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[Article]

Distribution, Abundance, and Population Trends of Bull Trout in Idaho

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Abstract.—Broad-scale declines in populations of bull trout *Salvelinus confluentus* over the past century or more led the Idaho Department of Fish and Game to implement statewide no-harvest regulations on bull trout in 1994 and ultimately led to a threatened listing under the U.S. Endangered Species Act in 1998. Despite this listing, quantitative evaluations of trends in abundance and estimates of population size over most of the species' historical range have not been made. We evaluated bull trout distribution, abundance, and trends in abundance using stratified sampling extrapolations of fish surveys (snorkeling and electrofishing) conducted at 2,521 survey sites (most distributed nonrandomly) across 77,447 km of stream. Bull trout were captured at 887 (35%) of the sites. Within the 262 local populations designated by the U.S. Fish and Wildlife Service within seven Idaho recovery units, the number of 70-mm total length and larger bull trout was estimated at 1.13 million; this estimate was most likely biased low due to sampling limitations. Long-term (>20 years) intrinsic rates of change (r) were negative for 10 of 16 bull trout populations up to 1994 (3 were significantly negative; 1 was significantly positive) and were positive for 14 of 17 populations after 1994 (1 was significantly negative; 5 were significantly positive). Over the entire period of record and all trend data sets, r averaged 0.01 ± 0.01 (mean $\pm$ 90% confidence interval), suggesting stability at a broad scale. During these same time periods, trends for other salmonids in much of the study area experienced similar declines through 1994 and increases after 1994, suggesting that environmental factors with influence over large geographical areas produced the recent positive trends. Once bull trout populations were detrended by use of linear regression residuals, there was little evidence of synchrony between populations. Our results suggest that despite declines from historical levels, bull trout in Idaho are presently widely distributed, relatively abundant, and apparently stable.

Declining populations of bull trout *Salvelinus confluentus* across large portions of the species' historical range (Rieman and McIntyre 1993; Rieman et al. 1997) prompted the Idaho Department of Fish and Game (IDFG) to implement statewide no-harvest regulations in 1994 and ultimately led to a threatened listing under the U.S. Endangered Species Act (ESA) for bull trout in the Columbia River basin (USFWS 1998). Since that time, considerable effort has been focused on describing basic population characteristics, estimating densities at individual sites, and identifying and correcting limiting factors to facilitate recovery of the species. In addition, several bull trout status assessments have been conducted throughout most of the species' range in the western United States (Ratliff and Howell 1992; Rieman and McIntyre 1993; Rieman et al. 1997), but most assessments have focused on the proportion of assumed historical range that is no longer occupied. For example, Rieman et al. (1997) used a series of workshops that asked biologists to characterize the status of bull trout based on empirical data or professional judgment. Their results suggested that bull trout were present in 36% of watersheds in the western United States and about 43% of watersheds in Idaho, but strong populations were reported in only 4% of watersheds in the western United States and about 3% of watersheds in Idaho. However, no population abundance or trend data were reported.

In Idaho, broad-scale estimates of population size have not been made; this is partly due to (1) a lack of quantitative data and (2) dissimilarities in the methods that were used to collect existing data. Similarly, much trend data have been collected by various agencies but with a variety of methods (e.g., redd counts, weirs, population surveys, etc.). To date, published summaries have included only subsets of existing trend data available in Idaho (e.g., Rieman and McIntyre 1996; Rieman and Myers 1997; Dunham et al. 2001); these data have not been updated in recent years. A summary of such information is desirable, because the abundance of individuals in various populations and trends in abundance are two important aspects of the status of any species (Dennis et al. 1991; Mace and Lande 1991; Allendorf et al. 1997). The level of synchrony among populations is also an important component of bull trout conservation, considering the metapopulation characteristics exhibited by this species (Dunham and Rieman 1999) and the fact that synchrony has been

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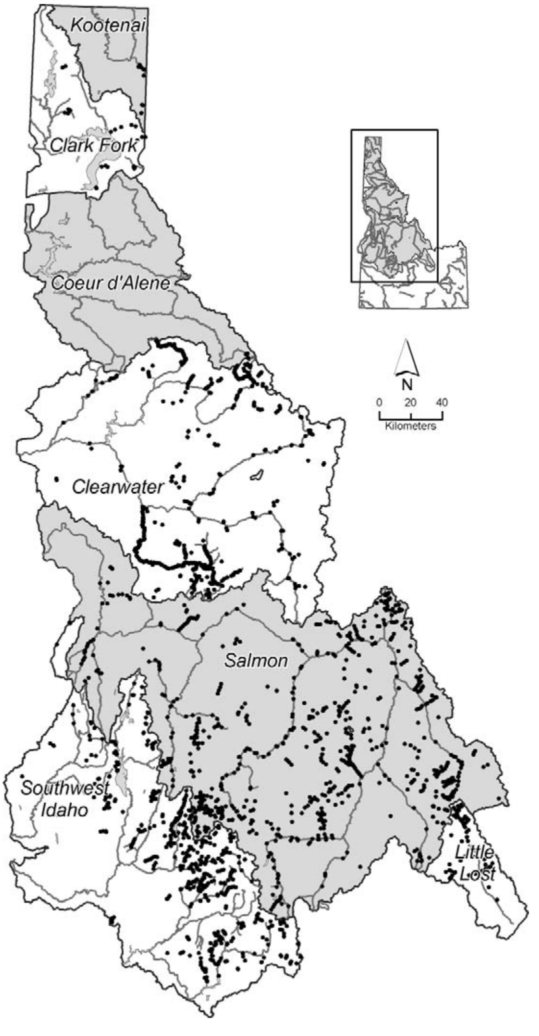

FIGURE 1.—Distribution of survey sites (black dots) within seven U.S. Fish and Wildlife Service-designated bull trout recovery units (USFWS 2000) in Idaho.

shown to increase as salmonid populations decline (Isaak et al. 2003). The objectives of this study were therefore to (1) estimate bull trout distribution and population size across the landscape, (2) evaluate temporal trends in abundance in as many areas of Idaho as possible, and (3) assess the level synchrony in abundance among populations of bull trout.

Study Site

The rangewide distribution of bull trout remains unclear, partly because of past confusion in distinguishing bull trout from Dolly Varden *S. malma* and Arctic char *S. alpinus* (Behnke 2002). Historically, bull trout in Idaho were probably present in most of the Columbia and Snake River basins up to Shoshone Falls and perhaps in one isolated drainage above Shoshone Falls (i.e., Little Lost River drainage) via a headwater capture event with the Salmon River drainage (Figure 1; Table 1). In this assessment, we chose to focus on current distribution, abundance, and trends rather than on the amount of presumed historical habitat currently occupied, because empirical evidence does not exist to describe the historical range of bull trout in Idaho at small scales (i.e., reaches within streams or even entire individual streams).

To facilitate summary of available information and for consistency in terminology used by the U.S. Fish and Wildlife Service (USFWS) in the draft bull trout recovery plan (USFWS 2000), we subdivided bull trout distribution in Idaho within seven recovery units (Figure 1). Core areas as defined by the USFWS are subsets of a recovery unit that often correspond to large river drainages (e.g., Lemhi River within the Salmon River Recovery Unit). Core areas are analogous to metapopulations, since they contain one or more local groups of bull trout that spawn within a particular stream or portion of a drainage system (Lohr et al. 2000). We did not attempt to define populations, but rather we used the 262 local populations identified by the federal recovery plan. Portions of three other recovery units occur in Idaho (Imnaha River–Snake River, Hells Canyon Complex, and Northeast Washington units), as does a portion of the Jarbidge River distinct population segment. We did not include these units in our analyses, because either they do not contain occupied habitat in Idaho or no data were available for the limited habitat they do contain. Bull trout abundance and trend data in lentic habitats were unavailable or suspected of large sampling error, so we excluded them from our analyses as well.

Methods

We gathered georeferenced, quantitative bull trout abundance data from a number of sources, including IDFG, U.S. Forest Service (USFS), U.S. Bureau of Land Management (BLM), and U.S. Bureau of Reclamation (BOR) fisheries biologists. Data included one- and multiple-pass electrofishing surveys, stream snorkel surveys, annual redd counts, and fixed-weir counts. Using these source data, we divided our analyses into extrapolations of abundance and population trends.

Extrapolations of abundance.—To estimate bull trout abundance statewide and within each recovery unit, we first coded (with ArcView geographical information system software) all streams on a standard, 1:100,000-scale hydrography layer for bull trout presence. This was accomplished by holding work-

TABLE 1.—Stream network (km) and distributional extent of bull trout (BUT) in Idaho for seven recovery units (RUs) identified in the draft recovery plan (USFWS 2000). Recovery units are Little Lost River (LLR), Southwest Idaho (SWI), Salmon River (SAR), Clearwater River (CLR), Clark Fork River (CFR), Kootenai River (KOR), and Coeur d'Alene River (CDR).

	Recovery unit							
Variable	LLR	SWI	SAR	CLR	CFR	KOR	CDR	Total
Total kilometers within RU	1,798	15,983	27,342	19,289	3,698	1,981	7,356	77,447
Total kilometers within RU that are presumed to contain BUT[a]	252	1,649	7,202	4,110	665	268	405	14,551
Total kilometers within RU that are presumed to lack BUT or where status is unknown[a]	1,546	14,334	20,140	15,179	3,033	1,713	6,951	62,896
Number of RU sites within presumed BUT current range	55	350	748	640	22	10	6	1,831
Number of RU sites within presumed BUT range that contained BUT	45	145	393	220	19	7	5	834
Number of RU sites outside presumed BUT current range	10	477	136	60	4	3	0	690
Number of RU sites outside presumed BUT range that contained BUT	1	23	24	3	1	1	0	53

[a] Based on biologist workshops held to categorize BUT occupancy (see Methods).

shops across the state, where numerous state, federal, tribal, and privately employed fish biologists used existing data (which they brought to the workshop), local knowledge, and professional judgment to place all stream segments into one of three categories: bull trout present, bull trout absent, or status unknown. Presence or absence described bull trout occupancy during any life stage, and the presence category did not require all life stages to occur at the location of interest. We used these designations solely to stratify our analyses and reduce variance and error in our extrapolations of bull trout abundance, but they were not meant to be unconditionally correct.

We overlaid the resultant stream hydrography layer with all georeferenced bull trout abundance data we could gather from the above-mentioned agencies (through agency contacts and requests after the workshops), regardless of whether bull trout were present. We considered all electrofishing and daytime snorkeling abundance data from 1997 to 2004 to be useful in approximating current bull trout abundance, but the bulk (88%) of the data was collected from 1999 to 2003. Most (86%) of the survey sites were not randomly distributed, but in general the sites were distributed broadly across the landscape (Figure 1). For snorkel survey sites ($n = 1{,}255$) and one-pass electrofishing sites ($n = 887$), the total number of bull trout observed or captured was used as the minimum abundance estimate. For multiple-pass electrofishing survey sites ($n = 383$), we estimated abundance using the maximum-likelihood method calculated with MicroFish software (Van Deventer and Platts 1989).

No attempt was made to differentiate between daytime snorkel counts, one-pass electrofishing capture data, or multiple-pass depletion estimates. Because all three techniques are known to underestimate true fish population size (Thurow and Schill 1996; Kruse et al. 1998; Mullner et al. 1998; Peterson et al. 2004), our site-specific abundance estimates should be viewed as approximations only and are probably underestimates. Instead of correcting the site-specific bull trout abundance estimates based on sampling efficiencies published in the literature (which may or may not be appropriate for the data we obtained), we chose not to modify the estimates because we realized that subsequent extrapolations of abundance across the landscape (see below) would also probably be underestimated and therefore would be conservative in nature.

We excluded fry from our analyses because of the inefficiency in capturing them (Peterson and Cederholm 1984; Reynolds 1996). However, because data were gathered from several sources and collected in a variety of ways, we could not standardize the cutoff length used to include subadults and adults and we could not make separate estimates for each life stage. Subsequently, a cutoff of 70 mm total length (TL) was used for density estimates at 19% of the survey sites, a cutoff of 75 mm TL was used at 6% of the sites, and a cutoff of 100 mm TL was used at 75% of the sites. Most (97%) of the data we gathered were collected during low to moderate flow conditions between mid-June (after spring runoff) and late September (before the onset of winter), which helped to standardize efficiencies in snorkel counts and electrofishing captures.

On a statewide basis and for each bull trout recovery unit, we performed the following steps to approximate abundance within each stream order (Strahler 1964): (1) summed the total length of stream in ArcView; (2) standardized our estimates of abundance to the number of bull trout per 100 m of stream (survey sites averaged 96 m in length); (3) calculated mean abundance and variance from all survey sites; and (4) multiplied mean abundance by the total number of 100-m reaches within a particular stream order to estimate total abundance for that stream order. We then summed the bull trout abundance and variance estimates for all stream orders to obtain total abundance estimates with

95% confidence intervals (CIs; see Meyer et al. 2006). We used the stratified random sampling formulas from Scheaffer et al. (1996) to calculate population totals (τ) and variances ($\hat{V}[\tau]$):

$$\tau = \sum_{i=1}^{L} N_i \bar{y}_i$$

and

$$\hat{V}(\tau) = \sum_{i=1}^{L} N_i^2 \left(\frac{N_i - n_i}{N_i}\right)\left(\frac{s_i^2}{n_i}\right),$$

where N_i = number of 100-m sections in stream order i, $\bar{y}_i$ = average number of bull trout from samples obtained from stream order i, L = the number of stream orders, s_i^2 = the standard deviation for stream order i, and n_i = the sample size for stream order i. When data were unavailable for one or more of the first through fourth stream orders, abundance estimates were not calculated. Abundance was not extrapolated at the level of core area, because sample sizes were sufficient to produce estimates at only a few core areas. Sample sizes were also low for the Clark Fork, Kootenai, and Coeur d'Alene River recovery units, and we suggest caution in using estimates from these three units.

Our intention was to produce separate estimates for each of the three stream categories (bull trout present, bull trout absent, and status unknown), but only 7% of the total stream kilometers were in the unknown category and only 2% of the survey sites were located on stream segments belonging to the unknown category. Consequently, we lumped the unknown survey sites and stream segments together with the absent survey sites and stream segments for abundance estimation purposes. We assumed that the compiled data, although not randomly distributed, did not result in any directional bias (negative or positive) in our extrapolations of abundance, but we had no way of testing the validity of this assumption. However, results from Kadmon et al. (2003) suggest that estimates based on 50 or more widely distributed study sites would be minimally biased.

Population trends.—Long-term trends in bull trout abundance were available from snorkel surveys, redd counts, weir captures, and electrofishing surveys within five of the seven recovery units in Idaho. For trend analyses, we only included data sets if data were available for most (≥8) of the years between 1994 and 2003, which we defined as representing recent trends. Although data from the Little Lost River Recovery Unit did not meet this requirement, we included them in the analyses because they were the best available data for the unit and they spanned the entire time period. Trends from 10 additional streams with 2–7 years of data were obtained but were not included in our analyses because the period of record was short or incomplete.

Redd count trends were available in four core areas within three recovery units. Core area redd counts were total annual counts and included summed totals from one to six individual trend sites. Weir trends were available for two core areas in one recovery unit and were summarized simply as the total number of fish in the annual upstream spawning run. Electrofishing trend data were used only from the Little Lost River Recovery Unit and were reported as yearly average density of bull trout at four electrofishing sites.

The majority of trend data came from snorkeling surveys. Since 1985, daytime snorkel counts have been conducted by IDFG personnel working on Bonneville Power Administration-funded research projects; the counts are referred to as general parr monitoring (GPM). Although originally designed to track trends for anadromous species, observations on all resident fish are also recorded. Petrosky and Holubetz (1986) provide a detailed description of snorkel techniques and sampling designs. All sampling for GPM occurs in the Salmon River and Clearwater River recovery units only, and 2,075 snorkel sites have been created to date.

Although a wealth of snorkel data was available for individual core areas in the Salmon River and Clearwater River recovery units, most sites were not consistently snorkeled from year to year, causing concern regarding adequate temporal data dispersion. To ensure that the snorkel data represented bull trout population trends instead of sampling effort variability, we set a first criterion of using only those snorkel sites where multiple sampling events occurred in each decade (1980s, 1990s, and 2000s). The resulting set of 367 snorkel sites was further pared down for trend analyses using a second criterion. Because the 367 snorkel sites were not all surveyed in every year, for each 2-year interval we only included sites that were surveyed in both years to estimate the rate of population change for the interval. For example, if surveys within a core area were conducted at 20 sites for both 2002 and 2003, the rate of change for that core area from 2002 to 2003 was estimated by dividing the total number of fish counted at the 20 sites in 2003 by the total number counted at the same sites in 2002. Sites that were surveyed in only 1 of the 2 years were not included in the analyses. This technique helped reduce site selectivity bias in the data by converting count data (strongly affected by which sites were surveyed) to annual rates of change, which required sampling consistency between years for calculation

(Connelly et al. 2004). Sufficient long-term snorkel data were available for calculating trends in this manner for 10 core areas.

For the snorkel trend data, it was also possible to compare the trends of bull trout to those of other salmonids, including brook trout *S. fontinalis*, westslope cutthroat trout *Oncorhynchus clarkii lewisi*, Chinook salmon *O. tshawytscha*, steelhead *O. mykiss*, and mountain whitefish *Prosopium williamsoni*. For this comparison, we combined all the GPM data that met the original inclusion criterion of having multiple sample events in each of the three decades ($n = 367$ sites). The trends were based on an average of 233 observations/year.

To analyze trends in abundance, we used linear regression with sample year as the independent variable and $\log_e$ transformed snorkel and electrofishing survey data, redd counts, or weir captures as the dependent variable. The $\log_e$ transformations allowed us to linearize the regression model and caused the slope of each line to be equivalent to the intrinsic rate of change (r) for the population (Maxell 1999). Following the advice of Peterman (1990) and Maxell (1999), we used a significance level of 0.10 to increase the power of detecting true trends. Because values of zero are incompatible with $\log_e$ transformations and because no bull trout were counted during snorkeling for at least 1 of the 19 years within 8 of the 10 core areas, we replaced zero values with values of 0.01 bull trout/100 m to calculate r for the eight core areas. The insertions decreased the standard error for these data sets by less than 1% and changed the slope by less than 0.1% compared with the untransformed trend data. For slope coefficient parameter estimates, 90% CIs that did not include zero were considered statistically significant.

We analyzed trends for the period before 1994, the period after 1994, and the entire period of record for each data set. We chose 1994 as the inflection point for several reasons. First, the resulting 10-year period of record before and after 1994 for most trend data sets was considered a minimum period needed for trend analyses (Brook et al. 2000). Second, no-harvest regulations were implemented in Idaho during that year, and overharvest was considered to be a causative factor in bull trout population declines (Meehan and Bjornn 1991; USFWS 1998). Finally, simple examination of plots of abundance over time suggested that an inflection point existed at about 1994.

We quantified synchrony in bull trout abundance by calculating Pearson's product-moment correlation coefficients for all pairwise comparisons of trend data sets. Spurious correlations that might result from a time trend in our long-term trend data sets were minimized by detrending the data sets using linear regression residuals (Koenig 1999; Isaak et al. 2003). Because temporal autocorrelation within individual time series often results in liberal estimates of statistical significance (type I error) when calculating correlations between time series, statistical significance for each pairwise correlation was determined by comparing the observed correlation with reference distributions obtained by 1,000 randomizations of a time series (Howell 2002; Isaak et al. 2003). We tested whether the mean correlation coefficient was statistically significant based on whether the 95% CI overlapped zero. To assess whether synchrony was influenced by the proximity of sites (e.g., Isaak et al. 2003), we used linear regression analyses to relate synchrony to the areal distance between trend site locations.

Results

At the 1:100,000 scale, 77,447 km of stream were identified throughout the seven recovery units in Idaho and we compiled 2,521 surveys of bull trout abundance from these units (Figure 1). The survey data included 1,799 surveys by IDFG as well as additional data obtained from the USFS (607 survey sites), BLM (59 sites), and BOR (56 sites). Among stream reaches where survey sites were located, 18% were first order, 33% were second order, 23% were third order, 14% were fourth order, 10% were fifth order, and 2% were sixth order. The combined sample length of all survey sites was 220 km of stream, or 0.3% of the entire stream network within the bull trout recovery units in Idaho. At the workshops held across Idaho, the participating state, federal, tribal, and private fisheries professionals estimated that bull trout occurred in 14,551 km of stream, or 19% of the available stream length within the recovery units (Table 1).

Bull trout were captured in 887 (35%) of the survey sites, including 834 (46%) of 1,831 survey sites within stream segments classified as having bull trout present (Table 1). Of the 690 survey sites within stream segments classified as bull trout absent, bull trout were captured at 53 (8%) sites. Two of 45 sites within the stream segments of unknown status contained bull trout. Bull trout were most likely to occur at survey sites in second- and third-order streams (present at 40% of these sites) and were least likely to occur at survey sites in streams that were fifth order and higher (present at <20% of these sites).

Extrapolations of Abundance

We estimated there was a minimum of 1.13 million (±0.29 million) bull trout exceeding 70 mm TL in Idaho (Table 2). Sixty-six percent (0.75 million bull trout) of this estimate was derived from those stream segments categorized as containing bull trout. The

TABLE 2.—Number of U.S. Fish and Wildlife Service-designated local bull trout (BUT) populations (USFWS 2000), number of sites surveyed from 1997 to 2004, and estimates of total BUT abundance (with 95% confidence intervals [CIs]) for seven recovery units (RUs) in Idaho (see Table 1 for RU codes). Estimates for RUs were calculated separately from the statewide estimate; thus, the sum of RU estimates does not equal the statewide estimate. Blank spaces indicate estimates that were unavailable due to insufficient data.

		BUT status within segments							
		Present			Absent or unknown				
RU code	Populations	Sites	Abundance	±95% CI	Sites	Abundance	±95% CI	Total abundance	±95% CI
LLR	10	55	45,124	23,772	10	410	803	45,534	23,786
SWI	54	350	78,293	21,904	455	65,063	42,846	143,356	48,120
SAR	126	748	387,671	65,629	136	254,040	181,880	641,711	197,047
CLR	45	640	43,259	9,655	60	3,135	4,019	46,394	10,458
CFR	27	22	86,666	37,999	4				
KOR	0	13	16,572	8,541	3				
CDR	[a]	6			0				
Statewide	262	1,834	748,532	101,795	668	380,232	184,047	1,128,764	210,323

[a] Number of populations not designated for this RU.

remaining 34% (0.38 million bull trout) was estimated to occur in stream segments classified as bull trout absent or unknown status.

Over one-half (0.64 million bull trout) of the total abundance was estimated to occur in the Salmon River Recovery Unit, and the second-largest estimate of abundance occurred in the Southwest Idaho Recovery Unit (0.14 million bull trout). Individual extrapolations could not be made for the Coeur d'Alene River Recovery Unit. Estimates for two other recovery units (Kootenai River and Clark Fork River units) were based on very few samples and could only be made for segments classified as having bull trout present; therefore, the estimates for these units should be used cautiously.

Nearly all (95%) of the overall abundance of bull trout occurred in first- through third-order streams (Figure 2). First-order streams made up 46% of the total

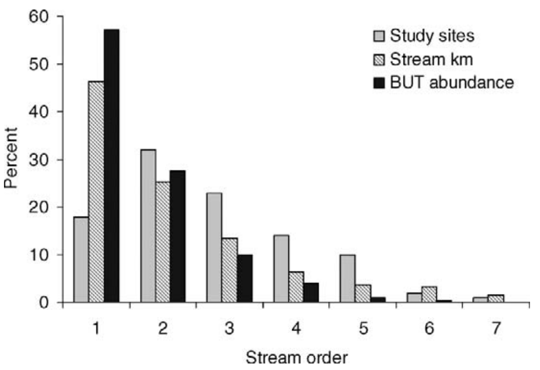

FIGURE 2.—Percentages of bull trout (BUT) survey sites, kilometers of stream surveyed, and total BUT abundance (total length > 100 mm) among first- through seventh-order streams in Idaho.

stream kilometers and 57% of the bull trout abundance but only 18% of the survey sites (Figure 2). Mean linear bull trout density (>70 mm TL) at all survey sites was highest in the Clark Fork River (22.1 fish/100 m) and Little Lost River (18.4 fish/100 m) recovery units and lowest in the Clearwater River (1.2 fish/100 m), Southwest Idaho (2.7 fish/100 m), and Salmon River (4.4 fish/100 m) recovery units (Figure 3). Estimates were less reliable for the three recovery units (Clark Fork, Kootenai, and Coeur d'Alene River units) from which little data were available. Average bull trout density among all recovery units was 10.3 fish/100 m, whereas the average density among all 2,521 survey sites (weighted equally) was 3.6 fish/100 m.

Population Trends

Visually, the trend data sets indicated that bull trout abundance generally declined in some areas of Idaho from the 1980s to the mid-1990s but was apparently stable in most areas and occasionally increased through 2003 in some recovery units (Figures 4, 5). Values of r were negative for 10 of 16 trend data sets before 1994 and were positive for 14 of 17 estimates after 1994 (Table 3). The 90% CIs were significant for three of the negative estimates and one of the positive estimates for pre-1994 trends; 90% CIs were significant for five positive estimates and one negative estimate for post-1994 trends. For all years of data combined (average = 19 years), trends were positive for eight estimates and negative for eight estimates, but only two positive and two negative trends were statistically significant.

Although the generally increasing trend in bull trout abundance over the decade preceding 2003 appeared to coincide with the implementation of the statewide no-harvest regulations in 1994, we found that for the long-term snorkel data in the Salmon River and Clearwater

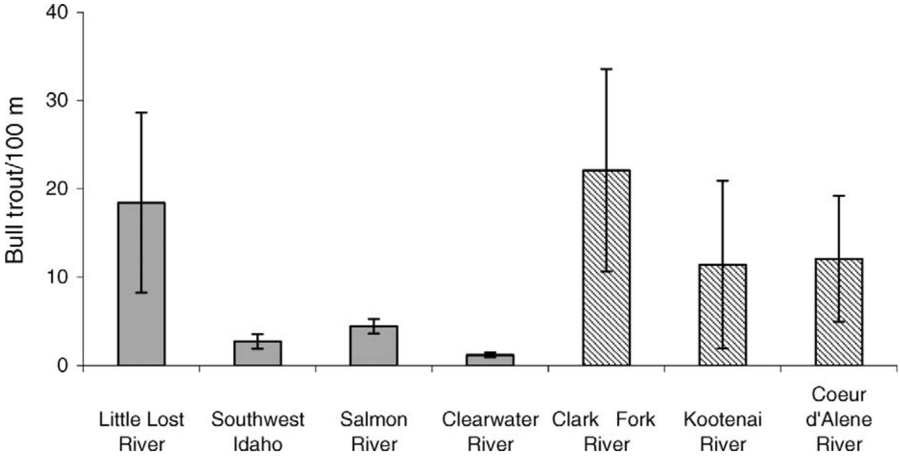

FIGURE 3.—Average (±95% confidence interval) linear bull trout density (fish/100 m) in seven recovery units in Idaho. Cross-hatched bars indicate recovery units for which data were sparse (i.e., these estimates were less reliable than the others).

River recovery units (i.e., GPM data set), abundances of all other salmonid species experienced statistically significant increases at the same time. The post-1994 estimate of r for the combined GPM data set ($n = 367$ sites) was 0.11 for bull trout and ranged from 0.07 to 0.20 for all other salmonids (Figure 6). None of the 90% CIs included zero, thus indicating that post-1994 growth values for bull trout and all other salmonids were statistically positive for the combined GPM data set. Bull trout abundance was positively correlated with abundances for all other salmonids but was most strongly correlated with the abundance of westslope cutthroat trout (correlation coefficient = 0.67). Furthermore, there were no negative correlations between abundances of any two salmonid species. For the 19 years of GPM data combined, r was estimated to be 0.01 ± 0.01 (mean ± 90% CI) for bull trout. The value of r ranged from −0.02 to 0.02 for all other salmonids for the entire time period, and the 90% CIs for all estimates overlapped zero.

We found little evidence of synchrony among detrended bull trout trend data sets (Table 4). Among correlation coefficients, 51 were positive (10 were significant) and 54 were negative (9 were significant). The mean correlation coefficient among all pairwise comparisons did not differ from zero (mean = 0.02; 95% CI = −0.02 to 0.08). There was no relationship between distance between trend site locations and the level of synchrony among populations (correlation coefficient = −0.01).

Discussion

Our results suggest that despite clear declines from historical distribution and abundance, bull trout in Idaho remain relatively widespread and abundant. In fact, bull trout were captured at 35% of all survey sites and 46% of sites designated as having bull trout present. These estimates are probably underestimates, since occupancy detection probability is typically much less than 1.0 (MacKenzie et al. 2006), especially for a cryptic species such as bull trout (Peterson et al. 2002; Peterson and Dunham 2003). Similarly, our estimate of over 1 million bull trout (age 1 and older) within the seven recovery units is probably less than the true overall abundance (see below). This estimate included both subadults and adults; although we realize that the number of spawning adults in a population is often considered crucial for the management of threatened species (Rieman and Allendorf 2001), estimation of adults only was not possible based on the available data. Nevertheless, the relative strength of bull trout populations in Idaho relative to that in other areas of the western United States (Rieman et al. 1997; Thurow et al. 1997) is unsurprising given the large expanses of protected wilderness areas (~23% of Idaho habitat) and other federal lands supporting bull trout habitat in Idaho, whereas an estimated 85% of ESA-listed species are in peril because of habitat loss (Wilcove et al. 1998).

Our results also suggest that bull trout abundance in Idaho is stable in most areas for which data were available; abundance may have even increased at some locations since the mid-1990s. Indeed, when considering data from the entire period of record, which on average started in 1985 and included the 13-year period leading up to the ESA listing of bull trout, most trends (12 of 16) were not statistically significant. Among the significant trends, there was equal balance between positive and negative (two of each type). For the

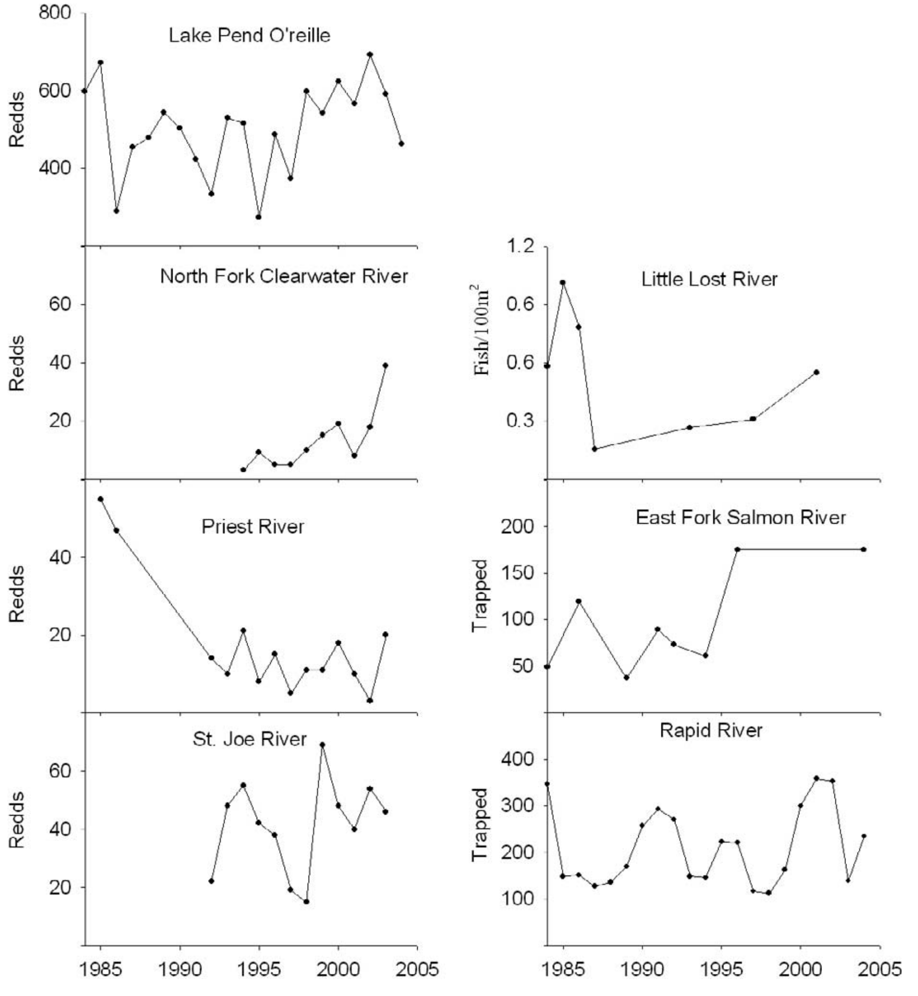

FIGURE 4.—Bull trout population trends in seven core areas of Idaho between 1984 and 2004; data were obtained via redd counts, electrofishing surveys (fish/100 m^2; Little Lost River only), and weir counts (number trapped; East Fork Salmon and Rapid rivers only).

combined GPM snorkeling data set only, *r* for the entire period of record was 0.01 ± 0.01 (mean ± 90% CI) for bull trout, again suggesting stability. After 1994, 14 of 17 bull trout trend data sets were positive, including five that were significantly positive; only one trend data set was significantly negative. In addition, for the combined GPM data set, post-1994 increasing trends were statistically significant for all salmonid species, including bull trout. The recent increasing trend for bull trout was especially true in the Clearwater River Recovery Unit, where three of four available post-1994 abundance trends were significantly positive.

Previous studies suggested that bull trout populations in Idaho were declining (Rieman and McIntyre 1993, 1996; Rieman and Myers 1997). However, in those studies, few of the trends analyzed were statistically significant and analyses were limited to redd count data that were collected until the mid-1990s. Our results concur with these earlier findings in that (1) among pre-1994 trends, most (75%) were not statistically significant and (2) among the significant trends, three were negative and only one was positive. Our post-1994 results showed a positive trend at some locations (Table 3), especially in the GPM data set (Figure 6). Unfortunately, our results include very little trend data for the Southwest Idaho, Kootenai River, Little Lost River, and Coeur d'Alene River recovery units; for the trend data that were available from these units, no survey sites were chosen at random. Clearly,

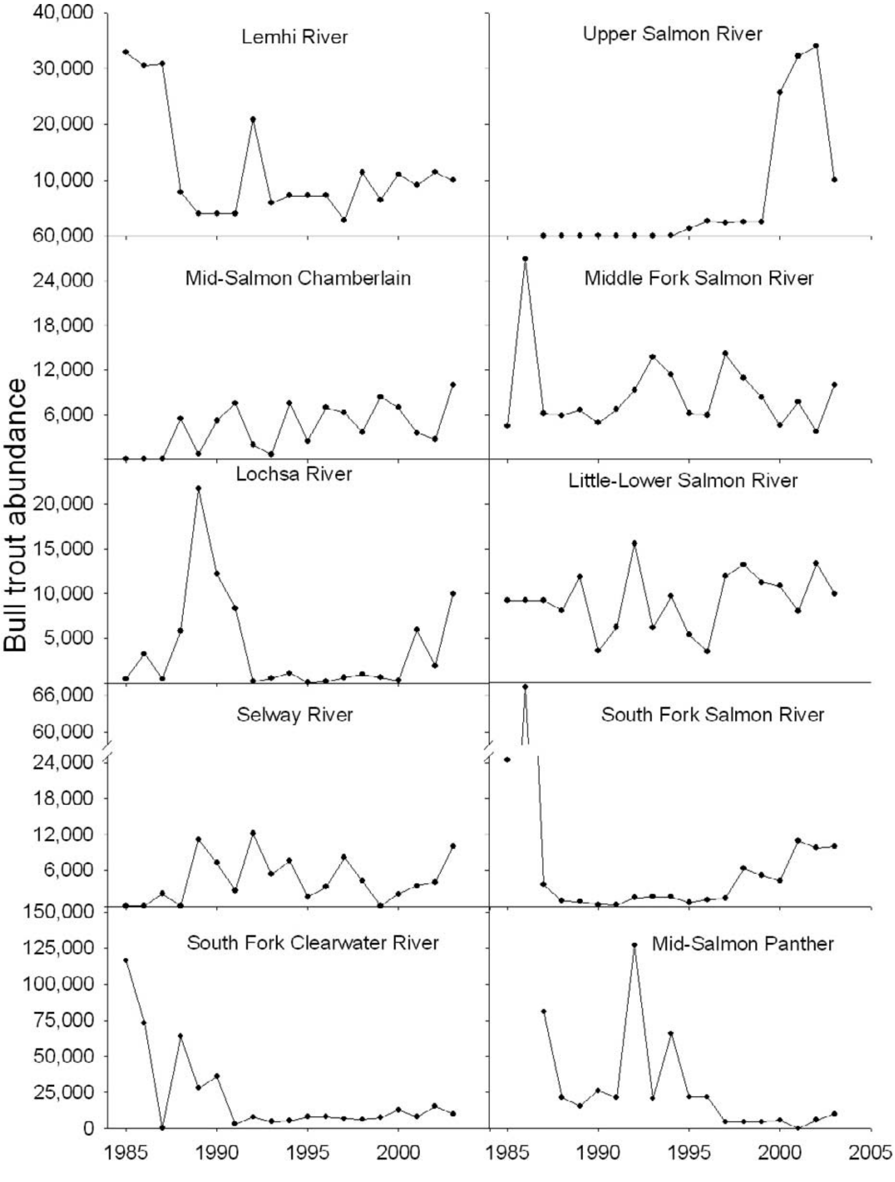

FIGURE 5.—Bull trout abundance estimates (see Methods) obtained via snorkel surveys conducted by the Idaho Department of Fish and Game at 367 general parr monitoring sites within 10 core areas of Idaho from 1985 to 2004 (Mid-Salmon = Middle Salmon River.

more information is needed from recovery units other than the Salmon River and Clearwater River units to definitively determine trends from these other areas.

Although our results suggest that bull trout in Idaho remain widely distributed and that abundance is stable for most populations with available trend data, we concede that such findings may not to hold true for the future. If current habitat and environmental conditions are maintained, bull trout populations in Idaho may fluctuate between periods of increasing and decreasing growth cycles over the next 50–100 years, and many populations can probably withstand periods of decline considering their current distribution, abundance, and potential connectivity. However, in the face of large-scale habitat alteration or thermal shifts (e.g., climatic changes due to global warming), reductions in current bull trout distribution and abundance are likely (Rieman et al. 2007).

TABLE 3.—Intrinsic rates of population change (r) with 90% confidence limits (CLs) for bull trout in 17 river drainages or core areas within five recovery units (RUs) of Idaho. The sampling method used in each drainage or area is shown (E = electrofishing, W = weir count, S = snorkeling, R = redd count). Trends in r were evaluated for the period before 1994, the period after 1994, and all years; asterisks indicate trends that were significant (i.e., confidence intervals did not include zero). Estimates that were unavailable due to inadequate data are indicated (NA).

Drainage or core area	Starting year	Years of record	Sites	Pre-1994 r			Post-1994 r			r for all years		
				Estimate	Lower CL	Upper CL	Estimate	Lower CL	Upper CL	Estimate	Lower CL	Upper CL
Little Lost River RU												
Little Lost River (E)	1984	6	22	−0.122	−0.373	0.129	0.091	−0.099	0.281	−0.025	−0.112	0.063
Salmon River RU												
Little–Lower Salmon River (S)	1985	19	34	−0.010	−0.097	0.077	0.063	−0.021	0.146	0.015	−0.016	0.045
Rapid River (W)	1973	32	1	−0.013	−0.039	0.012	0.047	−0.026	0.119	−0.001	−0.015	0.014
South Fork Salmon River (S)	1985	19	36	−0.365*	−0.670	−0.060	0.305*	0.200	0.411	0.032	−0.078	0.143
Middle Fork Salmon River (S)	1985	19	77	0.035	−0.082	0.152	−0.043	−0.131	0.046	−0.007	−0.043	0.030
Middle Salmon River–Chamberlain (S)	1985	16	10	−0.007	−0.456	0.443	0.006	−0.102	0.115	0.060	−0.017	0.138
Middle Salmon River–Panther (S)	1985	17	12	0.054	−0.195	0.303	−0.309*	−0.600	−0.018	−0.202*	−0.307	−0.096
Lemhi River (S)	1985	19	10	−0.176*	−0.335	−0.016	0.064	−0.016	0.144	−0.038	−0.089	0.014
East Fork Salmon River (W)	1984	8	1	0.003	−0.115	0.121	0.075	−0.474	0.624	0.057*	0.001	0.114
Upper Salmon River (S)	1985	17	25	0.068	−0.103	0.240	0.536*	0.312	0.759	0.557*	0.453	0.660
Clearwater River RU												
North Fork Clearwater River (R)	1994	10	4	NA	NA	NA	0.210*	0.097	0.324	NA	NA	NA
South Fork Clearwater River (S)	1985	19	85	−0.231	−0.617	0.156	0.075*	0.025	0.125	−0.052	−0.153	0.049
Selway River (S)	1985	19	26	0.546*	0.243	0.848	0.007	−0.303	0.317	0.123	−0.003	0.250
Lochsa River (S)	1985	19	43	−0.056	−0.418	0.306	0.344*	0.107	0.581	−0.026	−0.150	0.098
Clark Fork River RU												
Priest River (R)	1985	14	5	−0.158*	−0.269	−0.048	−0.033	−0.167	0.101	−0.093*	−0.147	−0.038
Lake Pend Oreille (R)	1984	21	6	−0.012	−0.057	0.032	0.041	−0.001	0.082	0.009	−0.007	0.025
Coeur d'Alene River RU												
St. Joe River (R)	1992	12	1	0.458	−0.716	1.632	0.029	−0.074	0.131	0.032	−0.040	0.104

The timing of an apparent increasing trend for bull trout in some recovery units in Idaho coincided with the statewide ban on harvest. However, anadromous waters in our study (Salmon River and Clearwater River recovery units) showed a significant post-1994 increase in abundance for all salmonid species (not just bull trout), suggesting that decreased fishing mortality of bull trout was not the only factor contributing to this increase. The recent positive trends may be attributable to more-favorable habitat conditions in terms of stream water temperature (Dunham et al. 2003), drought (Elliott et al. 1997), productivity (e.g., due to increased returns of anadromous fish; Schmidt et al. 1998; Wipfli et al. 1999; Scheuerell and Williams 2005), or some combination of these factors or unknown factors influencing large geographical areas. A better understanding of the proportion of total salmonid abundance made up of bull trout would better clarify the species' status relative to co-occurring native and nonnative salmonids, some of which may affect bull trout persistence. For example, brook trout negatively affect bull trout populations through competition (Gunckel et al. 2002; Rieman et al. 2006) and hybridization (Spruell et al. 2001; Kanda et al. 2002). In Idaho, brook trout potentially pose a considerable risk to bull trout populations, because 42% of the 262 local bull trout populations are sympatric with brook trout (Table 5). Despite the fact that overall trends for bull trout and brook trout appeared to be concurrently increasing in the Salmon River and Clearwater River recovery units, site-specific correlations were not investigated, and we suspect them to be negative. Further research determining the relationship between sympatric bull trout and brook trout in these drainages would be useful.

Several limitations inherent in the compiled data may have weakened the conclusions drawn from our estimates of bull trout distribution and abundance. First, data available from the Clark Fork River, Kootenai River, and Coeur d'Alene River recovery units were limited, making it difficult to draw any conclusions about bull trout abundance in these areas. The remaining recovery units contained sufficient data to extrapolate abundance, but the distribution of the study sites was nonrandom, thus weakening the inferences that could be drawn regarding bull trout abundance. The nonrandom nature of the data was

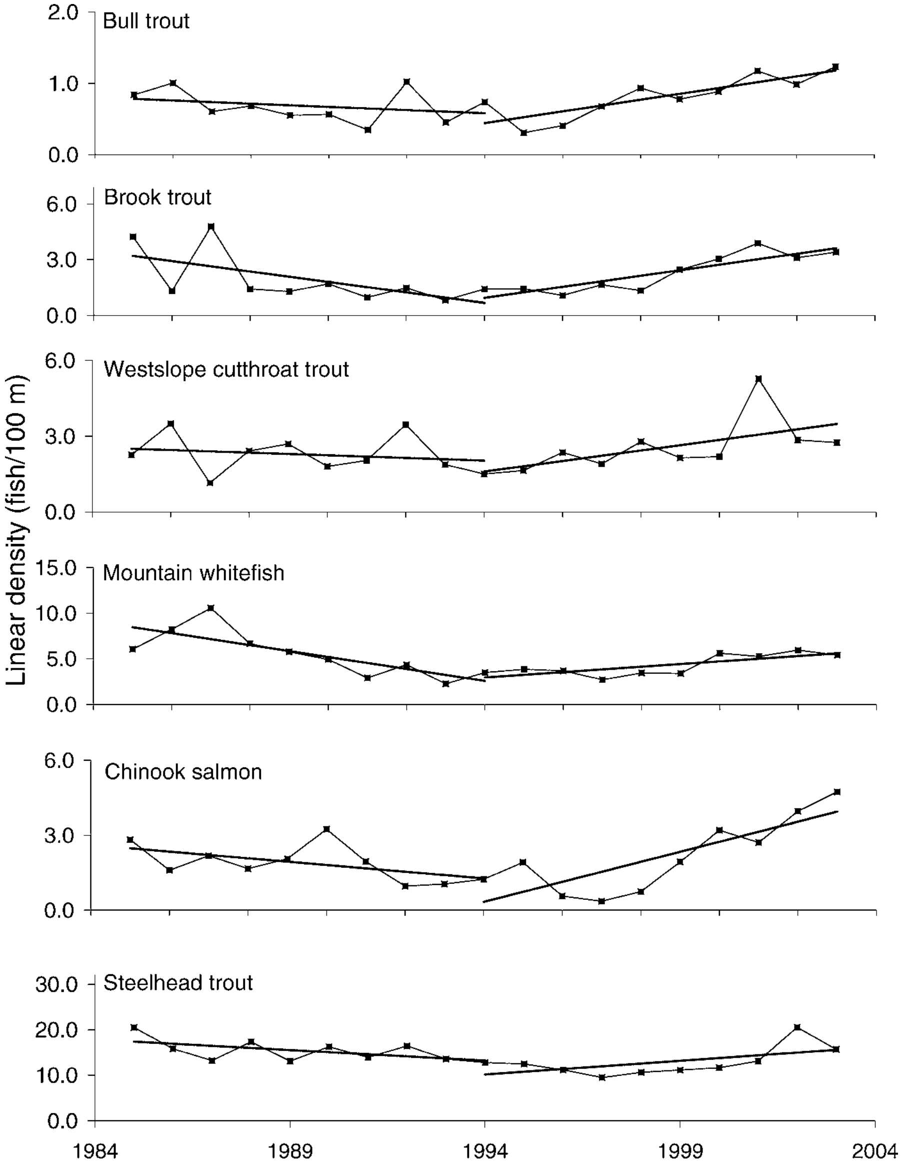

FIGURE 6.—Average linear densities (fish/100 m), pre-1994 trend lines, and post-1994 trend lines for six salmonid species surveyed via snorkeling by the Idaho Department of Fish and Game at 367 general parr monitoring sites in Idaho, 1985–2003.

evidenced by the fact that bull trout were estimated as present in only 19% of the total stream kilometers within the seven recovery units, yet 73% of the sites were distributed within stream reaches designated as having bull trout present. We controlled for this potential source of bias by extrapolating abundances separately for streams in the bull trout present category and those in the bull trout absent and unknown status categories. Also, the sheer volume of study sites (>2,500) alleviated much of our concern about the nonrandom nature of the data (Kadmon et al. 2003). Nevertheless, our study highlights the need for bull trout abundance data collection at more randomly distributed areas throughout the species' range in Idaho and the coterminous USA.

Second, biologists at the workshops were usually—but not always—able to pinpoint the upper range of bull trout for each individual stream. When the upper range was unknown and the biologists were reluctant to speculate where the distribution of bull trout ended, we

TABLE 4.—Pearson's product-moment correlation coefficients for all pairwise comparisons of detrended residuals from bull trout abundance estimates (obtained by redd counts, weir counts, and snorkeling) at 15 sites monitored for short and long-term population trends (significant correlations: $*P < 0.05$).

Site	LLS	RAP	SFS	MFS	MSC	MSP	LEM	USR	NFC	SFC	SEL	LOC	PRR	LPO	STJ
Little–Lower Salmon River (LLS)	1.00														
Rapid River (RAP)	−0.15	1.00													
South Fork Salmon River (SFS)	0.15	−0.03	1.00												
Middle Fork Salmon River (MFS)	0.16	−0.35*	0.70	1.00											
Middle Salmon River–Chamberlain (MSC)	−0.30	−0.18	−0.26	−0.10	1.00										
Middle Salmon River–Panther (MSP)	0.43*	0.10	0.03	0.13	−0.13	1.00									
Lemhi River (LEM)	0.40	−0.01	0.59*	0.18	−0.44*	0.61*	1.00								
Upper Salmon River (USR)	0.01	0.50	0.21	−0.52*	−0.32	−0.03	0.23	1.00							
North Fork Clearwater River (NFC)	−0.12	−0.62	−0.05	0.35	0.77*	0.44	−0.11	−0.46	1.00						
South Fork Clearwater River (SFC)	0.11	0.02	0.53*	−0.01	−0.06	−0.36	0.34	0.34	−0.12	1.00					
Selway River (SEL)	0.29	0.01	−0.48*	−0.01	−0.02	0.39	−0.41	−0.30	0.03	−0.51*	1.00				
Lochsa River (LOC)	−0.05	0.25	−0.21	−0.22	0.06	−0.50*	−0.58*	0.23	−0.30*	−0.05	0.35	1.00			
Priest River (PRR)	−0.10	−0.19	−0.01	0.02	0.68*	0.35*	0.17	−0.41*	0.61*	−0.06	0.13	−0.09	1.00		
Lake Pend Oreille (LPO)	0.10	0.12	−0.07	−0.44	−0.08	−0.28	0.15	0.41*	−0.13	0.47*	−0.19	0.18	0.18	1.00	
St. Joe River (STJ)	−0.31	0.10	−0.02	−0.26	0.24	−0.05	−0.23	0.07	0.33	0.01	−0.33	−0.05	0.21	0.23	1.00

assumed that bull trout were present up to the uppermost end of perennial streamflow. Since 57% of the overall bull trout abundance occurred in first-order streams, an overestimation here would have positively biased our overall bull trout distribution and abundance estimates. Bull trout are considered to be rare in streams with mean wetted widths less than 2 m (Dunham and Rieman 1999), but in our study bull trout were present at 28% of the 300 first-order study sites for which (1) width data were available and (2) mean width was 2 m or less.

Third, GPM sites were originally established to monitor anadromous salmonid populations (Petrosky and Holubetz 1986); thus, they contain a disproportionately high number of density estimates for third- and higher-order river sites. However, we estimated that most of the bull trout abundance occurred in lower-order streams. We attempted to control for any bias stemming from this incongruity by stratifying our estimates by stream order.

Fourth, we used snorkel and depletion (mostly one-pass) electrofishing data to estimate bull trout abundance, and these methods are known to underestimate occurrence (Peterson et al. 2002; Peterson and Dunham 2003) and abundance (e.g., Thurow and Schill 1996; Kruse et al. 1998; Mullner et al. 1998; Peterson et al. 2004). Furthermore, neither age-0 bull trout nor lentic environments were included in abundance estimates; these two exclusions ostensibly removed a sizeable portion of overall abundance. Finally, we extrapolated bull trout abundances based on stream kilometers calculated from 1:100,000-scale maps, but Shepard et al. (2005) found that the number of stream kilometers was 35% greater at the 1:24,000 scale than the 1:100,000 scale. It is likely that bull trout inhabit streams that are found on 1:24,000-scale maps but not on 1:100,000-scale maps; such streams were thus not included in our estimates. Since bull trout were relatively common in small streams (i.e., <2 m wide) in our study, the exclusion of these fish may have been substantial. Thus, the CIs reported here are applicable to the estimates we developed but not necessarily to the true population abundance, although they serve to illustrate the relative precision of the estimates.

We had little or no control over the above limitations; taken together, they undoubtedly reduced the precision and reliability of our estimates of bull trout distribution and abundance. Considering all potential sources of bias, we believe that bull trout distribution and abundance were probably underestimated for most recovery units. Nevertheless, we felt that such conservative estimates provided useful information for this status assessment.

Although our trend analyses indicated that many bull trout populations declined before 1994 and increased after 1994, once the data were detrended we found little evidence of synchrony among bull trout populations. Indeed, for the entire period of record, pairwise comparisons of populations produced nearly as many significantly negative correlations (9) as significantly positive correlations (10). We also found no evidence of a decrease in synchrony as distance between sites increased (coefficient of determination $r^2 < 0.01$), concurring with previous research that found statistically significant but similarly weak ($r^2 = 0.03$) relationships between distance and synchrony in Idaho bull trout (Rieman and McIntyre 1996). A study of Chinook salmon in Idaho found a stronger correlation between synchrony and the distance between populations (Isaak et al. 2003). These results suggest that Idaho bull trout populations at the spatial scale we investigated are not well connected with regard to dispersal and straying or have not declined to a point where higher synchrony rates would be observed.

We chose not to quantify the amount of bull trout historical range currently occupied because of the difficulty in delineating actual historical distribution. Rieman et al. (1997) estimated that in the mid-1990s, bull trout occupied about 44% of their former range; the estimate was based on patch occupancy rather than actual kilometers of stream occupied, and no estimate was given for Idaho. As mentioned above, the results from workshops used to designate bull trout status at all stream segments suggested that bull trout currently occupy 14,551 km, or 19% of the total stream kilometers, within the seven recovery units in Idaho. However, bull trout were found at less than half (46%) of the sample sites within segments classified as having bull trout present and were also found at 8% of survey sites outside of the species' presumed current range. Such a disparity may partly be the result of misclassification by the biologists participating in the workshops and to the difficulty of detecting bull trout when abundance is low (Peterson and Dunham 2003); detection may also be affected by the high mobility of bull trout and by their use of some habitats only seasonally (Swanberg 1997; Jakober et al. 1998; Baxter and Hauer 2000). Nevertheless, we believe that the proportion of currently unoccupied range that was historically occupied by bull trout is unknown and unknowable (compare Meyer et al. 2006) and therefore less important than current abundance estimates and population trends.

TABLE 5.—Number of local bull trout populations identified in the draft recovery plan (USFWS 2000) that are present in core areas of seven Idaho recovery units (RUs), and the number of local populations that are sympatric with nonnative brook trout.

Core area	Local populations	Local populations with brook trout
Little Lost River RU		
Little Lost River	10	3
Southwest Idaho RU		
Anderson Ranch	15	2
Arrowrock	15	4
Lucky Peak	1	1
Deadwood River	5	0
Squaw Creek	2	2
Upper South Fork Payette River	9	3
Middle Fork Payette River	1	1
North Fork Payette River	1	1
Weiser River	5	2
Salmon River RU		
Upper Salmon River	18	13
Pahsimeroi River	9	5
Lemhi River	6	4
Lake Creek	1	0
Middle Salmon River–Panther	20	11
Opal Lake	1	0
Middle Fork Salmon River	28	19
Middle Salmon River–Chamberlain	9	5
South Fork Salmon River	27	5
Little–Lower Salmon River	7	4
Clearwater River RU		
North Fork Clearwater River	11	3
Fish Lake (North Fork Clearwater River)	1	0
Lochsa River	16	1
Fish Lake (Lochsa River)	1	0
Selway River	10	3
South Fork Clearwater River	5	3
Middle Lower Clearwater River	1	1
Clark Fork River RU		
Lake Pend Oreille	15	3
Priest Lake	12	11
Kootenai River RU		
Kootenai River	0	0
Coeur d'Alene River RU		
Coeur d'Alene Lake basin	[a]	0

[a] Number of populations not designated for this RU.

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References

Allendorf, F. W., D. Bayles, D. L. Bottom, K. P. Currens, C. A. Frissell, D. Hankin, J. A. Lichatowich, W. Nehlsen, P. C. Trotter, and T. H. Williams. 1997. Prioritizing Pacific salmon stocks for conservation. Conservation Biology 11:140–152.

Baxter, C. V., and F. R. Hauer. 2000. Geomorphology, hyporheic exchange, and selection of spawning habitat by bull trout (*Salvelinus confluentus*). Canadian Journal of Fisheries and Aquatic Sciences 57:1470–1481.

Behnke, R. J. 2002. Trout and salmon of North America. Free Press, New York.

Brook, B. W., J. J. O'Grady, A. P. Chapman, M. A. Burgman, H. R. Akcakaya, and R. Frankham. 2000. Predictive accuracy of population viability analysis in conservation biology. Nature (London) 404:385–387.

Connelly, J. W., S. T. Knick, M. A. Schroeder, and S. J. Stiver. 2004. Conservation assessment of greater sage-grouse and sagebrush habitats. Western Association of Fish and Wildlife Agencies, Cheyenne, Wyoming. Available: http://sagemap.wr.usgs.gov. (June 2006).

Dennis, B., P. L. Munholland, and J. M. Scott. 1991. Estimation of growth and extinction parameters for endangered species. Ecological Monographs 61:115–143.

Dunham, J. B., and B. E. Rieman. 1999. Metapopulation structure of bull trout: influences of physical, biotic, and geometrical landscape characteristics. Ecological Applications 9:642–655.

Dunham, J. B., B. E. Rieman, and G. L. Chandler. 2003. Influences of temperature and environmental variables on the distribution of bull trout within streams at the southern margin of its range. North American Journal of Fisheries Management 23:894–904.

Dunham, J. B., B. E. Rieman, and K. Davis. 2001. Sources and magnitude of sampling error in redd counts for bull trout. North American Journal of Fisheries Management 21:343–352.

Elliott, J. M., M. A. Hurley, and J. A. Elliott. 1997. Variable effects of droughts on the density of a sea-trout *Salmo trutta* population over 30 years. Journal of Applied Ecology 34:1229–1238.

Gunckel, S. L., A. R. Hemmingsen, and J. L. Li. 2002. Effect of bull trout and brook trout interactions on foraging habitat, feeding behavior, and growth. Transactions of the American Fisheries Society 131:1119–1130.

Howell, D. C. 2002. Statistical methods for psychology. Duxbury Press, Belmont, California.

Isaak, D. J., R. F. Thurow, B. E. Rieman, and J. B. Dunham. 2003. Temporal variation in synchrony among Chinook salmon (*Oncorhynchus tshawytscha*) redd counts from a wilderness area in central Idaho. Canadian Journal of Fisheries and Aquatic Sciences 60:840–848.

Jakober, M. J., T. E. McMahon, R. F. Thurow, and C. G. Clancy. 1998. Role of stream ice on fall and winter movements and habitat use by bull trout and cutthroat trout in Montana headwater streams. Transactions of the American Fisheries Society 127:223–235.

Kadmon, R., O. Farber, and A. Danin. 2003. A systematic analysis of factors affecting the performance of climatic envelope models. Ecological Applications 13:853–867.

Kanda, N., R. F. Leary, and F. W. Allendorf. 2002. Evidence of introgressive hybridization between bull trout and brook trout. Transactions of the American Fisheries Society 131:722–782.

Koenig, W. D. 1999. Spatial autocorrelation of ecological phenomena. Trends in Ecology and Evolution 14:22–25.

Kruse, C. G., W. A. Hubert, and F. J. Rahel. 1998. Single-pass electrofishing predicts trout abundance in mountain streams with sparse habitat. North American Journal of Fisheries Management 18:940–946.

Lohr, S., T. Cummings, W. Fredenberg, and S. Duke. 2000. Listing and recovery planning for bull trout. Pages 80–87 *in* D. Schill, S. Moore, P. Byorth, and B. Hamre, editors. Wild Trout VII: Management in the new millennium, are we ready? Yellowstone National Park, Wyoming.

Mace, G. M., and R. Lande. 1991. Assessing extinction threats: toward a reevaluation of IUCN threatened species categories. Conservation Biology 5:148–157.

MacKenzie, D. I., J. D. Nichols, J. A. Royle, K. H. Pollock, L. L. Bailey, and J. E. Hines. 2006. Occupancy estimation and modeling: inferring patterns and dynamics of species occurrence. Academic Press, London.

Maxell, B. A. 1999. A power analysis on the monitoring of bull trout stocks using redd counts. North American Journal of Fisheries Management 19:860–866.

Meehan, W. R., and T. C. Bjornn. 1991. Salmonid distributions and life histories. Pages 47–82 *in* W. R. Meehan, editor. Influences of forest and rangeland management on salmonids fishes and their habitats. American Fisheries Society, Special Publication 19, Bethesda, Maryland.

Meyer, K. A., D. J. Schill, J. A. Lamansky, Jr., M. R. Campbell, and C. C. Kozfkay. 2006. Status of Yellowstone cutthroat trout in Idaho. Transactions of the American Fisheries Society 135:1329–1347.

Mullner, S. A., W. A. Hubert, and T. A. Wesche. 1998. Snorkeling as an alternative to depletion electrofishing for estimating abundance and length-class frequencies of trout in small streams. North American Journal of Fisheries Management 18:947–953.

Peterman, R. M. 1990. Statistical power analysis can improve fisheries research and management. Canadian Journal of Fisheries and Aquatic Sciences 47:2–15.

Peterson, J. T., and J. B. Dunham. 2003. Combining inferences from models of capture efficiency, detectability, and suitable habitat to classify landscapes for conservation of threatened bull trout. Conservation Biology 17:1070–1077.

Peterson, J. T., J. B. Dunham, P. Howell, R. Thurow, and S. Bonar. 2002. Protocol for detecting bull trout presence. Western Division of the American Fisheries Society, unpublished report.

Peterson, J. T., R. F. Thurow, and J. W. Guzevich. 2004. An evaluation of multipass electrofishing for estimating the abundance of stream-dwelling salmonids. Transactions of the American Fisheries Society 133:462–475.

Peterson, N. P., and C. J. Cederholm. 1984. A comparison of the removal and mark-recapture methods of population estimation for juvenile coho salmon in a small stream. North American Journal of Fisheries Management 4:99–102.

Petrosky, C. E., and T. C. Holubetz. 1986. Idaho habitat evaluation of off-site mitigation record. Annual report to

Bonneville Power Administration, Project 83-7, Idaho Department of Fish and Game, Boise.

Ratliff, D. E., and P. J. Howell. 1992. The status of bull trout populations in Oregon. Pages 10–17 *in* P. J. Howell and D. V. Buchanan, editors. Proceedings of the Gearhart Mountain bull trout workshop. American Fisheries Society, Oregon Chapter, Corvallis.

Reynolds, J. B. 1996. Electrofishing. Pages 221–254 *in* B. Murphy and D. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Rieman, B. E., and F. W. Allendorf. 2001. Effective population size and genetic conservation criteria for bull trout. North American Journal of Fisheries Management 21:756–764.

Rieman, B. E., D. Isaak, S. Adams, D. Horan, D. Nagel, C. Luce, and D. Myers. 2007. Anticipated climate warming effects on bull trout habitats and populations across the Interior Columbia River Basin. Transactions of the American Fisheries Society 136:1552–1565.

Rieman, B. E., D. L. Lee, and R. F. Thurow. 1997. Distribution, status, and likely future trends of bull trout within the Columbia River and Klamath River basins. North American Journal of Fisheries Management 17:1111–1125.

Rieman, B. E., and J. D. McIntyre. 1996. Spatial and temporal variability in bull trout redd counts. North American Journal of Fisheries Management 16:132–141.

Rieman, B. E., and J. D. McIntyre. 1993. Demographic and habitat requirements for the conservation of bull trout *Salvelinus confluentus*. U.S. Forest Service General Technical Report INT-302.

Rieman, B. E., and D. L. Myers. 1997. Use of redd counts to detect trends in bull trout (*Salvelinus confluentus*) populations. Conservation Biology 11:1015–1018.

Rieman, B. E., J. T. Peterson, and D. L. Myers. 2006. Have brook trout (*Salvelinus fontinalis*) displaced bull trout (*Salvelinus confluentus*) along longitudinal gradients in central Idaho streams? Canadian Journal of Fisheries and Aquatic Sciences 63:63–78.

Scheaffer, R. L., W. Mendenhall, and L. Ott. 1996. Elementary survey sampling, 5th edition. Duxbury Press, Belmont, California.

Scheuerell, M. D., and J. G. Williams. 2005. Forecasting climate-induced changes in the survival of Snake River spring/summer Chinook salmon (*Oncorhynchus tshawytscha*). Fisheries Oceanography 14:448–457.

Schmidt, D. C., S. R. Carlson, G. B. Kyle, and B. P. Finney. 1998. Influence of carcass-derived nutrients on sockeye salmon productivity of Karluk Lake, Alaska: importance in the assessment of an escapement goal. North American Journal of Fisheries Management 18:743–763.

Shepard, B. B., B. May, and W. Urie. 2005. Status and conservation of westslope cutthroat trout in the western United States. North American Journal of Fisheries Management 25:1426–1440.

Spruell, P., M. L. Barton, N. Kanda, and F. W. Allendorf. 2001. Detection of hybrids between bull trout (*Salvelinus confluentus*) and brook trout (*Salvelinus fontinalis*) using PCR primers complementary to interspersed nuclear elements. Copeia 2001:1093–1099.

Strahler, A. N. 1964. Quantitative geomorphology of drainage basins and channel networks. Section 4-2 *in* V. T. Chow, editor. Handbook of applied hydrology. McGraw-Hill, New York.

Swanberg, T. R. 1997. Movements of and habitat use by fluvial bull trout in the Blackfoot River, Montana. Transactions of the American Fisheries Society 126:735–746.

Thurow, R. F., D. C. Lee, and B. E. Rieman. 1997. Distribution and status of seven native salmonids in the interior Columbia River basin and portions of the Klamath River and Great basins. North American Journal of Fisheries Management 17:1094–1110.

Thurow, R. F., and D. J. Schill. 1996. Comparison of day snorkeling, night snorkeling, and electrofishing to estimate bull trout abundance and size structure in a second-order Idaho stream. North American Journal of Fisheries Management 16:314–323.

USFWS (U.S. Fish and Wildlife Service). 1998. Final rule to list Columbia River and Klamath River population segments of the bull trout as a threatened species. Federal Register 63:31647–31674.

USFWS. 2000. Bull trout draft recovery plan. U.S. Fish and Wildlife Service. Available: www.fws.gov/pacific/bulltrout/colkla/recovery/ (December 2005).

Van Deventer, J., and W. S. Platts. 1989. Microcomputer software system for generating population statistics from electrofishing data: user's guide for MicroFish 3.0. U.S. Forest Service General Technical Report INT-254.

Wilcove, D. S., D. Rothstein, J. Dubow, A. Phillips, and E. Losos. 1998. Quantifying threats to imperiled species in the United States. BioScience 48:607–617.

Wipfli, M. S., J. P. Hudson, Dominic T. Chaloner, and J. P. Caouette. 1999. Influence of salmon spawner densities on stream productivity in southeast Alaska. Canadian Journal of Fisheries and Aquatic Sciences 56:1600–1611.