Use of Redd Counts to Detect Trends in Bull Trout (*Salvelinus confluentus*) Populations

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Introduction

Bull trout (*Salvelinus confluentus*) is a species of growing interest in the Pacific Northwest (U.S.). It was recently proposed for listing under the Endangered Species Act (U.S. Fish and Wildlife Service 1997); however, uncertainty and debate regarding the status of remaining populations continues. Biologists throughout the region have expressed concern regarding the loss of historical populations and the risks facing those that remain (Howell & Buchanan 1992; Rieman & McIntyre 1993), but published data demonstrating such problems are few. A variety of monitoring data are available from management agencies but, as with other species (e.g., Pechmann et al. 1991; Reed & Blaustein 1995), time series are often short or highly variable, potentially limiting the power of simple tests for trends in the data. As a result, in a recent public policy conference regarding the future management of bull trout and the lands influencing their habitats, some argued that there is little statistically supported evidence that populations are declining and therefore no clear risk of extinction.

The most consistent and extensive monitoring information we could locate for bull trout is represented by redd (nest) counts maintained by the Idaho Department of Fish and Game and the Montana Department of Fish, Wildlife and Parks. We used the data provided by these agencies to determine whether the patterns within and among populations suggest any trends and to evaluate the difficulty of detecting potentially important trends.

Bull trout associated with three large lake systems in the Clark Fork River basin of northern Idaho (Pend Oreille Lake) and northwestern Montana (Flathead and Swan lakes) exhibit a migratory life history (Rieman & McIntyre 1996) analogous to that of anadromous salmonids. Adults spawn and juveniles rear in tributary streams. Juveniles migrate to a lake at 1 to 3 years of age where they mature. As adults these fish return to the natal stream to spawn, generally from August to early October. Because the adults are relatively large (>400 mm) and because streams are typically low and clear, the redds constructed by females are highly visible. Because migratory salmonids including bull trout demonstrate strong fidelity to natal habitats, some reproductive isolation is expected among streams and is evident in the genetic analysis of bull trout from the Flathead and Swan lake systems (F. Allendorf, personal communication). Bull trout associated with individual streams appear to represent discrete, local populations that are patchy in their distribution across larger river basins (e.g., Rieman & McIntyre 1995). Biologists have made annual redd counts as an index of adult escapement and long-term trends in populations. Numbers vary substantially through time, and redd counts in any year range from none to hundreds among streams. Extrapolations from these counts suggest that adult populations in each tributary range from tens to fewer than 1000 individuals (Rieman & McIntyre 1993). Many of these populations could be vulnerable to extinction through stochastic as well as deterministic effects (Rieman & McIntyre 1993).

Monitoring has been conducted since 1983 in the Pend Oreille Lake basin, since 1982 in the Swan Lake basin, and since 1979 in the Flathead Lake basin. Redd surveys are conducted by one or two people walking a stream in September and October. Multiple surveys have been used to identify the duration of the spawning period and to select survey times that produce estimates of the complete spawning population. In early years counts in some Flathead streams were considered incomplete relative to those in later years and were not used in this analysis.

Methods

To determine whether trends were evident we related annual redd count to year using nonparametric rank cor-

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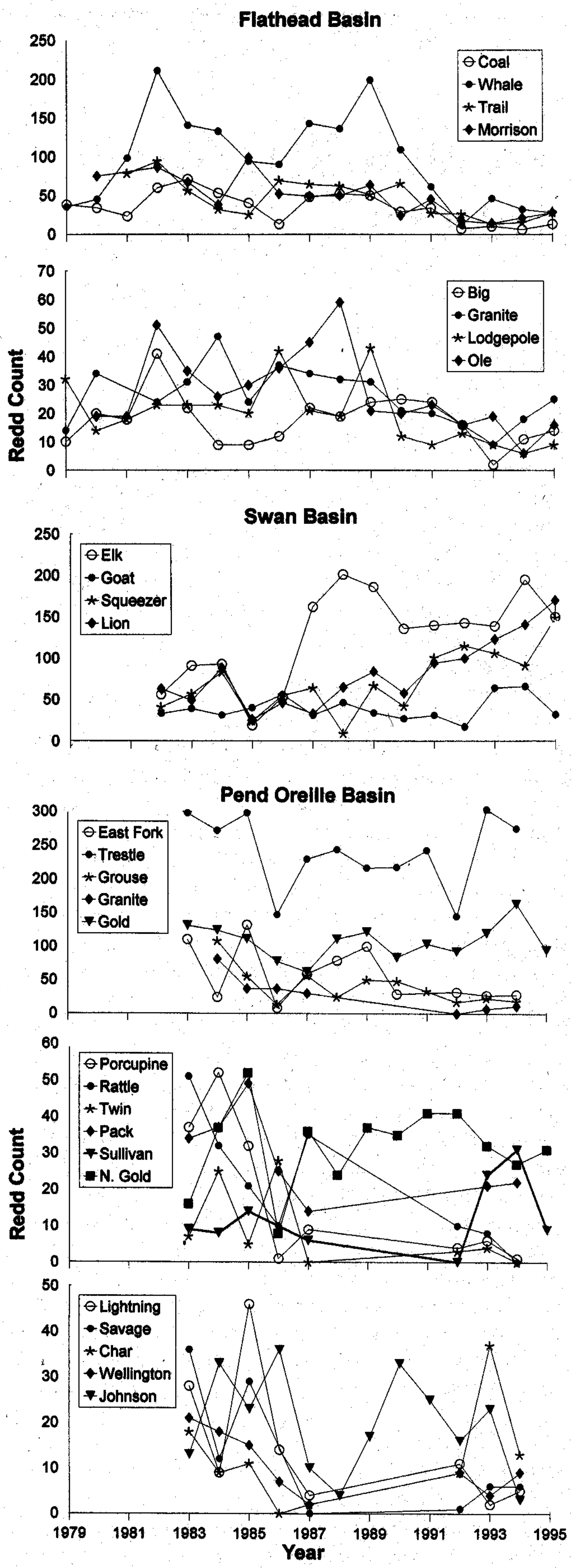

Figure 1. Bull trout redd counts for 28 streams in three basins of northern Idaho and northwestern Montana. The counts are grouped by basin and also by relative magnitude to allow better resolution through adjustment of scale in the figures.

relation. Any number of underlying models (e.g., linear, non-linear, monotonic, cyclic, step, or complex) might be assumed. Without much longer time series and more detailed understanding of the extrinsic factors and biology influencing the dynamics of these populations, however, we believe the simplest models are most appropriate and likely the most powerful (Berryman et al. 1988). We therefore conducted the analyses using both the Spearman and Kendall's rank correlation procedures (Liebetrau 1983; Zar 1996), testing only for a monotonic trend. The results from both methods were virtually the same and supported identical conclusions. We present only the analysis using Kendall's tau (Liebetrau 1983) because it is commonly used in this type of analysis (Berryman et al. 1988; Pechmann et al. 1991). We used tau-*b* (Liebetrau 1983) to compensate for the potential bias caused by ties in counts.

Although we believe each stream represents a discrete spawning group it is not clear at what scale long-term trends within or among populations may be generated. We tested for significant trends within streams, among streams within lakes, and among all streams. Within streams we estimated tau and noted significance at $\alpha = 0.05$ (two tailed) and at the value of α represented by the Bonferroni adjustment for multiple tests. To consider the relative difficulty in detecting significant trends within streams we used a normal approximation method (Sokal & Rohlf 1969) to estimate the sample size (years) necessary to conclude significance for the respective values of tau. To examine trends among streams within lakes we standardized redd counts to a common mean and standard deviation and pooled these as replicate observations for each lake basin. Because differences were apparent among lake basins we did not pool observations across basins. To consider trends among all streams we used a randomization procedure to compare the observed distribution of tau across streams against that expected with no temporal structure in the data. We repeatedly reshuffled the order of years and recalculated the correlation for each stream to produce the expected distribution. We compared the observed and expected distributions of tau with the Kolmogrov-Smirnov test (Zar 1996).

Results and Discussion

Redd count data were available for 28 streams, with sample sizes ranging from 7 to 17 years (Fig. 1). Either no

Table 1. Estimates of Kendall's tau, associated probabilities and sample sizes for bull trout redd counts in three basins of Idaho and Montana.

Basin stream	Kendall's tau	p[a]	Sample size: Existing	Sample size: At $\alpha = 0.05$[b]	Sample size: With adjustment[c]
Flathead Basin Montana[d]					
Big	−0.04	0.836	17	>100	>100
Coal	−0.41	0.021*	17	13	20
Whale	−0.26	0.138	17	28	44
Trail	−0.50	0.009**	15	10	15
Morrison	−0.60	0.002**	15	7	10
Granite	−0.33	0.078	16	20	29
Lodgepole	−0.47	0.010**	17	11	16
Ole	−0.34	0.070	16	18	28
pooled streams	−0.27	<0.001*	130	—	—
Swan Basin Montana[d]					
Elk	0.43	0.033*	14	13	16
Goat	0.02	0.912	14	>100	>100
Squeezer	0.52	0.010**	14	10	12
Lion	0.63	0.002**	14	7	12
pooled streams	0.32	<0.001*	56	—	—
Pend Oreille Idaho[e]					
Lightning	−0.50	0.083	8	10	17
Eastfork	−0.24	0.312	11	35	64
Savage	−0.39	0.224	7	15	26
Char	0.11	0.708	8	>100	>100
Porcupine	−0.62	0.034*	8	7	12
Wellington	−0.55	0.062	8	9	15
Rattle	−0.76	0.009*	8	6	9
Johnson	−0.18	0.408	12	54	>100
Twin	−0.47	0.105	8	11	19
Trestle	−0.11	0.630	12	>100	>100
Pack	−0.43	0.177	7	13	22
Grouse	−0.49	0.036*	11	10	17
Granite	−0.68	0.033*	7	7	10
Sullivan	0.18	0.553	8	56	>100
N. Gold	0.00	—	13	—	—
Gold	−0.06	0.760	13	>100	>100
pooled streams	−0.14	0.017*	149	—	—

[a] *Significance at $\alpha = 0.05$ is designated by * and with adjustment for multiple tests by **.*
[b] *Estimated sample sizes necessary to conclude significance at $\alpha = 0.05$.*
[c] *Estimated sample sizes necessary to conclude significance at $\alpha = 0.05$ adjusted for multiple tests.*
[d] *Redd counts are from annual surveys conducted by Montana Department of Fish, Wildlife and Parks, Kalispell.*
[e] *Redd counts are from annual surveys conducted by Idaho Department of Fish and Game, Coeur d'Alene.*

trend or negative trends were apparent within and among streams in the Flathead and Pend Oreille basins (Table 1). Negative trends were more apparent within Flathead streams, but pooled estimates were negative and significant in both cases. The relative lack of significant trends among Pend Oreille basin streams (i.e., α with adjustment) could be attributed to both greater variability and smaller sample sizes. Significant positive trends were found in 3 of 4 streams and in the pooled estimate for the Swan Lake basin (Table 1). The trends among all streams in all lake basins were predominantly negative and produced a distribution significantly different from that expected by chance (Fig. 2).

Although both positive and negative trends were apparent, we found that the predominant pattern was one of decline in both the Pend Oreille and Flathead basin streams. Many causes of decline in bull trout populations have been proposed throughout the Pacific Northwest, but habitat disruption and fragmentation, and predation, competition, and genetic introgression associated with the introduction and establishment of exotic species are the most prominent reasons cited by regional biologists (e.g., Howell & Buchanan 1992; Rieman & McIntyre 1993). Long-term trends in climate and hydrologic regimes might also be possibilities, but the apparent differences in patterns between the Swan and the other basins indicate that such effects are not dominant. Significant growth in the Swan populations demonstrates that declining trends in bull trout populations are not universal. Development and land-use disturbances have occurred in much of each of the three lake basins and negative associations with bull trout distributions and dynamics have

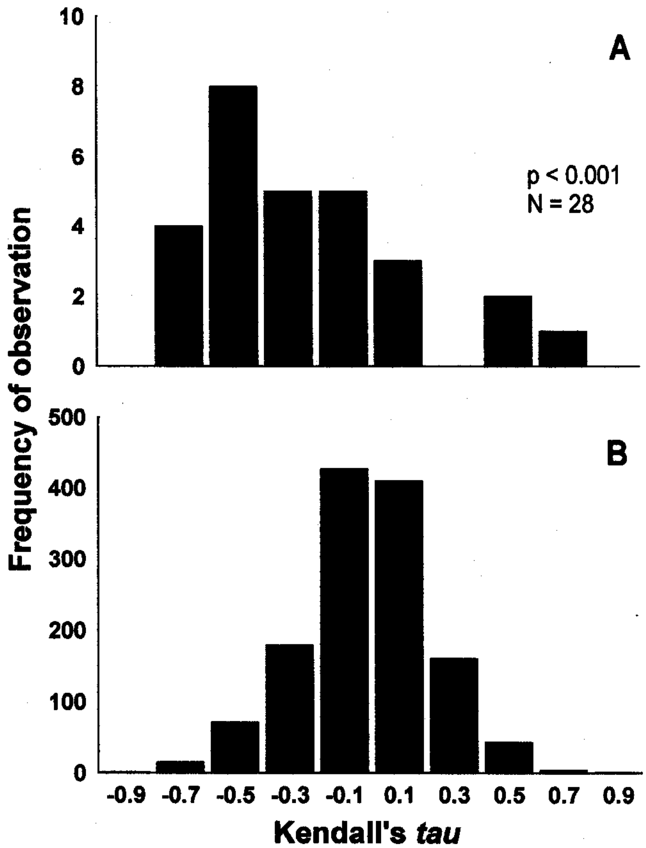

Figure 2. Frequency distributions for Kendall's tau for correlations of bull trout redd counts against year in 28 streams in Idaho and Montana: observed distribution (A) and expected distribution without trend (B) generated by repeatedly reshuffling year. The probability for the Kolmogrov-Smirnov test of differences is shown on A.

been found in other Swan basin streams as well (C. Frissell and C. Baxter, personal communication). More work is necessary to understand the factors influencing trends and risks in bull trout populations.

Management decisions that require statistically rigorous evidence of declining trends may be too late for many remaining bull trout populations. Our results demonstrate that variation in redd counts make the detection of declining trends in individual streams unlikely with limited data sets. Even where declines could be large (some Pend Oreille and Flathead streams have dropped to levels less than 10% of historical highs) detection of trends will often require more than 10 years of sampling (Table 1). To our knowledge these data represent the most extensive time series of bull trout population data anywhere. Although monitoring is often proposed as a mechanism for recognizing and mitigating management effects, few long-term efforts exist.

We do not mean to imply that new monitoring is unimportant. Further work with these and similar data sets may identify important covariates leading to development of more sensitive models or more precise estimates of abundance and trend. Until such work is in application, however, managers must act with caution. Declining trends are apparent in these data and appear to dominate two large systems. For many other populations subject to management effects across the species range, significant trends probably can't be proven before populations drop to critically low levels.

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