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# Technical Memorandum

Date: May 24, 2012 Project Number: 1948

To: Mark Hampton, NOAA Fisheries

From: Noble Hendrix

Project: Klamath population dynamics models to support EIR/EIS of Klamath dam removal

Subject: Model runs of EDRRA without KBRA effects on productivity

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Previous runs of the Evaluation of Dam Removal and Restoration of Anadromy (EDRRA) model for the Dam Removal Alternative (DRA) included the effects of the Klamath Basin Restoration Agreement (KBRA). Through the development of the EIR/EIS document, it has become important to obtain results from the EDRRA model for a DRA scenario without the KBRA actions on Chinook productivity in place. The technical memorandum that follows includes results from running the EDRRA model without KBRA improvements in productivity in the DRA and to provide results that can be used in the EIR/EIS process specific to address analyses needed for completion of the Biological Opinion as required under the federal Endangered Species Act. To achieve these objectives, the EDRRA model was run with KBRA effects on population productivity removed, but with the effects of KBRA hydrology remaining and the effects of KBRA active reintroduction to the upper Klamath basin remaining (as described in Hendrix 2010). These results were compared to the initial run of the model, in which KBRA was affecting productivity in the lower basin, upper basin stream type Chinook, and upper basin ocean type Chinook.

The EDRRA model was constructed to forecast annual abundances of Chinook salmon before, during, and after dam removal on the Klamath River and to explicitly incorporate uncertainty in the abundance forecasts. To quantify the uncertainty in the forecasts, two sources of information were used: 1) a Bayesian retrospective model that estimated historical production in the basin below Iron Gate Dam that provided posterior probability distributions to characterize the uncertainty; and 2) probability estimates of Chinook productivity based on a meta-analysis of Chinook production by Liermann et al. (2010), which were applied to forecasting the production in the tributaries to Upper Klamath Lake (Upper Basin). In both cases, Ricker (1974) stock-recruitment functions were used to define the relationship between spawners and age 3 ocean

fish, which is the first age at which they are vulnerable to the fishery. Because EDRRA was developed to support an economic analysis of the effects of dam removal, the Klamath Harvest Rate Model (KHRM , Mohr In Prep) was used to remove fish from the population by the ongoing fishery. For more information on the EDRRA model, please see Hendrix (2010).

In the initial version of EDRRA, the KBRA effects were assumed to improve productivity in the Ricker stock-recruitment relationships. The KBRA process on productivity (entitled KBRA in the subsequent analysis) was modeled by using truncated Normal distributions, in which less productive values of the distribution were excluded (e.g., Figure 1 A). In contrast, the model runs from this analysis (entitled No KBRA in the subsequent analysis) removed the truncation and thus the full distribution in productivity values were sampled (Figure 1B).

*Comparison between EDRRA No KBRA and EDRRA KBRA*

The results of running the EDRRA model are only valid in a relative sense. In other words, the results of two actions must be compared to each other in order to understand how the actions performed under one alternative compare to the actions under a different alternative. To compare the results of the DRA relative to the NAA a performance metric was calculated as (DRA – NAA)/NAA. The DRA performance metric was calculated for each of the 1000 DRA and NAA model pairs (see Hendrix 2010 for further details on the pairing of model runs under DRA and NAA). The DRA performance metric was computed here for the version of the EDRRA model with the No KBRA productivity distributions in place. I calculated the median DRA performance metric for the No KBRA model runs alongside those previously calculated under the KBRA model runs to show how allowing the full productivity distribution to be sampled leads to slightly different results than the model runs performed in Hendrix (2010).

The result of allowing the full distribution of productivity to be sampled (i.e., No KBRA effects on productivity) lead to slightly lower median values of the DRA performance metric relative to the KBRA in escapement in the absence of fishing (Figure 2). Escapement in the absence of fishing is a quantity used to compare DRA and NAA returns to the Klamath Basin; however, fishing occurs every year in the model. Before fishing occurs though, the KHRM model calculates the hypothetical escapement in the absence of fishing for that year. I keep track of this quantity as an overall estimate of productivity that could have returned to the basin for comparison purposes. In other words, the escapement in the absence of fishing is the abundance of fish that would return to the basin if the fishery was hypothetically closed that year. But in fact it is not closed. The fishery then occurs in that year and actual escapement feeds into the

production portion of the model. The annual differences in the DRA metric between the model runs was due to the different assumptions in productivity as a result of KBRA (i.e., sampling the full distribution under No KBRA versus sampling the truncated distribution under KBRA). The difference between the KBRA and No KBRA EDRRA model runs increased over the 50 year time series (Figure 2), because the KBRA EDRRA model run shifted the lower bound of the truncation over time such that the lower 25% of the distribution was excluded by 2061 (Hendrix 2010).

The DRA performance metric was also lower under the No KBRA model runs relative to the KBRA model runs for the escapement to the lower basin (Figure 3). The pattern in the DRA performance metric was similar as the escapement under no fishing (Figure 2) in which the later years (after approximately 2033) had larger differences between the KBRA and No KBRA model runs. Furthermore, there were some years where the median escapement to the lower basin was lower under DRA than NAA in the No KBRA model runs. This result was expected, because fish are returning to two basins under the DRA; therefore, there are some conditions under which escapement to the lower basin may be less under DRA than NAA as fish are returning to the Upper Basin under DRA. This is also the reason the escapement in the absence of fishing was used for comparing the overall returns to the system under DRA and NAA.

A similar pattern in DRA performance was observed between the KBRA and No KBRA runs of the EDRRA model for ocean commercial harvest (Figure 4) as for the escapement in the absence of fishing (Figure 2); the median performance metric for the No KBRA model run was below the KBRA model run, and the difference in the metric increased over the time period of the model simulations. The same pattern was evident in the ocean recreational harvest (Figure 5), which occurred due to the KHRM apportionment of harvest between the ocean commercial and ocean recreational components of the fishery.

The pattern in DRA performance was somewhat different for the KBRA and No KBRA EDRRA model runs for the river harvest (Figure 5). The river fishery is capped at a harvest of 25,000 fish (Mohr In Prep), and the increase in abundance under DRA relative to NAA could not be caught in the river fishery in many of the model iterations. As a result, the comparison of No KBRA to KBRA model runs was equivalent for most of the time series of the model. Only after approximately 2049 does there appear to be a slight improvement in the DRA metric for the KBRA model run versus the No KBRA model run (Figure 5); however, the scale for the river harvest is one order of magnitude less than the escapement in the absence of fishing (Figure 2), the commercial harvest (Figure 3), and the ocean harvest (Figure 4).

Finally, the pattern in the DRA performance metric for the tribal harvest (Figure 6) was similar to the ocean commercial and recreational harvest with the No KBRA performance being below the KBRA performance and the difference increasing over time (Figure 6).

*How to interpret the results of the EDRRA model*

The goal of the EDRRA model was to provide relative forecasts of abundance under DRA and NAA while incorporating uncertainty from multiple sources into the abundance forecasts. As a result, the EDRRA model evaluated performing the DRA versus performing the NAA over multiple states of nature. A state of nature is defined as a hypothesis about the state of the system (e.g., productivity of lower basin stocks, capacity in the lower basin, productivity of upper basin stocks, capacity of upper basin, effect of ocean conditions, etc.). In the EDRRA model, each state of nature is a parameter set. I use 1 parameter set to perform the NAA and the same parameter set to perform the DRA, which provides a pair of model runs under the same state of nature. The EDRRA model then does this a total of 1000 times to be able to calculate 1000 paired model runs. The performance metrics are computed on those paired runs.

Due to the paired nature of the model runs, the most robust metric of this analysis is the probability of having higher abundance under DRA than NAA. This is the portion of the distribution of DRA performance metric with values greater than 0. Focusing on the period after 2033 when active reintroduction has ceased and hatchery supplementation has ended, the portion of the distribution greater than 0 is approximately 0.78 for escapement in the absence of fishing under KBRA or odds of approximately 3:1 in favor of DRA (Table 1). The proportion is slightly lower at 0.75 for the No KBRA model runs (Table 2). Additional calculations of the probability of higher abundances under DRA relative to NAA are provided for the KBRA model runs (Table 1) and the No KBRA model runs (Table 2).

The relative difference between DRA and NAA ( i.e., (DRA-NAA)/NAA * 100%), may also provide information about the magnitude of improvement in DRA over NAA (note that this quantity is the same as the DRA performance metric that was compared previously between the KBRA and No KBRA model runs). The magnitude is more sensitive to model assumptions about the states of nature than the probability of DRA > NAA, however. Still, if one wanted a single value on the percentage improvement in abundance under DRA relative to NAA, the median would be a good estimate (so would the mean typically, but the abundances have skewed distributions and the mean is more sensitive to skewness). The median estimate for the relative

magnitude of change is 81.4% for the escapement in the absence of fishing for the KBRA model runs (Table 3). In other words, one would have 1.84 times the abundance of NAA fish by performing DRA. The credible intervals (Table 3 and 4) represent uncertainty in the relative magnitude of change due to performing the DRA action . The 95% credibility interval (region over which the outcome has a 0.95 probability of occurrence) is between -59.9% and 881% for escapement in the absence of fishing (Table 3); thus there is a 2.5% chance that the abundance under DRA will be *less than* -59.9% of NAA abundance and there is a 2.5% chance that the abundance under DRA will be *greater than* 881%. Thus, the remaining 95% of the distribution falls between these two values. I have computed these values for different periods in the modeled time series and for the KBRA model runs (Table 3 – equivalent to Table 8 in Hendrix 2010) and the No KBRA model runs (Table 4).

The overall result from conducting the No KBRA model runs is to reduce the DRA performance metric by a small amount. By allowing the full distribution of productivity values to be sampled over the time series (No KBRA), there is a decrease of approximately 0.03 to 0.04 in the probability that DRA > NAA over the 2033 - 2061 time periods relative to the KBRA model runs (Tables 1 and 2). Decreases in the magnitude of the DRA performance under No KBRA versus KBRA were on the order of 8% to 10% for the post 2033 time period (Tables 3 and 4).

**Literature Cited**

Hendrix, N. 2010. Forecasting the response of Klamath Basin Chinook populations to dam removal and restoration of anadromy versus no action. Report prepared to the National Marine Fisheries Service by R2 Resource Consultants, Inc. Available at: http://klamathrestoration.gov/sites/klamathrestoration.gov/files/EDRRA%20Report%20Hendrix%2012.15..11.pdf

Liermann, M., R. Sharma, C. Parken. 2010. Using accessible watershed size to predict management parameters for Chinook salmon, Oncorhynchus tshawytscha, populations with little or no spawner-recruit data: a Bayesian hierarchical modelling approach. Fisheries Management and Ecology 17: 40-51.

Mohr, M. In preparation. The Klamath Harvest Rate Model. National Marine Fisheries Service (NMFS), Southwest Fisheries Science Center (SWFSC). September 2010. 20 pp.

Ricker, W.E., 1975 Computation and interpretation of biological statistics of fish populations. Bull.Fish.Res.Board Can., (23) Suppl.1, vol.2:519–29.

Table 1. Probability that abundance is greater by performing DRA rather than NAA under the original model run in which KBRA improves productivity of Chinook populations.

| Metric | 2012-2020 | 2021-2032 | 2033-2061 |
|---|---|---|---|
| Escapement in the absence of fishing | 0.539 | 0.793 | 0.782 |
| Escapement Lower Basin | 0.496 | 0.543 | 0.557 |
| Ocean Commercial | 0.539 | 0.793 | 0.717 |
| Ocean Recreational | 0.539 | 0.793 | 0.717 |
| River | 0.4815 | 0.621 | 0.624 |
| Tribal | 0.538 | 0.793 | 0.718 |

Table 2. Probability that abundance is greater by performing DRA rather than NAA under the model run in which KBRA does not affect productivity.

| Metric | 2012-2020 | 2021-2032 | 2033-2061 |
|---|---|---|---|
| Escapement in the absence of fishing | 0.522 | 0.785 | 0.748 |
| Escapement Lower Basin | 0.468 | 0.52 | 0.516 |
| Ocean Commercial | 0.523 | 0.787 | 0.672 |
| Ocean Recreational | 0.523 | 0.787 | 0.672 |
| River | 0.464 | 0.625 | 0.607 |
| Tribal | 0.521 | 0.785 | 0.683 |

Table 3. Percent increase in abundance due to performing DRA versus performing NAA for three time periods: 1) prior to dam removal (2012 – 2020); 2) during active reintroduction in Upper Basin (2020-2032); and after active reintroduction ceases and Iron Gate Hatchery production ceases (2033-2061). The values in this table assume that KBRA improves the productivity of Klamath Chinook populations.. This table is equivalent to Table 8 in Hendrix (2010).

| | **2012-2020** | | **2021-2032** | | **2033-2061** | |
|---|---|---|---|---|---|---|
| **Metric** | **Median** | **95% CrI** | **Median** | **95% CrI** | **Median** | **95% CrI** |
| Escapement in the absence of fishing | 10.8% | (-79.7%, 492.6%) | 81.8% | (-61.7%, 836.5%) | 81.4% | (-59.5%, 881.4%) |
| Escapement to Lower Basin | 0.0% | (-72.2%, 385.7%) | 6.7% | (-77.5%, 474.8%) | 9.2% | (-75.8%, 489.6%) |
| Ocean Commercial | 9.2% | (-86.7%, 836.2) | 63% | (-61.9%, 1618.9%) | 46.5% | (-68.7%, 1495.2%) |
| Ocean Recreational | 9.2% | (-86.7%, 836.2) | 63% | (-61.9%, 1618.9%) | 46.5% | (-68.7%, 1495.2%) |
| River | 0.0% | (-92.3%, 1519.7%) | 8.7% | (-73.4%, 2778.1%) | 9.1% | (-77.4%, 2753.7%) |
| Tribal | 10.3% | (-88.6%, 1009.8%) | 71.5% | (-65%, 1948.2%) | 54.8% | (-71.0%, 1841.0%) |

Table 4. Percent increase in abundance due to performing DRA versus performing NAA for three time periods: 1) prior to dam removal (2012 – 2020); 2) during active reintroduction in Upper Basin (2020-2032); and after active reintroduction ceases and Iron Gate Hatchery production ceases (2033-2061). The values in this table assume that KBRA has no effect on the productivity of Klamath Chinook populations..

| | **2012-2020** | | **2021-2032** | | **2033-2061** | |
|---|---|---|---|---|---|---|
| **Metric** | **Median** | **95% CrI** | **Median** | **95% CrI** | **Median** | **95% CrI** |
| Escapement in the absence of fishing | 6.6% | (-80.1% , 473.3%) | 81.5% | (-60.1%, 853.5%) | 70.8% | (-61.2%, 779.4) |
| Escapement to Lower Basin | 0.0% | (-72.8%, 342.5%) | 4.7% | (-76.7, 465.9) | 2.2% | (-76.3, 432.6) |
| Ocean Commercial | 5.9% | (-87.2%, 798.2%) | 60.9% | (-62.1, 1632.6) | 38.7% | (-70.6, 1290.3) |
| Ocean Recreational | 5.9% | (-87.2%, 798.2%) | 60.9% | (-62.1, 1632.6) | 38.7% | (-70.6, 1290.3) |
| River | 0.0% | ( -93.1%, 1416.0%) | 9.3% | (-75.9%, 2976.5%) | 7.1% | (-81.3%, 2311.1%) |
| Tribal | 6.7% | (-88.8%, 939.3%) | 70.0% | (-66.6, 1970.2) | 45.5% | (-73.6,% 1551.3%) |

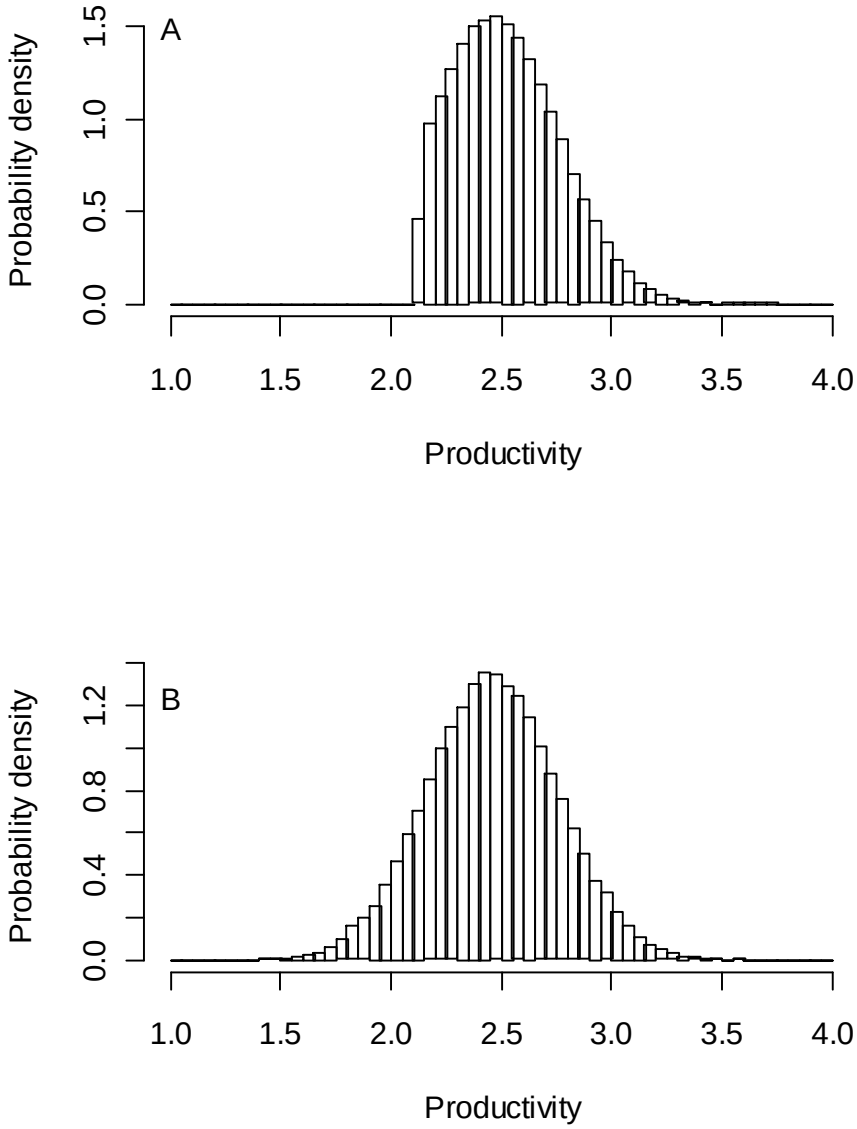


Figure 1. Examples of Normal distributions for productivity under two assumptions about KBRA effects. Plot shows the distribution of productivity values in 2035 for ocean type Chinook in the Lower Basin assuming KBRA improves productivity of Chinook populations by removing the lower values of productivity (A - KBRA ). If KBRA does not affect productivity, the entire distribution is sampled for productivity values in 2035 (B – No KBRA).

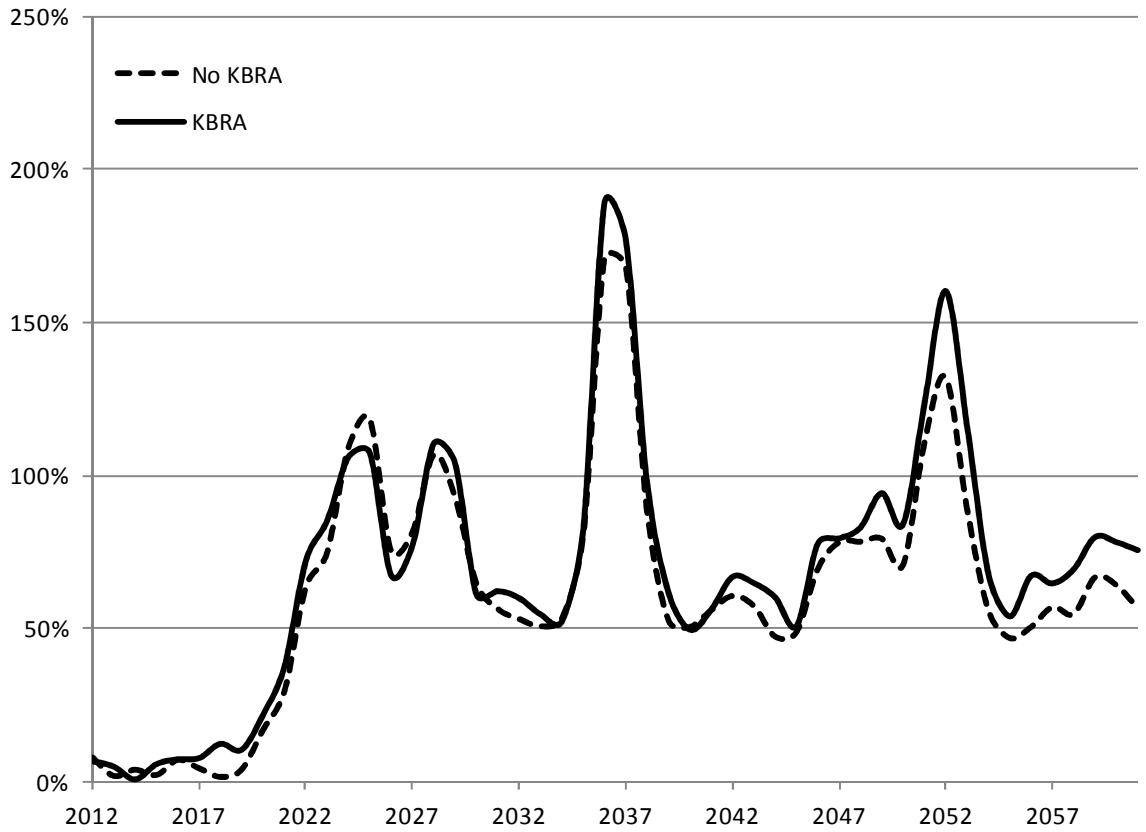


Figure 2. Relative performance of DRA to NAA ([DRA-NAA]/NAA * 100%) in escapement in the absence of fishing. Plot shows median performance assuming KBRA improves productivity of Chinook populations (KBRA) and without increasing productivity (No KBRA).

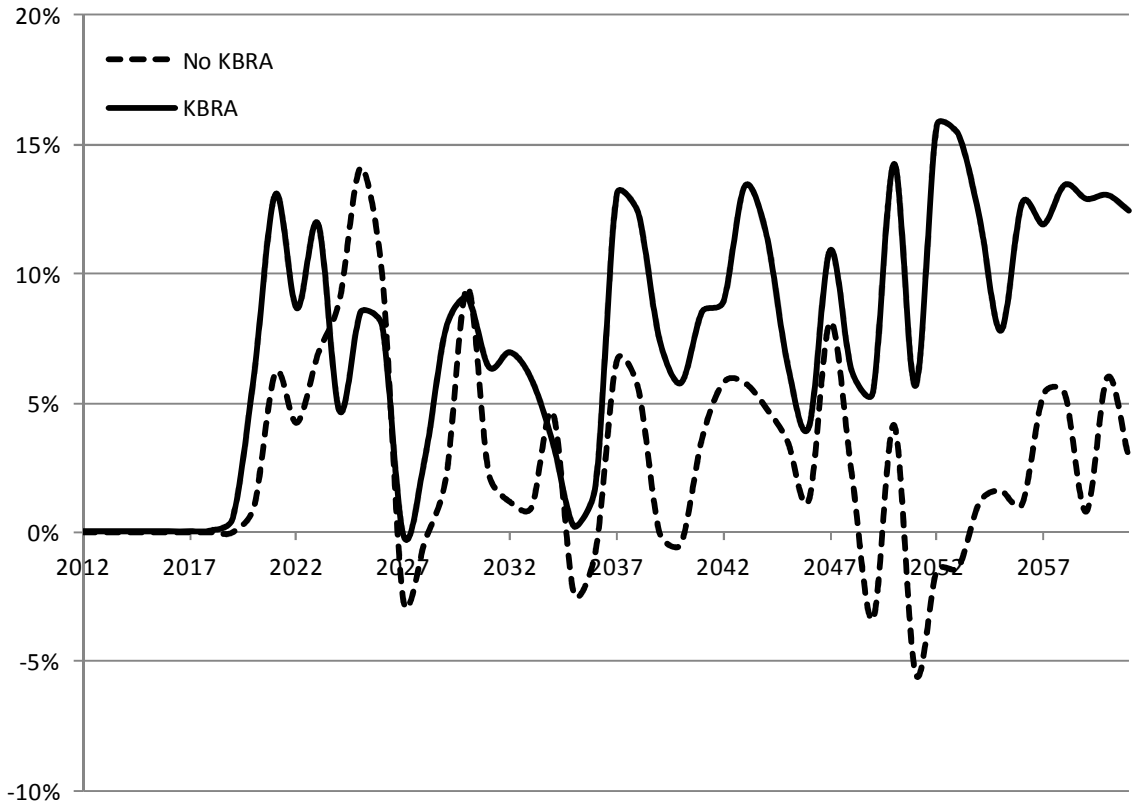


Figure 3. Relative performance of DRA to NAA ([DRA-NAA]/NAA * 100%) in escapement to the lower basin under two assumptions about KBRA effects. Plot shows median performance assuming KBRA improves productivity of Chinook populations (KBRA) and without increasing productivity (No KBRA).

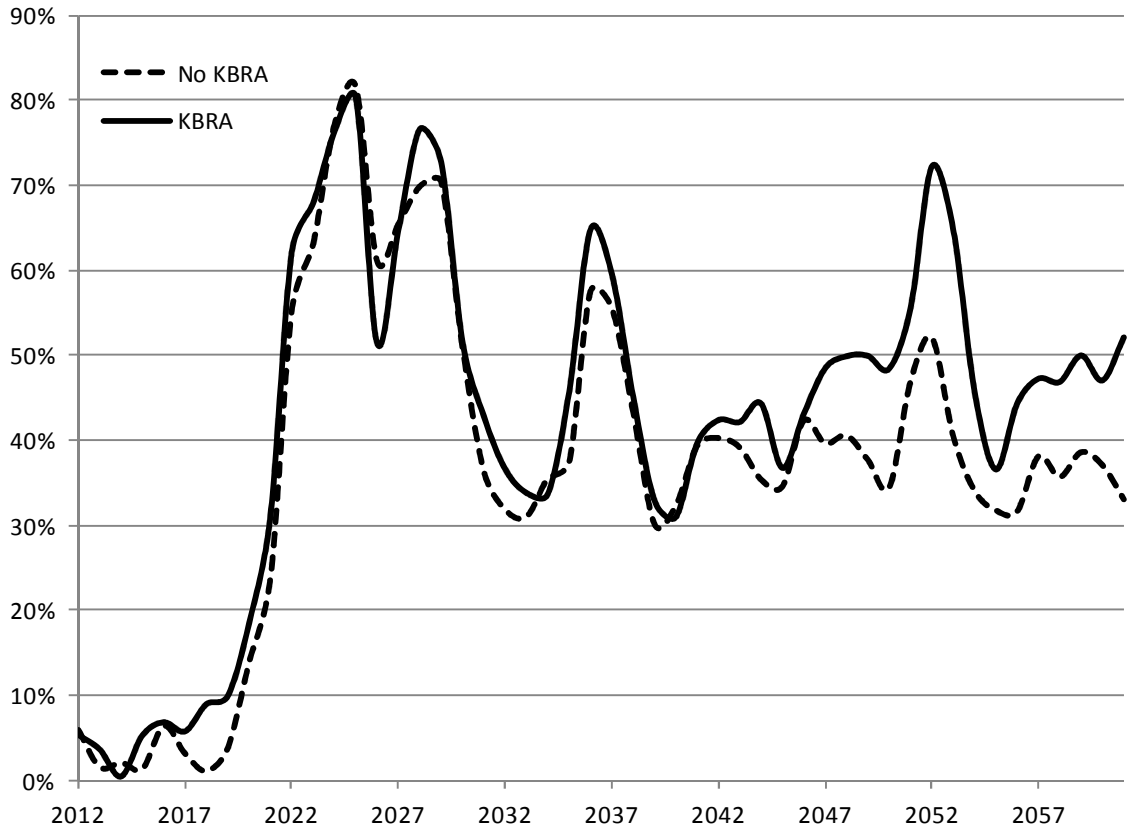


Figure 4. Relative performance of DRA to NAA ([DRA-NAA]/NAA * 100%) in ocean commercial harvest. Plot shows median performance assuming KBRA improves productivity of Chinook populations (KBRA) and without increasing productivity (No KBRA).

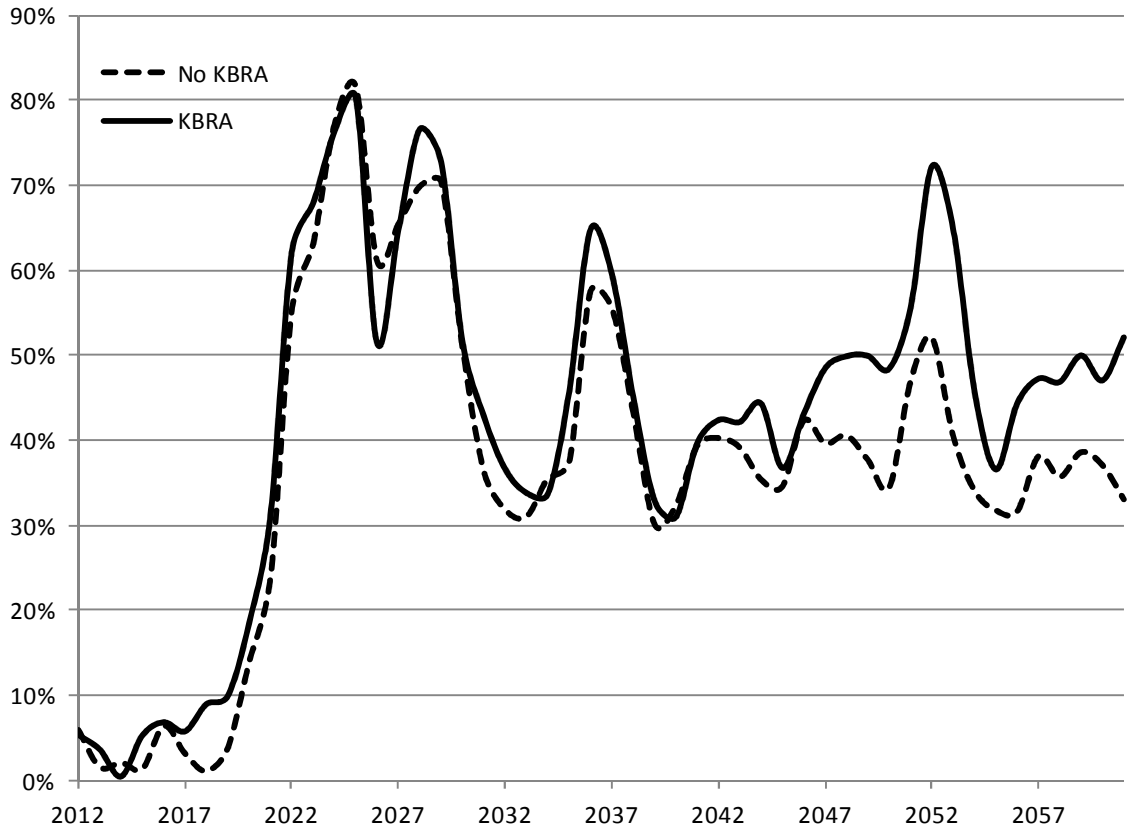


Figure 5. Relative performance of DRA to NAA ([DRA-NAA]/NAA * 100%) in ocean recreational harvest. Plot shows median performance assuming KBRA improves productivity of Chinook populations (KBRA) and without increasing productivity (No KBRA).

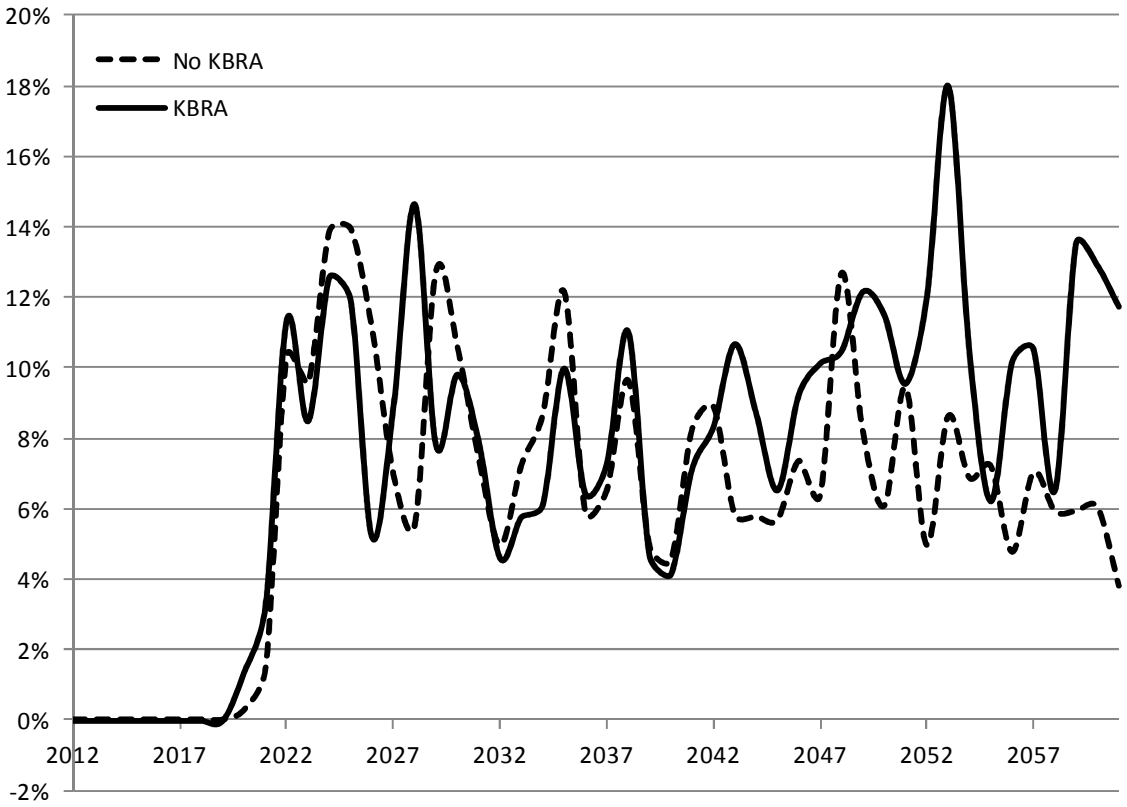


Figure 6. Relative performance of DRA to NAA ([DRA-NAA]/NAA * 100%) in river harvest. Plot shows median performance assuming KBRA improves productivity of Chinook populations (KBRA) and without increasing productivity (No KBRA).

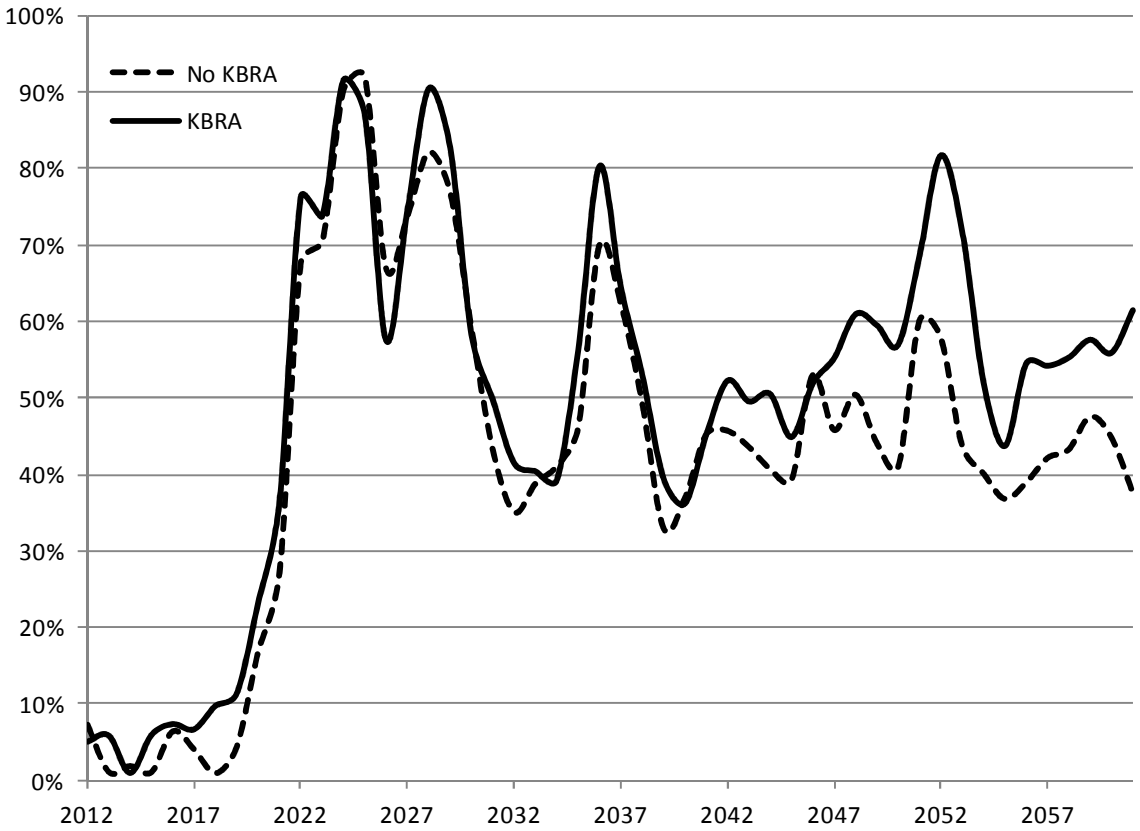


Figure 7. Relative performance of DRA to NAA ([DRA-NAA]/NAA 100%) in tribal harvest. Plot shows median performance assuming KBRA improves productivity of Chinook populations (KBRA) and without increasing productivity (No KBRA).