Chapter 2
Level 1 Hypotheses

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2.1 Hypotheses

This section demonstrates different approaches to testing hypothesis L1.1 (Page 5-1 of PATH Workshop 1 Information Package):

> There has been a similar trend in the state indicators for anadromous salmonid species/stocks that spawn in a variety of geographical locations in the Pacific Northwest.

The management implications of the hypothesis may be straight-forward: if all stocks (listed and otherwise) show similar patterns in escapement, recruitment, or other state variables, then some common forcing function (e.g., ocean conditions) would be the most likely candidate for the (joint) decline. On the other hand, if there are systematic differences among races, deems, or stocks, then stock-specific causes are more likely to be associated with the observed historical patterns.

In addition to the use of correlation and cluster analysis, PATH had planned to use discriminant analysis in an attempt to relate the cluster analysis groupings of similar stocks to natural and anthropogenic factors. Unfortunately, the modest number of stocks (16) for which run reconstructions have been completed precluded the use of discriminant analysis for this phase of the project. If more reconstructions can be completed, or the group decides to use the (S_{t+4}/S_t) method proposed by Carl Walters, we will carry out the discriminant analysis later. A brief description of the data and methods is included here to elicit comments from reviewers and PATH participants.

2.2 Available Data

Data for spring/summer, yearling migrant (stream-type) chinook from the following areas are used in this analysis[1]:

- John Day basin (Middle Fork, North Fork/Granite, and Upper Mainstem).
- Bear Valley/Elk Creek, Marsh Creek and Sulphur Creek in the Middle Fork of the Salmon.
- Wind and Klickitat, above Bonneville Dam but below other impoundments.
- Deschutes/Warm Springs, above two impoundments.
- Entiat, Wenatchee, and Methow subbasin in the mid-Columbia.
- Poverty Flats and Johnson Creek summer chinook in the South Fork of the Salmon River.
- Minam River spring chinook.
- Imnaha River spring/summer chinook.

[1]See Figure 3.1 for locations of spawning/rearing areas.

General information on how the number of spawners and recruits are calculated can be found in Chapter 4, section 4.2.1. More detailed information can be found in Beamesderfer et al (1996, forthcoming).

Data to be used in the potential discriminant analysis include the number of dams, number of irrigation diversions, number of mines, and distance to the ocean from each stock's rearing area. See Appendix 2.1 for information sources for these variables. Additional information on land use is expected within the next few months.

2.3 Analytical Methods

The following discussion of methods is taken from notes of a meeting of the "methods" group in November, 1995.

> The group discussed three issues with respect to the [correlation/cluster analysis] task: 1) the attributes of stock's time series to be used for clustering; 2) the standardization and/or transformation of those attributes prior to performing a cluster analysis; and 3) methods of clustering. We also briefly discussed what to do with the clusters once they had been obtained to relate explanatory variables to the clusters.
>
> At the Camp Cascade workshop it was proposed that S (spawners) and ln (R/S) be the primary attributes for clustering stocks. At Camp Cascade, we had thought that the NMFS data set would use S and the index stocks would use ln (R/S). However at the Portland meeting we decided instead to try four different sets of attributes for clustering:
>
> a) ln (R/S) alone;
> b) standardized S alone;
> c) standardized S and ln (R/S) jointly; and
> d) residuals from the regression of ln (R/S) vs S (a measure of the pattern of recruitment anomalies after removal of density dependence).
>
> The group also considered using stock productivities as an attribute on which to cluster, but decided that this was unnecessary if method "d" was used. The intercept from the regression of ln (R/S) vs S equals the stock productivity (Ricker "a") and the change in residuals equals change in productivity relative to the average for that stock. The group agreed that it was much better to use ln (R/S) rather than S wherever possible, since S carries the effect of changes in harvest, has greater intraseries correlation, and is not as much an indicator of survival.
>
> The above attributes can also be used for simpler analyses to compare trends in the Upper Snake with other regions, as already completed for S by Charlie Paulsen and Charlie Petrosky based on Spearman correlations with year (Section 8 of Workshop 1 handout). Other measures of change over time should also be considered: Pearson correlations with year, and a simple measure of the percent change from the start of the time period to recent years (the exact periods will have to be assessed with the specific data sets). These simple measures of trend can also be applied to attribute "d" in the above list, the residuals from the stock recruitment curve. Given the number of analyses being conducted, and intraseries correlation, it is important to

> use caution with respect to the degrees of freedom and statistical significance associated with each test of trend. Ways of dealing with these problems are discussed by Kope and Botsford (1990) and Botsford and Brittnacher (1992).
>
> There was some concern that the use of standard linear regressions of ln(R/S) vs. S (method "d") can lead to an overestimate of the "a" parameter, and an underestimate of the "b" parameter in the Ricker curve (Walters 1985). The error in parameter estimates arises because spawners are measured with error, and natural environmental variation influences future spawning levels, such that the "independent" variables are auto-correlated. This problem is particularly of concern for fisheries managers, since the optimum exploitation rate can be overestimated, and the optimum spawning stock can be underestimated (Walters 1985). However, we felt that since the primary purpose of the regressions was to derive estimates of recruitment anomalies, rather than harvest and escapement policies, these problems were not significant for this particular task.

Detrended state indicators were used to reduce problems of spurious correlation in data series that share a common (upward or downward) trend over time. Quoting again from the methods workgroup meeting:

> Lou Botsford suggested that it would be worth repeating some of the recommended analyses on detrended data. Patterns of correlation in the original data may occur primarily due to low frequency change, which may have very few degrees of freedom (e.g. a straight line with slope +1 and a straight line with slope -1 will be perfectly negatively correlated, even though most of the trends may be due to intraseries correlation). The residuals around the trend line (i.e. detrended data) have more degrees of freedom than the original data. Therefore correlations which show up both with the original data and the detrended data are likely to be of more importance than those which only show up on the original data.

The group at the November meeting agreed to standardize variables using two methods. The first would standardize to mean 0, unit variance, while the second would standardize using the formula:

$$y'_t = (y_t - \bar{y}) / \bar{y}$$

where y_t = the escapement metric (a-d, above), at time i.[2]

Based on these considerations as well as some raised by the reviewers of an earlier draft, we use the following indicators:

1. Natural log of recruits to the mouth of the Columbia per spawner [$\ln(R_t/S_t)$].
2. $\ln(R_t/S_t)$ detrended (i.e., the residuals of a linear regression of $\ln(R_t/S_t)$ against calendar year).
3. Spawning escapement only (S_t).
4. Spawning escapement detrended.
5. Ricker-regression residuals (i.e., the "e_t's" in regressions of $\ln(R_t/S_t)$= b0 + b1 S_t + e_t.
6. Ricker residuals detrended.
7. Ln(S_t).

[2] Note that the procedures actually standardize the variables to N(0,1).

8. $Ln(S_t)$, detrended.
9. $Ln\ (S_{t+4}/S_t)$, following a suggestion by Walters in his review of the retrospective analysis.
10. S_{t+4}/S_t, untransformed
11. Residuals from the regression of $Ln\ (S_{t+4}/S_t)$ on S_t
12. (11), detrended.

The basic data for these series — estimated spawning escapement and recruitment to the Columbia — can be found in **Table 2.1**.[3] An example of the transformed variables (for the Middle Fork of the John Day) is shown in **Table 2.2**. All variables are standardized to mean 0 and unit variance by the correlation and clustering procedures.

2.3.1 Correlation Methods

Pearson product-moment (Moore, 1979) and Kendall τ (Knight, 1966) correlations were used for all results reported here. The Kendall τ was suggested by Saila in his review of the retrospective analysis. Since Kendall's test is non-parametric, it makes fewer assumptions about the distribution of the variables. Since many of the state variables (e.g., spawning escapement) are expected to be non-normally distributed, it is reasonable to use at least one non-parametric correlation method. Spearman rank-order correlations are another possibility, not pursued here.

In assessing the correlation results, the large number of correlations performed should be kept in mind. If one uses a significance level of ***X*** %, then ***X*** % of the correlations can be expected to be significant in a randomly distributed sample. In addition, Lou Botsford has done some work (not reported here) adjusting correlation significance levels downward to account for intra-series correlation (Botsford, 1996). Therefore, we do not report on the significance of the correlations in this version of the chapter. Even given these caveats, however, some fairly clear patterns of correlation are evident, as will be seen in the results sections.

2.3.2 Clustering Methods

The methods work group has discussed clustering methods, with the following results:[4]

- We agreed that the cluster analysis approach should be hierarchical, generating a tree that links similar stocks… We did feel that it made sense to use correlations (either Pearson or Spearman) as a clustering criterion. We also felt that using a median instead of the mean might provide more robust results, results less sensitive to the particular choice of attribute or clustering

[3] Recuits are defined here as recruits to the mouth of the Columbia River. Although data for many populations are available prior to brood year 1970, the downstream stocks only have data from 1970 onward. Therefore, we perform the correlation and cluster analysis on the post-69 data only.

[4] These discussions were premised on the assumption that 50-75 stocks would be available for subsequent analysis. At present, however, only 16 stocks are available, so the number of clusters — about 4.8, depending on the method — is much smaller than originally envisioned. More importantly, the number of members of each cluster is quite small, averaging 2-4 stocks per cluster.

algorithm, and the effect of outliers. Use of the median would mean that the procedure would generate the median squared error instead of the mean squared error.

- Cluster analysis objectively groups objects, but there needs to be a somewhat subjective decision on how many groups to carry forward for subsequent analyses…. We felt that it was worthwhile examining the change in the similarity index as additional clusters are added before deciding how may groups to use (i.e. there may be big drops in similarity as groups are added). Ideally, one would want to choose a number of groups that is reasonable (e.g., less than 10) and avoid grouping together clusters that are clearly very dissimilar. If discriminant analysis is going to be performed on the clusters, it may be worthwhile repeating the discriminant analysis for more than one set of clusters (e.g. five and ten clusters) to assess the robustness of the selected explanatory variables.

We use one agglomorative method, Ward's minimum variance method (Ward, 1963). This starts with each stock as a separate cluster and groups them together until only two clusters remain. We also use one partitioning method (Anderberg, 1973), following another suggestion in Saila's review. The partitioning method starts with all stocks in a single cluster, and divides the stocks into up to **N** clusters, where **N** is the number of stocks. For the work here, we set **N** at a maximum of 4, so that several stocks would be in each cluster. Ward's method tends to be biased toward producing clusters with small within-group variances. My reading of a small subset of the clustering literature[5]suggests that it is difficult or impossible to generalize about what the most appropriate clustering method will be for any given situation. Instead, a substantial amount of research judgment seems to be involved in the choice of methods for any given situation.

2.3.3 Discriminant Analysis Methods

The clustering procedures produce categorical variables as output: which stocks are assigned to which clusters. At one extreme, each stock will be clustered by itself, while at the other all stocks can be joined into a single cluster. If one focuses on some intermediate level (i.e., clusters with more than one but less than **N** members, if **N** stocks are analyzed), one can use discriminant analysis techniques to explain cluster membership. We plan to use non-parametric discriminant analysis on the clustering procedure output, in combination with stock-specific data on environmental stressors to explain how the stocks are grouped together. Note that this is not done on the 16 stocks reported here. The discussion is included to give reviewers a flavor of the work that may be pursued if more stocks become available for analysis. The types of questions that might be answered by this analysis include:

- what streams appear to have similar patterns in survival over time?
- do stocks appear to cluster together regionally (e.g. Upper Snake, Mid Columbia, Lower Columbia)?
- what (other than geographic location) appears to differentiate the groups selected by the clustering algorithms?

[5] See, for example, Dale et al. (1970), Williams, 1971.

2.4 Results

2.4.1 Correlation Results

Results of the correlation analysis are shown in **Table 2.3**.

Because many of the variables have fairly strong auto-correlation[6], we defer a discussion of statistical significance of the results until a later version of this paper. Previous work by Botsford (1996) suggests that a Pearson R of approximately 0.5 to 0.6 will be needed to be significant with probability < 0.05. Once he has completed an analysis of the latest version of the stock-recruit data, we should be able to make some more rigorous statements about statistical inferences. Note, however, that the Botsford corrections will affect the significance of the coefficients, but not the coefficients themselves.

The most striking aspect of the results is that the Kendall τ is much more conservative than the Pearson R. The τ values are always lower than the Rs, generally by a considerable margin. This may be due to the non-parametric nature of Kendall's method. However, the general pattern of results is similar for both methods, in the sense that a pair of subbasins with a relatively high Pearson R usually have a relatively high Kendall τ value as well.

A second interesting feature is that the Wind River stock is never strongly correlated with any of the 15 other stocks, regardless of the measure used or correlation method. This is almost surely due to the very high spawning escapement in 1971 and 1972, combined with extremely low recruitment for those brood years (see **Table 2.1**). Although the methods for calculating escapement for the Wind have not changed over time (Olaf Langness, personal communication, July 1996), those two years are obviously anomalous, in comparison with other years of data for the Wind and with other stocks in 1971-72.

The reason for looking at 12 different status indicators is, of course, to see if different indicators give different pictures of relative stock performance over time. To structure the discussion, we first look at whether de-trending the indicators makes a difference for any given measure (e.g., spawning escapement). We then turn to whether the different indicators (e.g., spawning escapement vs. recruits per spawner) paint similar pictures.

In general, detrending makes a difference for the abundance measures, but not for the survival measures. Correlations for spawning escapement and Ln(spawning escapement) both decrease somewhat when the linear time trend is removed. On the other hand, for Ln (recruits/spawner) the residuals from the Ricker regression, [Spawners(t+4)/Spawner(t)], and its residuals, detrending seems to have little effect on the strength of the correlations, whether using Pearson or Kendall's methods. As Botsford (1996) notes, this is to be expected, since the survival measures already have some of the trends removed by virtue of the way they are calculated.

The abundance measures (spawning escapement and its natural log) are more closely correlated than the survival measures (R/S etc.), even after de-trending. On the other hand, the use of future spawning escapement as a proxy for recruitment (i.e., Spawners(t+4)/Spawner(t) as opposed to recruits to the Columbia/Spawner) does not seem to make a great deal of difference. This generalization holds whether one looks at the log transformation, residuals from a Ricker regression, or detrended versions of these measures.

[6] Auto-correlation refers to the fact that in time-series data, the value of a variable at time t is correlated with its value at time t-n. This means that one assumption of Pearson correlations (that the values are independent) may be violated.

Some caution should be used in assessing the degree to which the Spawners(t+4)/Spawner(t) results may generalize to other stocks. In calculating spawning populations, hatchery strays that spawn naturally are counted as spawners (but not as recuits from previous generations). In addition, during the post-69 period, harvest rates were low relative to earlier years, making it more likely that the Spawners(t+4) /Spawner(t) measure would be closely related to those defining recruitment to include harvested fish. Finally, the implied age structure (i.e., that age 4 spawners are the most important part of recruitment) may not be correct for all stocks. Nevertheless, the preliminary results shown here are encouraging.

2.4.2 Clustering Results

Dendograms of the clustering results are shown in **Figure 2.1A through 2.1L** for Ward's minimum variance method, and **2.2A through 2.2L** for the oblique principal components (Anderberg, 1973) method. There are two results (using Ward's and oblique principal components) for each of the 12 state indicators.

In reading the Ward's method dendograms, stocks that are clustered together have lines the same length, and are adjacent to each other. Shorter lines indicate weaker relationships, while longer lines indicate stronger ones. Pairs of adjacent lines of the same length may be ignored. For example, in **Figure 2.1A,** Bear Valley/Elk (BV/ELK) and Marsh Creeks are in the same cluster. This two-stock cluster is very closely related to the Imnaha and Minam, less closely related to Sulphur, and much less closely related to the Deschutes. The Deschutes and Methow are in the same cluster, as are the Middle fork of the John Day (MFJDA) and North Fork of the John Day (NFJDA), or Johnson and Poverty Flat.

As with the correlation results, the Wind River is usually an outlier, especially when using Ward's minimum variance method. A second outlier is Sulphur Creek, which had zero spawning escapement for 1984 (note that this was changed to "1" for the work here and in Chapter 4). As might be expected, the clustering patterns are similar to those for the correlations. The Ward's minimum variance method is more likely to result in clusters that are similar to the subbasins' geographic locations.

One result for the Ward's method that may not be apparent from the dendograms is the broad similarity among the stocks. Although there clearly are differences, the stocks are quite similar in the temporal patterns of the twelve state variables. In most cases, the stocks share about 70-80 percent of their trends' variance in common, as can be seen by examining the scale at the top of each figure. Again using **Figure 2.1A** as an example, the stocks are identical at up to 75% of the variability (1-0.25). Although this is not true for all state variables (e.g., **Figure 2.1E** or **Figure 2.1F**) it is true for nearly all of the survival (R/S) measures and variants thereon.

The clusters produced by the oblique principal component method are harder to explain, and often there is no obvious reason for the clusters chosen by the algorithm. In reading these dendograms, stocks that are in the same cluster (recall that there are only four clusters in each diagram) are located adjacent to one another. Using Figure 2.2A as an example, the Upper John Day, Middle Fork John Day, and North Fork Jon Day (UPJDA, MJDA, and NJDA) are in one cluster. The Wind is in a cluster by itself, while the Deschutes, Entiat, Methow, and Wenatchee are in another cluster. The remaining subbasins form the fourth cluster.

In some cases, as with the John Day stocks noted above, the oblique principal components method groups stocks geographically. In other cases, as with the algorithm's grouping of the Klickitat with the Middle Fork Salmon and South Fork Salmon stocks, there is no obvious explanation for the results.

2.5 Discussion

It is apparent from the results that all stocks do not have the same trends in either abundance or survival measures. This is true even though the stocks included are all from the Columbia, and are all the same species and run (spring/summer).

It is also apparent that different measures of stock status give somewhat different views of which stocks are most closely related and how close the relationships are. The Pearson correlations are consistently higher than the Kendall τ, and relationships based on abundance show stronger correlations than do the survival-based measures.

Perhaps the most interesting outcome of the analysis is the similarity between the R/S and S(t+4)/S correlations and clusters. In some ways this is not too surprising, in that all 16 stocks are subject to similar harvest patterns in the Lower Columbia. Nevertheless, it raises the possibility of performing a similar analysis on a much wider range of stocks for which no run reconstructions are presently available. It will be interesting to see if the similarity among the two definitions of survival generalizes to other stocks where run reconstructions are planned for later this summer. These include several stocks from the Willamette and coastal areas of Oregon and Washington, and several Columbia basin fall chinook stocks. If information on hatchery straying or spawners age structure is available, this could be included to make the analyses more accurate.

If this generalizes to other stocks, it may be possible to include 20-30 chinook stocks for which we have reasonably complete escapement and environmental data, but no run reconstructions. In addition, this could substantially expand the stocks used in the multivariate analyses in Chapter 4.

As already noted, a more rigorous examination of the results awaits additional information regarding the significance levels that should be used in assessing the Pearson correlations. At this point, it appears that the various survival measures (R/S, etc.) give results that are similar to one another, as are patterns of abundance measures (spawning escapement, etc.) although the two groups do not have the same pattern as one another. In addition, the patterns of relationships for the two correlation measures are quite similar. If this is borne out by additional work, it would be possible to drop many of the measures included in this work, resulting in a much more compact and comprehensible comparison of similarities and differences in state indicators among stocks.

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Knight, W. E. 1966. “A Computer Method for Calculating Kendall’s Tau with Ungrouped Data,” JASA, 61, 436-439.

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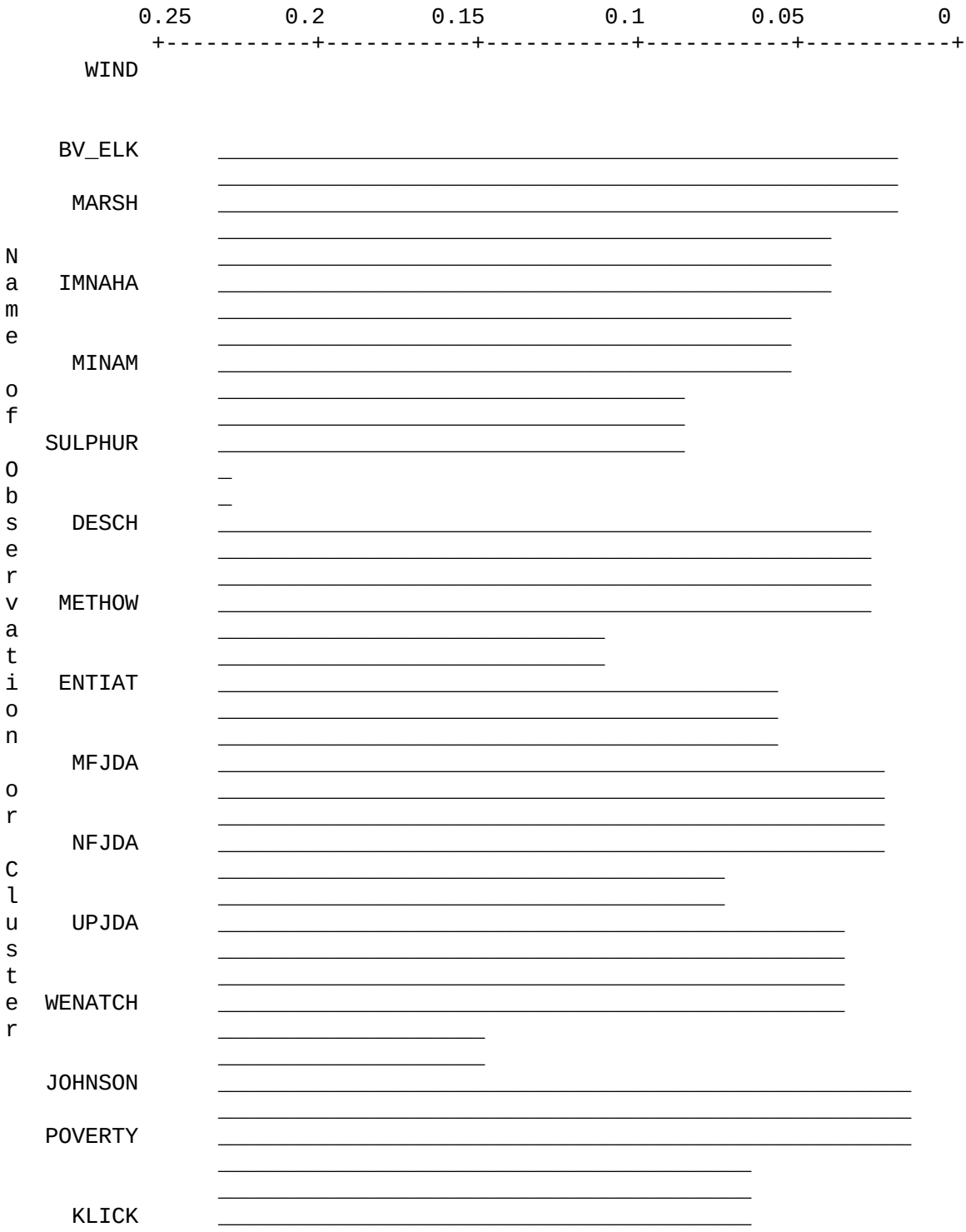
Ward, J. H. 1963. “Hierarchical Groupings to Optimize and Objective Function,” JASA, 58, 236-244.

Table 2.1: Shows estimated spawning escapement and recruitment to the Columbia River mouth for the stocks noted, taken from a recent update of Petrosky et al. (1995).

Table 2.2: Transforms for Middle Fork of John Day.

Table 2.3: Correlation Results.

Figure 2.1A: Log of R/S Semi-Partial R-Squared[7]



[7] The semi-partial R-squared is the clustering criterion used by the Ward's minimum variance method (Ward, 1963).

Figure 2.1B: Log of R/S detrended Semi-Partial R-Squared

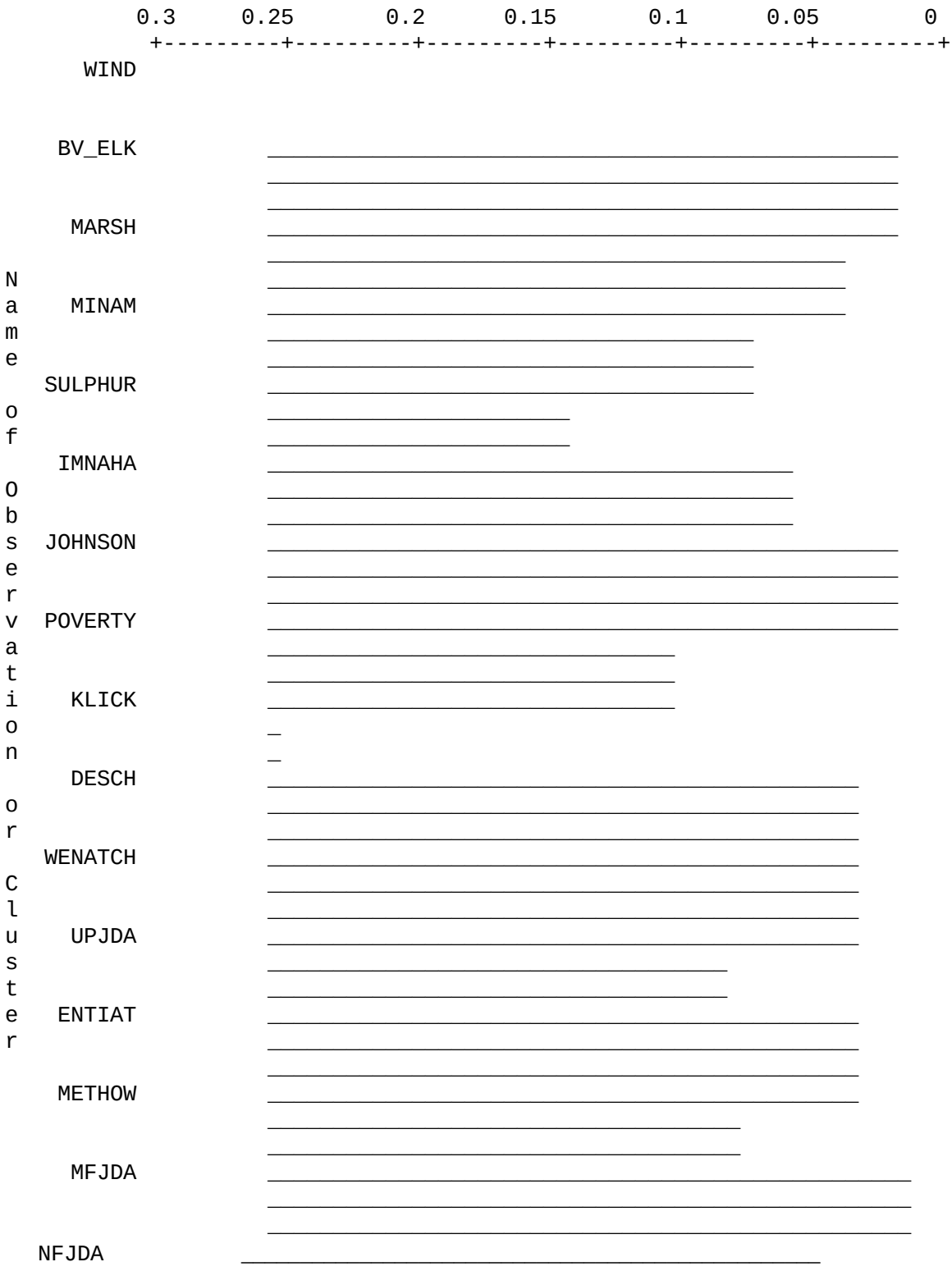


Figure 2.1C: Ricker Residuals Semi-Partial R-Squared

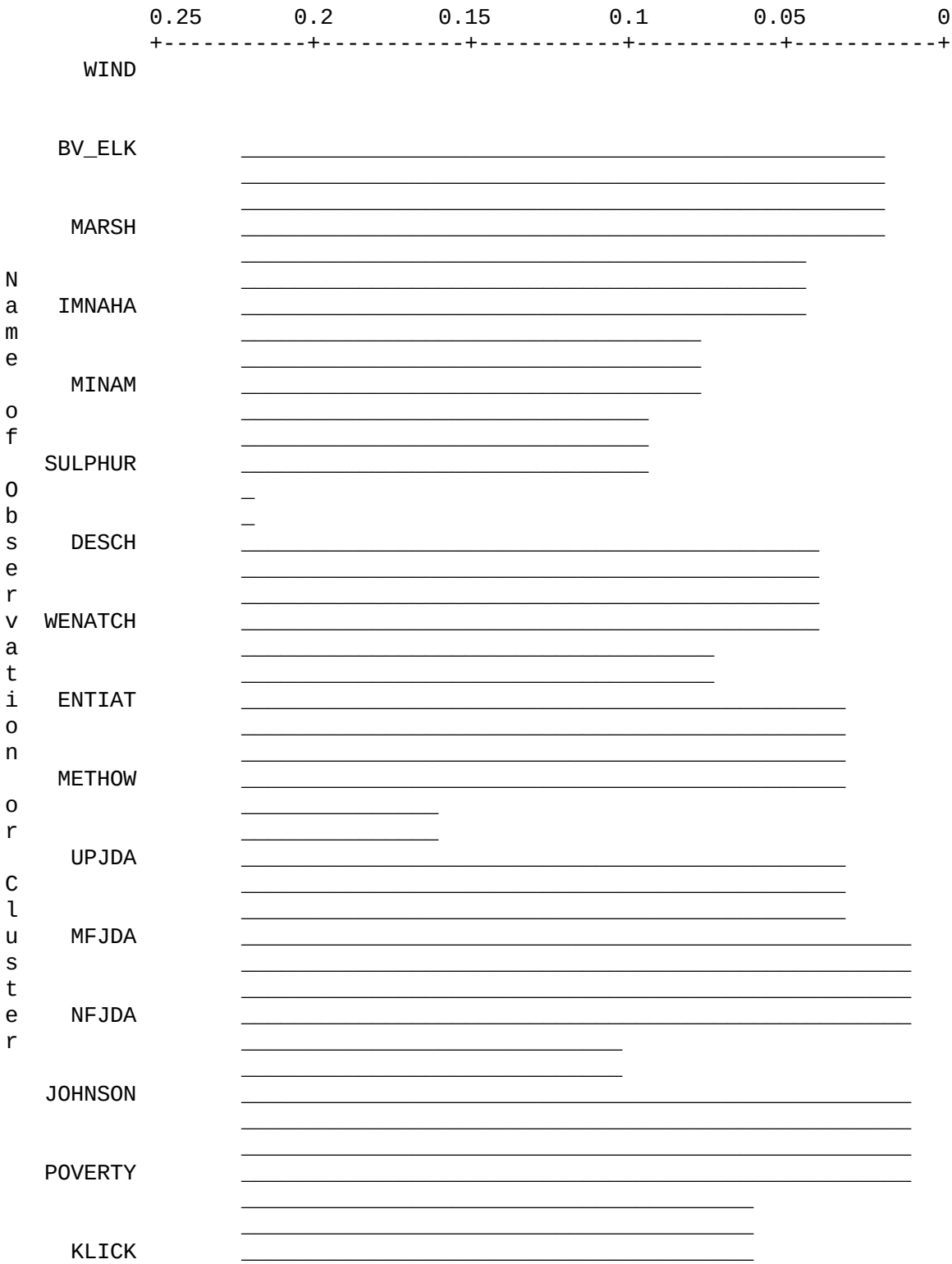


Figure 2.1D: Ricker Residuals detrended Semi-Partial R-Squared

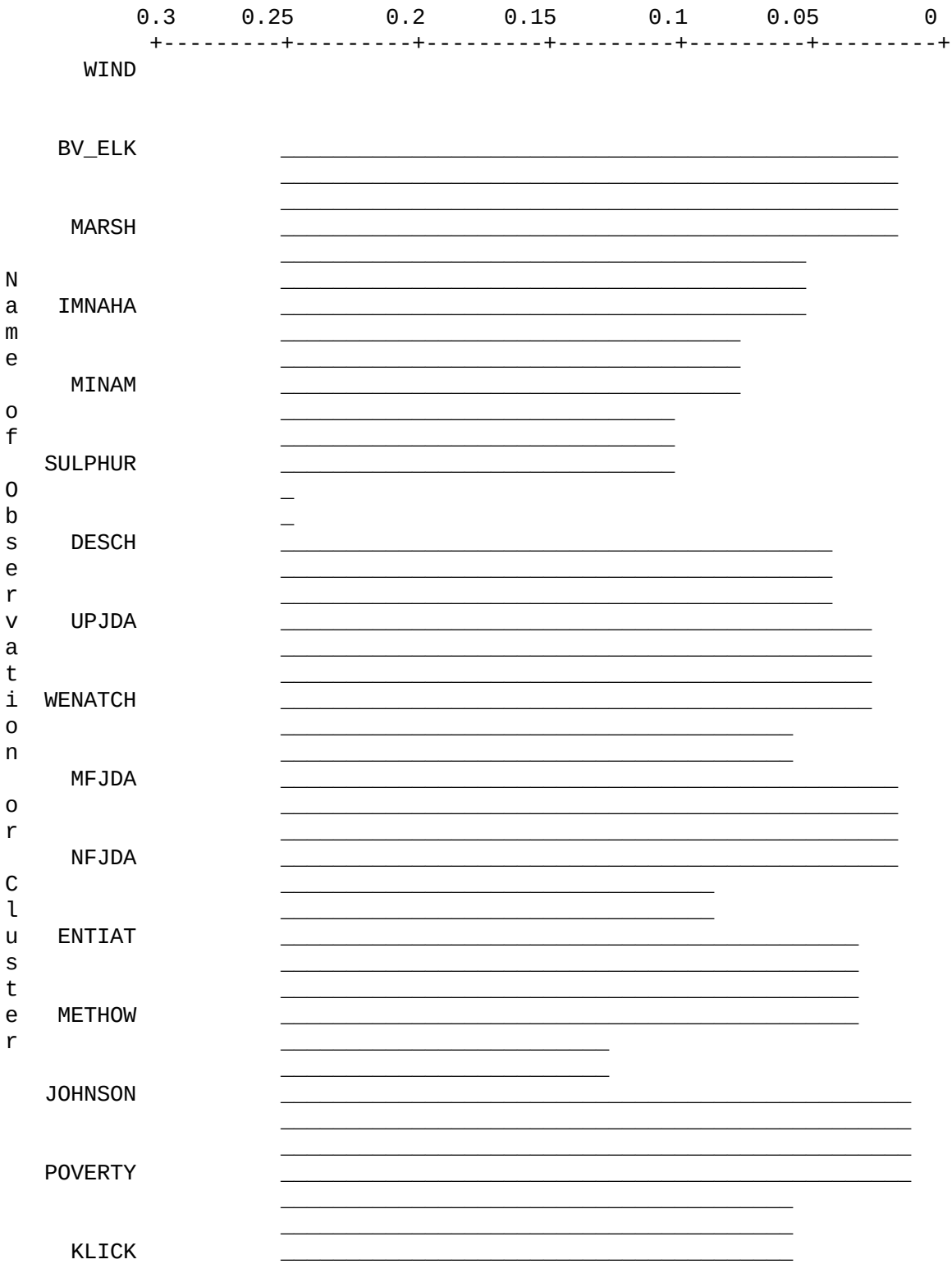


Figure 2.1E: Spawning Escapement Semi-Partial R-Squared

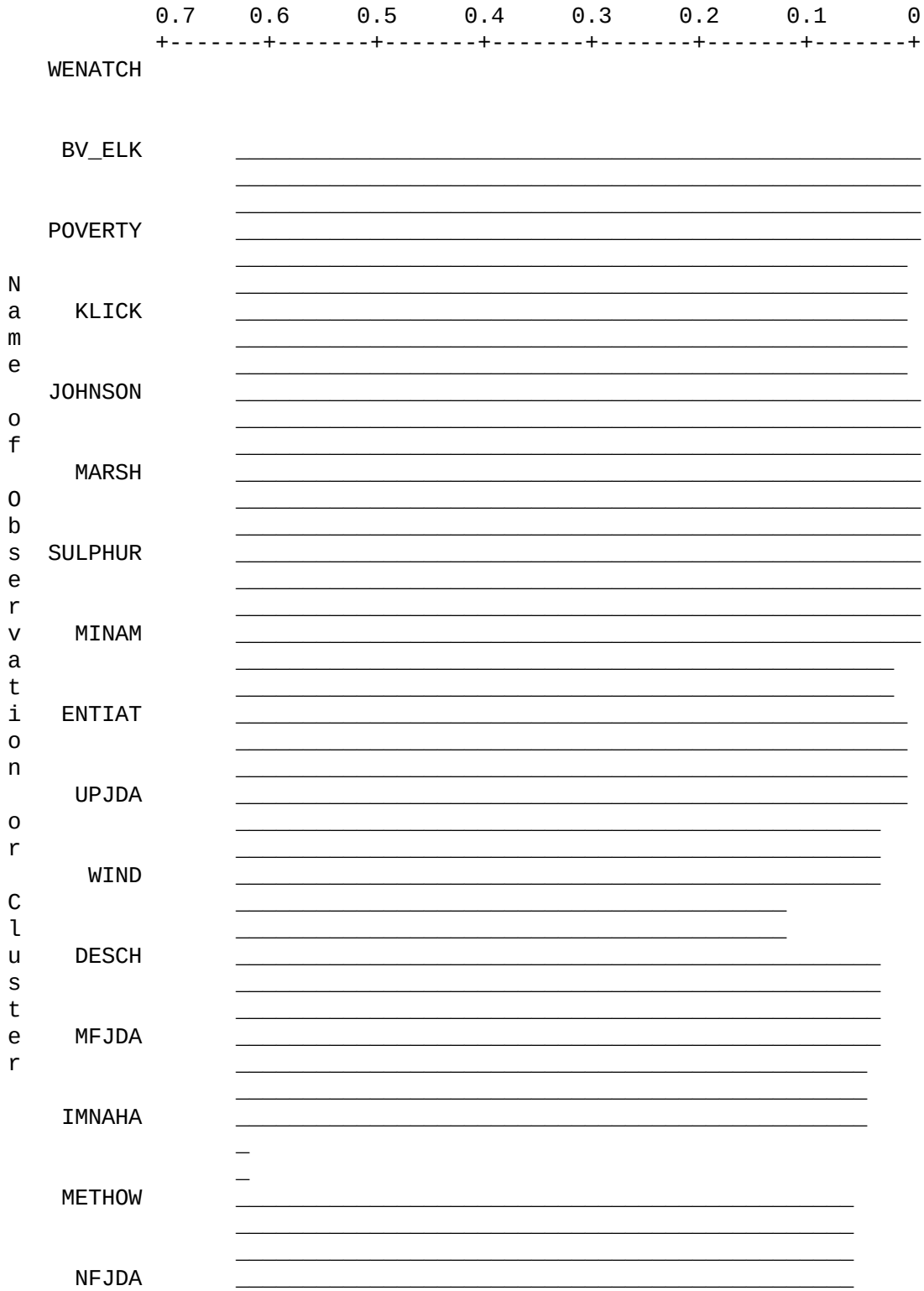


Figure 2.1F: Spawning Escapement, detrended Semi-Partial R-Squared

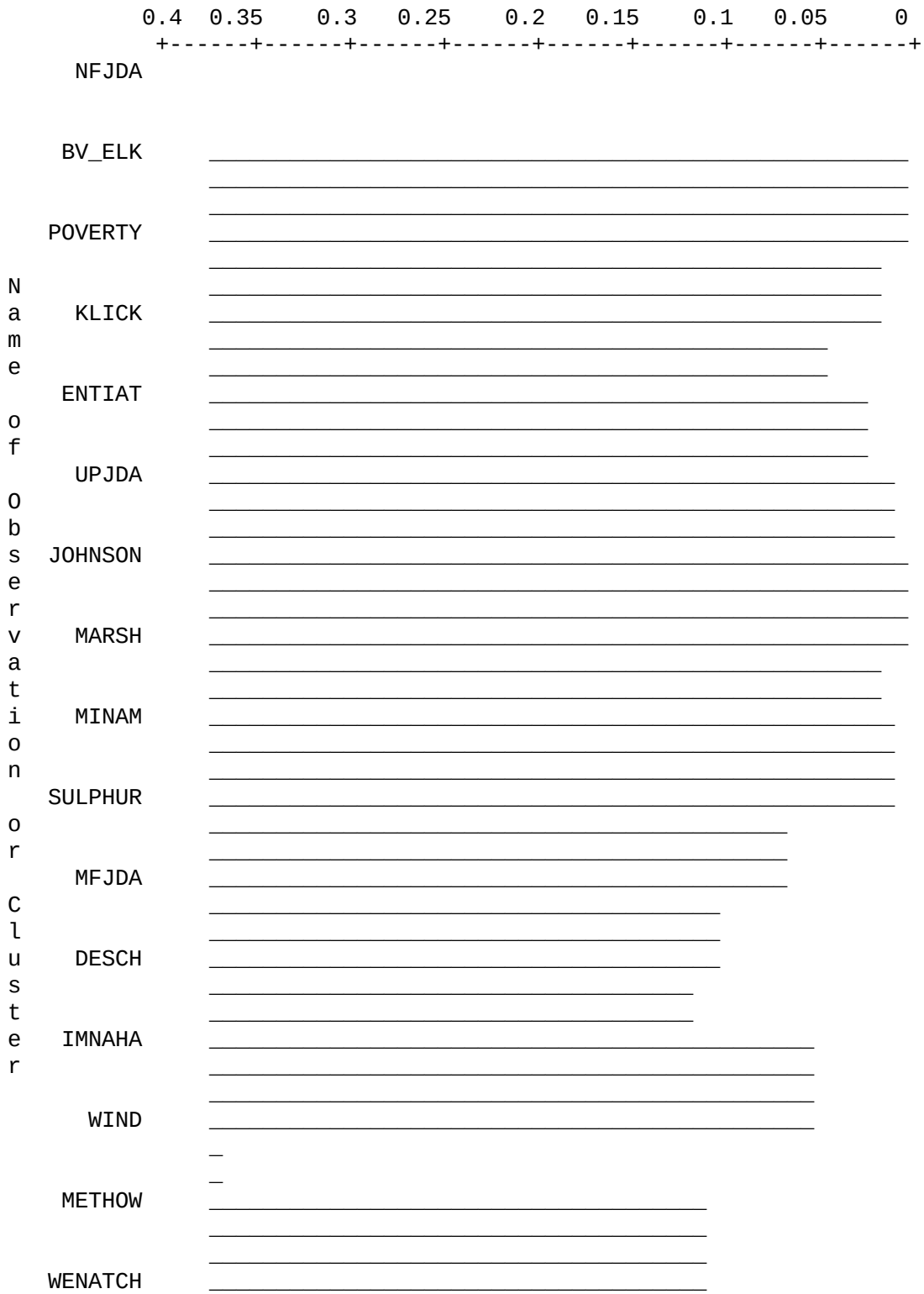


Figure 2.1G: LN (Spawning) Semi-Partial R-Squared

Figure 2.1H: LN (Spawning) detrended Semi-Partial R-Squared

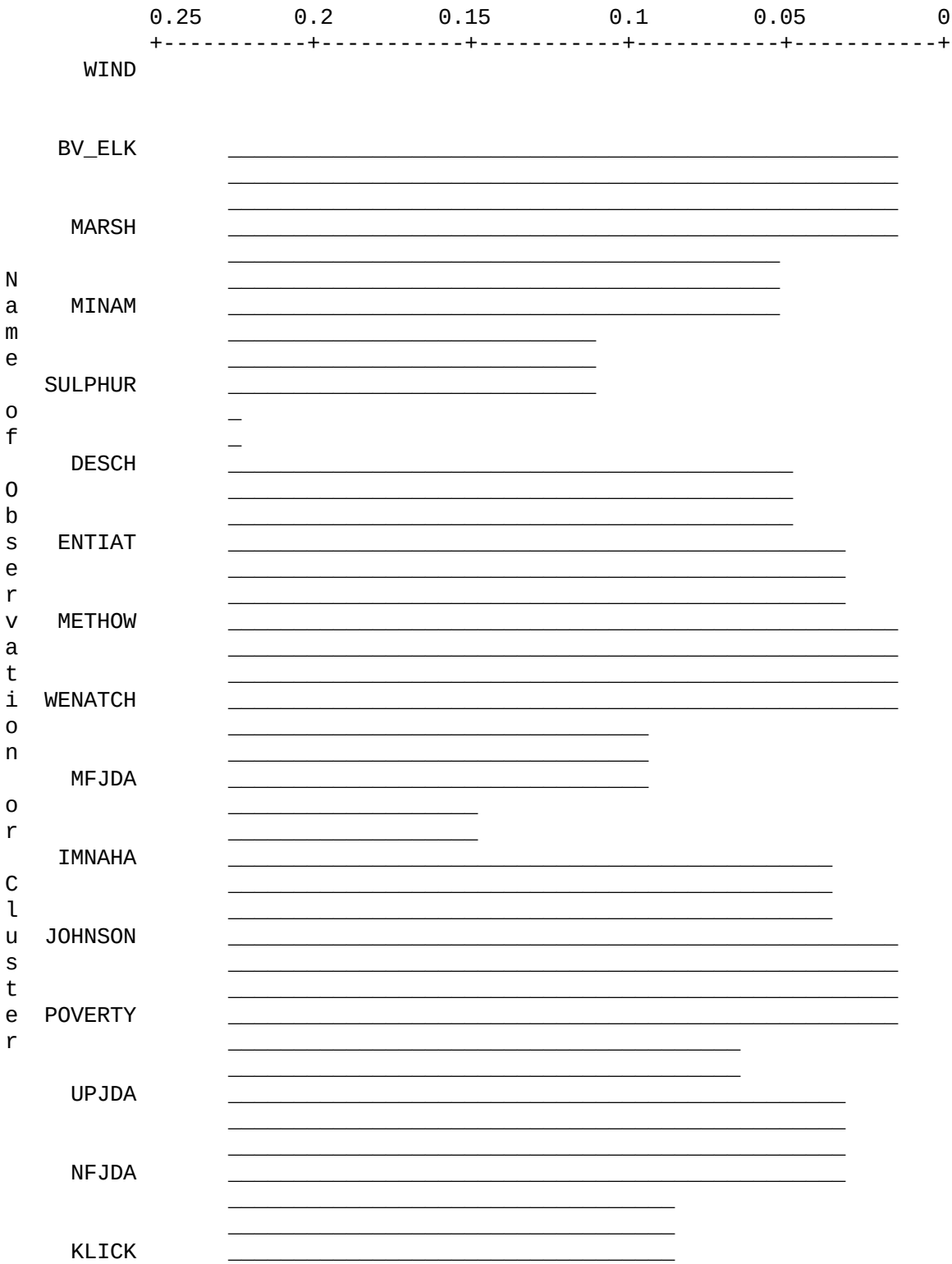


Figure 2.1I: LN ($St+4/S_t$) Semi-Partial R-Squared

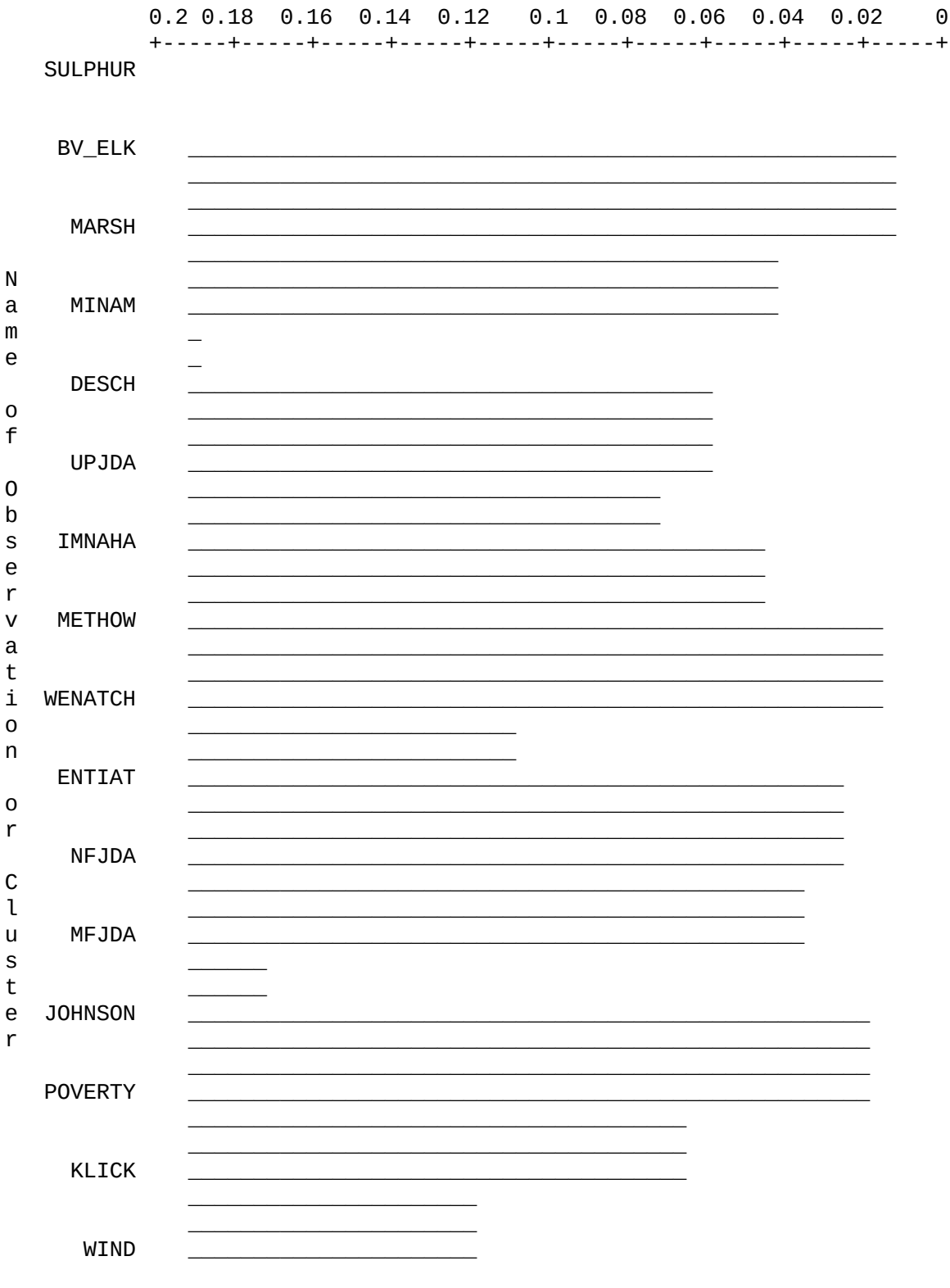


Figure 2.1J: (St+4/S_t) Semi-Partial R-Squared

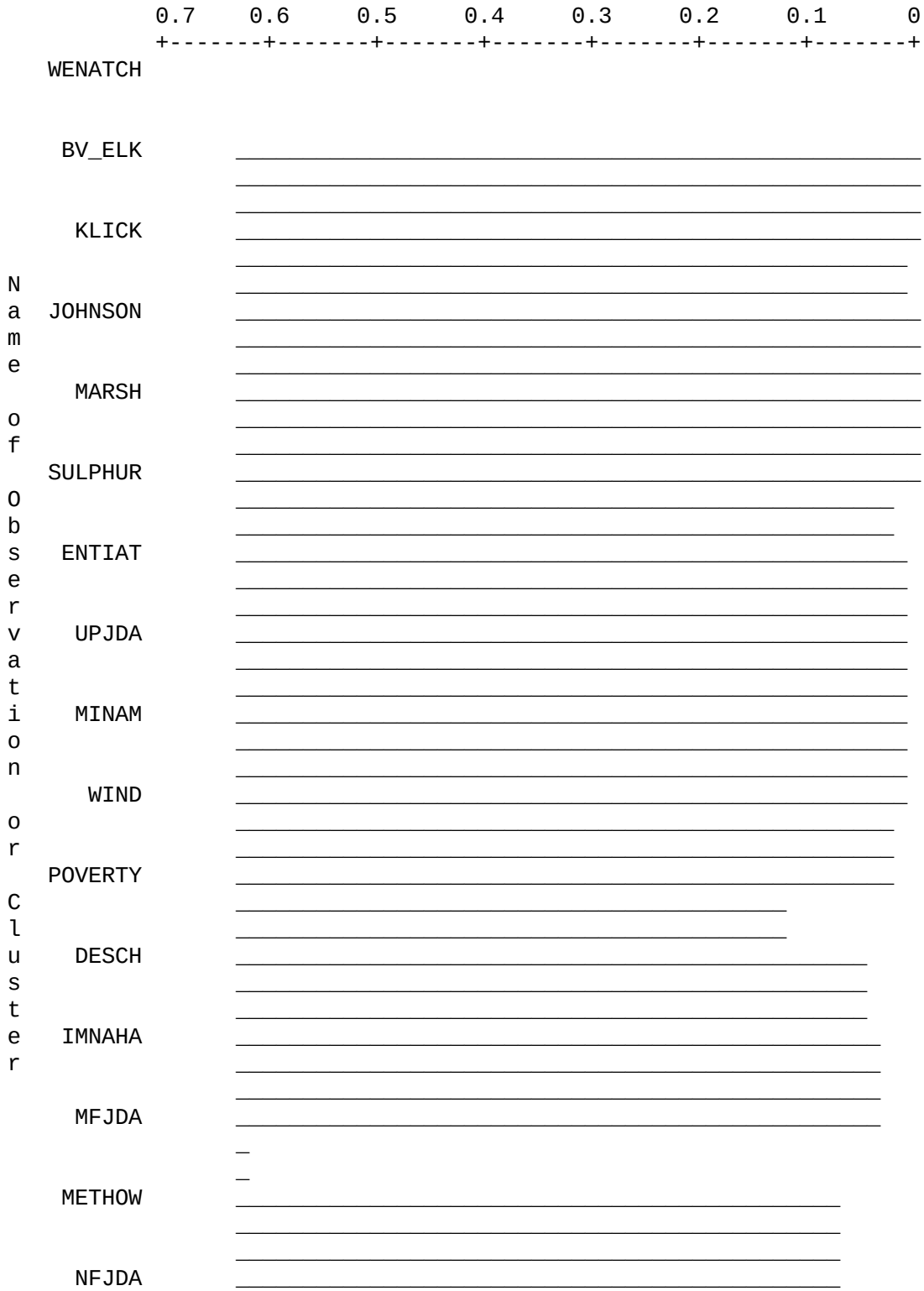


Figure 2.1K: (St+4/S_t) Residuals Semi-Partial R-Squared

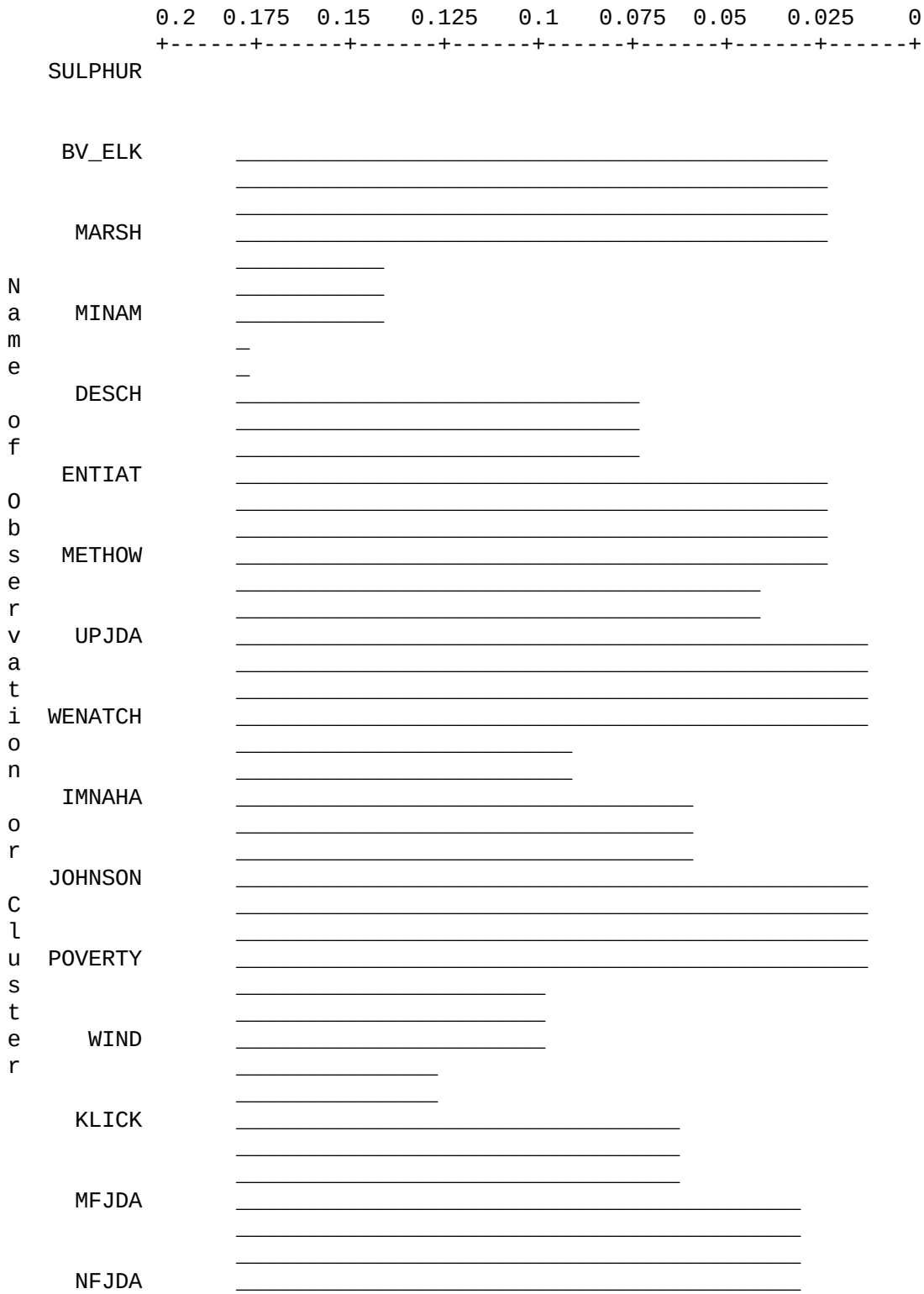


Figure 2.1L: (St+4/S $_t$) Residuals detrended Semi-Partial R-Squared

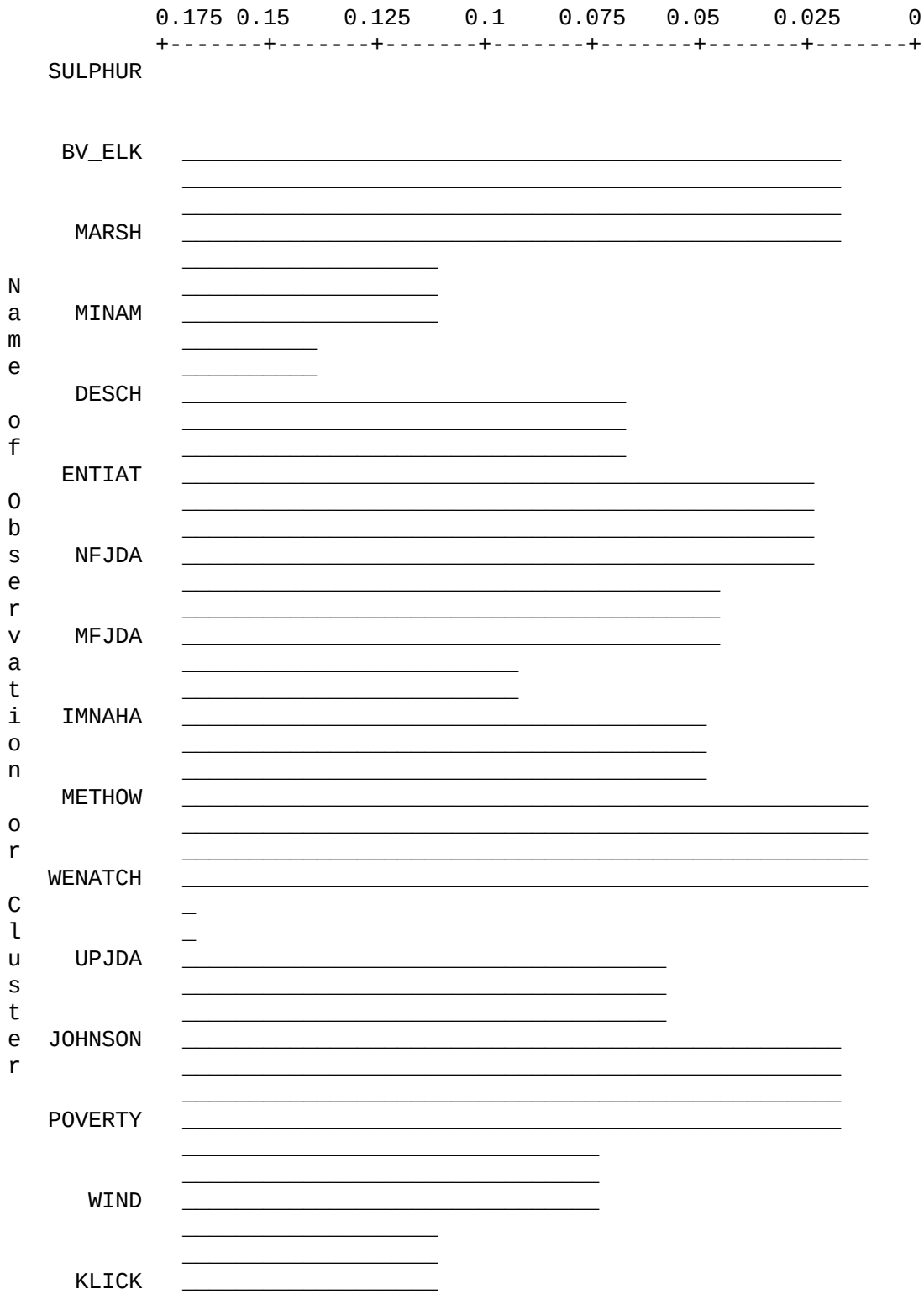


Figure 2.2A: Log of R/S Oblique Principal Component Clustering

```
                Number of Clusters
                 1   2   3   4
                 +---+---+---+---
          UPJDA ______________
                ______________
                ______________
          MFJDA ______________
                ______________
                ______________
          NFJDA ______________
                __________
                __________
N          WIND __________
a               ______
m               ______
e         DESCH ______________
                ______________
o               ______________
f        ENTIAT ______________
                ______________
V               ______________
a        METHOW ______________
r               ______________
i               ______________
a      WENATCH ______________
b               _
l               _
e        BV_ELK ______________
                ______________
o               ______________
r       IMNAHA ______________
                ______________
C               ______________
l      JOHNSON ______________
u               ______________
s               ______________
t         KLICK ______________
e               ______________
r               ______________
          MINAM ______________
                ______________
                ______________
       POVERTY ______________
                ______________
                ______________
       SULPHUR ______________
                ______________
                ______________
          MARSH ______________
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Figure 2.2B: Log of R/S detrended Oblique Principal Component Clustering

```
                Number of Clusters
                1   2   3   4
                ---+---+---+---+
          DESCH ______________
                ______________
                ______________
          UPJDA ______________
                __________
                __________
           WIND __________
                ______
                ______
N       ENTIAT ______________
a               ______________
m               ______________
e        MFJDA ______________
                ______________
o               ______________
f        NFJDA ______________
                _
V               _
a       BV_ELK ______________
r               ______________
i               ______________
a       IMNAHA ______________
b               ______________
l               ______________
e      JOHNSON ______________
                ______________
o               ______________
r        KLICK ______________
                ______________
C               ______________
l       METHOW ______________
u               ______________
s               ______________
t        MINAM ______________
e               ______________
r               ______________
       POVERTY ______________
                ______________
                ______________
       SULPHUR ______________
                ______________
                ______________
       WENATCH ______________
                ______________
                ______________
         MARSH ______________
```

Figure 2.2C: Ricker Residuals Oblique Principal Component Clustering

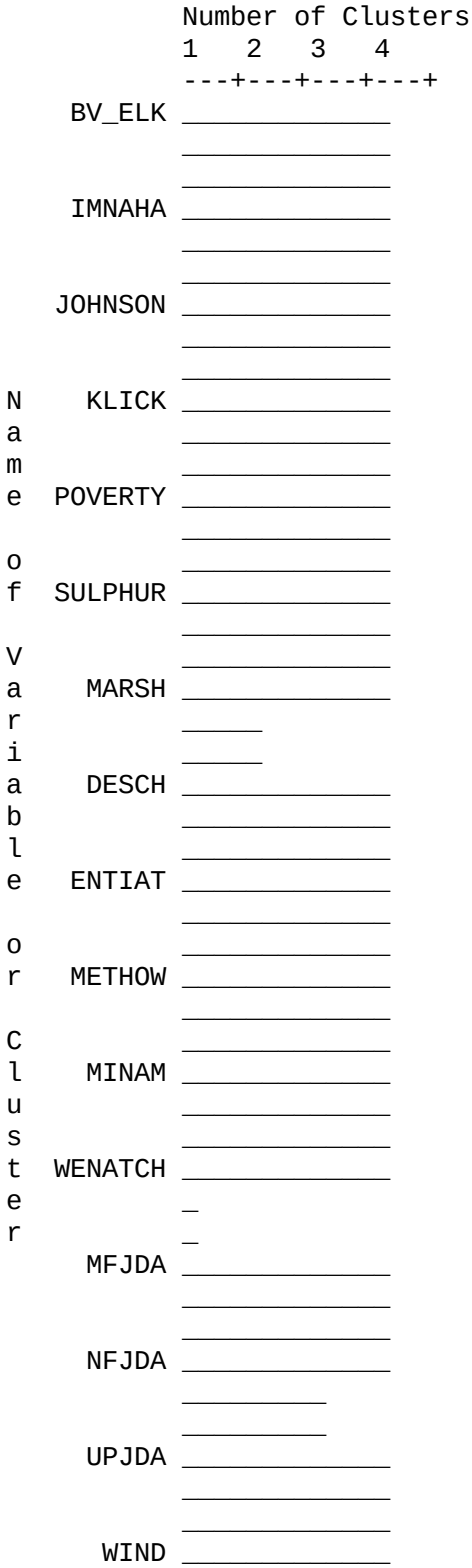

Figure 2.2D: Ricker Residuals detrended Oblique Principal Component Clustering

```
                Number of Clusters
                1   2   3   4
                ---+---+---+---+
        BV_ELK  _______________
                _______________
                _______________
        IMNAHA  _______________
                _______________
                _______________
       JOHNSON  _______________
                _______________
                _______________
N        KLICK  _______________
a               _______________
m               _______________
e      METHOW   _______________
                _______________
o               _______________
f        MINAM  _______________
                _______________
V               _______________
a     POVERTY   _______________
r               _______________
i               _______________
a     SULPHUR   _______________
b               _______________
l               _______________
e     WENATCH   _______________
                _______________
o               _______________
r        MARSH  _______________
                ______
C               ______
l        DESCH  _______________
u               _______________
s               _______________
t         WIND  _______________
e               _
r               _
        ENTIAT  _______________
                _______________
                _______________
         MFJDA  _______________
                _______________
                _______________
         NFJDA  _______________
                __________
                __________
         UPJDA  __________
```

Figure 2.2E: Spawning Escapement Oblique Principal Component Clustering

```
                Number of Clusters
                1   2   3   4
                ---+---+---+---+
     BV_ELK     _______________
                _______________
                _______________
    JOHNSON     _______________
                _______________
                _______________
      MINAM     _______________
                _______________
                _______________
N    NFJDA      _______________
a               _______________
m               _______________
e   POVERTY      _______________
                _______________
o               _______________
f   SULPHUR      _______________
                _______________
V               _______________
a     WIND      _______________
r               _______________
i               _______________
a    MARSH      _______________
b               ______
l               ______
e   ENTIAT      _______________
                _______________
o               _______________
r   IMNAHA      _______________
                _______________
C               _______________
l   METHOW      _______________
u               _______________
s               _______________
t   WENATCH      _______________
e               _
r               _
      UPJDA     _______________
                _______________
                _______________
      KLICK     _______________
                _______________
                _______________
      MFJDA     _______________
                __________
                __________
      DESCH     __________
```

Figure 2.2F: Spawning Escapement, detrended Oblique Principal Component Clustering

```
                Number of Clusters
                1   2   3   4
                ---+---+---+---+
        BV_ELK  _______________
                _______________
                _______________
       JOHNSON  _______________
                _______________
                _______________
         KLICK  _______________
                _______________
                _______________
N        MINAM  _______________
a               _______________
m               _______________
e      POVERTY  _______________
                _______________
o               _______________
f      SULPHUR  _______________
                _______________
V               _______________
a        MARSH  _______________
r               __________
i               __________
a        UPJDA  _______________
b               _______________
l               _______________
e        MFJDA  _______________
                _______________
o               _______________
r        NFJDA  _______________
                ______
C               ______
l         WIND  ______
u               _
s               _
t        DESCH  _______________
e               _______________
r               _______________
        ENTIAT  _______________
                _______________
                _______________
        IMNAHA  _______________
                _______________
                _______________
        METHOW  _______________
                _______________
                _______________
       WENATCH  _______________
```

Figure 2.2G: LN (Spawning) Oblique Principal Component Clustering

```
                Number of Clusters
                1   2   3   4
                ---+---+---+---+
         BV_ELK _______________
                _______________
                _______________
        JOHNSON _______________
                _______________
                _______________
          KLICK _______________
                _______________
                _______________
N        MINAM _______________
a               _______________
m               _______________
e        NFJDA _______________
                _______________
o               _______________
f      POVERTY _______________
                _______________
V               _______________
a      SULPHUR _______________
r               _______________
i               _______________
a        MARSH _______________
b               ______
l               ______
e       ENTIAT _______________
                _______________
o               _______________
r       IMNAHA _______________
                _______________
C               _______________
l       METHOW _______________
u               _______________
s               _______________
t      WENATCH _______________
e               _
r               _
         MFJDA _______________
                _______________
                _______________
          WIND _______________
                __________
                __________
         DESCH _______________
                _______________
                _______________
         UPJDA _______________
```

Figure 2.2H: LN (Spawning) detrended Oblique Principal Component Clustering

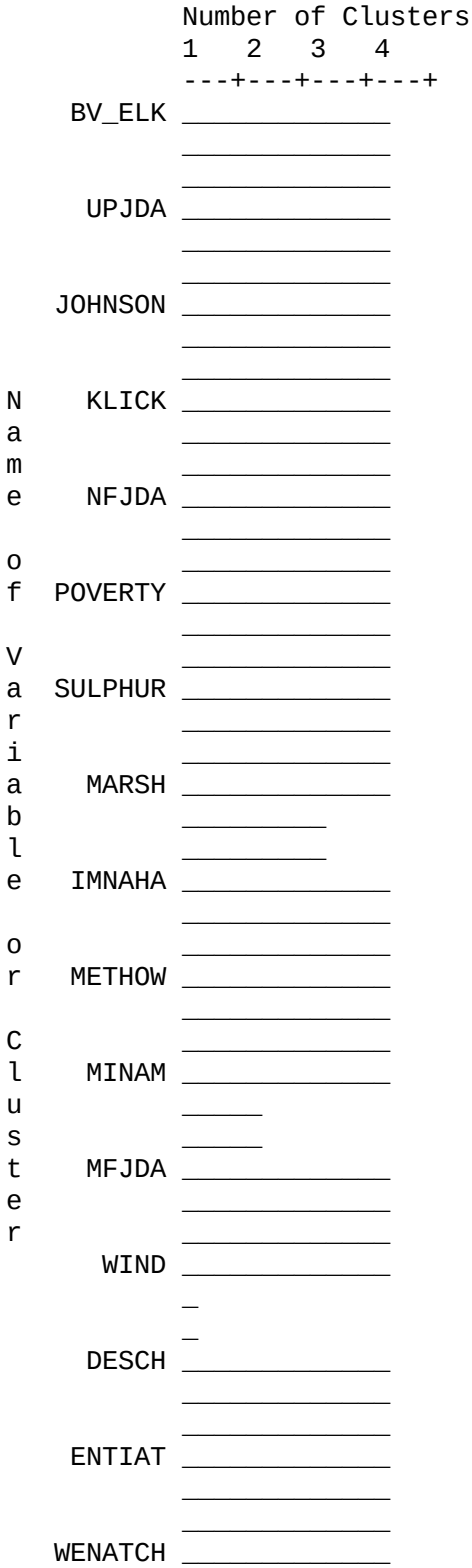

Figure 2.2I: LN (St+4/S_t) Oblique Principal Component Clustering

```
                Number of Clusters
                1   2   3   4
                ---+---+---+---+
        BV_ELK  _______________
                _______________
                _______________
        ENTIAT  _______________
                _______________
                _______________
       JOHNSON  _______________
                _______________
                _______________
N        MINAM  _______________
a               _______________
m               _______________
e      POVERTY  _______________
                _______________
o               _______________
f      SULPHUR  _______________
                _______________
V               _______________
a        MARSH  _______________
r               __________
i               __________
a        KLICK  _______________
b               _______________
l               _______________
e        NFJDA  _______________
                ______
o               ______
r       IMNAHA  _______________
                _______________
C               _______________
l         WIND  _______________
u               _
s               _
t        DESCH  _______________
e               _______________
r               _______________
         UPJDA  _______________
                _______________
                _______________
        METHOW  _______________
                _______________
                _______________
         MFJDA  _______________
                _______________
                _______________
       WENATCH  _______________
```

Figure 2.2J: (St+4/S_t) Oblique Principal Component Clustering

```
                Number of Clusters
                1   2   3   4
                ---+---+---+---+
         BV_ELK _______________
                _______________
                _______________
        JOHNSON _______________
                _______________
                _______________
          KLICK _______________
                _______________
                _______________
N     POVERTY   _______________
a               _______________
m               _______________
e     SULPHUR   _______________
                __________
o               __________
f       WIND    __________
                ______
V               ______
a       UPJDA   _______________
r               _______________
i               _______________
a       MFJDA   _______________
b               _______________
l               _______________
e       NFJDA   _______________
                _
o               _
r       DESCH   _______________
                _______________
C               _______________
l     ENTIAT    _______________
u               _______________
s               _______________
t     IMNAHA    _______________
e               _______________
r               _______________
         METHOW _______________
                _______________
                _______________
          MINAM _______________
                _______________
                _______________
        WENATCH _______________
                _______________
                _______________
          MARSH _______________
```

Figure 2.2K: (St+4/S $_t$) Residuals Oblique Principal Component Clustering

```
                Number of Clusters
                1   2   3   4
                ---+---+---+---+
     ENTIAT     _______________
                _______________
                _______________
    JOHNSON     _______________
                _______________
                _______________
    SULPHUR     _______________
                __________
                __________
N     KLICK     _______________
a               _______________
m               _______________
e     MFJDA     _______________
                _______________
o               _______________
f     NFJDA     _______________
                ______
V               ______
a     DESCH     ______
r               _
i               _
a    BV_ELK     _______________
b               _______________
l               _______________
e    IMNAHA     _______________
                _______________
o               _______________
r     UPJDA     _______________
                _______________
C               _______________
l    METHOW     _______________
u               _______________
s               _______________
t     MINAM     _______________
e               _______________
r               _______________
    POVERTY     _______________
                _______________
                _______________
    WENATCH     _______________
                _______________
                _______________
       WIND     _______________
                _______________
                _______________
      MARSH     _______________
```

Figure 2.2L: (St+4/S $_t$) Residuals Detrended Oblique Principal Component Clustering

```
                Number of Clusters
                1   2   3   4
                ---+---+---+---+
        ENTIAT  _______________
                _______________
                _______________
        IMNAHA  _______________
                _______________
                _______________
        METHOW  _______________
                _______________
                _______________
N     WENATCH   _______________
a               _______________
m               _______________
e         WIND  _______________
                _______________
o               _______________
f        MARSH  _______________
                ______
V               ______
a       BV_ELK  _______________
r               _______________
i               _______________
a     JOHNSON   _______________
b               _______________
l               _______________
e        MINAM  _______________
                _______________
o               _______________
r     SULPHUR   _______________
                _
C               _
l        UPJDA  _______________
u               _______________
s               _______________
t        MFJDA  _______________
e               _______________
r               _______________
         NFJDA  _______________
                _______________
                _______________
       POVERTY  _______________
                __________
                __________
         DESCH  _______________
                _______________
                _______________
         KLICK  _______________
```

Chapter 2 Appendix 1: Data Sources for Chapters 2 and 4.

Timothy Fisher, Beak Consultants

Abstract

This appendix describes the sources of stock abundance and ancillary environmental data for stocks analyzed in Chapters 2 and 4. In addition, it describes ancillary data that may be used for the discriminant analysis outlined (but not actually performed) in Chapter 2. That analysis will use either static data (e.g., geomorphology) or point estimates of dynamic data (e.g., number of irrigation diversions). In contrast, the analyses in Chapter 4 use only time-varying data, such as annual flows in spawning and rearing areas.

Ancillary and stock abundance data was gathered for approximately 74 stocks of chinook salmon from the Olympic Peninsula and Puget Sound to the Sacramento River. Most stocks for which abundance data are available are clustered in the Columbia River basin. Stock abundance data gathered was primarily redd counts and other spawning area abundance estimates, most of which are from the STREAMNET database of the PSMFC. Ancillary data gathered for spawning and rearing areas and the migratory path (including the Pacific Ocean) was grouped into the categories of climatological, anthropogenic, and geophysical factors. Climatological factors included ocean productivity indices, drought indices, streamflow, snowpack, air temperature, and precipitation. Anthropogenic factors included timber harvest, grazing, mines, diversions, dams, and point source pollution discharges. Geophysical factors included geology, physiographic province, ecoregion, distance to the Pacific Ocean, The sources of this data were mainly federal agencies such as NOAA, NMFS, USFS, and USACE, and state departments of environment, forestry and fish and wildlife. Some data was gathered from private landowners. In general, data from state and federal sources was readily available, while that from other interests was not. The exception was land use data, such as timber harvest, agriculture, and grazing, which was not generally available in a useable form. In all, sixteen stocks in the Columbia River basin had run reconstructions and therefore were included in this analysis. These stocks had reasonably complete data, except for land use information.

Methods

Beak Consultants, under subcontract to Paulsen Environmental Research, began by identifying stocks of chinook salmon which had spawning escapement estimates. These were pulled from the Big Eagle to NMFS (Big Eagle 1995). Beak identified over 120 stocks in Oregon, Washington, and California which had at least 20 consecutive years of escapement data. Originally the scope was to include Alaska and British Columbia as well. However, Alaska did not provide data prior to 1980, and the BC spawning escapement estimates were by and large too imprecise for purposes of reconstructing spawner-recruit data. Of the 120 stocks which fit the escapement data criteria, about 74 were retained after an initial consultation with WA, OR, ID, and CA biologists. These stocks were identified as having reasonably good escapement estimates from which run reconstructions could be made. This information will be used if the analyses in Chapters 2 and 4 are extended by using the S_{t+4}/S method tested in Chapter 2.

Of these, 16 have had reconstructions performed by the state biologists, and so have been retained for the preliminary analyses in Chapters 2 and 4. In order to relate the spawner-recruit and escapement data to

environmental conditions, ancillary data was gathered from various public sources for each of the 16 stocks. This included general information such as run type (spring, summer, or fall), spawning area location, drainage basin area, spawning streams, and rivers in the migratory path, which help to define the geographic limits of the ancillary data to be collected for each stock. Similar ancillary information was also gathered for the 58 (74-16) stocks where we had escapement but not recruitment data.

The ancillary data were gathered from many public sources. These included federal, tribal, and state government agencies. The data was then processed into variables which would reflect the effect of each factor on the stocks. Some data were static or were not available for a long time series; this was summarized as a single time-invariant variable for each stock. Following is a description of the types of ancillary data gathered, sources for the data, completeness of the data, and a description of how the data was processed into forms useful for the multivariate analysis.

Stock Data

For this preliminary analysis, we included sixteen stocks of chinook salmon for which the agency biologists had already performed run reconstructions. These stocks are listed in Table C2 A1-1; 13 are spring chinook, one a mixed spring/summer, and two are summer chinook stocks. The designation refers to the timing of adult upstream migration. All the stocks migrate as yearlings (Age 1), and all are located in tributaries to the Columbia River. The spawning area boundaries were determined from Petrosky et al (1995), STREAMNET, or from personal communication with state and tribal biologists. The EPA river reach number was determined form the location of the lower bound of the spawning area, from the EPA hydrologic unit maps for each state.

Geophysical Data

Geology

Data on the geological formations which underlie the spawning area of each stock were obtained from state geology departments. The data were usually in the form of maps produced by the state geology departments or the USGS. Idaho data were provided by the ID Geological Survey, Washington by WDNR Division of Geology, and Oregon by DOGAMI. Geology was characterized by listing the first through fourth most common formations underlying a spawning area watershed. The formations, compiled from the maps and then categorized by types by Beak's fluvial geomorphologist, were chosen to represent physiochemical groupings of rock formations that are meaningful to stream geomorphology, fish habitat, and aquatic productivity. These categories are:

Glacial/alluvial: Unconsolidated glacial or alluvial deposits. Includes flood deposits, glacial till, glacial drift and outwash. Low resistance to erosion, variable particle sizes. Chemistry depends on source material. Low pH and base saturation common in Northwest.

Mudstone: Includes siltstone, marine sandstone and argillite. Low to moderate resistance to erosion. Weathers to silt or clay. Generally high base saturation and pH.

Table C2 A1-1: Stocks of chinook salmon used in the preliminary analysis. RRN refers to the EPA river reach number of the lower bound of the spawning area of the stocks

Sandstone: Low to moderate resistance to erosion, varies depending on cementing agent. Weathers to sand. Quartz rich, low base saturation and pH.

Breccia: Includes tuffs and conglomerate. Variable resistance to erosion depending on cementing agent. Weathers to coarse grained pebble to cobble sized material. Chemistry variable depending on source rock.

Granite: Highly resistant plutonic rocks; includes gneiss and granodiorite. Weathers to sand and silt sized material. Low base saturation and pH.

Basalt: Resistant volcanic rocks; includes andesite. Often fractured or jointed, produces angular coarse fragments. Weathers to silt and clay. Rich in iron and magnesium, high pH and base saturation, low levels of exchangeable aluminum.

This information was thought to be important because it may mediate the effects of other environmental variables, such as flows or temperatures. The results of the geology and the other geophysical categories provide a good summary of the environmental conditions in the spawning areas of the stocks. They will be used in the planned discriminant analysis. These are presented in Table C2 A1-2.

Watershed Landform

Landforms were based on geomorphic processes, valley bottom form, and channel confinement (Hunt 1967, Orr and Orr 1985, Williams et al. 1975). USGS 1:250,000 topographic quads were used by our fluvial geomorphologist to determine the landform of each spawning watershed. They are probably more relevant to fish habitat than physiographic provinces or ecoregions. They will be used in the planned discriminant analysis. Landforms for the 16 stocks are presented in Table C2 A1-2. The following landform types were found for the 74 stocks in the full analysis:

Canyon: almost vertical walls, incised channel, moderate gradient
Narrow confined valley: mountain slopes, bedrock controlled channel, high gradient
Trench-like valley: alluvium filled valley, steep sideslopes, low to mod. gradient
Glacial trough: U-shaped glacial valley, low gradient, moderately confined
Glacial outwash plain: Glacial deposit in lowlands, meandering unconfined channel
Unconfined alluvial plain: no adjacent sideslope, meandering channel, low gradient

Physiographic Provinces

Physiographic provinces were determined from maps and text sources. The following provinces were found for the stocks in the full analysis: Columbia Plateau, Pacific Border, Pacific Mountains, and Rocky Mountains.

Table C2 A1-2: Geophysical characteristics of the spawning areas of the stocks of chinook salmon used in the preliminary analysis.

Ecoregions

Ecoregion was determined for each stock from the map of the ecoregions of the Pacific Northwest (Omernik 1995). Level III ecoregions were used even though Level IV delineation is available for most of Oregon and Washington. The following ecoregions were found for the stocks in the full analysis: Blue Mountains, Cascades, Coast Range, Columbia Plateau, Eastern Cascades Slopes and Foothills, Klamath Mountains, North Cascades, Northern Rockies, Puget Lowland, Snake River Basin / High Desert, Southern and Central California Plains and Hills, and Willamette Valley. They will be used in the planned discriminant analysis.

The distance in river kilometers to the Pacific Ocean were determined by consulting several sources: the Pit Tag Information System (PTAGIS), Oregon Rivers Information System (ORIS), and the Washington Rivers Information System (WRIS). This will be used in the planned discriminant analysis. River kilometer is cumulative from the point of entry into estuary to the lower bound of the spawning area reach for each stock. If the spawning area reach was not identifiable in the data sources then the river km of the mouth of the spawning stream was used. Only streams which have had PIT tagged fish released or recaptured were contained in the PTAGIS Specification Document; other streams were determined from either WRIS or ORIS.

Climatological Data

Streamflow

Streamflow was determined from USGS gauging station data contained on the latest release of the EarthInfo, Inc. CD-ROM database “USGFS Daily Values 1993: West 2”. Flow was determined for the spawning area and migratory path for each stock. The data are stored as mean, minimum, and maximum monthly flows for each year and stock. We used gauging stations which were located in the spawning area of the stock, and if there was no station in the spawning area, we used the next downstream station, next upstream station, or a station in a neighboring watershed. The stations used for the 16 stocks in this analysis and their locations are presented in Table C2 A1-3. This information was used in the analyses in Chapter 4.

Snowpack

Data on snowpack in the watershed of each stocks’ spawning area was obtained from the NRCS Pacific Division. The data is from SNOTEL and other NRCS monitoring sites in the Pacific NW. The data is in the form of monthly observations of snow depth and snow water equivalent (SWE) in inches. We used the maximum SWE for each winter as the measure of snowpack. Table C2 A1-3 shows the stations we used for each of the stocks in this analysis. This information was used in the analyses in Chapter 4.

Table C2 A1-3: Streamflow and snowpack station locations used for the stocks of chinook salmon used in the preliminary analysis.

Air Temperature and Precipitation

The data for air temperature (°C) and precipitation (inches) was obtained from the NOAA CD: "US Divisional and station climatic data and normals Volume 1 December 1994". We matched the river reach of the spawning area for each stock to the closest NOAA monitoring station which had at least 20 consecutive years of precipitation and temperature data. In some cases this was not the closest station to the reach, but many remote stations had few years of consecutive data. The stations we used for the stocks in this analysis are presented in Table C2 A1-4. We summarized the monthly minimum daily, maximum daily, and mean daily temperatures over each month, and used the monthly total precipitation. The data were available for the period 1961-1990, which is the current NOAA reporting period. This information was used in the analyses in Chapter 4.

Table C2 A1-4: Climate stations and drought index regions used for the stocks of chinook salmon used in the preliminary analysis.

	Climate		**Drought Index**
Stock	**Station**	**Location**	**State Division**
Wind R.	350897	Bonneville Dam	Cascade Mountains West WA
Klickitat R.	450217	Appleton	East Slope Cascades WA
Methow R.	459376	Winthrop 1 WSW	Okanogan Big Bend WA
Bear Valley/Elk Ck.	108676	Stanley	Central Mountains ID
Warm Springs R.	356532	Pelton Dam	Northern Cascades OR
Minam R.	355610	Minam 7 NE	Northeast OR
Imnaha R.	107706	Riggins	Northeast OR
Upper John Day R.	354291	John Day	North Central OR
Middle Fk. John Day R.	358726	Ukiah	North Central OR
N. Fk. John Day R./ Granite Ck.	353038	Fossil	North Central OR
Marsh Ck.	108676	Stanley	Central Mountains ID
Sulphur Ck.	101514	Cascade 1 NW	Central Mountains ID
Johnson Ck.	105708	McCall	Central Mountains ID
S. Fk. Salmon R.	105708	McCall Call	Central Mountains ID
Wenatchee R.	459074	Wenatchee	East Slope Cascades WA
Entiat R.	451350	Chelan	East Slope Cascades WA

Drought Index

The NOAA Time Bias Corrected Divisional Temperature-Precipitation-Drought Indices takes several forms. We chose the Divisional Monthly Modified Palmer Drought Severity (PMDI), which was obtained from the NOAA CD which also contains the temperature and precipitation data. This information was used in the analyses in Chapter 4. The index is calculated for state regions only, and the regions associated with the stocks in this analysis are shown in Table C2 A1-4: The divisions are roughly equivalent to the EPA Level III Ecoregions. A description of the PMDI from the NOAA CD follows:

> "This is a modification of the Palmer Drought Severity Index. The modification was made by the National Weather Service Climate Analysis Center for operational meteorological

purposes. The Palmer drought program calculates three intermediate parallel index values each month. Only one value is selected as the PDSI drought index for the month. This selection is made internally by the program on the basis of probabilities. If the probability that a drought is over is 100%, then one index is used. If the probability that a wet spell is over is 100%, then another index is used. If the probability is between 0% and 100%, the third index is assigned to the PDSI (Palmer Drought Severity Index). The modification (PMDI) incorporates a weighted average of the wet and dry index terms, using the probability as the weighting factor. (Thomas R. Heddinghause and Paul Sabol, 1991; "A Review of the Palmer Drought Severity Index and Where Do We Go From Here?" Proceedings of the Seventh Conference on Applied Climatology, pp. 242-246, American Meteorological Society, Boston, MA). The PMDI and PDSI will have the same value during an established drought or wet spell (i.e., when the probability is 100%), but they will have different values during transition periods."

PMDI classes are shown in Table C2 A1-5.

Table C2 A1-5: PMDI classes for wet and dry periods (NOAA 1994). Approximate cumulative frequency.

Range (percentile)	Range %	PHDI Category	Palmer Z
> 96	> 4.00	Extreme wetness	> 3.50
90-95	3.00, 3.99	Severe wetness	3.50, 3.49
73-89	1.50, 2.99	Mild to moderate wetness	1.00, 2.49
28-72	-1.49, 1.49	Near normal	-1.24, 0.99
11-27	-1.50, -2.99	Mild to moderate drought	-1.25, -1.99
5-10	-3.00, -3.99	Severe drought	-2.00, -2.74
<4	<-4.00	Extreme drought	<-2.75

Upwelling Index

This data was gathered from the NMFS FTP site (address and file location: *ftp://upwell.pfeg.nmfs.gov/outgoing/UPINDEX.MON*) on the Internet. This site supplies the monthly upwelling indices for points in 3° increments from 21°N to 60°N off the west coast of North America from 1946 to the previous month. We used the May index at 48°N (south of Cape Flattery, WA) for the stocks in this analysis. See Bakun (1975) for a description of how the indices are calculated. This information was used in the analyses in Chapter 4.

North Pacific Index

The North Pacific Index (NPI) is a measure of the strength of the Aleutian Low. Data were obtained from Mary Downton, National Center for Atmospheric Research. They are documented in Trenberth and Hurrell (1995). This information was used in the analyses in Chapter 4.

Anthropogenic Data

Water Withdrawals

Beak attempted to locate information on the number of withdrawals, use of the water withdrawn, quantity of water withdrawn, and the screening status of the diversions from each state entity responsible for keeping water right records. This data was subdivided into withdrawals in the spawning area (from the lower to the upper boundaries of the spawning area), and withdrawals from the migratory path (from the lower bound of the spawning area to the Pacific Ocean). Data were not generally available for yearly time steps, so we chose to summarize the data into a single, "current" set for each stock. Data for withdrawals in Idaho was obtained from IDFG and IDWR, data from Oregon was provided by ODWR, and data from Washington was provided from WDE, Water Resources Division. The data differed substantially from state to state (a common problem which we encountered with all data received from the states), but in general contained source stream, township, range, and section, and permitted use and quantity for each withdrawal. The data was never organized by year, although OR and ID did provide the date of the permitted water right. The type of diversion was never stated, and the screening status of the diversions was unknown. This information will be used in the planned discriminant analyses in Chapter 2.

Source stream, township, range, and section were all used to locate withdrawals in the spawning areas and migratory paths of the stocks. The migratory path of each stock used in this procedure and elsewhere is shown in Table C2 A1-6: We grouped withdrawals into four categories; fish/wildlife/stock, irrigation, municipal/industrial, and domestic/recreation. Only those withdrawals which were identified as current and deemed to be significant (criteria differed between states) were included. Since withdrawals are a time-invariant factor, the data is easy to present. The number of withdrawals for each stock is shown in Table C2 A1-7.

Mining

Mining data was obtained from the same state agencies as the geology data. Mine commodities were grouped into four categories: metals, aggregate/stone sand/gravel, phosphate/sulfur, and clay/dirt. We used the first listed commodity for each mine, which was assumed to be the major commodity produced. The Washington data was available in summary form only; data on individual mines is missing. Road and construction rock quarries do not seem to be catalogued in either WA or ID, and placers are identified only for Idaho. The Oregon data was compared to the historical DOGAMI database to locate some mines by hydrounit (which had been deleted from current database). The remaining mines in all states were located by TRS. Numerous errors in mine commodity and location were corrected. Some commodities were inferred by ownership. Once we had located mines in the watershed of each stock, we summarized the number of currently active mines in the watershed by commodity type. The number of mines for each stock is shown in Table C2 A1-7. This information will be used in the planned discriminant analyses in Chapter 2.

Hatchery Releases

Releases of hatchery fish were obtained form the STREAMNET database. We summarized hatchery smolt releases in the subbasin of each stock by year, species and number released. Most releases were of mixed CWT and non-tagged smolts, and all such releases should be in the data. There are missing groups which contained only non-tagged smolts: no 1960-1981 non-CWT releases of any species in OR and steelhead in WA. This information is planned for use in future refinements of the analyses in Chapter 4, once additional anthropogenic stressor data have been collected. A prototype of the use of this data is included in Chapter 11.

Dams

We summarized the number of dams in the migratory path and upstream of the spawning area of each stock by year. The data was obtained from two databases: the BPA Northwest Environmental Database (NED)

and the USACE National Inventory of Dams (NID). All structures count as dams if they are located in the migratory path, but only those identified as storage dams were included if the dam was located above the spawning area of a stock. This information will be used in the planned discriminant analyses in Chapter 2, and are also used in the analyses in Chapter 4.

Point Source Pollution

Data on point source pollution was obtained from the USEPA Region 10 SITEINFO database application on the World Wide Web (*http://www.epa.gov/region10/www/siteinfo.html*). This database contains point sources from four EPA sources: CERCLA sites, RCRA TSD sites, TRI (Toxic Release Inventory) sites, and NPDES sites (majors and a few minors). We queried the database for all point sources from Region 10, then matched these point sources by latitude and longitude to the hydrounits of the stocks. The number of point sources located in the hydrounit of each stock is shown in Table C2 A1-7. This information will be used in the planned discriminant analyses in Chapter 2.

Table C2 A1-7: Data for the time-invariant anthropogenic factors: withdrawals, mining, and point source pollution.

Stock	**Withdrawals**		**Number of mines**	**Pollution point sources**
	Spawning	**Migration**		
Methow R.	32	418	3	0
Entiat R.	36	350	0	0
Wenatchee R.	182	332	2	10
Imnaha R.	46	299	2	0
Minam R.	0	316	2	3
Sulphur Ck.	1	370	1	0
Bear Valley/Elk Ck.	11	371	6	0
Marsh Ck.	4	371	3	0
S. Fk. Salmon R.	0	385	1	3
Johnson Ck.	9	373	1	0
Wind R.	1	47	0	31
Klickitat R.	1	90	0	4
Upper John Day R.	30	703	7	0
N. Fk. John Day R. Granite Ck.	174	382	32	0
Middle Fk. John Day R.	27	552	13	0
Warm Springs R.	0	104	0	4

Table C2 A1-6: Rivers in the migratory path of the stocks of chinook salmon used in the preliminary analysis.

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