USFWS Bull Trout Workshop
Wednesday, October 31 2001 to Thursday, November 1 2001
Resort at the Mountain, Welches, OR

Workshop Report
May 7, 2002

Prepared by:

ESSA Technologies Ltd.
300-1765 W. 8th Ave.
Vancouver, B.C.
CANADA V6J 5C6

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1. Introduction

Bull trout (*Salvelinus confluentus*) in the coterminous United States were listed as threatened, under the Endangered Species Act, on November 1, 1999 (64 FR 58910). Earlier rulemakings had listed distinct population segments (DPSs – see Glossary for definition of terms) of bull trout as threatened in the Columbia River, Klamath River, and Jarbidge River basins (63 FR 31647, 63 FR 42757, 64 FR 17110). Although bull trout occurs in scattered localities in the Columbia, Klamath, Jarbidge, and St. Mary-Belly rivers, bull trout distribution and abundance, and habitat quality have declined over the entire range.

Numerous factors played a role in the decision to list bull trout as threatened. These include impacts of dams, forest management practices, livestock grazing, road construction and maintenance, mining, residential development, and non-native species.

The U.S. Fish and Wildlife Service (USFWS) is presently finishing a draft Recovery Plan for bull trout. Recovery of bull trout will require reducing threats to long-term persistence of populations, maintaining multiple interconnected populations of bull trout across diverse habitats of their native range and preserving life-history diversity. Specific draft objectives are to: 1) Maintain current distribution of bull trout and restore distribution in previously occupied areas; 2) Maintain stable or increasing trends in abundance of bull trout in all recovery units; 3) Restore and maintain suitable habitat conditions for all bull trout life history stages and strategies; and 4) Conserve genetic diversity and provide opportunity for genetic exchange.

Given the wide ranging nature of bull trout and the scale at which populations may be structured, an important component of effective recovery planning is to develop standardized guidance for monitoring and assessing the status of bull trout populations. Accurate assessment of population trends, distribution, and response to recovery actions is essential to evaluating recovery implementation. The utility of monitoring and evaluation is to aid decision-making. The success of a monitoring and evaluation program is reliant on the clarity and relevance of the questions asked of the program. Therefore, the first step of the monitoring and evaluation program is to specifically identify the questions to be answered relative to the recovery objectives.

Also in December 2000, the USFWS issued a Biological Opinion (BiOp) on the Effects to Listed Species from Operation of the Federal Columbia River Power System (FCRPS). As detailed in the BiOp, bull trout are clearly impacted by the FCRPS. For example, bull trout have been observed in the Bonneville Pool, The Dalles Dam reservoir, and below Bonneville Dam. It is also clear that bull trout in the tributaries are impacted by the FCRPS. For example, bull trout from the Imnaha, Grande Ronde, Tucannon, Wenatchee, Methow, and Umatilla rivers have been observed in mainstem areas of the Snake and Columbia rivers. Indirect effects of the FCRPS are not well understood, but are probably substantial. Loss of anadromous fish in the basin likely represents a significant loss of a cold-water prey base for bull trout, and loss of energy and marine-derived nutrients from the ecosystem. Attempts to offset the loss of anadromous fisheries have prompted numerous hatchery operations and introductions of nonnative trout. The effects of these mitigation activities may have less obvious impacts on bull trout, but may be as significant as the direct effects of the FCRPS. Thus, it is likely that FCRPS activities have impacted bull trout far from the hydropower projects and the mainstem Columbia River.

A limited number of scattered investigations have provided information on the abundance and distribution of bull trout populations in the Columbia River basin. These studies have focused on life history requirements, and habitat needs such as the use of migratory corridors and spawning and rearing habitats. There is currently no coordinated monitoring program for bull trout, and there is no framework for understanding the biology of the species to serve monitoring and evaluation needs for recovery planning. This information is critical to all efforts to conserve and protect this species. The BiOP identifies FCRPS requirements for listed bull trout and specifies reasonable and prudent measures (i.e. 10.A.2.1 and 10.A.3.1) as well as terms and conditions to implement the reasonable and prudent measures. Furthermore, the BiOP characterizes the legal obligations that all of the *Action Agencies* (Bonneville Power Authority, US Army Corps of Engineers, Bureau of Reclamation) have relative to Endangered Species Act (ESA) and bull trout with respect to the effects of the FCRPS.

Because very little information is available to determine the effects of FCRPS operations, one focus of the BiOP is to develop an understanding of the use of tributary streams by populations of bull trout and the status of these populations. Much of the bull trout information in tributary streams is limited and has been collected incidental to salmon and steelhead work. Thus, many sampling methods and monitoring approaches were developed without specifically considering the biology of bull trout. Existing evidence suggests that effective monitoring and evaluation for bull trout must include these considerations (Peterson et al. 2001). Furthermore, methods for monitoring and evaluation of bull trout are limited in their development, and much uncertainty remains. Critical information on the effects of FCRPS operations will require developing an understanding of bull trout abundance, life history, and migration behavior in key tributary streams where bull trout occur as well as their connectivity to the mainstem. This information is necessary to assess accurately trends in population abundance, distribution and the response of bull trout to FCRPS recovery actions. Thus, as part of their ESA responsibilities, it is essential that all *Action Agencies* support ongoing and new work to gain information on bull trout in the tributaries as well as in mainstem areas.

The USFWS seeks input from a variety of experts on developing guidance for implementing a coordinated region wide bull trout monitoring and evaluation program for evaluating recovery and Biological Opinion actions. To this end, the USFWS convened a workshop at the Resort at The Mountain on October 31-November 1, 2001 to initiate discussion of Recovery Monitoring and Evaluation (RME) of ESA-listed Columbia River bull trout populations. The workshop was attended by 37 participants from federal, state, tribal, provincial, and academic institutions and agencies throughout the Pacific Northwest and Canada, and was facilitated by David Marmorek and Calvin Peters of ESSA Technologies Ltd. (a participant list is provided in Appendix A). The USFWS has established a website for the Bull Trout workshop at http://pacific.fws.gov/crfpo/programs/bulltrout.htm. The workshop agenda and other workshop documents are available from this website.

Specific objectives of the workshop were to:
- Initiate dialogue on consistent monitoring protocols for indicators of population status and an overall design of a monitoring and evaluation program that will support USFWS recovery assessments;
- Discuss various types of monitoring and evaluation challenges in doing recovery assessments, explore potential solutions to these problems, and set future directions; and
- Assess the utility of forming a standing Recovery Monitoring and Evaluation Technical Advisory Group, and possible tasks for such a group.

Day 1 of the workshop consisted of a series of presentations summarizing:
1. Background on recovery planning, status, and current information for Columbia River Bull Trout and the importance of RME
2. Population structure
3. Evaluation of current methods for monitoring populations
4. Case histories of two bull trout populations (Yakima R., Washington and Flathead R., Montana)
5. Example RME approach
6. Overview of simulation work

On Day 2 participants were divided into two subgroups for more detailed consideration of (1) evaluation and design of monitoring programs; and (2) monitoring protocols. Subgroup facilitators summarized each subgroup's discussions in a final plenary session, followed by a general discussion of major issues and next steps related to RME for Columbia River bull trout.

The purpose of this report is to provide a summary of the workshop discussions, focusing primarily on major issues related to RME for Columbia River bull trout, and future directions for addressing these issues and challenges. The report is organized into the following sections:

1. Introduction
2. Brief summaries of each presentation, and a list of specific questions/discussion points raised in the presentation. Summaries are based on abstracts where available; where abstracts were not available the authors of the workshop report composed the summaries based on presentation slides. Slides can be viewed by going to the USFWS Bull Trout Workshop web page and selecting a presentation from the pull-down list.
3. Summary of major issues and discussion points related to presentations
4. Summary of Evaluation / Design subgroup discussions
5. Summary of Monitoring Protocol subgroup discussions
6. Summary of Final Plenary Discussions
7. Next Steps; Structure and Function of Proposed RME Technical Group

A Glossary of important terms used throughout the report is provided in Appendix D.

2. Summaries of Presentations

2.1 Background on recovery planning, status, and current information for Columbia River Bull Trout and the importance of RME

2.1.1 Background Info on Recovery Planning for Bull Trout (Tim Cummings)

Summary: Since November 1999, all bull trout populations in the coterminous United States have been listed as threatened under the U.S. Endangered Species Act. Recovery plans for these populations have three major components: Description of site-specific actions; objective, measurable delisting criteria; and estimates of time and cost for carrying out actions. Writing these plans is the responsibility of two groups. The "Recovery team" (FWS, State, and tribes) are responsible for developing an overall recovery plan with multiple chapters, developing recovery objectives and criteria, and providing guidance for consistency among chapters. The Recovery Team is also responsible for identifying "Recovery unit teams" (agencies, tribes, and private groups), which contribute to individual chapters in recovery plan and develop recovery criteria and actions specific to recovery units. The draft goal of recovery planning is to ensure the long-term persistence of self-sustaining, complex interacting groups of bull trout distributed across the species' native range. Specific objectives are to: 1) Maintain current distribution of bull trout and restore distribution in previously occupied areas; 2) Maintain stable or increasing trends in abundance of bull trout in individual recovery units; 3) Restore and maintain suitable habitat conditions for all bull trout life history stages and strategies; and 4) Conserve genetic diversity and provide opportunity for genetic exchange. More background on Listing and Recovery Planning for bull trout is available from the web at http://pacific.fws.gov/crfpo/publications.html - Bulltrout.

Slides: http://pacific.fws.gov/crfpo/programs/bulltrout.htm (select **Cummings** from pull-down menu)
http://pacific.fws.gov/crfpo/programs/bulltrout.htm (select **Cummings2** from pull-down menu)

Questions / Discussion Points:

- coordination of bull trout RME with other programs / species
- about 200 people involved in Recovery Teams; size of teams range from 8-40 people

2.1.2 Challenges in Designing Regional Scale Monitoring and Evaluation Programs (David Marmorek)

Summary: Major challenges in designing monitoring programs include linking monitoring to actions in an Adaptive Management cycle, defining relevant data quality objectives to focus the experimental design of a monitoring program, gaps in the spatial and temporal coverage of existing data sets, and combining multiple lines of evidence to draw conclusions on policy-relevant questions regarding status and trends. Strategies for meeting these challenges include developing techniques for incorporating results from monitoring programs into the decision-making process, adopting a formal approach to defining Data Quality Objectives (such as the approach used by the US Environmental Protection Agency in monitoring water quality; http://www.epa.gov/quality1/), targeting key uncertainties and assessing the relative benefits of reducing different types of errors (e.g. measurement error vs. model parameter error), using models to bridge gaps in data sources (e.g. use models to adjust for biases in regional surveys), and using models to integrate results from multiple lines of evidence (e.g. integrate results from intensively studied systems with results from regional surveys).
Slides: http://pacific.fws.gov/crfpo/programs/bulltrout.htm (select **Marmorek** from pull-down menu)
Questions / Discussion Points:

- use/role of utility and loss functions in regional-scale RME and Data Quality Objectives

2.1.3 Population Abundance, Trends, Distribution, Responses to Recovery Measures (Howard Schaller)

Summary: This presentation provided an overview of historical and present status and distribution of bull trout in the Columbia Basin, and the framework for recovery planning. Challenges to implementing RME include the large geographical scale, limited resources, complexity of bull trout life history, and variability in estimates of abundance, trend, and distribution. Potential methods for analyzing trends include simple regression models, Dennis models of population growth rates, and rank correlation / randomization methods (Rieman and Myers 1997). A potential strategy for designing a RME program organizes research into three tiers: Tier 1 activities include population-level monitoring of spawning abundance and trends, spatial distribution, and genetic diversity. Tier 2 includes intensive spawning area surveys, juvenile abundance, and biological characteristics. Tier 3 includes identification of precise management activities, life stage survival estimates, and assessment of effectiveness of recovery measures.
Slides: http://pacific.fws.gov/crfpo/programs/bulltrout.htm (select **Schaller** from pull-down menu)**Questions / Discussion Points**:

- importance of monitoring habitat attributes/capabilities and genetic characteristics in addition to population trends and status
- spatial component of 3-tier monitoring program
- importance of evaluation and integration of other existing RME programs
- problems with linear models for detecting trends when density-dependent processes exist

2.1.4 What information is available across the 22 recovery units? (Bao Le)

Summary: Provided preliminary data summaries showing quality and quantity of census data available for recovery units within the Columbia River DPS (see map 1 in Appendix B). For adult bull trout, census information includes redd counts, trapping (weirs, screw traps), mark/recapture, gill nets, creel surveys, radiotelemetry, and videography. Information for juveniles comes from electrofishing, snorkeling, and screw traps. Data summary tables are available on the web at http://pacific.fws.gov/crfpo/programs/bulltrout.htm (select **Total Data Summary** from pull-down menu)

2.2 Population Structure

2.2.1 Biogeography of Bull Trout populations and use of this information in conservation and management (Gordon Haas)

Summary: Canonical correlation analysis (CCA) can quantitatively partition historical and ecological information from morphometric data where these features are otherwise confounded. CCA is applied to sample site locality morphometric data and corresponding sample site locality coordinate data for bull trout from throughout their extensive range in North America. The historical biogeographic patterns for bull trout suggest recolonization from either two or three glacial refugia. The patterns from the Chehalis and Columbia refugia are largely concordant with other analyses based on molecular genetics. The morphometric analysis also suggests the additional possibility of a Nahanni or Bering refugium. The ecological patterns suggest the importance and extent of migration and anadromy within these historical groups and how this may have affected postglacial recolonization, present distributions and life-histories. Both patterns emphasize within-species biodiversity and the complex interplay of historical and ecological information in western North America. This approach could be used to provide a heuristic framework for conservation, management, and future research. It could also be more broadly undertaken in overall assessments of faunal and floral assemblages. This paper is published in CJFAS (Haas and MacPhail 2001; available from http://www.nrc.ca/cgi-bin/cisti/journals/rp/rp2_tocs_e?cjfas_cjfas11-01_58).
Slides: Not available
Questions / Discussion Points:

- differences in life history are not genetically based – any form can produce other forms, depends on initial feeding behavior (implies that we should protect habitat types, not phenotypes)
- validity of DPS designations given common historical origins of different stocks

2.2.2 Population structure – relative to monitoring and recovery (Bruce Rieman)

Summary: This presentation discussed population structure, distribution, gene flow, and movement in context of population persistence and recovery. Water temperature and elevation were used to model bull trout presence/absence in Southwest Idaho, both under current climate conditions and possible future climate scenarios. Results can serve as a starting point for where to monitor (e.g. spatial definition of a recovery unit's target population; stratification into low, medium, and high expected probability of presence). Gene flow, life history diversity, and metapopulation structure have important implications for persistence of populations in the face of catastrophic events, habitat loss and fragmentation, and climate change.
Slides: http://pacific.fws.gov/crfpo/programs/bulltrout.htm (select **Rieman** from pull-down menu)
Questions / Discussion Points:

- difficulty in directly measuring dispersal. Direct measures of straying and dispersal in bull trout are virtually non-existent. Population genetics and patch based models have provided some clues, but there is need for more detailed understanding of the process to better understand the reality and/or potential for metapopulation dynamics.
- effect of climate change on bull trout distributions. Because climate change could result in a reduction in the size of habitat "patches" it could have an important influence on the persistence of many populations, especially those near the southern margins of the range. The problem is that the influence of climate change on stream temperatures may be more complicated than an

association with air temperature might suggest. Stream temperatures are influenced by solar radiation, stream flow, groundwater, and a variety of other things, so it is not clear how and where stream temperatures will change with climate change.

- implication of Judge Hogan's ruling on coho for bull trout listing is unknown

2.3 Evaluation of current methods for monitoring populations.

2.3.1 Redd counts – measurement error (Jason Dunham)

Summary: Recent study of bull trout *Salvelinus confluentus* redd counts addressed four major issues: 1) relationships between adult escapements and redd counts; 2) inter-observer variability in redd counts; 3) sources of inter-observer variability; and 4) temporal and spatial variation in spawning activity (Dunham et al. 2001). This work found the association between adult escapements and redd counts was highly variable (redd:spawner ratios ranging from about 1-3). Both sources of data probably contained large estimation or observation errors. In particular, redd counts varied significantly among observers in replicate counting trials. Observer counts ranged between 28 and 254% of the best estimates of actual redd numbers. Counting errors included both omissions and false identifications. Results also suggested that spatial and temporal variability in spawning activity should be considered in delineation of index areas for redd counts and timing of counts, respectively. Observation and sampling errors will tend to distort patterns of spatial and temporal variability in redd counts, and existing redd counts may therefore only be useful for detecting relatively large changes in bull trout populations. Because significant declines in bull trout redd counts are widespread, it is possible that severe population declines have occurred. Efforts to improve future redd counts are warranted, and validation of redd counts should be an integral part of any monitoring program. This should include standardized training and periodic evaluation to address observation error. Further attention is also needed for sampling designs to make inferences about redd counts at relevant scales (e.g., local population, recovery unit). In some situations, alternatives to redd counts (e.g., genetics or direct population estimates of juveniles or adults) may be needed. Finally, it is important to consider the range of potential uses of redd counts. Most of the focus has been on estimation of temporal trends, for which existing data are problematic (Maxell 1999). Other uses for which redd counts are appear promising include population viability assessments (e.g., PVANC, see 2.6.2 below; Appendix C), risk classifications, and habitat associations.
Slides: http://pacific.fws.gov/crfpo/programs/bulltrout.htm (select **Dunham** from pull-down menu)
Questions / Discussion Points:

- between-year differences in spatial distributions due to changes in accessibility to some reaches (flows, obstructions); may also be due to population structures (earlier migrants can access more of the system)
- consistent bias from year-to-year is less of a problem than changing bias (e.g. due to change in observer)

2.3.2 Mark / recapture estimates (Jim Byrne and Dan Rawding)

Summary: Mark / recapture techniques were used to monitor the Swift Reservoir (Lewis R., Washington) bull trout population from 1994 to 2001. Redd counts were not possible because of the high gradient in the two spawning tributaries (Rush Creek and Pine Creek). Adult fish staging to spawn were captured by gillnetting and fitted with visible floy tags before release downstream. A joint hypergeometric estimating procedure (Dunham et al. 2001) was used to estimate population abundance from the number of marked fish resighted during snorkeling surveys conducted throughout the spawning period. Estimates of abundance for the NF Lewis River population from 1994 to 2001 indicate an increasing trend over this time period. 95% confidence intervals for the estimates have ranged from +/-16% to +/-37% (avg. +/-24%) for 7 of the 8 years. Areas for future investigation

include: 1) Maintaining and/or improving precision of population estimates by doing more surveys and increasing tagging and snorkeling efficiency; 2) Estimating juvenile outmigration and timing into reservoir using a screw trap; 3) PIT (Passive Induced Transponder)-tagging adults and juveniles for accurate age and spawn information; and 4) using small stream flat plate technology.
Slides: http://pacific.fws.gov/crfpo/programs/bulltrout.htm (select **Byrne and Rawding** from pull-down menu)
Questions / Discussion Points:

- floy tags did not have a big effect on predation rates on bull trout

2.3.3 AFS Western Division Protocol for Determining Bull Trout Presence (Jim Peterson)

Summary: The presentation outlined an analytical framework for estimating probabilities of bull trout presence when there are no fish detected in the sampling. The framework uses Bayes theorem to estimate posterior probabilities of bull trout presence, based on probability of detection and prior probabilities of bull trout presence. Probabilities of detection are a function of capture efficiency and fish abundance. Capture efficiency is modeled as a function of environmental factors using a beta-binomial regression. Fish abundance is modeled as a poisson distribution, with a mean density represented by a gamma distribution of densities in multiple sampling frames. Prior probabilities of bull trout presence are estimated using patch-based habitat models in which the probability of bull trout presence is a function (logistical regression) of patch area, patch isolation, and road density. Probabilities of detection are combined with prior probabilities of bull trout presence to estimate posterior probabilities of bull trout presence, which can be updated as sampling information is collected. Simulations showed that a combined approach to large-scale surveys, in which estimates of posterior probabilities are combined with sampling, can require less sampling effort and can lead to lower detection errors than sampling alone.
Slides: http://pacific.fws.gov/crfpo/programs/bulltrout.htm (select **Peterson** from pull-down menu)
Questions / Discussion Points:

- cost-efficiency of logistic regression between distribution and habitat attributes used to develop prior probability distribution

2.3.4 Fish Movement – Radio tracking Studies (Judy De La Vergne and Barb Kelly Ringel)

Summary: In 2000, we initiated a pilot project designed to identify movement patterns, spawning location, and habitat use of bull trout in the Wenatchee River Basin, a major tributary in the Columbia River Basin Distinct Population Segment (DPS). In 2000, we surgically implanted 30, 2 year radio transmitters and externally attached one thermal tag in upper basin fish that ranged in size from 520mm to 680mm. In 2001, we implanted 2 year transmitters in 10 additional fish; 6 in the lower basin and 4 in the upper basin. We monitor fish locations using both mobile and aerial tracking and fixed station data recorders. Tracking will continue for two years following tagging. Movement patterns exhibited so far include: 1) movements among tributaries above and below Lake Wenatchee; 2) previously undocumented post-spawn movements downstream to the Columbia River, and upstream and downstream into Lake Wenatchee; 3) spring and summer upstream movement from the Columbia River and from Lake Wenatchee into holding areas before spawning; and 4) movement into bodies of water thought too large for spawning and with identification of a new spawning area (upper Chiwawa River mainstem). Concurrent bull trout telemetry projects in the area provide important additional and similar information to our project about movement patterns. The USFWS implemented a telemetry project in 2000, in Icicle Creek, which indicated downstream movement patterns from 4 tagged bull trout after placed upstream of a fish hatchery barrier. In 2001, Chelan and Douglas County Public Utilities Departments tagged 39 bull trout in the Mainstem Columbia River and movement patterns are showing downstream and upstream movement into each the Wenatchee, Entiat, and Methow Rivers, their tributaries, and between the dams themselves. Endangered Species

Act consultations and permit processes will incorporate this new information into bull trout population and habitat baselines enabling the agencies to better protect bull trout populations.
Slides: http://pacific.fws.gov/crfpo/programs/bulltrout.htm (select **Delavergne/Ringel** from pull-down menu)
Questions / Discussion Points:

- to this point, unable to use radio-tags to tell how fish are using mainstem Columbia and how they are getting past dams during downstream movement

2.3.5 Sampling of juvenile bull trout via day snorkeling, night snorkeling, and electrofishing (Russ Thurow)

Summary: We evaluated the efficacy of multi-pass removal electrofishing, day snorkeling, and night snorkeling for estimating bull trout abundance in 2nd and 3rd order streams. Estimated sampling efficiencies were similar for 3-pass electrofishing and night snorkeling. Day snorkeling was less than one-half as efficient as the other two methods. We compared sampling efficiencies estimated from multi-pass electrofishing removal to sampling efficiencies estimated from the recapture of known numbers of marked individuals. Our analysis suggests that marking techniques had no significant effect on fish catchability. On average, the removal methods overestimated sampling efficiency by 49% for 3-pass electrofishing, 48% for night snorkeling, and 18% for day snorkeling. Further analyses suggested three potential causes of the overestimation. Sampling efficiency was, on average, low for the first pass and decreased considerably with successive passes, which suggested that fish were responding to the electrofishing process. We observed a consistent decrease in capture efficiency across passes among all size classes. Stream width, depth, and habitat characteristics significantly affected sampling efficiency and were related to the decreases in sampling efficiency with successive passes. The sampling efficiency overestimation also appeared to be related to the total number of trout collected. Our results suggest that removal estimates of fish abundance can be negatively biased and these biases appear to be related to fish response to the sampling method, stream characteristics and fish density. We suggest that biologists evaluate the efficiency of their sampling methods to avoid introducing systematic error into their data.
Slides: http://pacific.fws.gov/crfpo/programs/bulltrout.htm (select **Thurow** from pull-down menu)
Questions / Discussion Points:

- heterogeneity in sampling efficiency between passes could be a result of response of fish to sampling approach, or could be due to differences in vulnerability of fish (but data suggests catchability of difference size classes is equal)
- if sampling bias in electrofishing is systematic, 2 passes would give almost the same accuracy as more passes
- need to include a broader range of environmental and physical conditions to account for differences across Columbia Basin

2.4 Case Histories

2.4.1 Yakima River, Washington(Eric Anderson)

Summary: This case history provides information on the geography, biology, historic and current distribution, and reasons for decline of Yakima Basin bull trout. The Yakima Basin encompasses the entire Middle Columbia River Recovery Unit (Lohr et al 2000), and represents a relatively complex and data poor system for bull trout. The Yakima River Basin is located in south central Washington (see map 2 in Appendix B). The historic distribution and abundance of bull trout within the basin is unknown, but given the intensive development and fragmentation of the basin by tributary impoundments it is likely that bull trout were historically more wide spread and abundant than

currently observed. Current populations of bull trout in the Yakima River include Ahtanum Creek, Naches River, Rimrock Lake, Bumping Lake, North Fork Teanaway River, Cle Elum/Waptus Lakes, Kachess Lake, and Keechelus Lake. Of these, only the Rimrock Lake population is considered stable and increasing; the others are classified as depressed and declining. Major reasons for decline include dam construction (there are 5 major storage reservoirs in the Yakima basin, plus numerous diversion dams), and water quality degradation due to forest management practices and livestock grazing, agriculture, mining, and urbanization. More details on the Yakima Basin Case History can be found on the web at http://pacific.fws.gov/crfpo/programs/bulltrout.htm
Slides: http://pacific.fws.gov/crfpo/programs/bulltrout.htm (select **Anderson** from pull-down menu)

2.4.2 Flathead Lake and River, Montana (Wade Fredenberg)

Summary: This case history provides information on the geography, bull trout biology, historic and current population distribution, and reasons for population decline of bull trout in the Flathead Lake and River Complex. The Flathead complex is a recovery subunit of the Clark Fork Recovery Unit of the US Fish and Wildlife Service bull trout Columbia River Distinct Population Segment (Lohr et al. 2000), and represents a relatively complex and data rich system for bull trout. The Flathead Complex**,** located in Northwest Montana**,** includes Flathead Lake and its tributary system (North and Middle Fork Flathead, Stillwater, and Whitefish rivers), and the South Fork Flathead watershed upstream from Hungry Horse Dam (see map 3 in Appendix B). Historically, bull trout were abundant throughout the North, Middle, and South forks of the Flathead River drainage. All of the major rivers in the drainage were open to migration and interconnected prior to dam construction. The Flathead Basin has been physically isolated from the rest of the Clark Fork Basin by Kerr Dam since 1938, and due to natural thermal characteristics (warm outflow in the fall season), it's not likely that significant two-way genetic interchange with stocks from Lake Pend Oreille has occurred since the retreat of the last ice age about 10,000 years ago. Thirty local populations in the Flathead Basin, identified in the status summary that was prepared for the listing rule (USFWS 1998), are all adfluvial stocks. Both redd counts and juvenile density estimates exhibit declines starting in the early 1990's, hitting their lowest recorded levels in the mid 1990's. Redd counts and juvenile density estimates have increased slightly in the last several years, but are still below highest recorded levels in the early 1980's. Reasons for decline of bull trout in the Flathead Complex include construction and operation of large hydroelectric dams, and interactions with nonnative fish species. Of particular concern is the recent increase in nonnative lake trout in Flathead Lake, which is thought to be related to the spread of *Mysis* freshwater shrimp into the lake in the early 1980's. More details on the Flathead Basin Case History can be found on the web at http://pacific.fws.gov/crfpo/programs/bulltrout.htm**.**

2.5 Example RME approach

2.5.1 Proposed RME approach for the South Fork Flathead River bull trout population (Mark Taper)

Summary: Successful monitoring of species recovery faces a number of challenges. Much of standard PVA is inappropriate. Species do not exist in isolation. There is a need to incorporate community background into modelers' and managers' thinking. Changes in community background, as well as other anthropic changes, may lead to trends in parameters, which are not well treated in standard population dynamic models, nor in standard Population Viability Assessments (PVA). When describing a complex system, many alternative models may be reasonable and many types of data may be available. Appropriate methods need to be developed to determine the relative evidence for different models in the presence of multiple data streams, and to make predictions in a multiple model framework. It is also critical to develop sampling designs to optimally distinguish among multiple models. The metric of population health needs to be chosen carefully. Neither the probability of extinction within a specified time, nor the extinction time distribution are robust to model

misspecification. PVA is particularly susceptible to this problem because, almost by definition, the behavior of the model away from the concentration of the available data is important. Finally, many elements influencing a species population dynamics vary in both space and time. A factor such as local survival varies from site to site, and from year to year. There is also an important sampling error component. Some of these factors may not be normally distributed. There is a great need for new and flexible generalized mixed model estimation techniques.
Slides: http://pacific.fws.gov/crfpo/programs/bulltrout.htm (select **Taper** from pull-down menu)
Questions / Discussion Points:

- applicability of Monte Carlo Markov Chain (MCMC) methods: MCMC methods can be unstable, give multiple solutions
- utility of different time horizons – shorter time horizons more relevant to decision-making, but longer time horizons allow stochastic processes to stabilize, and can still provide useful relative measures

2.6 Overview of simulation work

2.6.1 Evaluation of prospects for detecting population decline through different measures: (Paul Wilson)

Summary: A stochastic age-structured matrix model was developed to test methods for estimating linear trends in ln(adult abundance) vs. time. Data from different life stages may be used to estimate trends in adult abundance; the analysis presented used only the most widely gathered adult index data (redd counts). The model can be fit to variance in redd count data, and that variance can be apportioned between process and observation error. This allows the model to project both "actual" and "observed" abundances, which were used to calculate statistical power of observing a decline of specific magnitude in population abundance (i.e. a negative slope) for different numbers of years of data collection. The annual data used were summed redd counts from eight streams in the Flathead Core Area. Pooling data from individual streams results in some canceling out of observation error, and leads to higher statistical power than could be achieved from estimating trends in individual streams. The model can also be used to: 1) explore the ability of using juvenile abundance indices (alone or in conjunction with redd counts) to predict adult abundance; 2) estimate power to detect population declines or increases of various magnitudes; 3) explore the effect of decreasing observation error on statistical power; and 4) generate probability distributions of future population trends for use in extinction or decision analysis.
Slides: http://pacific.fws.gov/crfpo/programs/bulltrout.htm (select **Wilson** from pull-down menu)
Questions / Discussion Points:

- modeling time horizon (10 years) vs. time horizon for making management decisions (2-3 years)
- model sensitivity to age-at-migration

2.6.2 PVANC: A computer-intensive method for inferring population persistence based on time series of redd counts (Danny Lee)

Summary: PVANC is a computer-intensive approach for simulating bull trout populations based on redd count data and life history characteristics. The approach produces a likelihood surface for γ (expected replacement rate) and σ (environmental noise), based on redd count time series and demographic parameters (e.g. age at maturity, spawning age distributions, carrying capacity). The model then simulates future abundance, drawing probabilistically from the distributions of γ and σ. Results are summarized as persistence profiles. In the test case (Pend O'reille, ID), the method was robust to demographic parameters because of a strong downward trend in the redd count data (i.e. $\gamma \ll 1$). In cases where $\gamma \approx 1$, persistence is more sensitive to assumed life history characteristics. Assuming 30% measurement error results in lower estimates of σ (because the measurement error

explains a larger fraction of the total variation), did not have a large effect on estimates of γ, and increased the probability of persistence (because of lower σ).
Slides: http://pacific.fws.gov/crfpo/programs/bulltrout.htm (select **Lee** from pull-down menu)
Questions / Discussion Points:

- useful to know what sampling error is to explain some of the overall variation
- more messy data provides more information than a few precise observations

3. Summaries of Major Issues and Discussion Points

3.1 Coordination among monitoring programs

There is a need to inventory and evaluate existing monitoring programs, and improve their coordination. This applies to different programs for bull trout (federal / state / tribal / local), and to monitoring programs for other species (e.g. salmon, steelhead, and inland cutthroat trout). Better consistency and coordination among multiple monitoring efforts will make more efficient use of scarce financial and personnel resources, and can improve the quality of information gathered. BPA Fish & Wildlife funding for bull trout monitoring is quite limited, because the majority of the F&W program historically has been focussed more on anadromous fish. Furthermore, a question that needs to be addressed is whether interagency agreements limit BPA funding on federal lands, where most of the spawning and rearing for bull trout occurs.

How to encourage coordination among monitoring programs?

- main focus of proposed RME Technical Group
- ESA has mechanisms to establish an integrated RME program; provides a regulatory "stick" but no funding mechanism for implementation
- use funding mechanisms as incentive/leverage for designing good monitoring programs, e.g.
  - set standards for monitoring program, and only fund programs that meet those standards
  - Provincial review teams have said that bull trout research programs will not be funded until the USFWS provides technical guidance
- use improved cost/personnel efficiency of coordinated programs to sell to decision-makers
- poorer information may delay delisting – provides a financial incentive for various entities to support good monitoring
- Oregon is using a modification of EPA's EMAP approach in coastal areas (integrated framework of regional and sub-regional monitoring) for coordination/standardization of multiple monitoring programs. The design involves sampling randomly-selected sites within the target population's defined spatial distribution and habitats (e.g. stream order). The resulting estimates of population status and trends correlate very well with estimates from fixed sites using traditional monitoring. ISRP has recommended applying this framework to Umatilla program
- Bottom-up (positive incentive) approach to coordination will probably work better than a top-down (regulatory stick) approach because it promotes buy-in from local "on the ground" scientists, and allows some flexibility for local programs to meet specific local needs (may be some trade-off between rigor and flexibility of monitoring programs)
- USFWS could include some coordination or study design requirements in their 10A1A (collecting) permits to study bull trout and Section 7 permits for actions of Federal Agencies
- There needs to be some exploration of how best to maintain a centralized repository of permit data

3.2 Modeling issues

Participants raised some issues regarding the preliminary population models presented at the workshop, including:

- linear models (ln(redds) vs. time) are inappropriate for measuring extinction probabilities because they don't account for density-dependent processes
- emigration rates can vary with flow; can create problems if models assume constant emigration rates
- surrogate information may be required to get feedback on shorter temporal scales (e.g. use temperature data to get inferences on trends in spatial distributions)
- data-intensive modeling approaches aren't applicable to all populations

Models are helpful for refining monitoring and trend estimation techniques, using existing data as example inputs to estimation algorithms. One problem with this is that we don't know if the populations with detailed data are representative. Also, selecting models using relative measures of model performance (e.g. AIC) may result in use of the best of a bunch of bad models. We need to complement the use of relative measures with measures of "model adequacy", through continued testing and evaluation.

Patch-based models of population structure and distribution (see Bruce Rieman's presentation) are a potentially useful starting point for determining where to monitor and how to stratify populations. Similar models are used to develop prior probabilities in Jim Peterson's AFS+ protocol for quantitatively estimating presence/absence.

3.3 Improvement of Current Monitoring Techniques

Redd counts are the primary method for estimating adult bull trout abundance and trends. Jason Dunham's presentation highlighted some of the potential errors in redd counts, with spatial/temporal variability, environmental/geomorphological conditions, and inter-observer variability as some of the major factors in the accuracy of redd counts. Workshop participants stressed the need for using alternative survey methods (e.g. mark-recapture studies or weir counts) to verify the accuracy of redd counts and estimate the magnitude of measurement error. Danny Lee's presentation suggests that measurement error is a more important consideration when using redd counts to estimate absolute abundance, and less important when estimating trends in abundance. Detection of trends will depend on the number of sites, the magnitude of process and measurement error, and how large the true trend is. **A key point is that a number of participants felt that more sites with highly variable data are better than fewer sites with less variable data, particularly if the amount of measurement error and observer bias is known. However, this is a question that needs to be further explored by simulation modeling and analyses.** If estimation bias is consistent or random over space and time, it is less of a problem than if it varies systematically.

The Monitoring subgroup had further discussions of the adequacy of adult and juvenile survey techniques, and developed a list of potential actions to take to improve these techniques. These discussions and the list of potential remedies are described in Section 5 of this report.

4. Summary of Evaluation / Design Subgroup Discussions

4.1 Further details/comments on Paul Wilson's simulation approach

Paul provided more details on the assumptions and calibration process used in his simulation approach. The subgroup agreed that Paul's model provided a useful framework for exploring alternative designs. Specific suggestions for improving the model were to:

- make fecundity proportional to age
- explore sensitivity of both types of errors:
  α = false detection of trend that isn't really there
  β = not detecting actual trend
- explore the implications of the observation that the variance of pooled estimates of abundance is less than variance of individual stream estimates

The second bullet has been addressed since the workshop. This is described in Appendix C.

4.2 Ideas for Developing Monitoring and Evaluation Strategies

The subgroup defined two goals of interest:

1. Assess trends in relative abundance of spawning populations within core areas
2. Assess trends in spatial distribution within core areas

Refining the design will involve tradeoffs between these goals. For example, detecting trends in abundance is easiest with fixed sites, whereas changes in spatial distribution involves probing outside of currently monitored sites. Fortunately, the same information can serve both goals (e.g. broad-scale sampling using AFS protocol to estimate probability of bull trout presence provides inference on trends in both spatial distribution and abundance).

There are three key elements to the design:

1. Sampling frame / stratification
2. Desired metrics / outputs
3. How to measure (see Monitoring subgroup discussions)

The Evaluation / Design subgroup focussed on elements 1 and 2, as described below:

4.2.1 Sampling frame / stratification

Subgroup discussions of sampling framework and stratification issues are summarized in Figures 1 and 2. Figure 1 shows the hierarchy of population units as defined in the recovery plans, and some of the relevant considerations / methods for monitoring at each level. The rules for aggregating information from lower to higher levels of the spatial hierarchy may vary across Core Areas and Recovery Units. Figure 2 shows how monitoring programs might narrow their scope and region of interest, beginning with entire core areas and ending with evaluating population abundance and trends for systematically (and strategically) selected representative sites.

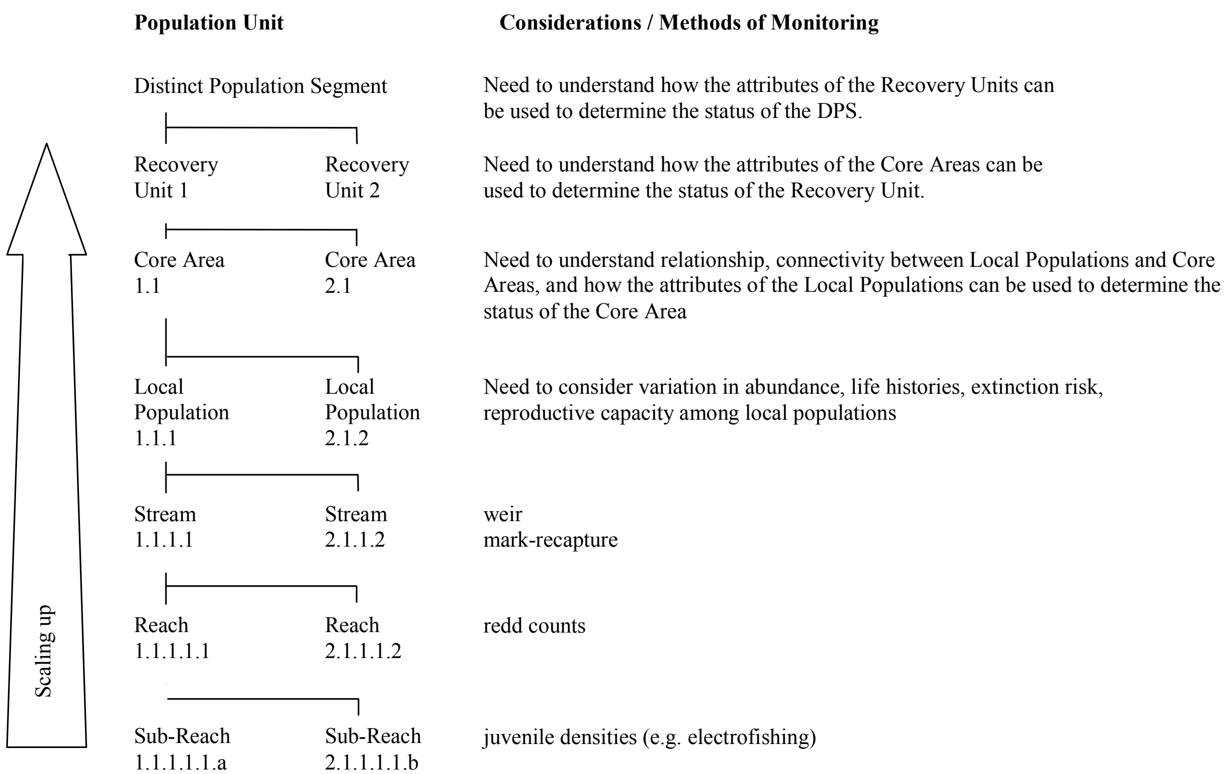


Figure 1. Hierarchy of population units. For estimates of trends in spatial distribution, the data collected at lower levels of this hierarchy should ideally be capable of being quantitatively related to the core area target population. Sampling does not need to be proportional to the abundance of strata (in fact, stratification is not required if each stratum is sampled in proportion to its spatial abundance). For estimates of trends in overall population abundance within a core area, it is important to know the relative representativeness of each index stream.

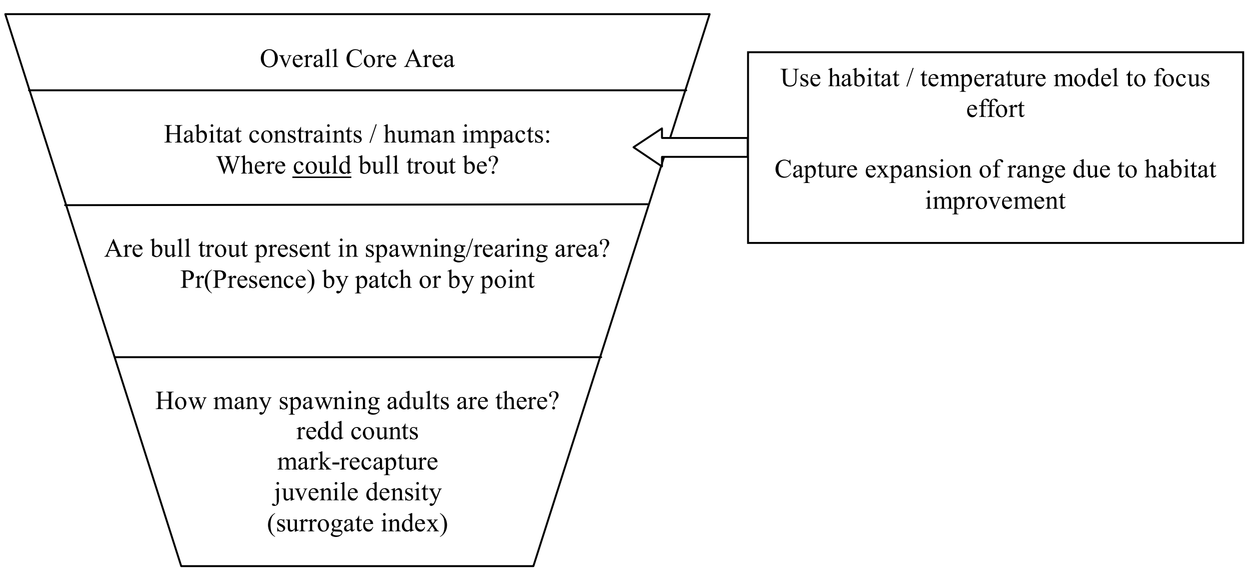


Figure 2. Focus of monitoring programs. Moving from the top of the diagram to the bottom narrows the focus on more specific questions and sub-regions/sites.

An example of a sampling frame / stratification framework is the Oregon coho EMAP approach. Since 1998, the State of Oregon has adopted an EMAP approach for selecting sampling sites for coastal coho. This approach uses a 1:100,000 GIS-based sampling frame for selecting statistically-based, spatially-balanced random sample sites. An initial reconnaissance was completed first to identify around 120 suitable sites (accessible to humans and fish) per Genetic Conservation Area (GCA). These sites are used in a 27-year rotating monitoring program. In any given year, 25% of the sites are sampled annually, 25% are sampled every 3 years, 25% are sampled every 9 years, and 25% of the sites are new in that year. The program estimates adult coho abundance with sampling errors of +/-15% at the GCA scale, +/-25% at the core area scale, and +/-35% at the local scale. They also sample for juveniles to see if spawning areas are expanding. Annual cost of the program is $2 million. More information on the EMAP program can be found on the EPA (Corvallis Lab) website at http://www.epa.gov/wed/pages/EMAPDesign/index.htm; a report titled "A Survey Design for Integrated Monitoring of Salmonids" containing specific information on the Oregon program can be found at http://osu.orst.edu/Dept/ODFW/spawn/reports.htm. It is worth exploring the applicability of this kind of approach to bull trout, taking into account the patch information, population structure, bull trout life history, data availability, and available financial resources.

4.2.2. Desired metrics / outputs

Population attributes to be monitored are population abundance, trend in abundance, and spatial distribution. The subgroup's initial ideas about what to measure to monitor these attributes are summarized in Table 1. Methods for measuring population attributes of adults and juveniles were discussed by the Monitoring Protocol subgroup and are summarized in Table 2 and accompanying text. The measures for each attribute and life stage can supplement one another (indicated by arrows between cells in Table 1). For example, information on juvenile presence/absence, distribution, and abundance can be used to infer something about these attributes of adult bull trout. Similarly, Monitoring spatial distribution over time can provide indications of population abundance. The subgroup discussed various complications in monitoring these attributes, including:

- the existence of alternative life histories
- multiple local populations within a core area
- time lags between habitat conditions and reproductive rates

Table 1. What to measure to monitor population attributes.

	Relative Abundance (Trend)	**Fish Presence/Absence Spatial Distribution (Trend)**
Adults	- # of spawning adults monitored annually - complete census every ≈ 5 years	% of points or patches with fish (capture effects of natural disturbances, range changes)
Juveniles	- measured where not feasible to estimate # spawning adults directly, or as supplementary index	% of points or patches with fish (capture effects of natural disturbances, range changes)

Figure 3 shows examples of metrics that summarize these attributes. Metric 1 is a simple time series of spawner abundance over time. Metric 2 standardizes the spawner time series to the long-term average, which allows the use of multiple indices over many streams. These two metrics are primarily related to monitoring abundance and trends. Linear trends could be fit to these kinds of data, if one assumed that survival rates were density-independent. Although survival is likely density-dependent, the current abundance of most bull trout populations is likely below levels at which density-dependent effects would be expected, unless there are depensatory effects (e.g. allee effects) that reduce survival rates at very low abundances. Metric 3 shows the cumulative frequency distribution (cfd) of sites with varying numbers of fish. The cfd moves to the right with an increasing regional trend in population abundance. Metric 4 provides an index of the dispersion of spawners across spawning sites within a core area. These metrics provide information on both abundance and spatial distribution. By constructing new curves in each year, metrics 3 and 4 can also provide information on trends in spatial extent / distribution and spawning site usage.

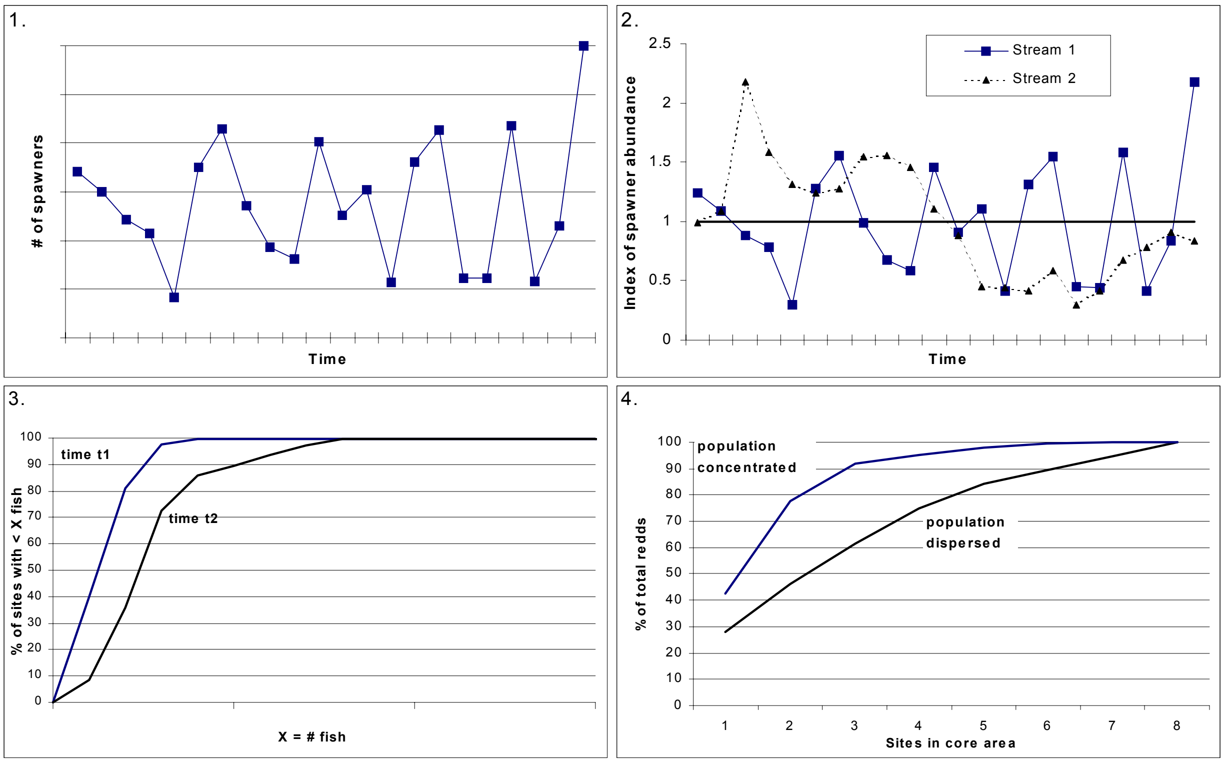


Figure 3. Example metrics.

5. Summary of Monitoring Protocol Subgroup Discussions

5.1 Example of Monitoring Approach – Measuring Juvenile Densities in Clear Branch Creek

Chuti Fiedler (USFWS) summarized the sampling approach being used in Clear Branch Creek (a tributary to the Hood River) to monitor juvenile and adult bull trout densities. The approach classifies subreaches into habitat types (e.g. plunge pool, high gradient riffle, side channel), then estimates fish density in each habitat type in an effort to provide a comparable measure of fish density in similar habitat types across its entire range. Comparing standard fish densities (# fish / unit area) across areas requires some understanding of differences in carrying capacity to determine whether differences in density are due to habitat productivity or abundance. The subgroup thought this was a useful approach for a small system, but pointed out that comparisons across populations using habitat types is complicated because:

- local populations are likely adapted to local conditions
- definitions of habitat types are not necessarily consistent or standard across the region
- sampling efficiency may not be consistent among different habitat types
- there can be large observer errors in classifying habitat types; better to use physical stream characteristics than subjective habitat classifications

5.2 Overview of Available Methods/Protocols for Monitoring Population Attributes

Table 2 provides an overview of the techniques available to monitor population abundance, presence/absence, and spatial distribution. Many of these techniques (e.g. redd counts, electrofishing, snorkeling) are already in widespread use, while others are not (creel surveys, minnow traps, dam counts). The information in Table 2 is based on the data summaries compiled by the USFWS and distributed at the workshop.

Table 2. Techniques for monitoring bull trout population attributes

	Relative Abundance (Trend)	**Fish Presence/Absence Spatial Distribution (Trend)**
Adults	• Redd counts • Mark-recapture • Traps, weirs (use for verification of redd counts) • Video • Electrofishing • Snorkeling • Ladders / Dam Counts (applicable to Upper Columbia, but don't know where fish came from; need to radiotrack to see if associated with specific recovery unit)	• Traps, weirs • Radiotelemetry • Creel survey (historical presence; used in Flathead to identify initial sampling sites) • Electrofishing (often correlates with juvenile abundance; but difficult to use on adfluvial populations; or when visibility is limited, flows high, lots of woody debris)
Juveniles	• Electrofishing • Snorkeling • Rotary screw trap • Minnow trap (safer than electrofishing; use in smaller streams) • Gillnetting	• Electrofishing • Snorkeling • Rotary screw trap • Minnow trap

5.3 Issues Related to Monitoring Adult Bull Trout

The subgroup discussed a number of issues related to implementation of various methods for monitoring bull trout populations. Many of these were discussed in the context of redd counts (the primary method for estimating adult abundance), but most apply to all monitoring protocols. Major issues included:

a) Reliability of estimates can vary from one area / observer to another, depending on many factors:
   - Productivity of the system
   - Stream gradient (e.g. more difficult to do redd counts in high gradient system)
   - Substrate size (affects visibility)
   - Time of spawning and relation to local conditions (seasonal floods, dewatering can restrict access to fish and/or observers)
   - Presence of other species (particularly coho – difficult to distinguish redds)
   - Life history (resident vs. migratory, frequency of spawning)
   - Observer error and variability (see Jason Dunham's presentation for further discussion)
   - Frequency of surveys

b) Representativeness of index sites – should gather a few years of data before selecting index sites to account for interannual variability in distribution

c) Temporal sampling window – how representative of overall timing (e.g. difficulty of sampling later in the year when flows are high can cause monitoring programs to miss the tail end of the spawning season)

d) Minimum sampling frequency should be once per generation (every five years)

e) Researchers need to correctly follow full AFS protocols as designed to ensure quality control / comparability of results; may have different protocols for different purposes (e.g. protocol for presence/absence survey may be less rigorous than for abundance surveys). Researchers also need to realize that this protocol is designed for small streams and that there are some practical problems with applying these protocols to larger streams. Work is underway to develop protocols with wider application.

f) Techniques for monitoring spatial distribution (e.g. radiotracking, traps) are useful for identifying potential sites for more intensive surveys (an important first step in assessing population trends)

g) What is the degree of invasiveness to the species being monitored? Think about in context of the population - can you absorb some population risk/loss to collect information.

5.4 Issues Related to Monitoring Juvenile Bull Trout

Major issues related to monitoring juvenile population attributes were:

a) Juvenile densities are higher than adult densities, and therefore can be easier to measure (use juvenile densities to supplement adult monitoring techniques)

b) No universally applied definition of juveniles (can be based on size or age)

c) Need to assess the consistency between juvenile and adult data – but there are few data sets where you can compare adult and juvenile data (Flathead, northern B.C). Comparison is complicated by having only a few years of data, time lags, covariance with flow and habitat conditions.

d) Juvenile monitoring is complicated by mixture of resident and migratory life histories

e) Monitoring of juveniles complicated by possible density-dependent mechanisms when densities are high

5.5 Additional Steps Needed to Improve Sampling Techniques

Given the above constraints and challenges to implementing good monitoring techniques, the subgroup identified some necessary steps for improving the reliability and consistency of monitoring protocols for bull trout:

a) Develop a table of protocols vs. stream characteristics with guidelines for where to apply various methods / protocols. Table 3 is an example:

Table 3. Example table of protocols specifying where to apply alternative monitoring approaches.

Stream type	**Adult abundance**	**Juvenile abundance**
High gradient stream, good visibility	Mark-recapture	
Low gradient stream, poor visibility	Weir / trap	Electrofishing
Low gradient stream, good visibility	Redd count; use weir/trap to estimate measurement error	Snorkeling

b) Develop a way to standardize reporting of redd count results to allow comparison among populations. For example, use redds/unit area consistently across basins, or express redd counts as % of habitat capacity to account for differences in productivity (assuming that a standard definition of habitat capacity can be developed).

c) Provide standardized training in established protocols for various techniques. Require annual updates to keep up expertise and allow for refinements in protocols over time.

d) Assess bias in sampling approaches. For example, compare redd counts to mark-recapture estimates or weir counts.

e) Identify a suite of tools available, then have each Recovery Team develop a proposed (or existing) monitoring and evaluation approach. The proposed approach could be given to the proposed standing Design group for evaluation and refinement. Monitoring programs would thus incorporate both local knowledge of the system (and what kinds of techniques are likely to work or not work) and modeling/statistical expertise.

f) Develop protocols for juvenile monitoring methods, and how to interpret and compare data.

g) Identify opportunities for using PIT-tags; hope for improvements in technology to allow better monitoring.

6. Summary of Final Plenary Discussions

Subgroup discussions were summarized and discussed in a final Plenary session Three main discussion themes emerged:
- how much sampling is possible?
- how much sampling is required?
- coordination

Points raised for each of these topics are discussed below.

6.1 How much sampling is possible?
- Monitoring effort will not be standard across the entire basin because of different levels of financial / personnel resources
- We may not need to sample at all levels of the population hierarchy shown in Figure 1
- Tailor spatial / temporal frequency of sampling to purpose of information collected, e.g.:
    - can scale up inferences about trend from local populations to larger population units without having to aggregate data and quantitatively weight each stratum
    - detecting trends in abundance may require more frequent sampling than spatial distribution
    - detecting trends in spatial distribution requires more statistical rigor in selecting sample sites

  - can monitor some simpler measures than those listed in Table 2 (e.g. egg distribution and fish condition)
  - the proposed 3-tier monitoring structure can accommodate this need for flexibility in sampling intensity: "rapid assessments" of broad patterns in Tier 1, then use more intensive sampling (Tier 2 and 3) to verify/validate the rapid assessments
- Management decisions must be and are made based on incomplete information and crude measures of population abundance/distribution/trend – e.g., USFWS listed Columbia River bull trout based on the current level of information
- 3-step decision process to determine how much sampling to conduct:
  1. What information do we need?
  2. Is it feasible, given budget/personnel constraints, to collect the desired information?
  3. If the answer to #2 is No, how best to either reduce information needs or how to get more resources?

6.2 How much sampling is required? What are the ultimate objectives of bull trout RME?

- RME should produce enough information to convince decision-makers and ourselves (bull trout scientists) that we can answer several questions with confidence
  - are the populations increasing, declining, or stable at a level that will allow the population to persist?
  - what is the probability of population persistence given current conditions?
  - have the conditions that led to population declines been reduced / eliminated sufficiently to allow population persistence
- when biological recovery criteria are finalized through the Bull trout recovery plan, then we can also begin to establish criteria for economic recovery (in addition to biological recovery) to help sell the monitoring/recovery plans to the public (e.g. Montana's goal is to recover <u>fishable</u> populations) and provide a buffer for stochastic events
- effort expended in monitoring may vary with the level of interest in the management problems. e.g., productive timberlands vs. wilderness.

6.3 Coordination with other programs

- There are other data available (e.g. collected in forestry areas) – use this opportunistic information as much as possible
- 4d consultation will reveal what kinds of data collection is going on in the region

7. Next Steps; Structure and Function of Proposed RME Technical Group

Information on the status, biology, habitat requirements, and distribution of bull trout is incomplete. Monitoring and evaluation efforts by the USFWS, the U.S. Forest Service, Indian Tribes, and the region's state fish and wildlife agencies are ongoing. The monitoring and evaluation needs will require a well coordinated and well-funded cooperative effort among researchers, managers, and other involved parties. In order to maximize the amount of information useful to recovery planning garnered from current studies, and to help direct and prioritize future studies, the USFWS has proposed establishment of a standing, multi-agency Recovery Monitoring and Evaluation Technical Group (RMEG). The group would serve to foster coordination among monitoring programs, standardize and guide development of monitoring techniques, and review analytical techniques for characterizing population and habitat status. As it is expected that monitoring will be necessary after delisting, it also may be useful for the group to continue, in some form, as well.

7.1 RMEG Functions

The tasks of the RMEG can be divided into four main areas:

7.1.1 Program review and coordination

The RMEG would review monitoring proposals prior to submission to any funding body or their scientific review panels (e.g., Independent Scientific Review Panel, or ISRP). The goals would be to help ensure funding and coordination of strategic studies at the regional level, ensure that the work is relevant to pressing management decisions, promote the use of standard survey and research methods whenever appropriate, help coordinate and integrate databases among the various monitoring and research agencies, and explore the possibility of developing a centralized database for bull trout The RMEG would help ensure that monitoring and evaluation activities being conducted or proposed could be executed in such a manner as to have some benefits to recovery efforts and objectives. Coordination and standardization would help make status descriptions in different recovery units or DPS's more comparable, as well as help avoid unneeded duplication of effort and resources, and make stable funding more likely. The group may promote jointly conceived investigations and provide incentives for cooperation by endorsing proposals for these types of projects to various funding bodies. The intent would not be to discourage independent research or local projects, but to promote wise, cost efficient use of funds through collaborative and/or complementary projects. The process would involve soliciting input from cooperators on their specific monitoring and research needs and then summarizing those needs. The RMEG could also serve as a forum for finding out what research is happening in the region and disseminating results of studies.

7.1.2 Guidance on scale of monitoring designs and implementation of monitoring programs

The RMEG would provide advice to researchers and planners on issues regarding the scale of the sampling frame. This would include recommendations for and review of methods for inferring population status at policy-relevant levels from data gathered primarily at finer scales. The RMEG would also consider strategic issues related to allocation of sampling effort among recovery units and among hierarchical levels within recovery units. The RMEG would also provide guidance on how to distribute sampling effort across life stages. Ultimately, all of this effort should be directed towards evaluating how well existing monitoring programs can assess recovery criteria, both within and among recovery units (recovery criteria are currently under development). In summary, the RMEG needs to look at the gaps between what we have in existing monitoring programs and what we need to have to accurately evaluate status and trends against recovery criteria. Once those gaps are explicitly identified, then the RMEG can recommend the most effective means of allocating available resources to reduce or eliminate them.

7.1.3 Guidance on specific monitoring techniques

This task would involve setting consistent standards for monitoring protocols and for useful experimental designs, establishing consistent methods of reporting survey results, and establishing standards for training field personnel. The RMEG would be a forum for sharing information on experiences with particular techniques. This would include receiving feedback on the performance of and difficulties encountered in applying recommended techniques to diverse areas, and for providing recommendations on how to deal with unanticipated exigencies in ongoing studies. For example, development of remedies for real-world limitations on studies may involve exploring the utility of surrogates for biological response (i.e. physical parameters), followed by setting up of intensive monitoring areas to establish surrogate validity.

7.1.4 Review of analytical methods

The RMEG would also serve as a forum for validating, enhancing, and comparing modeling tools. It is expected that population and habitat models will be used extensively to describe the status of DPS's and recovery units, as well as populations at smaller scales. Examples of the kinds of models and analytical methods which will be used are described elsewhere in this report; they include methods for determining bull trout presence, for estimating trends in abundance, and for relating presence and/or abundance to habitat variables.

7.2 RMEG participation and oversight

The RMEG would be chaired by the USFWS, and would report to the Service's Bull Trout Recovery Coordinator and the multi-agency Bull Trout Recovery Team. The Bull Trout Recovery Team would act to guide and help coordinate the RMEG. The RMEG would interact with biologists on recovery unit teams, and with other bull trout researchers. The Recovery Team and the various recovery unit teams could request the RMEG provide specific reviews and technical guidance on research proposals and monitoring plans.

The RMEG would ideally consist of 10-12 representatives, in order to ensure a broad range of expertise and representation among interested agencies, while remaining small enough to provide timely recommendations and reviews, and enable 3-4 annual meetings of the group. Joint meetings of the RMEG and the Recovery Team may also be scheduled. The Recovery Team would help to clarify and update the management questions guiding the RMEG's functions. The RMEG chair would be a USFWS technical or policy representative, and the group would include an additional USFWS technical representative. Participants will be drawn from the U.S. Forest Service, U.S. Geological Survey, state and provincial fish and wildlife agencies, Indian tribes, and academia.

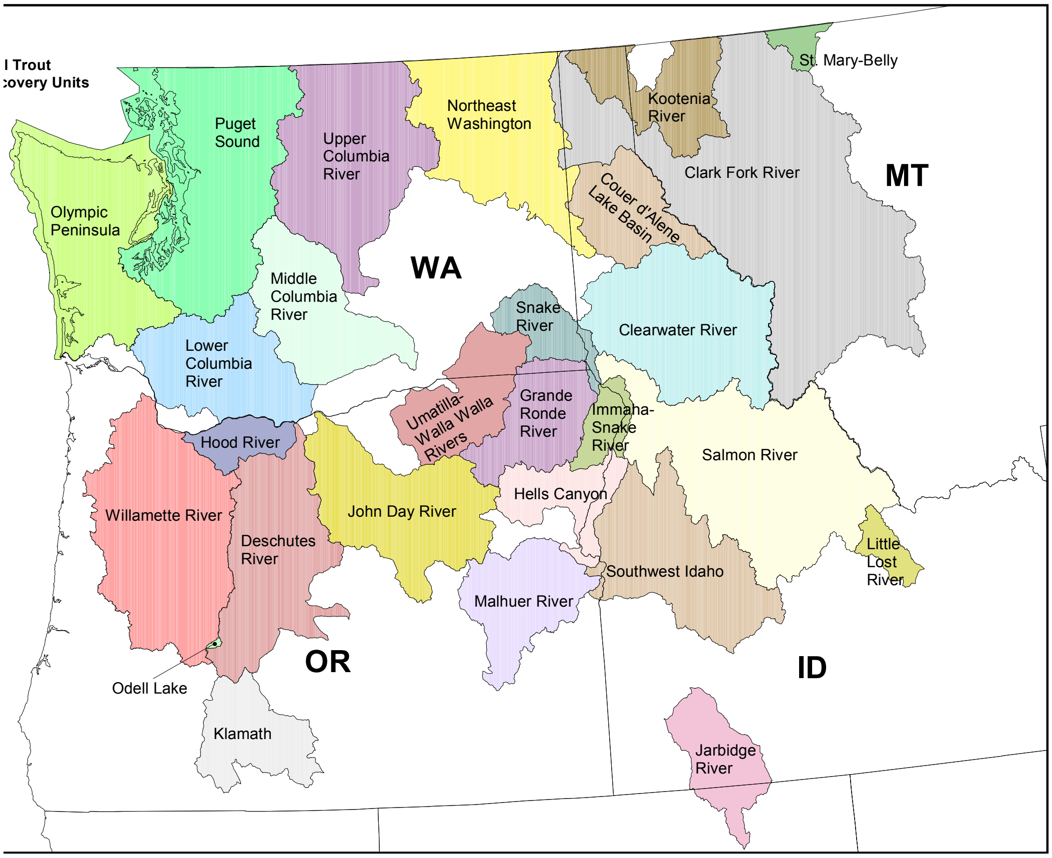
Candidates may be nominated by interested agencies or by the USFWS. Members should have an understanding of the science and management questions involved, and preferably have research related backgrounds. The group will include participants with field experience with monitoring methods, as well as those with more theoretical and analytical backgrounds. It would ideally include investigators with experience in fisheries research and monitoring techniques, statistical methods, and study design. Other desirable skills are expertise in bull trout biology, population dynamics, conservation biology, ecology, and other disciplines relevant to the recovery domain. Qualifications that will be sought include:

1. High achievement in a relevant discipline, which may include ecology, genetics, fisheries, statistics, hydrology, limnology, river geomorphology, or other appropriate disciplines.
2. High standards of scientific integrity, independence, and objectivity.
3. A demonstrated interest in, and ability to work effectively in, an interdisciplinary, interagency team setting.
4. Extensive knowledge of bull trout biology, status, or habitat.
5. A record of scientific accomplishment documented by contributions to peer-reviewed literature or other evidence of success in creative scientific endeavor.
6. A demonstrated ability to forge creative solutions to complex problems.

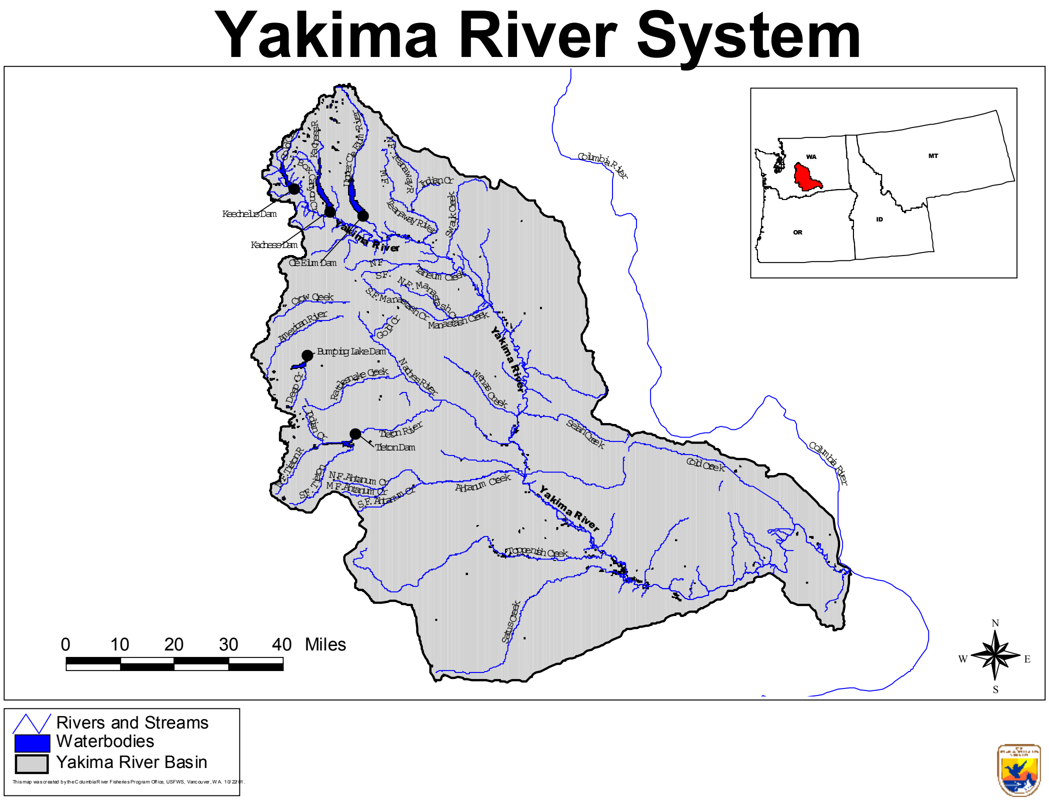
Appendix A. List of Workshop Participants

Name	Agency	Email	Subgroup D = Design M = Monitoring
Eric Anderson	WDFW	anderea@dfw.wa.gov	M
Phaedra Budy	UCFWRU / Utah St.	phaedra.budy@cnr.usu.edu	D
Jim Byrne	WDFW	byrnejbb@dfw.wa.gov	M
Chip Corsi	IDFG	ccorsi@idfg.state.id.us	M
Jim Craig	USFWS	jim_l_craig@fws.gov	M
Tim Cummings	USFWS	tim_r_cummings@r1.fws.gov	M
Judy De La Vergne	USFWS	judy_delavergne@fws.gov	D
Ted Down	B.C. Min. of Water, Land, and Air Protection	ted.down@gems7.gov.bc.ca	M
Jason Dunham	USFS (Rocky Mtn)	jbdunham@fs.fed.us	D
Chuti Fiedler	USFS	cfiedler@fs.fed.us	M
Wade Fredenberg	USFWS	wade_fredenberg@fws.gov	D
Gordon Haas	U. Alaska	haas@sfos.uaf.edu	D
Phil Howell	USFS	phowell@fs.fed.us	M
Barb Kelly Ringel	USFWS	barbara_kellyringel@fws.gov	M
Bao Le	USFWS	bao_le@r1.fws.gov	D
Danny Lee	USFS (Arcata, Ca)	dclee@fs.fed.us	D
Sam Lohr	USFWS	sam_lohr@fws.gov	M
Bruce McIntosh	ODFW	bruce.mcintosh@orst.edu	D
David Marmorek	ESSA	dmarmorek@essa.com	D
Joe Maroney	Kalispel Tribe	jmaroney@knrd.org	M
Alan Mauer	USFWS	alan_mauer@fws.gov	M
Calvin Peters	ESSA	cpeters@essa.com	M
Jim Petersen	USGS (CRRL)	jim_petersen@usgs.gov	M
Jim Peterson	USGS, GCFWRU	peterson@smokey.forestry.uga.edu	D
Joe Polos	USFWS	joe_polos@r1.fws.gov	M
Ron Rhew	USFWS	ron_rhew@r1.fws.gov	D
Bruce Rieman	USFS (Rocky Mtn)	brieman@fs.fed.us	D
Howard Schaller	USFWS	howard_schaller@fws.gov	D
Brad Shepard	Montana State	bshepard@montana.edu	M
Shelly Spalding	USFWS	shelley_spalding@fws.gov	M
Dave Staples	Montana State	staples@montana.edu	D
Mark Taper	Montana State	taper@rivers.oscs.montana.edu	D
Russ Thurow	USFS (Rocky Mtn)	rthurow@fs.fed.us	M
Dave Tredger	B.C. Min. of Sust. Res. Mgmt.	dave.tredger@gems4.gov.bc.ca	D
Paul Wilson	USFWS	paul_h_wilson@fws.gov	D
John Young	USFWS	john_young@fws.gov	M

Appendix B. Maps

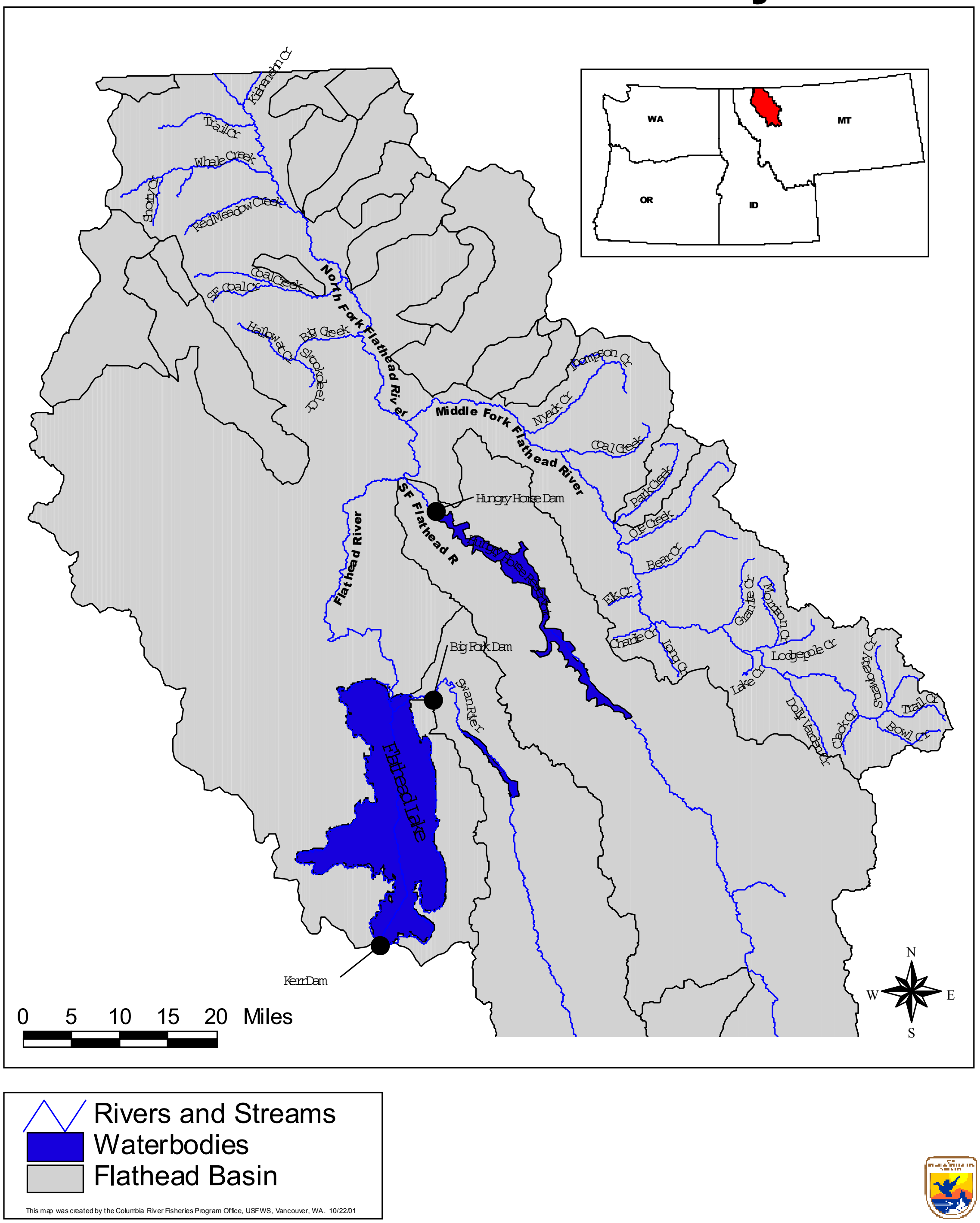


Map 1. Bull trout recovery units.



Map 2. Yakima River Basin

Flathead Lake and River System



Map 3. Flathead Lake and River

Appendix C. Example of Methods for Detecting Population Trends: Flathead Lake Core Area
(Paul Wilson)

Introduction

One of the four criteria for categorizing the status of recovery units, and on which recovery goals are based, is trend in adult bull trout abundance. Trends in abundance can be estimated on different spatial scales. The analysis presented here focuses on the estimation of trends in core areas, which constitute the basic unit on which to gauge recovery within a recovery unit (Draft Recovery Plan, Chapter 1). The goals of trend analysis may include:

- Determining whether a given unit is tending to increase or decrease in abundance--trend influences probability of extinction
- Determining improvement in overall life stage survival needed to reverse declines;
- Determining whether status has improved or deteriorated at some point(s) in future, and which, if any, management actions are responsible
- Estimate monitoring effort needed: With current methods, how long will it take to reliably detect increasing or decreasing trend?

The analysis presented here addresses the last of these goals. Data on adult abundance (or indices on adult abundance) is an obvious choice for analyzing trends in adult abundance. However, data on other life stages (juvenile, subadult) may also provide information on trends in adult abundance. It may be used either as a surrogate (when adult abundance data are unavailable or difficult to collect), or as a supplement to adult data, potentially increasing the precision with which trends are estimated.

Previous work on inferring trends from redd count data has used both linear trend estimation (Maxell 1999) and non-parametric sign tests (Rieman and Myers 1997). Rieman and Myers evaluated the difficulty of detecting significant trends using data from streams in the Pend Oreille Lake basin (Idaho) and Flathead and Swan Lakes (Montana). They found significantly negative trends in several streams within the Flathead and Pend Oreille basins; however, many were non-significant and their method did not allow estimation of the magnitude of trends. They concluded that variation in redd counts makes the detection of declining trends in individual streams unlikely with "limited data sets". When they pooled counts within basins, results showed declining trends are apparent in the Flathead and Pend Oreille basins. Maxell (1999) performed a power analysis of the ability to detect trends in individual spawning populations in the Flathead River, Montana. He found that in general, acceptably high power to discriminate between declining or increasing trends and no trend was not achieved in less than 15 years unless the absolute value of the percent change in redd numbers per generation was 50%. The range of levels of variation in redd numbers he used was intended to be representative of the levels found in individual spawning populations in the Flathead and Swan river systems.

Considerations in Estimating Population Trends

Trends in abundance could be estimated at any of several different spatial scales in a large Distinct Population Segment (DPS) such as the Columbia River bull trout DPS, due to the hierarchical structure of population units. Core areas have been defined in the recovery planning process as constituting the basic unit on which to gauge recovery within a recovery unit. A bull trout core area encompasses a core population, which usually consists of multiple local populations. This analysis explores the prospects for estimating trends in such a core area.

The magnitude of current or future trends can't be measured exactly. Any methods used will have to come to grips with inherent variability causing departure from a fixed trend line ('process error') and our inability to measure precisely the actual number of adults in a given year ('observation error' or 'measurement error'). The fact of measurement error, and the potential to reduce it, has implications for monitoring effort. For instance, if core area trend estimation is sensitive to observation error in redd counts, more effort to reduce this error may be called for. On the other hand, if trend estimation is more sensitive to the number of streams sampled, surveys of more streams within the core area using current methodology may be more appropriate.

Abundance data, such as redd counts, can be used to estimate the power of simple tests of hypotheses about the magnitude and direction of trends. Under the assumption that the number of redds correlates well with the number of spawning females, and that the variability observed in the existing data is a good predictor of the variability which will be seen in future data, the prospects for discriminating between increasing and decreasing trends of various magnitudes can be estimated.

Another method to explore trends in adult abundance is through estimates of abundance at some pre-adult life stage. For instance, in the Flathead River of the Flathead Subunit, Clark Fork Recovery Unit, juvenile abundance has been estimated through the use of electrofishing since 1980. These data can also be used to estimate trends in adult abundance, either alone (e.g. Shea and Mangel 2001) or in combination with redd counts or other estimates of adult abundance.

Raw adult and juvenile data can be used directly to estimate statistical power of population trends. However, simulated populations can also be constructed, imitating aspects of the life cycle by explicitly modeling different life stages. Models will allow us to determine which aspects are most important to understand well. They can be used to determine whether existing sampling methodologies are adequate to answer questions of management interest, suggest where to best allocate sampling effort, and help direct research efforts. Simulation models can be used to test the utility of different methods of trend estimation in areas where abundance data is limited. We can look at the ability of juvenile abundance indices to predict trend in spawners, or the utility of both redd counts and juvenile data to predict adult trends, e.g. through a Bayesian approach. Further, we can explore the impact of specific hypotheses about variation in vital rates (survival rate or fecundity); for example, correlation among rates or correlations between annual values of a single vital rate, or density-dependent mortality in particular life stages.

Assumed underlying trend

In this analysis, it is assumed that underlying population growth is exponential. In this case, the trend of population can be estimated by a linear regression on the natural logarithm of the time series of abundance estimates. The Greek letter 'λ' (lambda) is commonly used to describe the finite annual growth rate, which specifies the amount of change in the population from one year to the next, according to $N(t+1) = \lambda N(t)$. The slope of a line through the natural log of abundances is an estimate of 'r', the intrinsic growth rate of the population [$r = \ln(\lambda)$]. The kinds of population change corresponding to different values of λ are shown in Figure C-1. A value of $\lambda > 1$ is equivalent to $r > 0$; $\lambda = 1$ means $r = 0$; and $\lambda < 1$ indicates $r < 0$.

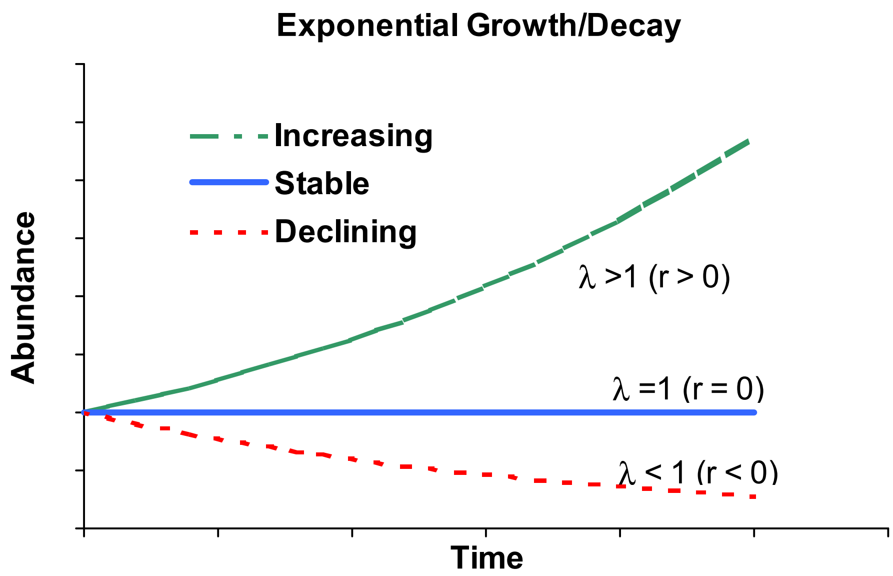


Figure C-1. Three kinds of exponential trends

Simulation exercise

The value of r can be estimated in different ways; two methods are used in this analysis. The first is simple linear regression; i.e. take the log of redd count data as the dependent variable and fit a line with time as independent variable. The slope of the line is then an estimate of the intrinsic rate of increase (r), and the confidence interval is derived from the standard error of slope estimate. An alternative method, is the 'Dennis' model annual transition method. This approach is part of a procedure for estimating population viability developed by Dennis et al. (1991). In this method the mean and variance of $Ln(R_{t+1}/R_t)$ are calculated, where R_t represents the redd count estimate in year t. The mean is an estimate of r and the confidence interval is estimated from the variance.

Within the Flathead Complex of the Clark Fork Recovery Unit, the Flathead Lake basin has a relatively long time series of redd counts for 8 streams within the core area. The Flathead Lake Core Area consists of 30 local populations, all of which are adfluvial stocks. Details on the Flathead complex Case History can be found at http://pacific.fws.gov/crfpo/programs/bulltrout.htm. For this analysis, redd counts from the eight stocks, half from tributaries to the North Fork Flathead River, half from the Middle Fork, are pooled to create an index of the adult abundance of the entire core area. The log-transformed data are plotted in Figure C-2. The equation represents the least squares fit of a line through the logarithm of redd counts as a function of time.

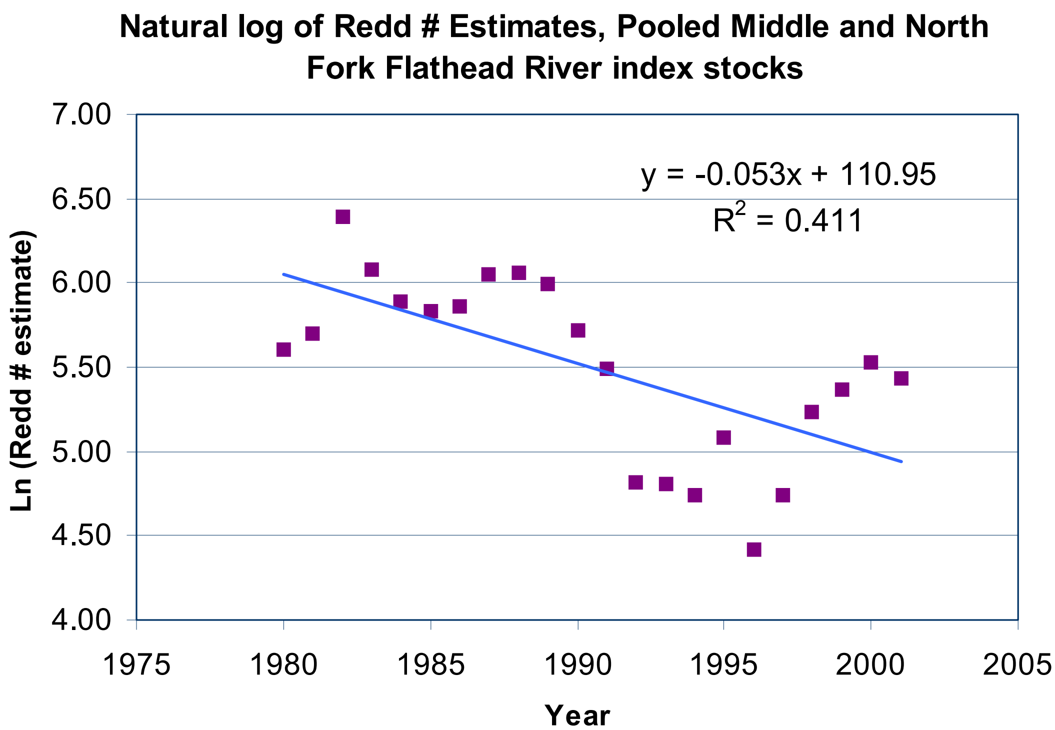


Figure C-2. Log of redd counts vs. year, Flathead River basin stocks combined.

The slope of the line is an estimate of *r* over the time period. Departures from the line are due to process error, which affects the actual probability distribution of trend, and observation error, which affects only the precision of estimates of trend (assuming no temporal trend in the bias). The sign and magnitude of the slope estimate indicate a sharp decline over the period. The standard error of the slope estimate is 0.014, and the p-value of the null hypotheses that the slope is not different from zero is 0.0013.

The next step is to create a model of bull trout populations in the Flathead Lake basin. Projection matrix models are commonly used to represent behavior of populations in endangered species contexts (e.g. Morris et al. 1999). They are used to model an age- (or stage- or size-) structured population, and allow the projection of future population trends and numbers in each class. This type of model requires estimates of vital rates over at least two to three life stages to estimate average population behavior. Matrix elements (probabilities of transition from one stage to another) determine population fate. Population numbers in the various classes are represented in a population vector; a process known as matrix multiplication determines how abundances change from year to year. The projection matrix can be either deterministic or stochastic; a population modeled with a deterministic matrix will reach an equilibrium point, where the age structure is constant, and the numbers of each class change by a fixed portion each iteration (usually a year). A stochastic matrix allows the projection matrix or the vital rates within it to vary randomly each iteration; consequently the simulated population does not follow a fixed trend, and the numbers and age structure vary randomly from year to year, though the expected growth rate is determined by the expected values of the vital rates. The finite growth rate a deterministic population will achieve (at stable age distribution) and the expected growth rate of a stochastic population is represented by λ. This value is analogous to growth rate estimates from the Dennis model and regression approach; it can be estimated from the elements of the deterministic matrix, without the need for actually projecting the population vector over numerous iterations.

The structure of the matrix created for this exercise is intended to reflect important characteristics of the complex life history of Flathead Lake bull trout. The life history is explained in more detail in the Flathead case history and Fraley and Shepard (1989). Juvenile fish rear in tributaries for 1-3 years before moving back downstream to the river and lake, where they spend several additional years as subadults prior to maturity at the age of about six years. Some mature fish spawn every year, others spawn every other year, and there's evidence that some fish spawn once out of three years (Deleray et al. 1999). The matrix was configured to reflect the flexibility in the life cycle, and to enable it to match available data on the age structure at different stages. The life cycle of females only is modeled, for simplicity and because number of redds is closely related to the number of adult females (though much of the data come from both sexes). A diagram of the model life cycle is shown in Figure C-3. The life stage abbreviations are defined in Table C-1.

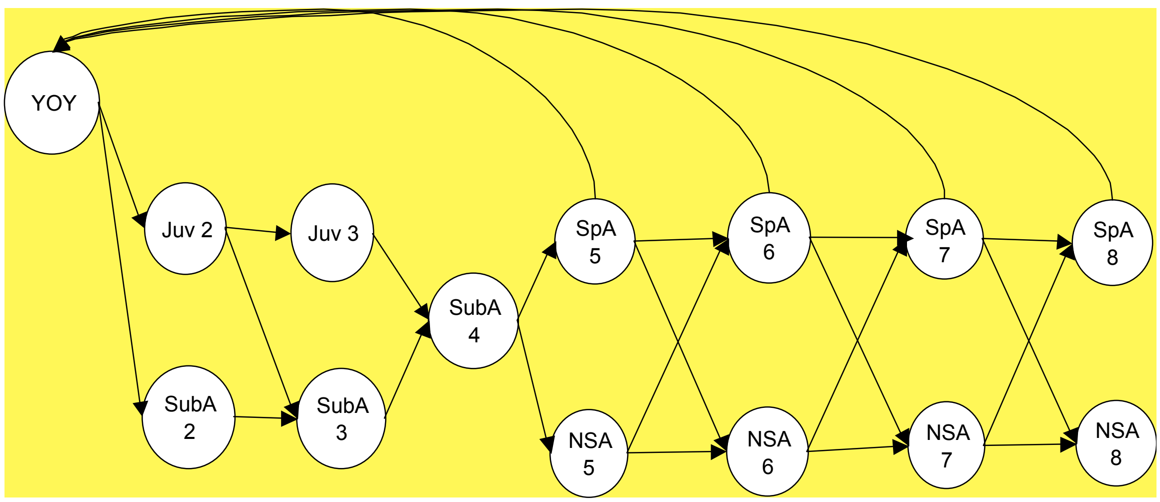


Figure C-3. Model life cycle of female bull trout in Flathead R. See Table C-1 for definition of life stages. Each arrow represents a non-zero transition probability.

Table C-1. Definition of life stages in model. The subscript *x* refers to age; see Figure C-3 for age range for a particular life stage.

Abbreviation	*Definition*
YOY	Young-of-the-year (age 1 fish)
Juv_x	Juveniles of age *x* in tributaries
$SubA_x$	Subadults of age *x* in lake
SpA_x	Spawning adults of age *x*
NSA_x	Non-spawning adults of age *x*

The resulting matrix is 14 by 14, with one or two transition possibilities for each stage. The maximum age of spawning is assumed to be 8 years, as only a minute fraction of the spawners in four streams where age was estimated were 9 years or older (Fraley and Shepard 1989). Fish are first capable of spawning at age 5, although most don't spawn for the first time until age 6 or 7. Adults that spawn in a given year and survive may spawn the next year, or not spawn the next year. Similarly, adults that don't spawn in a given year may or not spawn the next year. It was assumed that there was some mortality associated with the spawning migration to the tributaries, but that after spawning, adults had the same probability of surviving to next age as adults that didn't spawn. Spawning females produce eggs (fecundity is assumed unrelated to age) and the eggs undergo first year mortality, forming the 'young-of-the-year' class (YOY). In their second year, YOY may either migrate out of the tributaries to the mainstem North or Middle forks, and to the lake ('subadults') or remain in the tributaries for an additional one or two years. When the juvenile fish migrate to the lake, they remain in the subadult stage until age 5. At age 5, they may remain in the lake, or migrate to the tributaries to spawn ('SpA_5'). After age 5, they are considered adults, whether they remain in the lake or migrate to spawn, or return to the lake from spawning.

Deterministic calibration

A set of 23 parameters determines the value of the matrix elements (transition probabilities). The parameters represent survival probabilities from one age to the next, the probabilities of going from one stage to the next (e.g. juvenile to subadult), the probability of spawning vs. not-spawning (adults only), and fecundity of spawning adults. The matrix is 'calibrated' by attempting to match a number of quantities derived from data from the Flathead basin. This process involves simultaneously varying several parameters; consequently, there is no unique solution. The exercise is intended to produce realistic behavior for the core population of interest, based on available relevant population information. The resulting parameterization is the basis for the stochastic calibration (described below) used to judge the efficacy of different monitoring strategies.

The transition probabilities were varied to match four different data sets. Three are from Fraley and Shepard (1989): 1) estimated age structure of juveniles migrating from tributaries (becoming subadults); 2) estimated age structure of spawners; 3) estimated fraction of adults which spawn each year. The last data set is the redd count data. The dominant eigenvalue of the projection matrix is an estimate of λ (Morris et al. 1999); parameters were constrained so that the matrix λ was close to the antilogarithm of the mean trend estimated from the log of redd counts [i.e. $\exp(r)$].

The target values of age structure, spawning fraction and lambda, estimated from data, are shown, along with the resulting values from the deterministic matrix in Table C-2.

Table C-2. Target value of quantities from literature, and resulting matrix values.

Quantity	*Target value*	*Matrix value*
Percentage of juveniles outmigrating at age 2	18%	18%
Percentage of juveniles outmigrating at age 3	49%	50%
Percentage of juveniles outmigrating at age 4	32%	32%
Percentage of spawners age 5	18%	18%
Percentage of spawners age 6	42%	43%
Percentage of spawners age 7	34%	33%
Percentage of spawners age 8	5%	5%
Percentage of adults spawning each year	57%	57%
λ (Lambda)	0.948	0.949

Stochastic matrix

Adding random variation to the vital rates of the matrix enables a time series of randomly varying population vectors to be produced. A time series of numbers at any life stage can be output. The time series can be repeated many times, with randomly varying vital rates, to develop distributions of numbers at a particular life stage (e.g. spawners). Simulated observation error can be added to the life stage numbers, to mimic a time series of data. Either 'actual' spawners (redds) or 'observed' redds can be output. Trends can then be estimated by the same methods which are applied to actual data.

In stochastic projections, in each year the parameters constituting the elements of the matrix are drawn from probability distributions. A unique projection matrix is created for each year within a replicate. This creates simulated process error in the population trajectories. To simulate observation error in redd counts, the 'actual' number spawning in the index areas is multiplied by lognormal observation error. Exactly one redd produced per (female) spawner is assumed (though variability in this could be introduced as well). The actual number of redds falling in index areas is modeled as a binomial process with p = .45 (45% of spawning area is surveyed on average in Flathead basin, from Deleray et al. 1999, Table 40). 'Observed' redd counts are then expanded to represent all redds by dividing by .45.

The steps in the derivation of 'observed' redds from 'actual' spawners can be described as follows. The probability a female spawns in index area is $p_I = 0.45$. The number spawning in index areas is $N_I = Bin(N, p_I)$, where N is the "true" number of female spawners in stream in the current year. The observed redds in index areas is then

$$N_{I,obs} = N_I \exp(Z\sigma_V - \sigma_V^2 / 2)$$

where Z is a normally distributed random variable with mean 0 and standard deviation 1, and σ_V = standard deviation of observation error (after Hilborn and Mangel 1997, eq. 7.33). The estimate of total redds is then $N_{obs} = N_{I,obs} / 0.45$.

All vital rates, with the exception of fecundity, are modeled as beta random variables. These rates are naturally bounded by zero and one, as they are either survival rates or probabilities of going from one stage to the next. The beta distribution is bounded by 0 and 1 and has a flexible shape within those bounds, which make it useful for modeling transition probabilities. Kaye and Pyke (in press) recommend it usually be the first distribution explored when developing a stochastic matrix model with element selection. Fecundity is modeled as a normal random variable.

The starting point for calibration of the stochastic matrix is the mean values of the parameters estimated in the deterministic calibration. The procedure involves choosing standard deviations for the vital rate probability distributions. The goal is to choose vital rate parameters that result in a mean slope of many replicate time series of observed redd counts that matches a target r (e.g., the value estimated from the raw redd counts), while also reproducing the variance in the raw redd counts. The target variance used is $\ln(R_{t+1}/R_t)$; this removes the effect of population size and trend on variance, and is therefore a better representation of the underlying combined process and observation error than the variance of the raw redd counts. The fitting is an iterative process, involving matching the observed trend from regression while the coefficients of variation (CV) of vital rates are varied at each of several different values of standard deviation of observation error. The final calibration used four different CV levels (20%, 15%, 7.5%, 7.5%) for four categories of mean vital rates (lowest, low, medium, high). The average value of r from the stochastic simulations was matched to the value from deterministic model by varying the mean of the first year (YOY) survival rate.

Total variance in $\ln(R_{t+1}/R_t)$ observed from the pooled Flathead streams (~ 0.11) is split into approximately equal amounts of process and observation error (the value of the process only variance used in this analysis was 0.056). This magnitude of observation error results in an "absolute relative bias" (as in Dunham et al. 2001) of 12%; Dunham et al. found a.r.b. ranged from 30 – 54% in the individual streams they investigated.

The simulations were run for 1000 games of 50 years each. The population vector was set at the stable age distribution prior to the first year. The total population size was chosen so that after 25 years, the total redd count would be on the order of the observed redd count for the Flathead core area. The first 25 years were treated as a "burn-in" period, so that the estimation period would be seeded with a random population vector each game, with the expectation of that vector at the stable age distribution. For each trial, a trend can be estimated for a time series from the model output observed redds. The mean and standard error of the trend was estimated for 5, 10, 15, 20 and 25 years of output, using both the slope method and the Dennis et al. (1991) annual transition method. The resulting *r* estimates are approximately normally distributed with either method.

Power analysis

The utility of population trend estimation in judging the status of the listed populations will depend on our ability to distinguish among hypotheses about the true expected value of the trend. An example of a question we may want to try to answer is "If we continue to monitor redds in the Flathead the way we have been, how long will it take to determine that adult abundance in the core area is decreasing (or increasing) with a given level of confidence?" The hypotheses to be tested might be, say, H_o: $r \geq 0$ vs. H_a: $r < 0$. In this exercise, the *r* value estimated from the raw data or the average estimated from the stochastic matrix output would be the true, underlying value of the population. Since the estimated *r*'s are approximately normally distributed, and assuming they are also independent and identically distributed, a Student's t-test should allow us to estimate the probabilities of Type I and Type II errors (α and β, respectively). A Type I error would be to incorrectly reject the null hypothesis ($r \geq 0$); a Type II error would be not to reject the null hypothesis when it is actually false (incorrectly concluding the population is stable or increasing). Statistical power is equal to $1 - \beta$ and is defined as the probability of correctly rejecting the null hypothesis, given that the alternative hypothesis is true (Steidl and Thomas 2001).

The expected power of a test of these hypotheses using redd count data, given a specified true trend (i.e. effect size) and assuming the underlying variability in redd counts is as observed, can be estimated for various lengths of time from the model output. For a given number of years, for each game, the mean and standard error of the slope of the logarithm of the simulated redd counts vs. time is estimated. The mean and standard error of the natural log of the annual transition is also calculated for each game. For either method, for each game the product of the one sided t-value for n-1 degrees of freedom (where n is number of years) and $\alpha = .05$ ($t_{.05(1),n-1}$) and the standard error is added to the mean estimate of *r* to get an estimate of the upper 90% confidence bound on *r*. The number of games where the upper bound of *r* is less than zero is divided by the total games (1000) to estimate the power of the test for each method at a nominal Type I error rate of .05. The results are shown in Figure C-4.

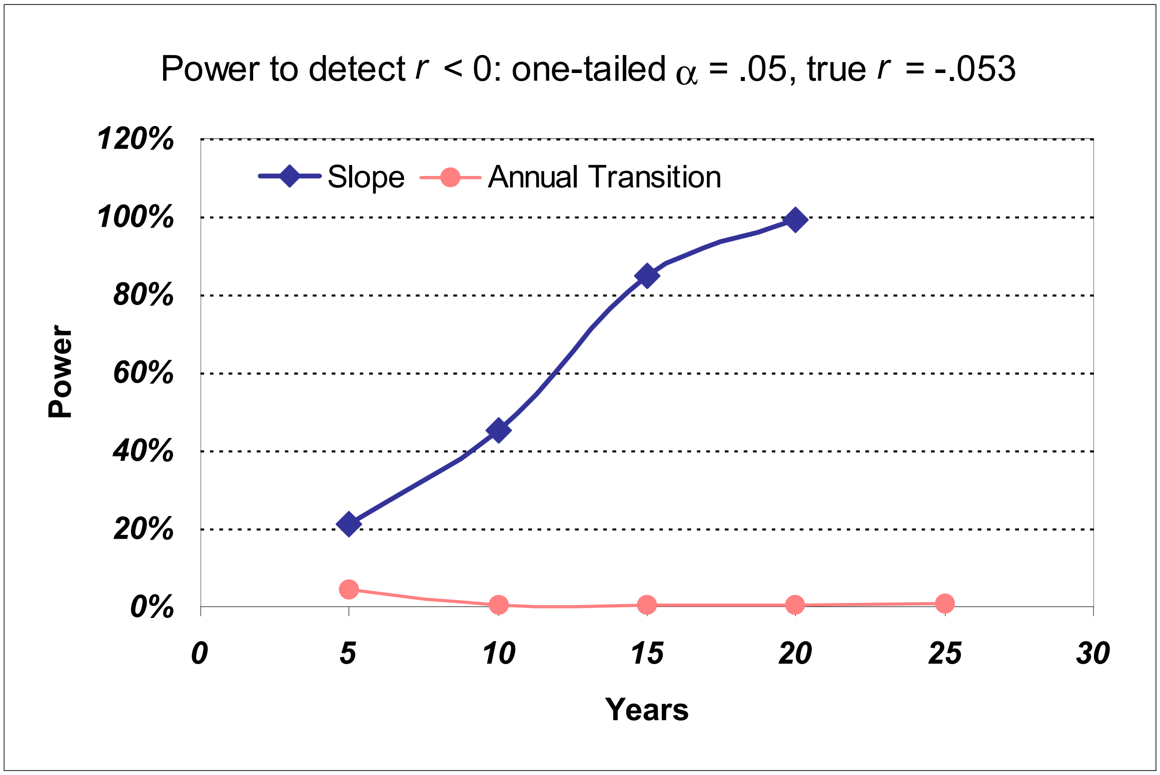


Figure C-4. Expected power to detect $r < 0$ from simulated observed redds, given observed mean and standard error of trend, for slope and Dennis et al. annual transition methods.

Discussion

The analysis suggests that a trend as large as was observed for the Flathead Lake core area could be detected with adequate power in as few as 15 years. This should also apply to a trend of the same absolute value (as measured by r), but of positive sign. This encouraging result holds only for the slope method; the annual transition method showed negligible power to detect the trend for the given effect size; and even declined with time. The reason this method performs poorly is that the standard error of $\ln(R_{t+1}/R_t)$ is much higher than the standard error of the slope of the line, and it doesn't decrease as quickly as the standard error of the slope does with additional years. Because of the large inter-annual variation in redd counts, the annual transition method is probably not a useful estimator of population trends in bull trout. Transition methods may prove more useful if running sums of redd counts are used instead of annual raw counts; e.g. two year moving sums as in Rieman and McIntyre (1993) to reflect every-other-year spawning, or the Dennis-Holmes technique, which uses a running sum from redd count and age structure data to approximate the total population (Holmes 2001). If age and spawning frequency data were sufficient to estimate spawners and recruits from each brood, it might be possible to get a better estimate of the population trend, and hence to more quickly to discriminate between hypotheses tested in this analysis.

Rieman and Meyers (1997) found significant trends much more evident with pooled basin data than with data from individual streams. Using the aggregate redd counts for the Flathead Lake basin, rather than trying to estimate trends for local populations, doubtless increases the attainable power of the hypothesis test for a given time period and actual trend. The variance in $\ln(R_{t+1}/R_t)$ for the individual Flathead Lake stocks ranges from 0.28 to 0.65 (mean 0.46); the variance for the aggregate is 0.11. It may be that

that observation errors in individual streams tend to cancel each other out, to some extent, making power to detect trends much greater with data from different streams pooled.

Additional applications of matrix model

The analysis performed here can be extended to more comprehensively address the question of how (and how well) population trends might be estimated from various types of data. Different values of the underlying trend can be simulated, to develop estimates of power to detect declines (or increases) of different magnitudes. The allocation of variance between process and observation error can be varied, and the effects on power of decreasing observation error through different strategies can be explored.

Another application is to investigate the ability of juvenile abundance indices to predict trend in spawners. Montana Fish Wildlife and Parks (MFWP) has used electrofishing to assess abundance of age I and older bull trout in different sections of 5 streams in the Flathead basin (Deleray et al. 1999). The mean and variance of observed trends can be used to calibrate the stochastic matrix model and “observed” juvenile abundance indices output from the model can be used to predict the actual trend in adult abundance, in a similar fashion as was done with simulated redd counts. The calibration would involve simultaneously matching the observed variance in $\ln(N_{t+1} / N_t)$ for both redd counts and juvenile indices. Estimates of confidence intervals on juvenile indices are made by MFWP; these could be used to estimate observation error in order to realistically allocate total juvenile variance.

The utility of using both redd counts and juvenile data to predict adult trends, perhaps through a Bayesian approach, can also be explored. Whether using both adult and juvenile data, or either kind of data alone, the estimates of trends can be presented as probability distributions. Instead of a traditional power analysis where choices about acceptable α and β levels must ultimately be made, inferences could be made directly from the posterior distribution of *r*. A Bayesian analysis of trends may allow for clearer and more accurate assessments of relative risk. Bayesian decision theory can easily incorporate more decision possibilities than just a ‘non-significant’ or ‘significant’ effect allowed by frequentist hypothesis tests, and can synthesize biological information and degrees of risk aversion through the use of loss functions, which set the cost of making wrong decisions (Wade 2000). With a Bayesian approach, or with any of the different prediction methods, the effect of more realistic variation in vital rates, e.g. correlation among rates or correlations between annual values of a single vital rate, can be investigated.

The simulation model could also be used to investigate the utility of collecting detailed age data on spawners and non-spawning adults. The goal would be to estimate the prospects for detecting trends through a time series of brood year spawner-to-spawner estimates. The collection of this kind of data would be simulated in a similar fashion as was redd count data; i.e., modeling process variation in the ‘true’ adult numbers at different ages, and adding sampling (observation) error to mimic the process of making estimates of age structure from samples of the population.

Potential modifications to analysis

The analysis presented an example of trend estimation using as much of the entire available time series of redd counts as possible [1979 redd counts were excluded, because of differences in stream sections surveyed from subsequent years, as well as omission of one stream, per Deleray et al. (1999) pg. 176]. Use of a fitted trend to predict future population behavior requires the assumption of stationarity; i.e. that there was no systematic change in survival rate during the fitting period, and will be none in the future (at least as far as the interval over which extrapolation is made). The lack of systematic survival changes in the future is, by assumption, what we are testing. We can explore different hypotheses about the magnitude and direction of future trends and our ability to detect them. The assumption of stationarity in the observed data may not hold, however, and would affect the accuracy of inferences about the usefulness of the observed trend as a predictor of future behavior. An example of non-stationarity which may apply to the Flathead data used is that fishing regulations changed over time, with the fishery in the lake and North and Middle fork rivers being closed in the 1990s (Table A2, Deleray et al. 1999). This change in anthropogenic mortality may make fitting a constant survival rate to the observed trend over whole period questionable. This could be dealt with by revising the matrix to explicitly incorporate fishing mortality in the adult life stages. The timing of different management regimes in the past may also suggest a useful starting point for monitoring future trends. Further, the effects of modifying harvest rates on future trends could be explored.

Several assumptions used in the simulation are undoubtedly unrealistic, but were used for simplicity and/or because data allowing more realistic parameterization was not on hand at the time of the analysis. Fecundity was assumed independent of age; since adult length and weight is related to age, however, fecundity likely increases with age. Data relating length to age, and fecundity to length in bull trout are available and can be used to develop an age-fecundity relationship (W. Fredenberg, USFWS, personal communication). The spawning age data the model was fit to (Fraley and Shepard 1989) indicated there were no spawners over the age of eight years, and only a small fraction at age eight. However, since that paper was published, harvest rates have been substantially reduced (Deleray et al. 1999), likely leading to some adults surviving to spawn at older ages (W. Fredenberg, pers. comm.). A more realistic model of the current age distribution of spawners would likely include a higher fraction of age 8 spawners, as well as a 9- and possibly a 10-year-old component. Also, it may be more realistic to assume a post-spawning, rather than pre-spawning mortality.

Alternatives methods of estimating of Type I and Type II error probabilities

At the workshop, it was pointed out that the power analysis shown in Fig. 4 presumes the nominal Type I error rate (α) is accurate, though it, like β, is a consequence of the model and should be confirmed (D. Lee, USFS, personal communication). The stochastic model was recalibrated to give a mean r value of zero; output of simulated observed redd counts could then be used to estimate the mean and upper confidence bound of r for each game. The number of instances where the upper bound for the nominal α was less than zero was tallied, and divided by the number of games to estimate the true Type I error rate at the nominal α. Results using the slope method indicated that the "true" α was generally higher than the nominal value. This is due (in part, at least) to the fact that the observed α is actually an estimate of the upper bound of α. This is because the null hypothesis that is being tested is that r is greater than or equal to zero, rather than any unique value in that region. Setting the true r in the stochastic matrix to its lowest possible value in this region (zero) results in a higher probability of a Type I error than if the matrix was calibrated to any other value in that region.

An alternative approach to estimation of β and α is proposed by Lindley et al. (2000). They suggest that standard methods which control for the Type I error rate and accept the resulting Type II error rate are inappropriate when monitoring endangered species. They believe a more logical and precautionary approach is to set the Type II error rate at an acceptably small value (i.e., power at an acceptably high value) that yields a reasonable Type I error rate. Steidl and Thomas (2001) also note that others have suggested that Type II errors be considered paramount when monitoring endangered species; or at least that Type I and Type II errors be balanced based on their relative costs. Shrader-Frechette and McCoy (1992) give reasons why in applied cases, Type I error is often more acceptable than Type II error, whether the null hypothesis is "positive" (no harm) or "negative" (no benefit). Type II error leads to possible harm or loss of benefit, respectively. In endangered species recovery activities, if a Type II error is committed, a population could be on its way to extinction before the decline is detected and preventative action is taken. Conversely, if the population is monitored after initiating recovery actions, and the population is actually increasing, a Type II error would lead to the mistaken inference that the actions are not having the desired effect, perhaps jeopardizing continuance of those actions.

Lindley et al. (2000) perform power analysis for a hypothesis test similar to that in this analysis, using an assumption that the value of the parameter of interest can be described by a non-central t-distribution. Using their method, the power of the test of the two hypotheses about *r* can be set at different values, and the expected value of α that results can be estimated for different sample sizes (e.g. numbers of years of data). From the percentiles of the estimates of the standard error of the slope, confidence bounds on α can also be estimated. Using the distribution of standard error of the slope from the simulations with mean *r* set at -0.053, the resulting expected values and 80% confidence intervals on α are shown in Figures C-5 through C-7, for set power values of 0.80, 0.90, and 0.95, respectively.

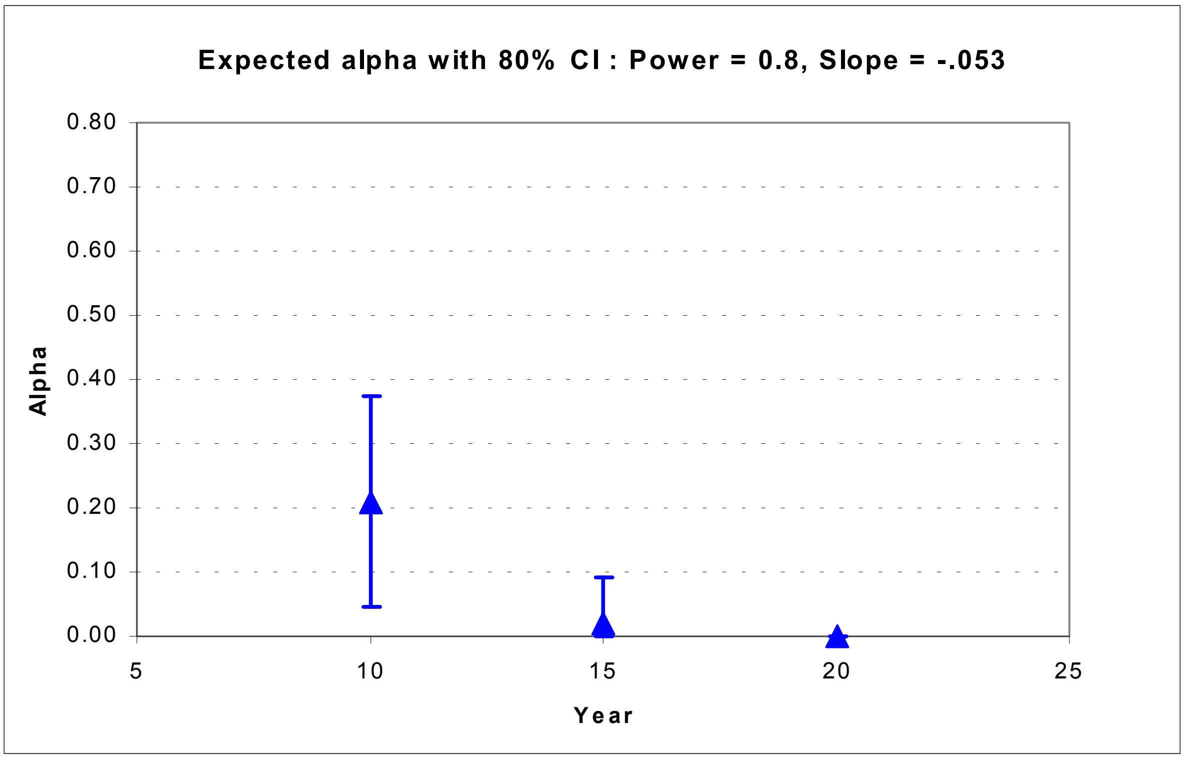


Figure C-5. 80% confidence interval on α, power = 80%.

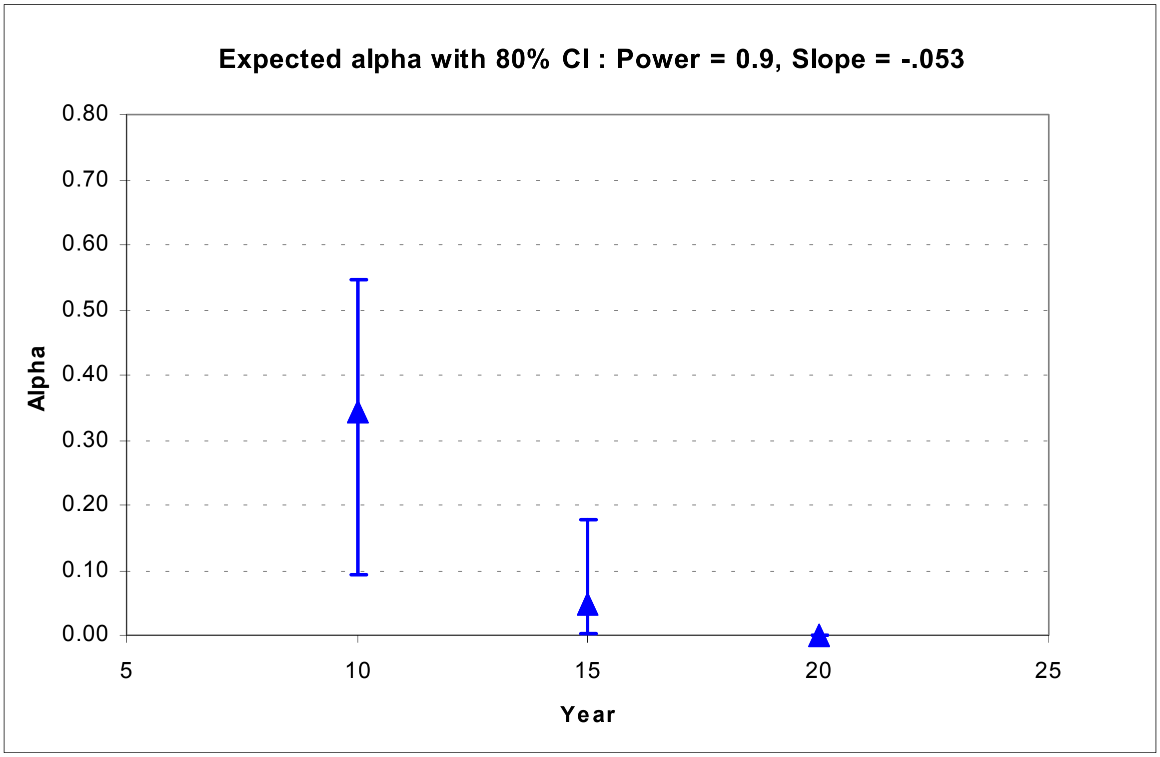


Figure C-6. 80% confidence interval on α, power = 90%.

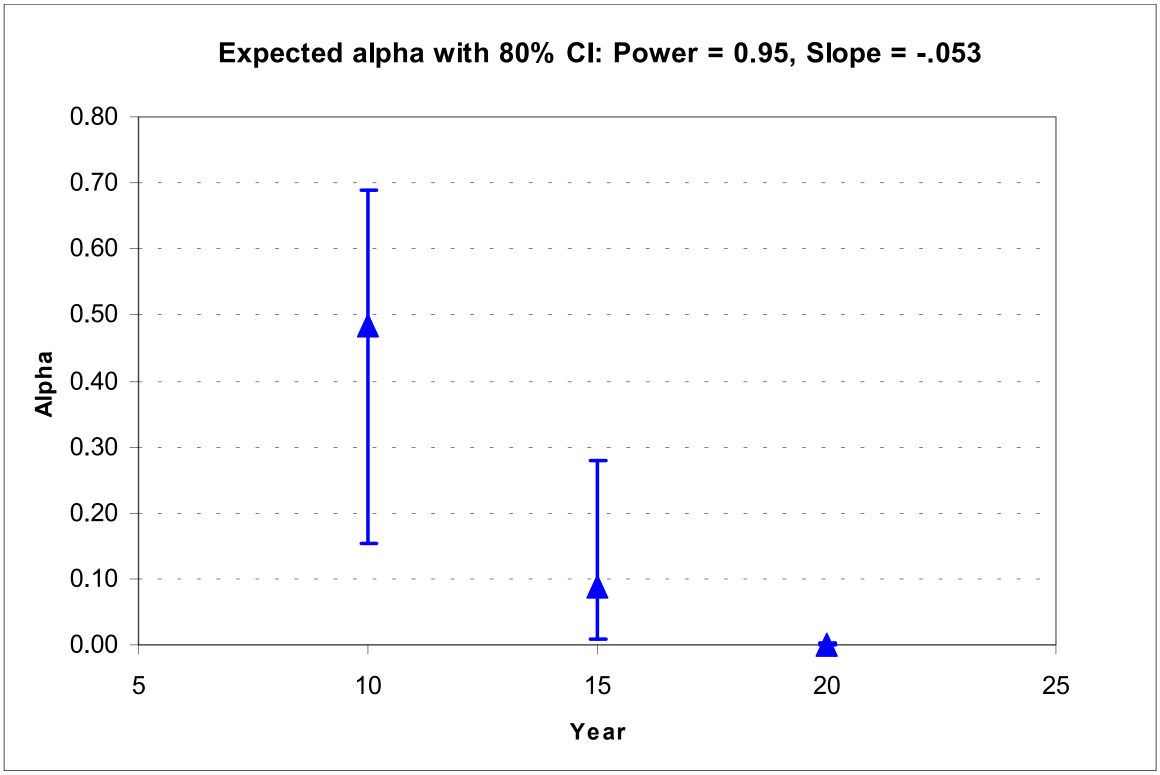


Figure C-7. 80% confidence interval on α, power = 95%.

The figures show agreement with the general conclusion from the original analysis: a high power with a reasonably low Type I error rate may be achievable within 15 years or so. After 20 years, we can expect very high power with very low α. The figures also show the tradeoff between power and α: lower (i.e. more desirable) values of α are achieved more quickly at lower power.

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Appendix D. GLOSSARY

Adaptive trait	Characteristics that improve an individual=s survival and fitness
Adfluvial bull trout	Bull trout that migrate to a lake or reservoir to mature
Anadromous bull trout	Bull trout that migrate to the ocean or an estuary to mature
Artificial propagation	Human intervention in the spawning, incubation, or rearing life-history phases of fish
Char	Members of the genus *Salvelinus*
Complex interacting groups	Refers to the replication of spawning populations of bull trout that are connected within a geographic. The area should be able to support the full range of life-history stages and spawner consist of overlapping generations.
Core area	The combination of core habitat (i.e., habitat that could supply all elements for the long-term security of bull trout) and a core population (i.e., bull trout inhabiting core habitat) of bull trout
Core habitat	Habitat that contains, or if restored would contain, all of the essential physical elements to provide for the security of and allow for the full expression of life history forms of one or more local populations of bull trout
Core population	A group of one or more local bull trout populations that exist within core habitat
Distinct population segment (DPS)	A listable entity under the Endangered Species Act that has met tests of discreteness and significant according to Service policy
Entrainment	Process by which aquatic organisms are pulled through a diversion or other device
Fluvial bull trout	Bull trout that migrate to rivers to mature
Foraging, migrating, and overwintering habitat	Relatively large streams and mainstem rivers, lakes, reservoirs, and estuaries that subadult and adult migratory bull trout use to forage, migrate, mature, or overwinter
Functionally extirpated	Describes an area where a species has been extirpated, however few individuals may occasionally be found there but are not thought to constitute a viable population
Genotype	Genetic composition of an organism or specific gene
Habitat connectivity	Suitable conditions allowing bull trout access to various habitats

Hydrologic unit code	Hierarchical coding system developed by the U.S. Geological Survey used to identify watersheds
Hyporheic zone	Area of saturated sediment and gravel beneath and beside streams and rivers where groundwater and surface water mix; water movement is mainly in a downstream direction
Interspecific competition	Competition for resources involving more than one species
Local population	A group of bull trout that spawns within a particular stream or portion of a stream system
Migratory corridor	Stream reaches used by bull trout to move between habitats
Migratory life history form	Bull trout that migrate from spawning and rearing habitat to grow and mature
Nonnative species	Species not indigenous to an area, such as brook trout in the western United States
Phenotype	Expressed physical, physiological, and behavioral characteristics of a organism that may be due to genetics, the environment, or an interaction of both
Recovery subunit	Portions of large recovery units treated separately to improve management efficiency
Recovery team	Team of Service biologists and representatives from fish and wildlife resource agencies in Idaho, Montana, Oregon, and Washington and native American tribes responsible for providing guidance in developing the bull trout recovery plan
Recovery unit	A grouping of bull trout on which recovery planning is based. Biological and genetic factors, political boundaries, and ongoing conservation efforts were all considered in identifying major units on which to base recovery (*i.e.*, the basis of chapters in the recovery plan); gene flow is thought to have been historically or currently possible within recovery units
Recovery unit teams	Teams of people with technical expertise in various aspects of bull trout biology from Federal and State agencies, tribes, and industry and interest groups responsible for assisting in developing chapters of the bull trout recovery plan focused on individual recovery units
Resident life history form	Bull trout that do not migrate, all life-history stages can be found in spawning and rearing habitat
Spawning and rearing habitat	Stream reaches and the associated watershed (usually the drainage area upstream) that provide all habitat components

	necessary for spawning and juvenile rearing of a local bull trout population
Subpopulation	A reproductively isolated group of bull trout spawning within a particular area of a river system; the basic unit of analysis used in listing bull trout, but not used in the recovery plan
ATake@	Activities that harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or attempt to engage in any such conduct to a listed species
Transplantation	Moving wild fish from one stream system to another without the use of artificial propagation