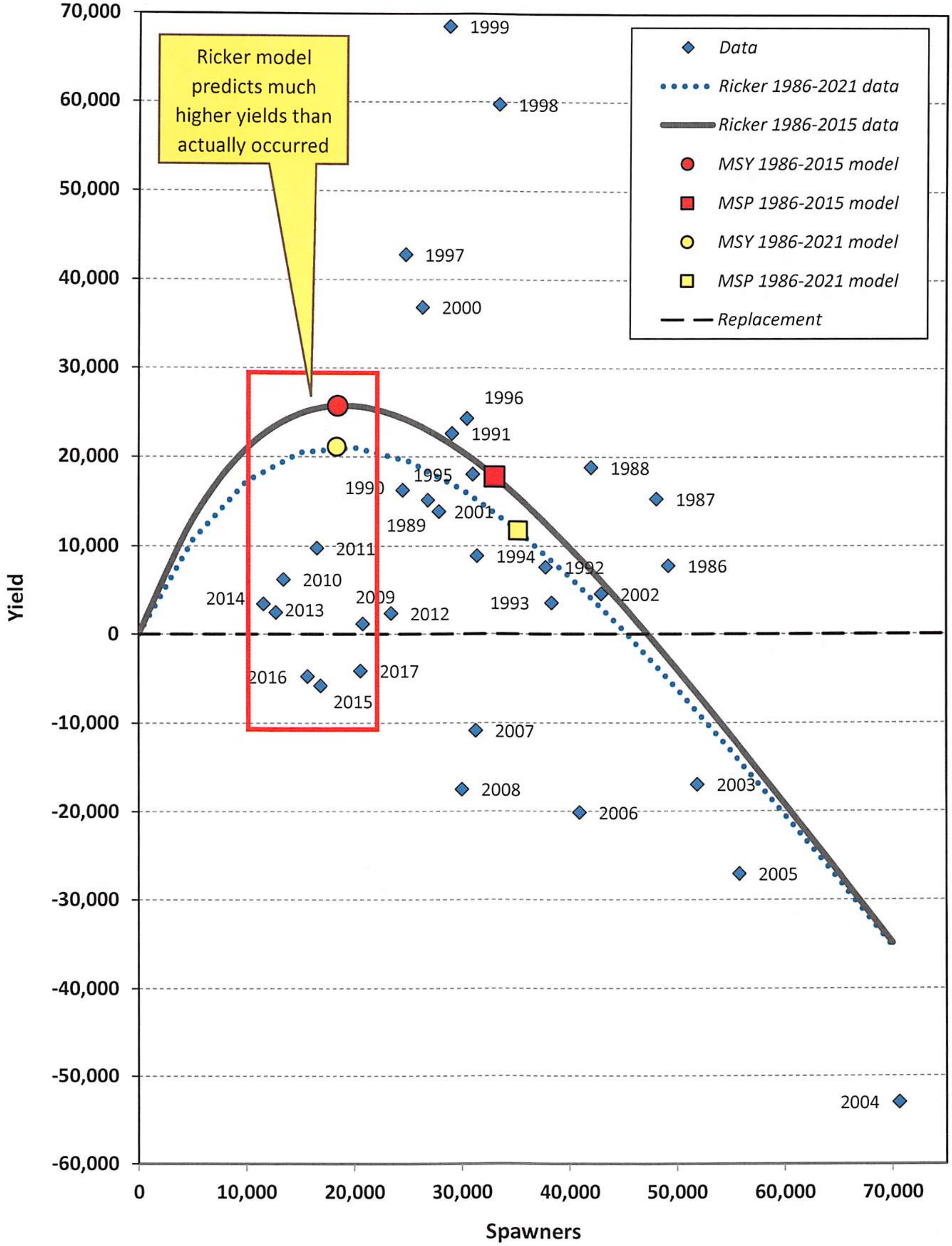

Figure 5. Yield analysis from stock recruitment data for Kenai Late-Run King salmon based on Ricker mode analysis. The area of model failure is highlighted by a red box.

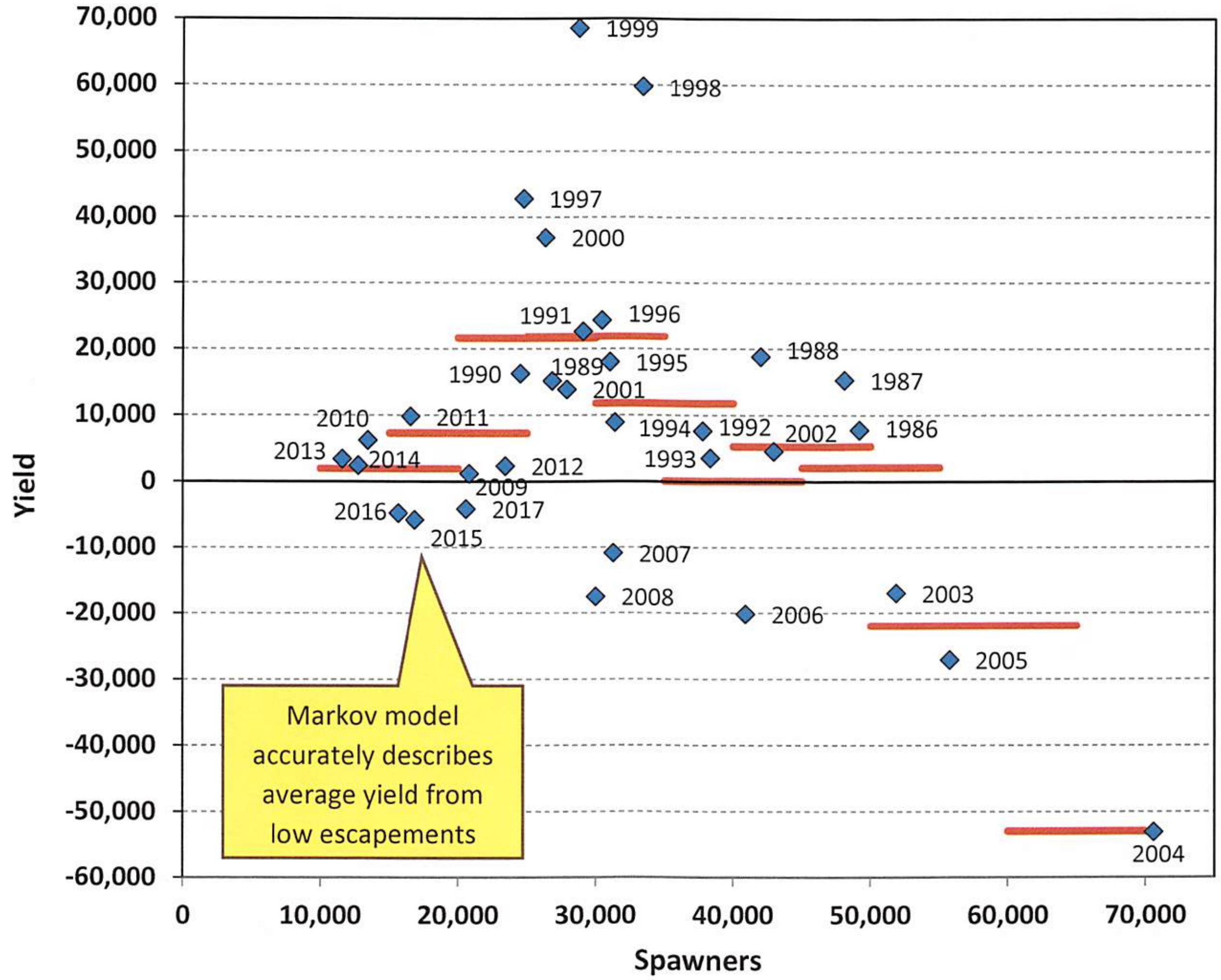

Figure 6. **Yield analysis from stock recruitment data for Kenai Late-Run King salmon based on Markov Table. The horizontal lines show average yields from moving incremental escapement ranges.**

Table 2. **Markov yield table for Kenai Late-Run King salmon constructed using data from brood years 1986-2017.**

Escapement interval	Number of years	Mean Spawners	Mean Returns	Return per Spawner	Mean Yield	% of years Yield > 0.8msy[a]
10,000 - 20,000	6	14,500	16,300	1.1	1,900	0%
15,000 - 25,000	8	20,400	27,600	1.3	7,200	13%
20,000 - 30,000	10	25,300	46,900	1.8	21,600	40%
25,000 - 35,000	11	29,700	51,500	1.7	21,800	55%
30,000 - 40,000	16	33,000	44,700	1.4	11,700	19%
35,000 - 45,000	5	40,400	43,300	1.1	2,900	20%
40,000 - 50,000	5	44,600	49,900	1.1	5,300	20%
45,000 - 55,000	3	49,700	51,700	1.0	2,000	0%
50,000 - 60,000	2	53,800	31,800	0.6	-22,000	0%
55,000 - 65,000	1	55,800	28,600	0.5	-27,100	0%
60,000 - 71,000	1	70,600	17,600	0.2	-53,000	0%

[a] *Current model in McKinley et al. (2024) estimated MSY = 21,000.*

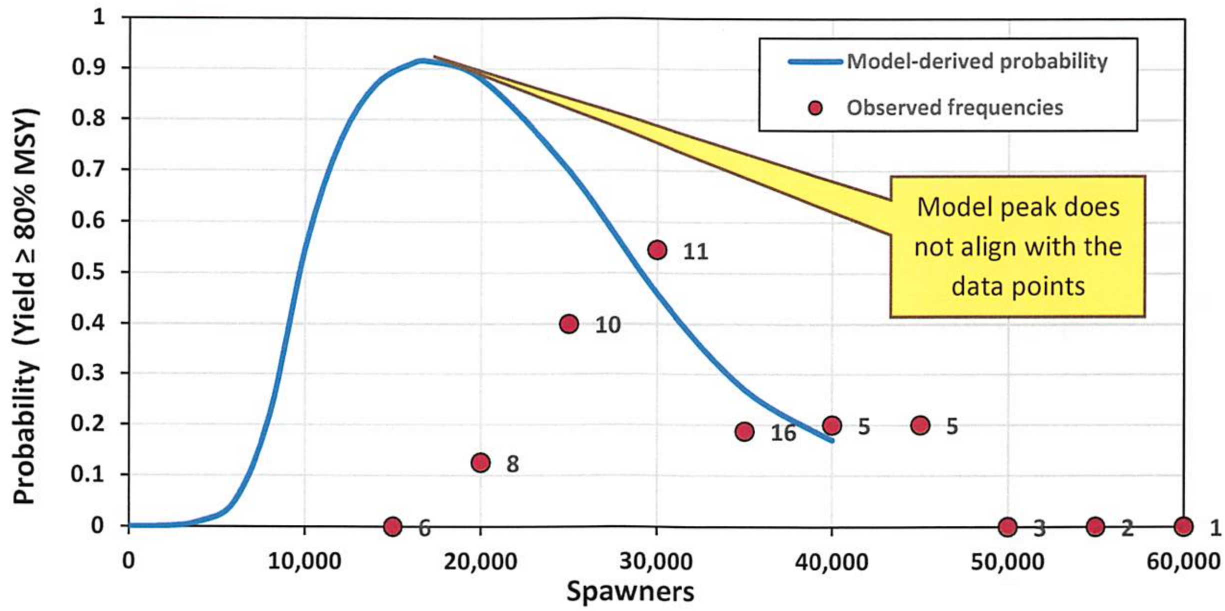

Figure 7. Optimal yield profile (OYP) plot for Kenai late-run Chinook salmon 75 cm METF and longer showing probability that a specified spawning abundance will result in 80% of maximum sustained yield (McKinley et al. 2024) in relation to observed frequences of annual yields exceeding the model-derived estimate of MSY as reported in Table 1. Sample sizes are reported for observed frequencies.

Discussion of Optimal Yield Profiles

OYPs generally depict confidence in probabilistic estimates from complex state-space model analyses of spawner-recruit functions and related parameters including escapement which produce MSY. These profiles are being used to inform identification of sustainable or biological escapement goals from spawner-recruit analysis.

OYPs are intuitively difficult to understand due to the complexities of the corresponding statistical modeling derivation. Fleischman & Reimer (2017) define these as the probability that a given spawning escapement would produce average yields exceeding X% of MSY based on yields calculated at incremental values of spawners for each of a series of potentially plausible sets of model parameters that could have resulted in the data that were observed. Basically, these describe our level of confidence that the average yield from a given escapement produces the prescribed level of yield (e.g., 80% of the model-estimated MSY).

Figure 7 depicts the OYP reported by McKinley et al. (2024) in support for the current SEG. The figure also shows average frequencies of yields of at least 80% of the current model estimate of MSY observed in spawner-recruit data. The probabilities in the OYP and the data frequencies are expressing different things but there should be a correspondence if the analysis model accurately describes the data. The peaks of the OYP and observed frequences should occur around at the same spawning escapement. If a given escapement is predicted with high confidence to produce 80% of the estimated MSY on average, then the frequency of observations producing at least that level of escapement should be around 50%. As with the yield analysis, the disparity in these plots reflects failure of the Ricker stock-recruitment model to accurately describe recruitment from low escapements.

This comparison also highlights the difficulty of interpreting the meaning of the probabilities identified in the OYPs. High probabilities presumably reflect high levels of confidence in spawner-recruit estimates of spawners which produce MSY but this is clearly a different metric from the frequency that a given spawning escapement will produce MSY. OYPs should be used with reluctance due to the potential for misleading interpretation of the likelihood of sustained yields associated with a given spawning escapement (even in the best of cases where the model accurately describes the data).