Bull Trout Recovery:
Monitoring and Evaluation Guidance

Prepared for

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Executive Summary

Distribution, abundance, habitat, genetics are all considered important characteristics of population viability and recovery. Consistent with this, four broad “recovery objectives” have been established for ESA listed bull trout under the USFWS draft Bull Trout Recovery Plan (USFWS 2002):

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;
3. restore and maintain suitable **habitat conditions** for all bull trout life history stages and strategies; and
4. conserve bull trout **genetic diversity** and provide opportunity for **genetic exchange**.

Nested within these general recovery objectives, quantitative “recovery criteria” for bull trout have been established within defined bull trout Recovery Units. These criteria could potentially be assessed through a range of alternative metrics/indicators (see Table 1). Some of these are metrics/indicators that are being used currently by fisheries agencies (e.g., number of reproductive bull trout adults), others are actively being developed within pilot studies for use as primary metrics/indicators (e.g. delineations of bull trout patches and assessments of patch occupancy, connectivity indices), while other candidate metrics still need to be explored (e.g., indices of genetic variation, spatial patterns of bull trout patches). Development of broad scale monitoring and evaluation strategies will be essential for evaluating progress towards bull trout recovery objectives/criteria across the region, assessing changing status, and evaluating the effectiveness of specific recovery actions. There are, however, serious challenges in determining how, when and where to best monitor bull trout populations and their habitats, as well as in establishing statistically sound and rigorous evaluation approaches. The Bull Trout Monitoring and Evaluation Technical Group (RMEG), a multi-agency body chaired by USFWS fisheries technical staff, is working to overcome these challenges so as to provide recommendations for monitoring and analyses that can reliably inform evaluation of bull trout recovery objectives.

Distribution (Recovery Objective 1) – Chapters 2 and 3

Challenges

Distribution is defined as the spatial extent and pattern of bull trout local populations within a core area, with local populations being defined as reproductive groups of individuals that share a common gene pool. Unfortunately, information on bull trout population structure is lacking for many watersheds. This has created problems and inconsistencies in the identification and delineation of local populations within core areas as part of the Bull Trout Recovery Plan process. Variation in approaches has resulted in bull trout in individual tributaries within recovery units often being designated as separate local populations (splitting), while in other recovery units there has been a tendency to lump tributaries together into a single local population. The absence of a consistently defined population sampling unit makes it difficult currently to reliably track changes in distribution. In order to improve evaluations of bull trout distribution there are six principal questions that the RMEG must address:

1. How to define metrics that will be used to judge the recovery objective of ‘maintain current distribution’
2. How to consistently identify sampling units for monitoring distribution?
3. How to develop a sampling design to determine if distributions are changing?

4. What monitoring protocols to use at each sampling unit to determine bull trout presence?
5. What level of power (statistical reliability in conclusions) will be acceptable for concluding distributions are contracting, stable or expanding?
6. What combinations of sampling designs and monitoring protocols meet acceptable levels of statistical reliability?

RMEG analyses

The RMEG has adopted a process whereby the geographical boundaries for potential local populations can be represented by bull trout "patches"—contiguous areas within a stream network where spawning and early juvenile rearing could occur and potentially support a local population. These patches are intended to provide the basis for a consistent sampling unit that can be used to track changes in the distribution of bull trout populations. Potential distribution metrics/indicators being evaluated by the RMEG include the proportion of bull trout patches occupied in a core area, the trend in patches occupied and the number, size and spatial distribution of these patches (see Row 1, Table 1). A two stage filtering process is being used by the RMEG to identify bull trout patches: 1) identification of 'potential' patches for bull trout (which may not be currently occupied for various reasons), and 2) identification of 'realized' bull trout patches which are currently occupied based on both existing information and new sampling. The contrast of 'potential' and 'realized' bull trout patches will additionally relate to an evaluation of connectivity, another important element in the recovery process.

The RMEG has developed novel GIS-based approaches for generating broad-level delineations of bull trout patches based on water temperature, elevation and catchment size criteria. The RMEG is currently working to delineate bull trout patches and create patch sampling strategies for bull trout distribution within a series of test watersheds throughout the Columbia River Basin. For each of these test cases the RMEG is working in partnership with regional biologists who are assisting in refining/adapting the RMEG's broad patch delineations as necessary to account for localized conditions.

Measures of changing distribution will first require an evaluation of the presence of bull trout within and among patches. The RMEG has also developed simulation approaches to determine which sampling designs could most reliably detect changes in patch occupancy. These models are intended to evaluate a range of tradeoffs across potential sampling methods, sampling effort, sample sizes, effect sizes, costs and acceptable levels of statistical reliability. The RMEG is also using test watersheds to evaluate whether EPA's General Random-Tessellation Stratified (GRTS) sampling approach can provide the base design for monitoring in bull trout patches.

RMEG Recommendations	Further Work Required
Bull trout *patches* should be applied as a consistent spatial template, defined through the methods described in Chapter 2. Methods described in Chapter 3 should be used for defining the probability of detecting bull trout in patches. Field sampling should focus on determining how bull trout site and patch detection probabilities may vary based on habitat conditions in the different core areas. Determine the proportion of occupied patches (based on detected redds or juveniles as described in Chapter 3) within a Core Area, as an initial metric of distribution.	Test and refine methods of patch delineation in different core areas. Use existing information from pilot studies (e.g. Boise, Lewis, John Day) to assess how Pr(detection) at the site and patch scale varies with easily estimated habitat variables (e.g., stream order, stream size, gradients, conductivity etc.). Work with local fisheries biologists to determine what size classes of bull trout are indicative of multiple age classes in different core areas. Determine how the ability to detect bull trout varies in different bull trout core areas, so as to fully inform the appropriate monitoring effort required to track change in bull trout patch occupancy. Explore the effects of different definitions of bull trout occupancy (e.g., simple presence of juveniles vs. multiple age classes of juveniles). Determine metrics describing the size and spatial pattern of potential and occupied patches.

Connectivity (relates to Recovery Objectives 3 and 4) – Chapter 4

Challenges

Connectivity refers to the maintenance of suitable stream conditions that allow bull trout to move freely upstream and downstream with habitat linkages that connect to other habitat areas. Two of the Bull Trout Recovery Plan objectives relate to connectivity: 1) conserve genetic diversity and provide opportunity for genetic exchange; and 2) restore and maintain suitable habitat conditions for all life history stages and strategies. These objectives imply that measures/monitoring of connectivity must then be considered from two distinct perspectives: 1) connectivity among local populations (i.e., effective dispersal) and 2) connectivity to the migratory corridor associated with each local population (i.e., unrestricted migration opportunities and the full expression of life history strategies).

RMEG analyses

The RMEG is evaluating methods that could be used to quantify three aspects of bull trout habitat that relate to connectivity: 1) barriers (thermal/physical); 2) distance between bull trout “patches” (dispersal); 3) distance to migratory rearing areas (expression of life history). Potential connectivity metrics/indicators being evaluated by the RMEG include patch size, indices of connectivity and isolation/dispersal, condition of migratory corridors, diversity of migratory patterns, suitable stream lengths, and measures of genetic diversity/bottlenecks (see Rows 3 and 4, Table 1). The RMEG have been exploring the ability to quantify connectivity from GIS overlays of natural and human constructed movement barriers, and the geographic extents of bull trout patch delineations (local populations).This information is being used in test watersheds to construct a Connectivity Index that provides a metric for quantifying historical and current connectivity networks within a core area, and that can be used to predict or track increasing or decreasing connectivity as a result of future restoration actions. RMEG’s Connectivity Index will additionally be used for evaluating the role of connectivity in the long term persistence of occupied bull trout patches (also by employing estimates of local colonization and extinction rates from patch occupancy data). The RMEG intends to pursue further evaluation of connectivity through population genetics and measures of population structure.

RMEG Recommendations	Further Work Required
Use connectivity indices that incorporate the distances between focal and donor patches, patch sizes and barriers, using a GIS-based approach similar to those evaluated by RMEG and described in Chapter 4.	Develop a robust and parsimonious index that explains observed patterns of patch occupancy. Test candidate indices in strategically selected areas through detailed studies that employ occupancy data, tagging/telemetry studies that record actual movement patterns of tagged fish, and molecular markers for assessment of "effective" dispersal (measurements of actual biological response to connectivity). Simulation models should be developed to determine how much connectivity is required to maintain bull trout populations, and how often gene flow events are necessary to maintain population structure.

Abundance (Recovery Objective 2) – Chapter 5

Challenges

A variety of sampling techniques can potentially be employed for monitoring bull trout abundance; all, however, have some degree of uncertainty around the obtained abundance estimates. For example, redd counts represent a widespread and relatively inexpensive technique for estimating spawning adult abundance. However, redd counts are frequently limited by some combination of strong observer variability, redd superimposition, poor delineation of test digs and redds, and substrate. Trapping of adult bull trout at weir or fish ladders can provide direct information on adults but is dependent on efficient, continuous trap operation/inspection and also fails to account for resident adults that do not migrate below the traps. Snorkel counts can provide a relatively inexpensive, non-invasive technique for estimating abundance by bull trout size class, but has been shown to consistently underestimate abundance and have low precision due to the frequent low densities and high spatial variability of bull trout populations. Additionally, snorkeling may not be feasible in small, shallow streams and can be ineffective at cold temperatures. Electrofishing is not generally used for monitoring adult bull trout abundance due to the perceived risk of injury or mortality to larger fish. There are benefits to electrofishing, however, in that important monitoring data can be obtained by having fish in-hand (e.g., precise lengths, sex, maturity, genetics). The higher sampling efficiency of single-pass electrofishing also provides a less biased estimate of abundance than snorkeling. Similar to snorkeling, however, single-pass electrofishing appears to consistently underestimate abundance, and has limited feasibility in large rivers (e.g., inability to block net). Electrofishing depletion estimates (i.e., multiple-pass electroshocking) provide a more unbiased and precise estimate of true population abundance than single-pass estimates of abundance, but require a much greater commitment of personnel and time, presenting a potential limitation for many monitoring programs. Mark-recapture techniques provide arguably the most accurate technique of estimating bull trout abundance and trend, and simultaneously provide information on fish vital rates, movement patterns and population structure. However, mark-recapture is also typically the most expensive monitoring technique and requires a high degree of effort and handling of fish.

For bull trout recovery to be accepted, numbers of spawning fish in core areas must demonstrate a stable or increasing trend for two generations at or above target recovery abundance levels. However, determining bull trout abundance presents distinctive sampling challenges. Within a population or core area bull trout can exhibit different complex life-history strategies (resident, migratory), may occupy a diversity of habitats, are cryptic in their behaviour and often occur at naturally low densities. Estimates of adult abundance usually provide more complete information than juveniles about population health, because adults have successfully transitioned through all life-stages and the habitats that support each life stage. Since the recovery criteria for abundance are based on reproductive adults and there are difficulties in extrapolating between juvenile and adult abundance, the RMEG has only considered sampling techniques and survey design applicable to estimating adult abundance. It is likely that different attributes of adult abundance will need to be measured using different methods in different regions, reflecting variation in bull trout life history, habitat type, logistical considerations and available resources.

There are also critical issues of scale that must be considered for monitoring abundance. Abundance sampling is typically implemented at the scale of local populations (i.e., stream reaches, small watersheds). However, bull trout abundance recovery objectives/criteria are generally assessed at the core area scale. Therefore practitioners are faced with the challenge of reliably scaling up from measurements made at these smaller scales (local population) to the required scale of the core area. Compounding this is the impracticality of attempting to implement some abundance monitoring techniques across all populations in a core area due to the high cost and considerable effort required. Developing a robust, yet economically feasible approach for estimating bull trout abundance across larger spatial scales (core areas/subbasins) requires resolving a number of challenges.

RMEG analyses

Designing surveys to estimate abundances and changes over time (trend) requires the parsimonious allocation of field sampling across space (core area) and time (usually years). Knowledge of spatial and temporal variation of the technique and indicator of choice (e.g., redds versus adult fish) is critical for the efficient allocation of visits to new sites, or to revisits to existing sites. Current RMEG efforts have focused on identifying the sampling challenges associated with estimating abundance for bull trout, synthesizing lessons learned with regard to different sampling techniques and approaches, and developing an annotated flow chart summarizing pros and cons of each technique for addressing different abundance metrics. Potential abundance metrics/indicators being evaluated by the RMEG include the numbers of reproductive adults, numbers of fish in different size classes, numbers of migratory adults, numbers of resident adults, population growth, number/proportion of occupied sample sites, and indices of genetic variation (see Row 2, Table 1). The RMEG is also beginning to explore the use of GRTS and rotating panel designs for abundance monitoring across larger spatial scales.

RMEG Recommendations	**Further Work Required**
At a patch and site scale:	
Focus on estimating adult abundance using appropriate methods for each region, accounting for the variation in bull trout life history, habitat type, logistical considerations and the resources available.	Quantity biases inherent in different abundance sampling techniques under different conditions. Explore whether better methods could be developed for extrapolating from juvenile to adult bull trout abundances.
At a core area scale:	
Use a probabilistic panel survey design (e.g., GRTS) for sample allocation to estimate abundance. Such designs offers both flexibility and potentially satisfactory statistical power, while providing an economically feasible approach for estimating bull trout abundance across larger spatial scales (e.g., core area/subbasin).	Panel designs may not be appropriate for all abundance measurement techniques (e.g., weirs). In small core areas, a census may be less expensive to undertake than a panel design.
Use a nested survey design potentially stratified by key populations and habitats, and using a combination of abundance sampling techniques. Most sites would be sampled using inexpensive, non-invasive sampling techniques (e.g., redds, snorkeling), while a subset of these sites would also be sampled with more invasive but more informative techniques (e.g., mark-recapture, weirs). This subset would be used to estimate the bias associated with the less intensive methods. Then one would “scale up” to core area abundance estimates, using bias corrections to the less intensive, non-invasive methods.	

Table 1. Overview of the USFWS Bull Trout Recovery Plan recovery objectives, quantitative recovery criteria (which will vary specific to each Recovery Unit), and the potential metrics/indicators to be explored by the RMEG for evaluating recovery criteria.

Recovery Objectives	**Recovery Criteria** (examples)	Metrics/Indicators (**Primary** vs. candidate)
1. Maintain current **distribution** of bull trout and restore distribution in previously occupied areas	Habitat is sufficiently maintained or restored to provide for the persistence of broadly distributed local populations within each core area.	• **Proportion of bull trout patches occupied** • **Trend in patches occupied** • Number, size and spatial pattern of potential habitat patches
2. Maintain stable or increasing trends in **abundance** of bull trout. Abundance levels will be defined for each recovery unit.	Adult bull trout are sufficiently abundant to provide for the persistence and viability of each core area and to support both resident and migratory adult bull trout. This level of abundance is estimated to be 'X' spawning fish per year in local populations and core areas. Measures of bull trout abundance within all core areas show stable or increasing trends based on 10 to 15 years (representing at least 2 bull trout generations) of monitoring data.	• **Number of reproductive adults** • **Number of fish within different size classes** • **Number of migratory adults** • **Number of resident adults** • **Population growth** • Number/proportion of occupied sample sites • Indices of genetic variation
3. Restore and maintain suitable **habitat conditions** for all bull trout life history stages and strategies	Habitat within each core area is connected so as to provide for the potential full expression of migratory behavior	• **Patch size** • **Connectivity Indices** • **Isolation/Dispersal** • Condition of migratory corridor • Diversity of migratory pattern
4. Conserve bull trout **genetic diversity** and provide opportunity for **genetic exchange**	Habitat within each core area is connected so as to allow for the refounding of extirpated populations, and provide for the potential of genetic exchange between populations	• **Patch sizes** • **Connectivity Indices** • **Isolation/Dispersal** • Suitable stream length • Genetic diversity / bottlenecks

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Glossary

Abundance (bull trout) – Total number of bull trout occurring within a defined area at a particular point in time.

Adfluvial bull trout – Bull trout that migrate from tributary streams to a lake or reservoir to mature (one of three bull trout life histories). Adfluvial bull trout return to a tributary to spawn.

Age class – A group of individuals of a species that have the same age, e.g., 1 year old, 2 years old, etc.

Autocorrelation – The correlation of an ordered series of observations with the same series displaced by the same number of terms. In can present problems in regression analyses using time series data.

Barriers (natural) – Barriers such as waterfalls and desiccated stream reaches that prevent fish movements. These are rarely included in existing GIS coverages, and, as yet, are difficult to predict.

Barriers (human-caused) – Barriers such as human constructed dams, diversions and road crossings that prevent fish movements.

Bias – A consistent difference between an estimator's expectation and the true value of the parameter being estimated

Block-netting – Use of mesh netting secured to the streambed at selected sampling break points to prevent upstream and downstream fish movements.

Bull Trout Recovery Plan – Official (draft) plan developed by the USFWS to ensure recovery for bull trout across its range by reducing threats to the long-term persistence of populations and their habitats, ensuring the security of multiple interacting groups of bull trout, and providing improved access to habitats that will allow for the full expression of various bull trout life-history forms.

Bull Trout Status Review – 5-year review undertaken by The U.S. Fish and Wildlife Service of bull trout to ensure that the classification of species as threatened or endangered on the federal List of Endangered and Threatened Wildlife and Plants is accurate. The 5-year review represented an assessment of the best scientific and commercial data relating to bull trout available at the time of the review.

Catchment area – The area drained by a river or body of water.

Char – A fish belonging to the genus *Salvelinus* and related to both the trout and salmon. The bull trout, Dolly Varden trout, and the Mackinaw trout (or lake trout) are all members of the char family. Char live in the icy waters (both fresh and marine) of North America and Europe.

Conductivity – A measure of the ability of water or other substances to conduct electric current.

Connectivity (bull trout) – Suitable stream conditions that allow bull trout to move freely upstream and downstream with habitat linkages that connect to other habitat areas.

Conservation unit – A segment of biological diversity that shares an evolutionary lineage and contains the potential for a unique evolutionary future. Conservation units are composed of one or more metapopulations.

Core area – The combination of core habitat (*i.e.*, habitat that could supply all elements for the longterm security of bull trout) and a core population (a group of one or more local bull trout populations that exist within core habitat) constitutes the basic unit on which to gauge recovery within a recovery unit. Core areas require both habitat and bull trout to function, and the number (replication) and characteristics of local populations inhabiting a core area provide a relative indication of the core area's likelihood to persist. A core area represents the closest approximation of a biologically functioning unit for bull trout.

Core habitat – Habitat that encompasses spawning and rearing habitat (resident populations), with the addition of foraging, migrating, and overwintering habitat if the population includes migratory fish. Core habitat is defined as 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 habitat may include currently unoccupied habitat if that habitat contains essential elements for bull trout to persist or is deemed critical to recovery.

Core population – A group of one or more bull trout local populations that exist within core habitat.

Cryptic behaviour – Any behavior performed for the purpose of minimizing conspicuousness of an organism.

Delisting (ESA) – The removal of a species from the list of threatened and endangered species and recognition that protection under the Endangered Species Act (ESA) is no longer warranted.

Demographic support – Immigration from surrounding populations with the net effect of increasing abundance, population growth rate or other demographic characteristics such that the population of interest may be more likely to persist.

Detection probability – The probability of detecting an individual with a standard sampling effort given the individual is present in the sampling unit of interest. Alternatively the proportion of individuals within a sampling unit that are collected with a standard sampling effort.

Diffusion approximation models – Viability models which treat the change in log population size as a process of diffusion with drift, much as gas molecules diffuse through a series of small jumps. These models allow the rate at which the state variable (population size) first hits a lower boundary to be calculated.

Digital elevation model (DEM) – A digital representation of ground surface topography or terrain, most commonly built using remote sensing techniques but they may also be built from land surveying.

Dispersal – Processes by which a population maintains or expands its distribution.

Dispersal distance – The distance from a natal area that an organism could travel in search of new habitats to occupy.

Distinct population segment (DPS) – A listable entity under the Endangered Species Act that meets tests of discreteness and significant according to federal policy. The U.S. Fish and Wildlife Service has formally determined there are five bull trout distinct population segments across the species range within the coterminous United States—Klamath River, Columbia River, Jarbidge River, Coastal-Puget Sound, and St. Mary-Belly River. Each meets the tests of discreteness and significance under joint policy of the U.S. Fish and Wildlife Service and National Marine Fisheries Service and these are the units against which recovery progress and delisting decisions will be measured.

Discharge (stream) – With reference to stream flow, the quantity of water that passes a given point in a measured unit of time, such as cubic meters per second or, often, cubic feet per second.

Distribution (bull trout) – The spatial extent and pattern of bull trout local populations within a core area. The *potential distribution* is the geographic range where bull trout have historically occurred. The *current distribution* is the proportion of that potential distribution which is currently occupied, and the spatial distribution or pattern of occupied areas.

Donor patch – A patch that has the potential to produce individuals that may disperse to other patches.

Effective population size (Ne) – The number of breeding individuals that would give rise to the same amount of random genetic drift as the actual population, if ideal conditions held.

Electrofishing – A fish sampling method using battery powered back-packs or boat-mounted units that generate a pulse of direct current into the water. This generates muscular contractions, called galvanotaxis, in fish causing them to turn and swim towards the source of the electrical current.

Empirical data – Information based on observation and experience.

Environmental Monitoring and Assessment Program (EMAP) – A research program developed by the US EPA to generate the analytical tools necessary to monitor and assess the status and trends of national ecological resources.

Episodic event – An event that occurs sporadically or incidentally.

Extirpated populations – Populations that have been eliminated from a particular local area; although a few individuals may occasionally be found, they are not thought to constitute a viable population.

Fish ladder – A device to help fish swim around a dam.

Fluvial bull trout – Bull trout that migrate from tributary streams to larger rivers to mature (one of three bull trout life histories). Fluvial bull trout migrate to tributaries to spawn.

Focal patch – The patch of immediate interest in an analysis; the patch receiving immigrants from surrounding patches.

Fragmentation – The loss of full interconnectedness of various habitats and populations.

GENPRES – A computer program that allows single-season and multi-season estimation of occupancy.

Generalized Random-Tessellation Stratified (GRTS) design – A spatially-balanced probabilistic survey design developed by the US EPA under their Environmental Monitoring and Assessment Program. GRTS overcomes some of the shortcomings of simple random sampling and systematic sampling by providing a spatially balanced set of sites that represent the population from which the sample sites will be drawn.

Gene flow – The loss or gain of alleles from a population due to the emigration or immigration of fertile individuals, or the transfer of gametes, between populations.

Genetic diversity – Variation in the nucleotides, genes, chromosomes, or whole genomes of organisms. It is this variation which allows populations to adapt to changes in environmental conditions.

Geographic Information System (GIS) – A collection of computer hardware, software, and geographic data for capturing, managing, analyzing, and displaying all forms of geographically referenced information.

Gradient – The degree to which something inclines; a slope.

Habitat geometry – The size, shape, and or spatial distribution of a habitat patch or patches.

Headwater – The source of a stream. Headwater streams are the small swales, creeks, and streams that are the origin of most rivers. These small streams join together to form larger streams and rivers or run directly into larger streams and lakes.

Hybrids – Offspring that result from any crossing of individuals of different genetic composition, typically different species.

Hydrologic regime – The characteristic pattern of precipitation, runoff, infiltration, and evaporation affecting a watershed.

Hydrologic unit (HUC code) – Watersheds that are classified into four types of units: regions, subregions, accounting units, and cataloging. The units from the smallest (cataloging units) to the largest (regions). Each unit is identified by a unique hydrologic unit code consisting of two to eight digits based on the four levels of classification in the hydrologic unit system.

Index – A number, ratio or formula derived from a series of observations and used as an indicator or measure (as of a condition, property, or phenomenon).

Interacting reproductive units – Multiple local populations that may have overlapping spawning and rearing areas within a geographic area.

Intermittent stream – A stream that flows only at certain times of the year as when it receives water from springs (or by surface water) or when water losses from evaporation or seepage exceed the available streamflow.

Isolation – Segregation of a group of organisms from related forms in such a manner as to prevent genetic mixing.

Juvenile (bull trout) – Bull trout aged 1-2 years; bull trout generally considered to be juveniles if shorter than 150 mm fork length.

Large woody debris (LWD) – Woody material such as trees and shrubs; includes all parts of a tree such as root system, bowl, and limbs. Large woody debris refers to the woody material whose smallest diameter is greater than 10 centimeters, and whose length is greater than 3 meters.

Limiting factor – An environmental factor that tends to limit population size.

Linear regression – A statistical model to account for (predict) the variance in an interval dependent, based on linear combinations of interval, dichotomous, or dummy independent variables.

Local population – A group of bull trout that spawn within a particular stream or portion of a stream system. Multiple local populations may exist within a core area. A local population is considered to be the smallest group of fish that is known to represent an interacting reproductive unit. For most waters where specific information is lacking, a local population may be represented by a single headwater tributary or complex of headwater tributaries. Gene flow may occur between local populations (*e.g.*, those within a core population), but is assumed to be infrequent compared with that among individuals within a local population.

Logistic regression – Statistical model for binomially distributed response/dependent variables. It is useful for modeling the probability of an event occurring as a function of other factors.

Log-linear regression – A non-dependent statistical model for accounting for the distribution of cases in a crosstabulation of categorical variables. It represents an analog to multiple linear regression for categorical variables.

Mark-recapture – A method commonly used to estimate population size and population vital rates (e.g., survival, movement, and growth). This method is most valuable when it is not possible to detect all individuals present within a population of interest.

Metadata – Data about data. An item of metadata may describe an individual datum, or content item, or a collection of data including multiple content items.

Metapopulation – A group of semi-isolated subpopulations of bull trout that are interconnected and that probably share genetic material.

Migration – The periodic extended passage of groups of animals (especially birds or fishes) from one region to another for feeding or breeding.

Migratory corridor (bull trout) – Stream reaches used by bull trout to move between habitats. A section of river or stream used by fish to access upstream spawning areas or downstream lake environments.

Migratory life history form (bull trout) – Bull trout that migrate from spawning and rearing habitat to lakes, reservoirs, or larger rivers to grow and mature.

Monitoring protocol – A set of standardized procedures that explain how particular monitoring data are to be collected, managed, analyzed, and reported.

Nonnative species – Species not indigenous to an area, such as brook trout in the western United States.

Occupancy model – Model that can estimate the rate at which occupied sites go extinct or vice versa, the rate at which unoccupied sites become occupied by a particular organism.

Occupied patch – A habitat patch that supports a reproducing population; a local population.

Patch – The limits or boundaries of environmental conditions that can support a biological response. For bull trout, a patch would be represented by contiguous areas within a stream network where spawning and early juvenile rearing could occur and potentially support a local population.

Patch network – The collection of habitat patches or local populations interconnected by streams open to migration and dispersal.

PIT tags (Passive Integrated Transponder) – Tiny identification chips which are injected into specimens for permanent identification and are valuable for mark-recapture analyses.

Population – A reproductive community of individuals that share in a common gene pool.

Population growth rate (λ) – The change in the number of individuals in a population per unit time.

Population structure – Variation in the frequency of different alleles and genotypes within a population across space.

Population viability assessment (PVA) – A species-specific analytical method that estimates the probability that a particular population will go extinct within a given number of years.

Potential local population – A local population that does not currently exist, but that could exist, if spawning and rearing habitat or connectivity were restored in that area, and contribute to recovery in a known or suspected unoccupied area.

Probabilistic sampling – A sampling method that utilizes some form of random selection of sampling sites.

Recovery action – Activity undertaken under a species recovery plan in order to reduce or remove threats.

Recovery unit (bull trout) – Recovery units are the major units for managing recovery efforts; each recovery unit is described in a separate chapter in the recovery plan. A distinct population segment may include one or several recovery units. Most recovery units consist of one or more major river basins. Several factors were considered in our identifying recovery units, for example, biological and genetic factors, political boundaries, and ongoing conservation efforts. In some instances, recovery unit boundaries were modified to maximize efficiency of established watershed groups, encompass areas of common threats, or accommodate other logistic concerns. Recovery units may include portions of mainstem rivers (*e.g.*, Columbia and Snake rivers) when biological evidence warrants inclusion. Biologically, recovery units are considered groupings of bull trout for which gene flow was historically or is currently possible.

Redd – A nest constructed by female trout or salmon in streambed gravels where eggs are deposited and fertilization occurs. Redds can usually be distinguished in the streambed gravel by a cleared depression, and an associated mound of gravel directly downstream.

Redd superimposition – Reuse of redd sites by later-spawning salmon and trout, which can affect survival of fertilized eggs and embryos and reduce overall reproductive success.

Refounding – Reestablishment of a species into previously occupied habitat.

Resident life history form (bull trout) – Bull trout that do not migrate, but that reside in tributary streams their entire lives (one of three bull trout life cycles).

Resilience – The ability to recover from or adjust easily to changed conditions.

Riverscape – The variable size, composition, and configuration of a river in response to the pulsing of discharge.

Robust design – A design in which sample sites are selected randomly for the first sampling interval. In succeeding intervals, the same sites are sampled each time.

Rotating panel design – Survey design which consist of panels of monitored sites, each panel with a particular pattern of visits across years to allow for estimation of spatial and temporal variation.

Salmonid – Fish of the family Salmonidae, including trout, salmon, chars, grayling, and whitefish. In general usage, the term most often refers to salmon, trout, and chars.

Salmonid silhouette – An artificial 2-dimensional representation of a salmonid created from cut out plastic sheeting and decorated with spots and other markings using black ink. The silhouette is used to estimate underwater visibility in different stream habitats by determining the distance at which markings can no longer be distinguished by snorkelers.

Sampling frame – The list or map of the sampling entities which represent the units of analysis.

Sampling unit – One of the units into which an aggregate is divided for the purpose of sampling, each unit being regarded as individual and indivisible when the selection is made. It this unit that provides the basis of analysis.

Simulation model – A mathematic model generally coded within a computer program that attempts to replicate the functioning of a particular system. These models are used to simulate the behaviour of the system based on a varied set of user-defined parameters and initial conditions, and in this way gain insight into the real functioning of the system.

Site-specific probability of detection (SSPD) – The probability of detecting an individual in a single sample given that the species occurs within the encompassing patch.

Source population – Strong subpopulations that are within a metapopulation and that contribute to other subpopulations and reduce the risk of local extinctions.

Spawning and rearing habitat (bull trout) – Stream reaches and the associated watershed areas that provide all habitat components necessary for spawning and juvenile rearing for a local bull trout population. Spawning and rearing habitat generally supports multiple year classes of juveniles of resident or migratory fish and may also support subadults and adults from local populations of resident bull trout.

Species – The basic category of biological classification, composed of related individuals that resemble one another, are able to breed among themselves, but are not able to breed with members of another species.

Stochastic – The term is used to describe natural events or processed that are random. Examples include environmental conditions such as rainfall, runoff, and storms, or life-cycle events, such as survival or fecundity rates.

Stock – The fish spawning in a particular lake or stream(s) at a particular season, which to a substantial degree do not interbreed with any group spawning in a different place, or in the same place at a different season. A group of fish belonging to the same population, spawning in a particular stream in a particular season.

Stream order – Stream order is a measure used to define stream size based on a hierarchy of its tributaries. When two first-order streams come together, they form a second-order stream. When two second-order streams come together, they form a third-order stream. Stream sizes range from the smallest, first-order, to the largest, twelfth-order.

Subadult (bull trout) – Bull trout aged 3-4 years.

Temporal symmetry model – Mark-recapture model of the type developed by Pradel (1996) where capture histories are analyzed simultaneously with both forward and reverse-time modeling. Such models permit direct estimation of population growth rates without the need to completely enumerate the population or to estimate all vital rates.

Tributary – A stream that flows to a larger stream or other body of water.

Type 1 (α) error – The error of rejecting a null hypothesis when it is actually true. This is the error of observing a perceived difference when in truth there is none.

Type 2 (β) error – The error of failing to reject a null hypothesis when the alternative hypothesis is the true state of nature. This is the error of failing to observe a difference when in truth there is one.

Viability – The capacity for a population to persist and conceivably expand over wide geographical limits.

Vital rates – Relative frequencies of vital occurrences (e.g., survival, movement, and growth) that affect changes in the size and composition of a population.

Watershed – The area of land from which rainfall (and/or snow melt) drains into a stream or other water body. Watersheds are also sometimes referred to as drainage basins or drainage areas. Ridges of higher ground generally form the boundaries between watersheds. At these boundaries, rain falling on one side flows toward the low point of one watershed, while rain falling on the other side of the boundary flows toward the low point of a different watershed.

Year class (cohort) – Fish in a stock born in the same year. For example, the 1987 year class of bull trout includes all bull trout born in 1987, which would be age 1 in 1988. Occasionally, a stock produces a very small or very large year class which can be pivotal in determining stock abundance in later years.

Young of the year (YOY) – Fish that are less than one year old; hatched during the spawning season. For Bull trout these are generally recognized as fish less than 50 mm in fork length.

Chapter 1: Introduction

1.1 Bull trout recovery planning

Bull trout (Salvelinus confluentus) is an imperiled species of char native to the Pacific Northwest. Combinations of habitat degradation (e.g., Fraley and Shepard 1989), barriers to migration (e.g., Rieman and McIntyre 1995), and the introduction of non-natives (e.g., Leary et al. 1993) have led to the decline of bull trout populations across their native range (Rieman et al. 1997). Consequently, bull trout in the coterminous United States were listed as threatened, under the Endangered Species Act (ESA), on November 1, 1999 (64 FR 58910) (USFWS 2002). The U.S. Fish and Wildlife Service (USFWS) is charged with developing federal recovery plans for listed bull trout. Distribution, abundance, habitat, and genetics are all considered important characteristics of population viability and recovery (McElhaney et al. 2000). Consistent with this, four broad “recovery objectives” (USFWS 2002) have been established for bull trout under the USFWS draft Bull Trout Recovery Plan:

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;
3. restore and maintain suitable **habitat conditions** for all bull trout life history stages and strategies; and
4. conserve bull trout **genetic diversity** and provide opportunity for **genetic exchange**.

1.2 Bull trout population units

For ESA listing purposes the range of bull trout has been broken into distinctive population segments (DPSs) as the base units for assessing species recovery (USFWS 2002). DPSs are units of a population that are considered: 1) ‘discrete’ (to some extent separated from the remainder of the species or subspecies); and 2) ‘significant’ (biologically and ecologically). Bull trout DPSs are further subdivided into recovery units (RUs), core areas and local populations (Figure 1.1). Recovery units were delineated based on the distribution and biology of bull trout as well as considerations for paralleling existing state fisheries management frameworks. Each recovery unit currently has its own individualized (draft) recovery plan. There are currently 4 DPSs and 22 recovery units listed for bull trout but the rationales and associated delineations of these population units are currently undergoing a process of review and may change in the future.

Core areas are defined as combinations of core habitat and core populations of bull trout that form a biologically functioning unit. Core areas were identified in an attempt to reflect existing bull trout metapopulation structure (USFWS 2002). The bull trout core area list (currently 121 identified) has remained essentially unchanged since the time of original listing and most core areas are naturally delineated based on watershed boundaries. Given the relatively stable designation of core areas they have been used as the organizational structure for the recent evaluation of bull trout conservation status undertaken for the federal 5-year Bull Trout Status Review, and represent the primary population unit for bull trout recovery planning. Current analyses by the RMEG have therefore focused on design of monitoring and evaluation for bull trout core areas and for local populations within core areas.

Local populations are defined as groupings of bull trout that spawn within particular streams or portions of a stream system, and represent interacting reproductive units. There may be one or multiple local populations within a single core area. Local populations of bull trout are, however, less precisely defined than core areas due to current lack of specific knowledge about bull trout distribution, local movement patterns and genetic exchange. Variation in approaches to identification has resulted in bull trout within individual streams in some areas being designated as separate local populations (splitting), while in other areas there has been a tendency to lump tributaries together into a single local population. Establishing a more standardized sampling unit [for example, one approach is to adopt a process for delineating bull trout "patches" - contiguous areas within a stream network where spawning and early juvenile rearing could occur and potentially support a local population] is a key element for improving the regional bull trout monitoring framework.

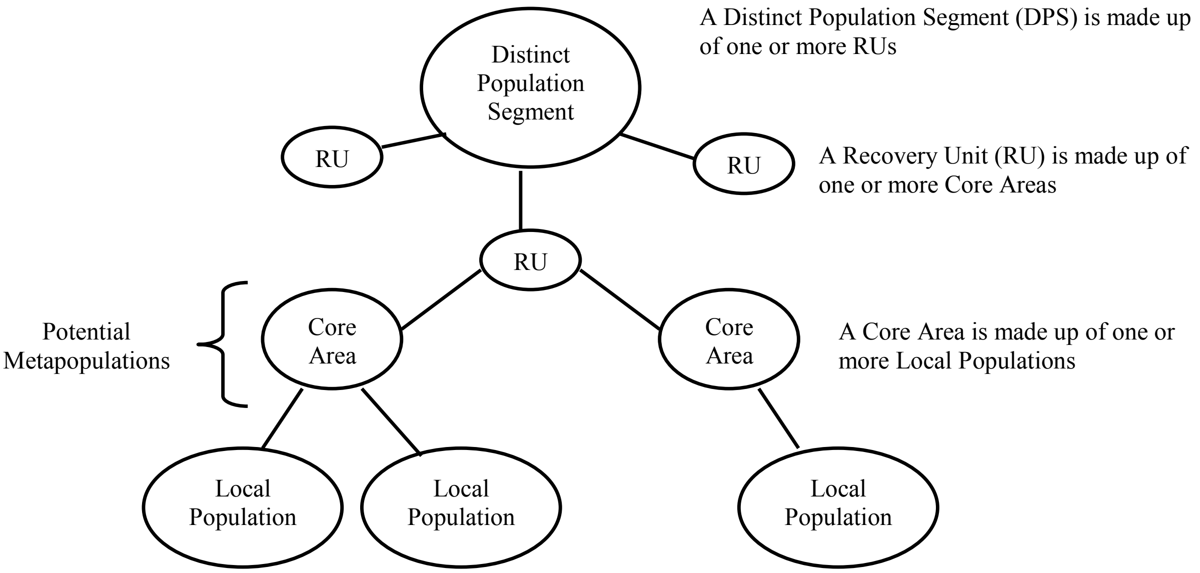

Figure 1.1. Structuring of defined population units within the USFWS Bull Trout Recovery Plan.

1.3 Bull Trout Recovery Monitoring and Evaluation

The criteria for evaluating achievement of recovery objectives for bull trout population units are further clarified under the draft Recovery Plans for each of the four bull trout DPSs (www.fws.gov/pacific/bulltrout/recovery.html). Each of these recovery criteria could, however, be assessed through a range of alternative metrics/indicators, each with a large suite of alternative sampling techniques that could be used to capture this information (Table 1.1). Exploring the alternatives and developing the most reliable and cost-effective strategies for broad scale monitoring and evaluation is essential for determining progress on bull trout recovery objectives/criteria across the Region, and for assessing the effectiveness of specific recovery actions.

Table 1.1. Overview of the USFWS Bull Trout Recovery Plan recovery objectives, quantitative recovery criteria (which will vary specific to each Recovery Unit), potential metrics/indicators that could be used for evaluating these criteria and the sampling techniques that could be used for collecting information in the field to determine/derive these metrics/indicators. Metrics/indicators in bold text are those considered by the RMEG as the primary metrics/indicators for evaluating recovery criteria, and that have been the initial focus of directed RMEG analyses. Metrics/indicators in unbolded text represent additional candidate metrics that that the RMEG intends to evaluate.

Recovery Objectives	Recovery Criteria (examples)	Metrics/Indicators (primary vs. candidate)	Potential Sampling Techniques
1. Maintain current distribution of bull trout and restore distribution in previously occupied areas	Habitat is sufficiently maintained or restored to provide for the persistence of broadly distributed local populations within each core area.	• Proportion of bull trout patches occupied • Trend in occupied patches • Number, size and spatial pattern of potential habitat patches • Stream temperature and potential habitat models	• Electroshocking (juveniles) • Redd counts (adults) • Snorkeling (juveniles)
2. Maintain stable or increasing trends in abundance of bull trout. Abundance levels will be defined for each recovery unit.	Adult bull trout are sufficiently abundant to provide for the persistence and viability of each core area and to support both resident and migratory adult bull trout. This level of abundance is estimated to be 'X' spawning fish per year in local populations and core areas. Measures of bull trout abundance within all core areas show stable or increasing trends based on 10 to 15 years (representing at least 2 bull trout generations) of monitoring data.	• Number of reproductive adults • Number of fish within different size classes • Number of migratory adults • Number of resident adults • Population growth • Number/proportion of occupied sample sites • Indices of genetic variation	• Weirs (adults) • Mark-recapture/mark resight (juveniles/adults) • Redd counts (adults) • Multi-pass electroshocking (juveniles) • Single-pass electroshocking (juveniles) • Night snorkeling (juveniles) • Day snorkeling (juveniles) • Ne indices
3. Restore and maintain suitable habitat conditions for all bull trout life history stages and strategies	Habitat within each core area is connected so as to provide for the potential full expression of migratory behavior	• Patch size • Connectivity Indices • Isolation/Dispersal • Stream temperature and potential habitat models • Condition of migratory corridor • Diversity of migratory pattern	• Inventory of physical and thermal barriers • Radio tracking to document diversity of migratory pattern • Otolith chemistry to document diversity of migratory pattern
4. Conserve bull trout genetic diversity and provide opportunity for genetic exchange	Habitat within each core area is connected so as to allow for the refounding of extirpated populations, and provide for the potential of genetic exchange between populations	• Patch Sizes • Connectivity Indices • Isolation/Dispersal • Suitable stream length • Genetic diversity / bottlenecks	• Inventory of physical and thermal barriers • Radio tracking to document diversity of migratory pattern • Otolith chemistry to document diversity of migratory pattern • Pedigree analysis • FST, DCSE, DNEI

1.4 RMEG Guidance on Bull Trout Monitoring and Evaluation

As part of the overall responsibility of designing an effective monitoring and evaluation program for bull trout, the USFWS has established the Bull Trout Recovery Monitoring and Evaluation Technical Group (RMEG). The bull trout RMEG is a multi-agency body chaired by USFWS fisheries technical staff and independently facilitated. The group consists of 14 members representing a balance of skills in population dynamics, char biology, field studies, biometrics, and experimental design. The USFWS has asked the RMEG to undertake the following tasks: 1) summarize bull trout monitoring and evaluation needs, 2) review analytical methods of characterizing bull trout population and habitat status, 3) increase the utility of current data collection for recovery planning, 4) direct and prioritize future monitoring efforts associated with bull trout recovery, 5) develop and standardize design elements, and 6) foster coordination among monitoring programs.

There are serious challenges in determining how, when and where to best monitor bull trout populations and their habitats, as well as in establishing evaluation approaches that are statistically sound and rigorous. The RMEG has been asked to overcome these challenges and to provide recommendations for monitoring and analyses that can reliably inform evaluation of bull trout recovery objectives. The RMEG has begun to address monitoring and evaluation components related to all four Recovery Plan objectives: distribution, abundance/trends in abundance, habitat conditions and genetic diversity/exchange. Initial RMEG efforts have focused principally on distribution questions, with more recent efforts targeting abundance and connectivity (habitat condition and genetic exchange). The RMEG, however, has to date only been evaluating limited aspects of bull trout habitat (i.e., temperature) and genetic exchange as they relate specifically to connectivity, and has yet to address broader monitoring and evaluation of physical habitat conditions or genetic diversity.

The intent of the RMEG is to provide guidance and support to bull trout recovery efforts in three primary areas: 1) monitoring design; 2) specific monitoring techniques; and 3) analytical methods for assessing recovery. Towards this goal the following chapters provide the current suite of RMEG recommendations/ guidance for improving monitoring and evaluation of bull trout recovery objectives, with example case studies based on RMEG pilot studies undertaken to date.[1] Chapter order in this document is not entirely consistent with the ordering of recovery objectives but provides a logical progression of ideas that are ultimately the foundation for the recovery objectives. The chapters in this document are intended as both: 1) a high level overview of the RMEG concepts/products under development; and 2) a broad explanation to regional managers and field biologists in the USFWS and other agencies of how to apply these concepts (with explicit analytical details provided in appendices).

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[1] RMEG analyses remain a work in progress that will be refined and expanded as new information becomes available from ongoing bull trout work in the Region.

Chapter 2: Identifying the Geographical Boundaries of Local Populations

INTRODUCTION

2.1 The organization of bull trout

Bull trout have been defined as a distinct species (Cavender 1978, Haas and McPhail 1991), however, the relationship between various groups of bull trout within the species can be complex (see Taylor et al 1999; Spruell et al 2003; Whiteley et al. 2006). Within the Draft Recovery Plan (DRP) bull trout have been grouped into Distinct Population Segments (DPSs), Recovery Units, Core Areas and local populations (USFWS 2002). Core Areas are composed of one or more local populations, Recovery Units are composed of one or more Core Areas, and a DPS is composed of one or more Recovery Units. Biological concepts in conservation biology suggest that bull trout can be grouped into conservation units (a segment of biological diversity that shares an evolutionary lineage and contains the potential for a unique evolutionary future) (Spruell et al. 1999, Spruell et al. 2003), metapopulations and local populations. Metapopulations are composed of one or more local populations and conservation units are composed of one or more metapopulations. In the DRP, core areas were identified in an attempt to reflect existing metapopulation structure. Within a metapopulation, the demographic characteristics of a local population (i.e. those approximating panmictic breeding) are expected to be influenced through dispersal from other local populations. In the classic sense local populations may be prone to extinction but persist through demographic support (Hanski and Gilpin 1997). The basic unit for ensuring long-term sustainability is the aggregation of local populations into metapopulations.

2.2 Delineating populations

A population can be defined in biological terms as a reproductive community of individuals that share in a common gene pool (Dobzhansky 1950). Various attributes have been used to evaluate the degree to which groups, in this case of bull trout, are related. Ultimately, attributes useful for delineating groups of populations all relate to reproduction and genetic exchange. For bull trout in many watersheds, relatively little information exists on population structure. This can make delineating populations a difficult task. Close examination of the DRP reflects this difficulty. In some Core Areas population boundaries appeared to be defined at the tributary level. In other cases population boundaries were defined by grouping individual tributaries. Thus, the DRP appeared to identify local populations in an inconsistent manner.

2.3 Purpose – Consistently identify spatial units that represent local populations

To monitor and evaluate recovery adequately, it will be necessary to delineate consistent sampling units (i.e. local populations), minimize the potential for bias, and improve the ability to compare and contrast conditions and trends among recovery units. Ideally, information to derive these units would be readily available, applied consistently, and reflect biological population structure. To accomplish this, we considered the utility of the 6-digit Hydrological Units (HUC6) because they are readily available and generally consistent. However, HUCs are based on hydrologic features and may not reflect the biological characteristics of bull trout that define population structure. While HUC6 is probably the scale most closely associated with bull trout local populations, their boundaries can be substantially different (Figure 2.1; see Dunham et al. 2002). In addition, bull trout populations may use waters in both the US and Canada to complete their life-cycle. Thus, we believe a useful alternative is the habitat patch.

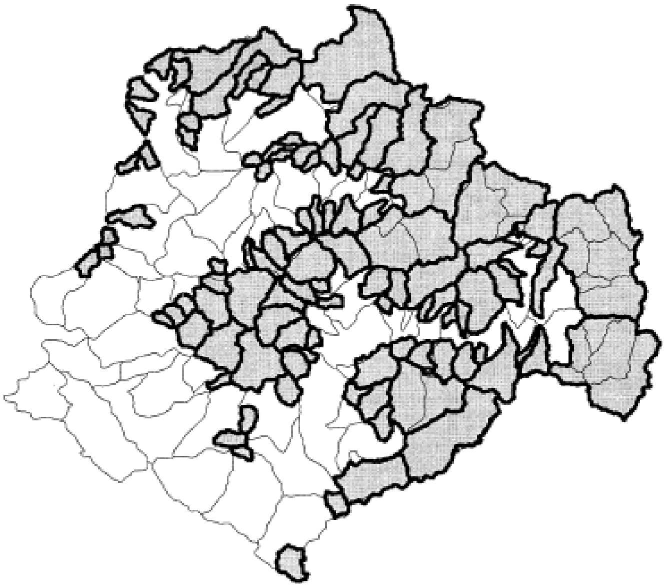


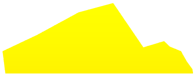
Figure 2.1. Sixth-field HU (thin lines) and patches (heavy lines with shading) for bull trout in the Boise River drainage show that patch and HU watershed boundaries can be substantially different (from Dunham et al. 2002).

BULL TROUT PATCHES

2.4 The patch concept

A patch has been defined as "the limits or boundaries of environmental conditions that can support a biological response" (Dunham et al. 2002). The concept rests on the observation that animal populations are not uniformly distributed across the landscape. Instead distributions are usually tied to specific habitat features; features that are patchy in nature and can potentially be mapped. Patches mapped from current habitat features, therefore, may be able to capture some of the range of environmental conditions that are considered suitable to support a population. A bull trout patch represents a spatial template by which the biologists can partition the landscape to identify bull trout habitat. Patches are meant to represent local populations, the basic unit for monitoring and evaluating recovery, and are defined as a contiguous geographical area that contains the spawning and early rearing habitat used by a bull trout population.

Defining a patch requires identifying the critical environmental variables that regulate distribution. In watersheds that are large enough to support bull trout populations, it appears that temperature requirements for spawning and early rearing are key for dictating bull trout distribution (for example, migratory corridors are not components of a patch). Figure 2.2 shows how a patch may be defined from a bull trout's seasonal temperature requirements.



size can be used to classify landscapes into a mosaic of patches that could support local populations. Existing data confirm that bull trout populations commonly show significant genetic differentiation at the scale of individual patches (Spruell et al. 1999), but genetic differentiation and gene flow may vary widely across the species range (Whiteley et al. 2003). The biological significance of small amounts of genetic differentiation should not be discounted (Hedrick and Kalinowski 2000).

A CASE STUDY

2.6 Criteria used for defining patches

The purpose of the Case Study was to apply the approach for developing bull trout patches and ascertain the utility of the patching approach (see below, 2.7, General Approach). The specific objective of this exercise was to describe bull trout patches in the Lewis River Core Area, Washington (Appendix A.1), an area with limited information on the population structure of this species. We followed a patching approach that was developed by the RMEG as a modification of the approach in Dunham and Rieman (1999).

We used maximum annual stream temperature, stream order and catchment area as filters for determining potential bull trout habitat. Many other factors identified by Dunham and Rieman (1999) may also influence bull trout distribution (e.g., connectivity, stream gradient, geology, hydrologic regimes, presence of nonnative species, road density, solar radiation). However, maximum annual stream temperature (and the corresponding elevation) has previously been indicated as useful for identifying the range of this species (Rieman and McIntyre 1995) and patch size (catchment area) and may be the most important factor determining bull trout occurrence (Dunham and Rieman 1999). Maximum annual stream temperature, stream order and catchment area are variables that can be easily estimated. Thus, these variables could potentially provide managers with a simple procedure for delineating likely bull trout patches.

Maximum annual stream temperatures can be estimated using a water temperature monitoring network throughout a subbasin during the summer. These data can be linked to a location, and subsequently to an elevation. Often this information is available from past monitoring efforts. Existing information from state and federal agencies, academic institutions, and other reliable sources can be compiled to build temperature:elevation relationships within a subbasin. If local information is not available, or the resulting dataset insufficient to build temperature:elevation relationships (e.g. due to large data gaps), it may be possible to acquire this information from a similar subbasin proximate in geographic location.

Anecdotal information suggests that known bull trout spawning tends to occur in 1st-3rd order streams. Stream order can be determined from a variety of maps or mapping functions and can be influenced by the map scale. For the purpose of developing patches, a scale of 1:100,000 is appropriate and readily attainable. Stream order can be used to approximate relative stream size. Patches contain 1st, 2nd and 3rd order streams. Streams that are 4th order or larger may be considered too large for spawning and rearing. These larger streams may be eliminated as part of a patch (or possibly used as the lower boundary of a patch).

Catchment area can be determined for watersheds or subwatersheds within a subbasin using information easily acquired from the internet. Recent digital elevation models (DEMs) and stream layers can be obtained free of charge from government agencies. This information can then be analyzed using ArcGIS to determine catchment areas for each stream network above a calculated elevation that is within the acceptable temperature threshold for bull trout. Catchment areas that are smaller than deemed necessary for persistence of bull trout populations can then be dropped from further consideration.

The use of these three filters provides a starting point for determining distribution of bull trout within a subbasin. There may be exceptions to the potential distribution identified using this tool. Some bull trout populations may exist outside these patches due to geologic anomalies or other factors in the subbasin (e.g. habitat degradation). Conversely, bull trout distribution within an identified patch may also be limited or nonexistent due barriers, hydrologic regimes or other factors. However, by using this tool, it is possible to implement a sampling approach that focuses limited resources in areas that may have a higher probability of supporting bull trout populations in a subbasin.

2.7 Proposed filters for delineating bull trout patches

To maximize the utility and consistency of the approach, it is necessary to develop a general protocol. The process must be easily adapted to the range of knowledge and data available across the species' range. The intent is to create a series of patch networks that are as consistent as possible across the range to allow application and comparison of a general monitoring approach. We suggest that a useful approach is to apply a series of filters depending on knowledge of the system. Because bull trout spawning and rearing appears to be constrained by stream temperature, the ideal approach is to delineate suitable patches with extensive knowledge of the gradient in stream temperatures across all streams. Stream size, gradient and barriers to migration may also be important constraints. Where little field information is available, elevation might be used as a surrogate of temperature and catchment area or stream order might be used to capture information about stream size (e.g., Dunham and Rieman 1999). If and when additional information is available (i.e. refined temperature models, actual spawning and rearing distributions) more refined patch delineation can occur. In all cases, rules used and data sources should be thoroughly documented. When possible, the filtering process for identifying bull trout patches should consider two stages: 1) identification of realized (suitable and occupied) bull trout patches; and 2) the identification of potential (suitable but unoccupied) patches for bull trout. The contrast of potential and realized bull trout patches may be an important step in the recovery process.

Temperature

Potentially suitable patches in a particular basin are initially determined by identifying continuous coldwater patches that can support bull trout. The basin may be patchy in regard to availability of cold water, or water within the entire basin could be cold enough to be suitable for bull trout. Ideally, specific relationships between stream temperature and elevation or other process based determinants of stream temperature (e.g., radiation, ground water) could be developed on a local scale to accurately predict the lower bounds for the network of habitats representing patches. However, data resolution and modeling capacity will vary across the species range and a mix of approaches for predicting stream temperatures and bull trout patches may prove necessary. In areas lacking stream temperature data, patches could be crudely approximated using the bull trout lower limit model developed in Rieman et al. (2007). In areas with moderate to high availability of stream temperature data, simple empirical relationships between stream temperature and elevation could be developed or new statistical and mechanistic temperature models could be applied to provide precise predictions across river networks (Cox and Bolte 2007; VerHoef et al. 2006).

The specific temperature metric and threshold value chosen for delineating suitable bull trout patches warrants careful consideration. Numerous metrics have been developed (Dunham et al. (2005) provide a useful summary and instructions for intermetric conversion), many of which are highly correlated, but no systematic treatment has assessed their relative merits for delineating bull trout habitat. Previous work linking juvenile bull trout distributions and stream temperatures has relied on variants of mean and maximum summer temperatures (Rieman and Chandler 1999; Dunham et al. 2003; D. Isaak, unpublished data). The most comprehensive treatment of this topic is a report by Rieman and Chandler (1999), which summarizes frequency of occurrence relative to several temperature metrics derived from an extensive regional temperature database. In analyses based on these data, Dunham et al (2003) found that the probability of occurrence for small bull trout was expected to drop below 0.5 when daily summer maximum temperatures exceed 16ºC, but occurrence remained common at daily maximums of 18–19ºC (see Rieman and Chandler 1999). More recently, surveys of juvenile distributions in 20 central Idaho streams documented occurrence in mean summer stream temperatures nearing 13ºC and 7-day maximums of 17.5ºC, although high abundances rarely occurred at means >11ºC or 7-day maximums >15ºC (D. Isaak, unpublished data). Thus, the approach used to identify the lower bound of a patch should be explicitly identified, reasoned and documented (i.e. elevation at which the 7-day maximum temperature did not exceed 15°C).

Stream size or catchment area

In early work bull trout were rarely found in small streams (e.g. <1-2m; Dunham and Rieman 1999; Rich et al. 2003) even within larger stream networks of occupied patches. In addition, bull trout spawning has not been widely documented in very large streams. At a 1:100,000 scale, bull trout are generally believed to spawn principally in 1st-3rd order streams. This pattern appears to hold for bull trout in the Jarbidge, Boise, Flathead, Imnaha, Walla Walla, John Day and Lewis subbasins. This suggests that both upper and lower bounds in stream size or a strong discontinuity in stream size (e.g. tributary junctions) may define a second dimension of suitable habitat. Presumably processes associated with hydrology, geomorphology, or temperature of streams are important. It is possible, however, that the inference about stream size is simply a general failure of biologists to find bull trout spawning in large bodies of water where bull trout are difficult to observe. Further work and local information will help refine these observations and general knowledge. While information on the width of small streams may not be readily accessible, stream order and catchment area are easily estimated using GIS information and might be used as surrogates for the delineation of patch boundaries. Catchment area can also be useful in identifying boundaries of perennial flow. In the Boise basin for example, catchments < 400 ha often support streams that appear too small for bull trout (e.g. < 2m) or are not perennial and thus not available to juvenile rearing year-round. Catchment area then might be used as another surrogate of habitat availability in the delineation of habitat patches. However, variability in climate and geology may require the development of local information to identify the relationship between catchment area and stream size or discharge.

Additional considerations for developing bull trout patches (non exhaustive)

Identifying local populations and their boundaries is the ultimate goal of this exercise. Bull trout patches are intended to be a geographical representation of local population boundaries. In other words, bull trout patches are a surrogate for or a compliment to more precise information on local population structure and the physical boundaries of local populations. As such, additional criteria, particularly in areas that are relatively data rich, could be useful to characterize suitable patches. Local information on areas where adult bull trout are known to spawn and juvenile bull trout are known to rear (or be present) should be used to modify initial patch delineations to reflect the actual distribution of local populations. If bull trout spawning and early rearing has been documented for multiple years in a particular area, existing patch boundaries should be extended or additional patches should be developed to include these areas. The rule sets to delineate patches in this area should also be evaluated to try and understand why this area was not captured initially and modified to better reflect actual distributions of bull trout. Local information on natural fish passage barriers may modify patch delineations based on environmental (catchment size, temperature) gradients. Similarly, local information on permanent, human constructed fish passage barriers may modify patch delineations. Other species, such as brook trout, may influence bull trout distribution (e.g., Rieman et al. 2006) or identification (via hybridization) and might be important to consider in patch delineation (Rieman et al. *in press*) if local information are adequate for that purpose.

Finally, information on population genetics may provide specific and precise information on a population's structure that can influence the determination of population boundaries.

Metadata

For each area and patch, a list of rules used for classifying patches, their biological justifications, and information sources should be documented and peer-reviewed for scientific consistency.

General approach

The RMEG approach to describing bull trout patches follows an approach modified from Dunham and Rieman (1999) and a detailed example is presented in Appendix A.1. In general, patches are identified using temperature:elevation relationships, determining stream orders and determining catchment areas for subwatersheds that fall within the acceptable thresholds for stream temperature and order. Briefly, obtain digital elevation data (DEM) available in 10, 30, 90 meter cell sizes usually by quad sheet 24k, 100k, and 250k respectively. State agencies sometimes have state-wide DEM mosaics but file sizes are usually large and may be split into smaller tiles. Then obtain stream data for the study area (or streams), which can be generated from the elevation data. If using existing stream data, use the same scale as that for the DEM data. Existing stream data is the preferred choice if it is available and has good geometry and attribute information such as stream name and stream type (perennial or intermittent). If existing data is not available streams can be generated using GIS functions.

If using existing stream data, the DEM will need to be reconditioned using the process of stream burning or fencing. This process overlays the streams on the DEM data and the cells corresponding to each linear feature are lowered by a specified amount to enforce correct drainage.

Determine stream temperatures based on the best data and models available for the area. One simple approach is to use a temperature:elevation regression, and determine the threshold elevation level (elevation at which stream temperature is not expected to exceed 16ºC). Initially, the regression should be generated for all data throughout the Core Area. Since temperature:elevation relationships tend to be curvilinear, it is helpful to identify the largest part of the curve that is linear and includes 16ºC. The regression equation should then be applied to generate differences between expected and actual temperatures for all the elevation points used in the model. These differences should be grouped by basin such that no basin is larger than 3rd order. When expected temperatures for a basin are, on average, greater than 15% different from the actual temperatures a separate model should be developed for that basin and points from that basin should be removed from the overall relationship (see Appendix A.1 for an example). Before developing basin-specific information, it is necessary to determine whether sufficient data is available. In general, a minimum of 10 data points cooler than 16ºC and 10 data points warmer than 16ºC. Once appropriate temperature:elevation regressions have been developed for all basins in the Core Area, use a GIS to create a polygon of areas where the elevation is greater than the threshold level. Overlay the streams on the elevation polygon and create a point where each stream intersects the polygon. These points will be used later to create patches with the GIS watershed function. These points identify sections of streams above a specified elevation.

Improved methods for predicting stream temperatures are emerging in many areas. These include empirical flow-temperature models using satellite data on forest cover and mechanistic models of stream temperature (Dan Isaak, personal communication). A 7-day moving average summer maximum temperature appears to be emerging as a more reliable index than a whole summer maximum temperature. The most widely applicable approach is to use air temperature-water temperature relationships, which can predict water temperatures based on longitude and latitude (Rieman et al. 2007). Thus, a variety of alternative approaches may be used. Whichever approach is used should be justified and well documented.

Where the elevation is greater than the threshold level, identify the order of each stream segment. Create a point where any 1st, 2nd or 3rd order stream intersects a stream that is larger than 3rd order. These points will be used later to create patches with the GIS watershed function. These points identify sections of streams above a specified elevation and of a suitable size.

Use a GIS to create flow direction and flow accumulation grids from the DEM data. These are required in the next step to create the patches.

The watershed function uses the flow direction grid and the points created earlier to define a watershed for each point. Next the area is calculated for each watershed and they are filtered based on a threshold size. The resulting set of watersheds > 400 ha are BASIC bull trout patches.

Use a GIS to create a final map of BASIC bull trout patches.

As test cases, the concept of patches of suitable bull trout habitat outlined above has been applied to Core Areas in the Lewis (see A.1), John Day and Jarbidge river subbasins. These examples follow from the preceding discussion and the original application of these concepts in the Boise River, and help illustrate how the availability of information or lack of it might influence the patch approach.

2.8 General RMEG recommendations for identifying the geographical boundaries of local populations

Recommendations	Further Work Required
Bull trout *patches* should be applied as a consistent spatial template, defined through the methods described in Chapter 2.	Test and refine methods of patch delineation indifferent core areas.

Chapter 3. Patch Presence as a Building Block for Assessing Bull Trout Distribution

INTRODUCTION

3.1 Distribution and population structure

The distribution of a species is a fundamental component of its ability to persist over ecological and evolutionary time scales (Simberloff 1988; Wahlberg et al. 1996). Habitat loss and degradation as well as the extinction of local populations are major threats to a species' persistence (Groom et al. 2006). A local population can be defined in biological terms as a reproductive community of individuals that share in a common gene pool (Dobzhansky 1950). The smallest functional unit of biological interest is generally the local population (or stock, see Ricker 1972). Multiple local populations may interact to form metapopulations (Hanski and Gilpin 1991). In general, a metapopulation can be defined as a collection of relatively isolated, spatially disjunct, local populations interacting through dispersal. As such, distribution may be defined through the number and spatial arrangement of local populations within a metapopulation or of individuals within a local population. Related to the distribution of populations within a metapopulation is the "occupancy" of the metapopulation. Occupancy is the probability that a randomly selected site or sampling unit in an area of interest is occupied by the species of interest (MacKenzie et al. 2006). For instance, the occupancy of a core area can be estimated as the proportion of occupied local populations within the core area.

Metapopulation theory assumes that dispersal among local populations influences the probability that any given local population will go extinct (Hanski 1991). Distribution then is a function of the persistence of local populations, but can also influence that persistence and, in turn, that of the metapopulation (Brown 1984). For example, if a metapopulation contains a relatively large number of local populations well distributed across a range of environments, then the rate of immigration in any given population would be expected to be relatively high, while the simultaneous extinction of multiple populations would be less likely. Conversely, if a metapopulation contains a relatively small number of local populations or those populations are far apart, then immigration for any population should be relatively low. A smaller number of populations in close proximity may increase immigration into any one, but they may also be more prone to simultaneous extinctions. Metapopulation theory provides one important framework for the concept of distribution (Hanski et al. 1993, Nee et al. 1991, Gaston et al. 1997).

3.2 Bull trout distribution

The recovery of bull trout will depend in part on how local populations are distributed. Multiple local populations distributed and interconnected throughout a watershed provide one indication of a resilient, functioning core area. The Draft Recovery Plan (USFWS 2002) for bull trout defines geographical boundaries for Core Areas. These are intended to represent metapopulations of bull trout and presumably one or more local populations of bull trout are contained within each Core Area. The geographical boundaries for potential local populations can be represented by bull trout patches encompassing continuous habitats suitable for spawning and early rearing (Dunham et al. 2002). Patches then represent a fundamental sampling unit for monitoring the distribution of bull trout in core areas

Conservation biology may consider a variety of spatial components in the distribution of species and populations. McElhany et al. (2000) suggested that the spatial structure of local populations (i.e. their distribution in space relative to each other) and the diversity among local populations (i.e. the representation of distinctly different life histories or environments) were important characteristics defining the viability of salmon populations. Similar measures will be important to consider for the evaluation of bull trout recovery, but any measure of distribution will require estimation of the occurrence of bull trout within and among sampling units. Chapter 2 outlines the process for delineating patches as sampling units. This chapter describes an approach to determine whether or not a population of bull trout is present in the patch. Further guidance on which patches to sample, how many patches to sample, when and how often to sample will be considered in subsequent work. Information developed in the effort to determine whether patches are occupied will ultimately allow the derivation of several measures of distribution useful in defining recovery (such as the occupancy of the Core Area and the connectivity characterized by spatial arrangement or distances among occupied local populations).

3.3 Defining presence

One measure of distribution is the presence or absence of an organism in various locations. Relative to monitoring bull trout status and recovery, the critical metric is whether a population of bull trout is present in (occupies) a patch. While this seems intuitive, it is prudent to clearly define what is meant by the presence of a bull trout population. This definition can be informed by considering that a bull trout patch is intended to represent the area of spawning and early rearing for a population. A population would typically include spawning over multiple, consecutive years. A single, temporally isolated spawning event or occasional use by subadults produced in another watershed would not necessarily indicate that a population was present. As such, we consider a population to be present if multiple age classes (as estimated by size classes[2]) of pre-migratory juvenile or resident bull trout (e.g., Dunham and Rieman 1999) are found. Sub-adult and mature bull trout can exhibit extensive movements associated with ranging and spawning and may not spawn in all areas where they are observed (Fraley and Shepard 1989, Brenkman et al. 2001, Downs et al. 2006). In addition, bull trout redds can be difficult to identify and enumerate (Rieman and Myers 1997, Dunham et al. 2001). Thus, in any given year, we suggest that the presence of adult bull trout and at least two bull trout redds must be observed at a site to indicate that spawning occurred. If no bull trout redds are detected, the patch should be sampled using snorkeling or electrofishing following the methods described in this chapter to provide a more rigorous conclusion regarding the presence or absence of bull trout.

The criterion for determining whether a bull trout population is present in a patch could be one of the following:

1. a single pre-migratory juvenile or resident bull trout is found within a patch, suggesting recent recruitment and not random ranging;
2. a chosen minimum number (>1) of bull tout is found at a site;
3. multiple size classes of bull trout are found at a site suggesting successive years of recruitment; or
4. presence of adult bull trout and at least two bull trout redds are be observed within a patch suggesting spawning by more than a single randomly ranging individual.

The RMEG will evaluate these alternative criteria for determining presence as it relates to the attributes of distribution.

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[2] The size classes used to identify pre-migratory or resident bull trout may vary by Core Area, and should be established in consultation with local biologists.

3.4 Determining presence (or absence?)

Any sampling approach should support a reasonable level of confidence in the conclusion. Bull trout would be detected in a site when they are present and captured or observed through any sampling program. In this case the probability of presence = 1.0 and there is no uncertainty in the conclusion. Bull trout would not be detected in a site when they are absent, but it is also possible for bull trout to be present in a site and not detected during sampling. The objective of any sampling effort then is to detect bull trout when they do actually occur, but also to minimize the probability of false absences. A large number of independent samples can effectively do this, but the statistical objectives for any estimate must be balanced against the logistics and cost associated with sampling and multiple objectives of occupancy sampling. The Western Division of the American Fisheries Society first proposed a method to determine the presence of bull trout in individual patches (Peterson et al. 2002). The approach combined estimated sampling efficiencies and assumptions about the abundance and distribution of bull trout within streams to estimate the probability of detecting bull trout with a given level of effort, or conversely, the probability that bull trout occur in a stream given that no individuals were detected in sampling (Peterson et al. 2002). Models based on empirical studies allowed biologists to estimate sampling efficiency as a function of select stream channel or habitat characteristics. Preliminary exploration of these models indicated that the probability of detecting bull trout in a single sample of an occupied patch was relatively low (i.e. < 0.12) and that any confidence in the conclusion about presence drawn from the failure to detect bull trout would commonly require substantial sampling effort (e.g. > 20 sample sites), depending on the stream characteristics, sampling method, and required power. The authors cautioned that the protocol should be reviewed and revised as additional data became available. Application of this method in the field has had mixed results. The design and statistical concepts of the method have provided an important foundation for more rigorous field studies of bull trout occurrence and distribution. The sampling requirements for a reasonable probability of detection, however, have proven logistically impractical for many studies, and some biologists have questioned the accuracy of the results based on their own sampling experience.

Recently the problem of false absences in the estimation of occupancy for species that are rare or patchily distributed has received considerable attention (e.g. McKenzie et al. 2005). New methods have focused on the development of detection models through the process of repeated sampling rather than direct estimation of abundance and sampling efficiency. Briefly, these methods estimate the probability of detecting individuals in a sampling unit (e.g. a patch) through repeated sampling in units where a species is ultimately found to occur. For example, if a patch known to support a local bull trout population is electrofished in each of 20 randomly distributed sites and bull trout are found in 8 of those sites, a first approximation of the detection probability for similar patches would be 0.40 (i.e. 8/20) The statistical details of the methods and application of this general approach are the subject of entire books, but application with bull trout appears promising. Preliminary results from a few studies suggest that the detection probabilities for electrofishing sites in many bull trout patches (i.e. the probability that a bull trout is detected in a single sample given they are present in the patch) may commonly range from 0.20 to 0.40 or even higher (Table 3.1; Appendix B.2); considerably higher than the typical estimates emerging from the original AFS protocol (i.e.,. 0.02-0.12). The implication is that a reasonable probability of detection in a patch, given bull trout are present (i.e., > 0.80), or minimal probability of presence, given no detection (e.g. 0.20 – 0.05), might be achieved with a more modest number of sample sites than previously thought. Note that these detectability estimates come from studies where presence was defined as encountering one bull trout < 150 mm in length. For the presence criteria 2 and 3, the detectability might differ, thereby changing the needed sample size.

Table 3.1. Frequency of detection in 1997 and 2007 for small (<150mm) bull trout in 13 streams known to support reproducing bull trout populations in central Idaho. Repeated sampling was conducted with single pass electrofishing of approximately 30 meters of stream as outlined in Rieman et al. 2006. Samples were distributed systematically throughout the length of accessible habitat.

	Number Sites Sampled		Number Sites Bull Trout Detected		Proportion of Sites Bull Trout Detected	
Stream Name	'97	'07	'97	'07	'97	'07
Canyon Cr.	14	16	13	15	0.92	0.94
Clear Cr.	8	19	1	9	0.13	0.47
Rattlesnake Cr.	20	16	8	4	0.40	0.25
Queens R.	17	13	3	6	0.18	0.46
Crooked R.	20	15	8	6	0.40	0.40
L. Weiser R.	20	11	4	7	0.20	0.64
Dewey Cr.	18	--	0	--	0.00	--
Bear R.	12	11	3	1	0.25	0.09
Roaring R.	15	18	4	10	0.27	0.56
Sheep Cr.	18	19	4	1	0.22	0.05
Skeleton Cr.	19	17	9	9	0.47	0.53
Trail Cr.	13	6	7	6	0.54	0.50
Lodgepole Cr.	15	8	10	8	0.67	0.62
Mean					0.36	0.39

3.5 Preliminary estimates of sampling effort

To explore the question of an adequate number of sites to sample in a patch, we adapted the Peterson and Dunham's (2003) approach. We assumed that a sample site would consist of making one pass through a standard reach of stream with a common sampling protocol (e.g. single pass electrofishing with no block-netting). Our objective was to estimate the number of sample sites required to be confident that bull trout were not present in a patch when they were not detected in any samples. In this case we assumed that a probability of presence less than 0.20 was adequate to support a conclusion of absence, but any level confidence can be explored. Based on the site-specific detection probabilities outlined above we assumed these values would fall between 0.1 and 0.5 to bound the possibilities. If we assume the same detection probability at each sample site (i.e. the probability is not influenced by environmental characteristics) the estimated probability of presence given no detection shows a nonlinear relationship to the number of sites sampled (Figure 3.1). The effort required for a set probability of presence given bull trout are not detected, increases with a decline in site-specific detection probability. In this case between 2 and 3 samples are required for a site-specific detection probability of 0.5 and 14 samples for a detection probability of 0.1. The number of samples required to reduce the probability of presence to less than 0.20 would be minimal with a site-specific detection probability of 0.5, but considerably more with one of 0.1. In either case, however, the results suggest that a reasonable conclusion regarding the presence of bull trout in a patch should be possible with fewer than 20 sites and perhaps even fewer than 5 or 10.

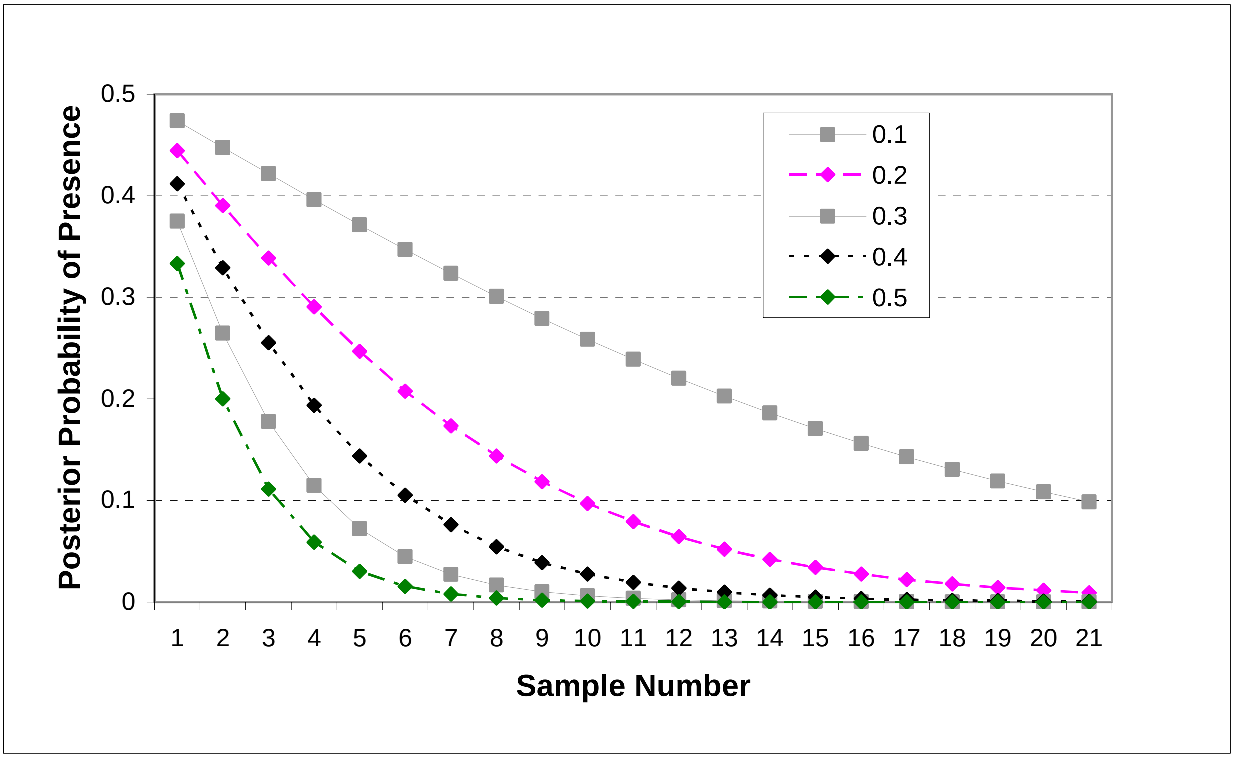


Figure 3.1. Estimating the probability of a patch being occupied (bull trout being present) if no bull trout are detected during sampling. The prior probability of presence was set at 0.50 (uninformed). Site-specific detection probabilities were 0.1 and 0.5 (based on Peterson and Dunham 2003).

3.6 A sampling framework

The application of these methods to routine sampling of bull trout patches will require a method for distribution of sampling sites and appropriate estimates of site specific detection probabilities. In application, the most efficient approach would be to choose sample sites that are accessible or thought most likely to hold bull trout to minimize the total effort required to detect fish. By detecting fish quickly biologists could spread their effort more effectively to other patches maximizing the number of patches sampled in a season. The problem is that when bull trout are not detected it will be necessary to sample repeatedly until the probability of presence is minimized to an acceptable level. Estimating that will depend on the assumed site-level detection probability. Additional sampling in patches where bull trout are ultimately detected will be required to help refine those estimates, at least until generally consistent estimates or models of those efficiencies are available. To meet these two needs we anticipate a sampling framework that works to both inventory patches and refine estimates of site specific detection probability simultaneously. If methods are standardized and results archived in a consistent fashion, the range of observed detection probabilities and development of detection-covariate models could be shared among practitioners.

We expect that site-specific detection probabilities will vary with characteristics of the stream environments that influence sampling efficiency and the distribution and abundance of bull trout within occupied patches (Peterson et al. 2002; Peterson et al. 2004; Thurow et al. 2006). Table 3.1 summarizes repeated sampling from several bull trout populations in central Idaho. Although the sampling was not intended for an estimate of detection probability and samples were collected systematically rather than in purely random fashion, they do provide some information about the frequency of detection in existing populations. In this case the data indicate that site level detection probabilities can vary widely (near 0 to near 1), but are probably, generally above 0.10. In this case only a single observation was less than 0.10 and most were above 0.20. The mean and mode were between 0.30 and 0.40. With enough replicated sampling it could be possible to build empirical models of site level detection probability that incorporate covariates representing the range of sampling conditions for bull trout environments and explain that variation. For example, these observations are strongly associated with site elevation suggesting that detection probability could improve substantially at higher elevations within a patch. If standardized sampling procedures are adopted and sampling results are archived consistently, the development of new models should be possible allowing the prediction of detection probabilities based on routine environmental characteristics. Once those models are developed the need for repeated sampling in any patch for further detection model development will be lessened.

Our goal was to define an initial survey that rigorously estimates patch presence and at the same time, is practical in the field. The Environmental Protection Agency's Environmental Monitoring and Assessment Program (EMAP) developed a general approach for selecting sites in stream networks incorporating randomization and spatial balance, called GRTS (Generalized Random- Tessellation Stratified design; Stevens and Olsen 2004). GRTS is a GIS-based approach and lends itself to a relatively broad application by many users (Firman and Jacobs 2001). GRTS- based designs allow one to make a statistical inference about the status and trend of stream attributes (e.g., the presence or absence, or abundance of bull trout) in a predefined stream network (in this case a bull trout patch). GRTS has been successfully used to evaluate the status of, for example, stocks of salmonids or trout in Oregon (e.g., coastal coho, Jacobs et al. 2002; Lower Columbia coho, Suring, et al. 2006), redband trout, Dambacher and Jones 2007; bull trout, Starcevich et al. 2004)). To assist with the development of specific survey designs in stream networks, the application of GRTS requires users to define the area of interest, the appropriate digital representation of the target stream network, and the size and density of sample sites. Following from previous examples with salmonids and considering the biology of bull trout, we defined the area of interest as a patch, the stream network as represented by the 1:100,000 hydrographic Digital Line Graphs (to reduce the number of sites in intermittent or ephemeral streams), site size as a continuous, 50 m segment of stream., GRTS allows the selection of a "master sample", a number of sites well in excess of the number needed for a particular survey. The list is ordered in a way that allows the selection of *n* spatially balanced sites that might be needed for a particular survey. The RMEG suggests using a master sample for each patch based on an average distance between sites of 0.25 km.

A CASE STUDY

3.7 Evaluating the occupancy of a patch

Theoretical concepts and approaches to evaluating bull trout patch occupancy have been reasonably well developed (see Dunham et al. 2002, Peterson and Dunham 2003). For the purpose of recovery, this chapter has attempted to refine previous information and provide a practical approach to evaluating patch occupancy that may be consistently applied across the range of bull trout. Relatively little empirical information is available to evaluate this approach. The goal of this exercise was to examine the ability to detect presence of bull trout in the Baldy Creek Patch (BCP) of the John Day River Core Area (Oregon) (see Appendix B.2). Based on previous surveys, bull trout were known to occupy the BCP, presumably at relatively high densities (ODFW 2005). The primary objective was to evaluate the occupancy of this patch. Secondary objectives were to provide an additional empirical estimate of the power to detect patch occupancy (done by sampling 21 sites in the BCP), and to provide further insight on the minimum number of sites that must be sampled to evaluate patch occupancy.

A GENERAL APPROACH

3.8 Overview

To maximize the utility of the approach, it is necessary to develop a protocol that allows bull trout patch occupancy be assessed among multiple patches in core areas across the range of the species. The goal of the approach is to balance the ability to make statistical inferences about patch occupancy with the realities of logistical and financial constraints. The approach for sampling for presence in a patch described below is the first step toward this goal.

The approach we propose could incorporate both formal and informal sampling efforts. For example, once patches are identified, data from previous surveys, non-random or non-standardized methods may exist to support the conclusion that bull trout occupy a patch (i.e. multiple year classes of juvenile bull trout were observed during a recent sampling event). These patches may be considered occupied without additional sampling. In general, previous data can be used to classify a patch as occupied, but it cannot used to estimate the probability of presence (given no detection) if the sampling methods are not consistent with that purpose. If bull trout have not been confirmed present for a patch of interest then, we recommend the following steps:

Basic approach

This approach to evaluating patch occupancy requires: 1) an assumed or estimated site-specific detection probability for the sampling method employed; 2) the probability of presence (given no detection), deemed acceptably low; and 3) the random identification of spatially-balanced sample sites to achieve a sample framework that allows for estimation of presence and the refinement of detection probabilities. Briefly, the approach includes defining a patch of interest, obtaining a list of randomly distributed sample sites for the entire patch, sampling those sites to maintain a random order until bull trout are detected or until an acceptably low probability of presence is obtained (see Figure 3.1) and, on occasion, multiple sampling a large number of sites ($\geq$10) after bull trout are detected for refinement of the detection models.

1. Identify a patch (see Chapter 2). If appropriate data exists to conclude that bull trout are present as defined above, it is not necessary to survey the patch, unless this patch is selected for detection probability model sampling. If appropriate data do not exist to determine that this patch is occupied (i.e. the patch has not been surveyed or it has been surveyed but bull trout have not been detected), a formal survey should follow.
2. For a given patch, the GRTS design will generate numerous sites (each associated with UTM coordinates) in a specific order. We recommend that sites are selected for *potential sampling* to provide the opportunity for strong inference about presence <u>and</u> further refined estimates of site-level detection probability. Use Figure 3.1 with assumed site detection probability to determine how many of the sites you would sample. In many cases because of access it may be easier to sample sites out of order (e.g. if last site is the closest to the road). In other cases biologists may believe they are much more likely to find bull trout in some sites than others and wish to change the order to minimize the total number of sites to be sampled. If the intent is simply to determine bull trout presence, then this can be done, and as long as bull trout are detected there is no problem with the statistical inference from the data. However, if bull trout are not detected then it is important to sample all of the selected random sites to preserve the validity of the statistical inference (see Figure 3.2, 6a through 6e). It is more important to sample a limited number of sites and retain the capacity to estimate a valid probability of presence than to sample more sites but violate the statistical assumptions of the estimator. Once you have developed a reliable model of site-level detection probability, you can more precisely determine the number of sites that you need to sample in a patch. Some patches will be intensively sampled to help estimate and make

inferences about detection probabilities (Figure 3.2, 5a through 5e). For intensively sampled patches, where site-level detection probability relationships are estimated, then it is preferable to sample 21 sites or at least 13 sites retaining a fully random distribution generated in the GRTS process (Table 3.2). The benefit of regional coordination of intensive patch sampling will be more reliable models of detection probabilities which can be widely applied.

3. Circumstances may exist that prevent the sampling of a given site. Thus, while not absolutely necessary, total effort may be minimized by conducting reconnaissance surveys to evaluate the viability of (ability to sample) the selected sites. This might be done through the review of maps and access points or directly in the field. At each site the reach to be sampled is defined as the reach of stream from centered on a UTM coordinate. If a site cannot be sampled or would not be expected to contain bull trout because it is not potential habitat it would not be eligible. This can occur for a number of reasons including: a private landowner may not allow access to the site, a site may be dry, a site may be < 1 m wide, or a site may be too steep (> 18% gradient). If all of the required sites are eligible then select the first in order as sample sites. If any of these sites are ineligible, evaluate the next site that was generated by the GRTS design. This process is repeated until the required number of eligible sites are selected for sampling.
4. Select a field protocol to apply at each site. Typical methods include electrofishing and day or night snorkeling. In general we anticipate that electrofishing or night snorkeling will have the highest site specific detection probabilities. By standardizing the method and effort it should be possible to develop many observations that will support further refinement of empirical models and better assumptions for future sampling. Longer sampling reaches (e.g. ≥ 100m), multiple passes, and the use of blocknets can increase the probability of detection at a site, but with an increased cost in time and effort. In general it appears that the additional effort may not be justified compared to the opportunity to sample more sites and thus increase the patch detection probability when fish are relatively rare or at low densities. Unless there are standard methods used in other work that would be useful to maintain (i.e. there is an existing body of information based on 100m reaches) or there are other objectives (i.e. block nets would also allow more accurate estimates of abundance) that can be met simultaneously, we suggest 50 m. single pass electrofishing is suitable for the purposes of standardization. The detection frequencies summarized in table 3.1 or appendix B.2 could be used as first approximations of site level detection probabilities.
5. The criterion for site occupancy is evidence of spawning and recruitment as outlined above. Sample each site for pre-migratory juvenile or resident bull trout based on the above method, and note size classes (< 150 mm; see Dunham and Rieman 1999). . Continue to sample sites until there is evidence that the patch is occupied, or until all sites in the list are sampled with no evidence of occupancy. It is not necessary to sample additional sites, unless the data are to be used to estimate detection probabilities. Information on standard stream channel and habitat characteristics should be recorded for each sample site. Water temperature, stream size (measured as wetted width or cross sectional area), and cover are thought to influence sampling efficiency and thus detection probability depending on the method employed (Peterson et al. 2002; Peterson et al. 2004; Thurow et al. 2006)
6. If the random sites are sampled and bull trout are not found (Section 3.3), the probability of presence can be estimated using the procedure of Peterson and Dunham (2003). The estimate clearly depends on the assumed site-level detection probability and the prior probability of presence for bull trout in the patch. The estimates can be made with any assumption about both values, but can also be revised in the future as better data become available. The prior probability of presence may be set to 0.5 if essentially nothing is known about the likely occurrence of bull trout in the patch (i.e. the probability of presence or absence is equal if we have no information). Alternatively, if bull trout are known to occur in some proportion of similar patches in nearby

systems (e.g. bull trout actually occur in 10 of 30 inventoried patches in similar systems) the prior probability of presence (0.33) could be inferred from those data. . Similarly site specific detection probabilities could be set at the same value for each sample, but if additional information becomes available showing that detection is strongly associated with patch or habitat characteristics the estimated detection probability can be set for each sample site based on that information (i.e. a refined empirical model of detection). If the resulting probability of presence is not deemed acceptably low, further sampling can be conducted until required level of confidence is achieved.

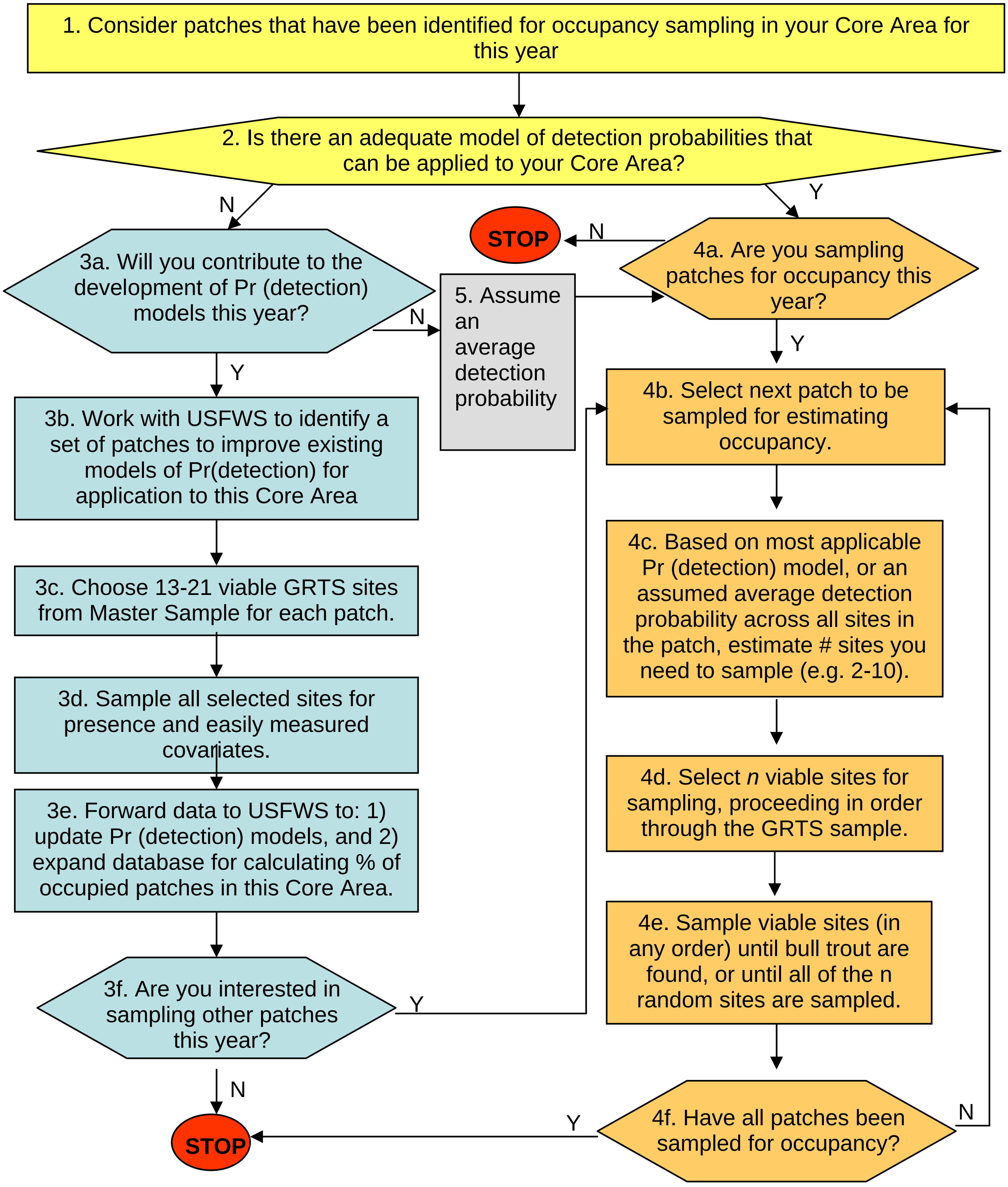


Figure 3.2. Flow chart illustrating approach to sampling patches for presence estimation and detection probability modeling

Table 3.2. Description of the flow chart for occupancy sampling and detection model development (Figure 3.2).

Box	Comment
3a.	This is a collaborative effort across many Core Areas.
3b.	These patches should have diverse habitat characteristics that complement existing data sets used in Pr(detection) models. The patches should also have known bull trout presence (i.e. don't want to have 13-21 sites with no bull trout present).
3c.	The density of sites in the GRTS sample needs to be high enough to give you plenty of sites to work with. Consider a worst case scenario with a very low (0.10) probability of detection. With 21 sites, if no bull trout were detected across all sites, the probability that bull trout are absent from the patch is 0.9 (Figure 3.1). With 13 sites and no bull trout detected, the probability that bull trout were absent would be 0.8. More sites also increase the likelihood of having a high contrast in habitat covariates. As models are developed, they will provide the ability to reduce the number of sites per patch that need to be sampled, because we will have a better ability to estimate the Pr(detection) in different habitats. As time goes on, and more patches are sampled, the RMEG will do further refinement of this requirement.
3d.	Field measured covariates would include those shown previously to affect Pr(detection) (e.g. temperature, presence of large wood, depth and width of stream). Other covariates could be estimated through GIS and other information (e.g. elevation, gradient, watershed size, stream order).
4c.	This is the number of sites required to have an acceptable posterior probability of absence, given no detections (see Figure 3.1; e.g. 80% power to detect true absence after sampling all sites).
4d.	Viable sites can be physically sampled, have possible access, and have water present. The density of sites in the GRTS sample needs to be high enough to give you plenty of sites to work with.
4e.	You can choose to first sample sites which have easier access, and/or are more likely to have bull trout. However, if you don't find any bull trout in these sites, you need to keep sampling.
5.	You can assume whatever probability of detection you want, and then come back and revise your estimates later as better models become available. You can also go back and do more sampling in the patch if you aren't satisfied with the result.

Metadata

Whether occupancy is being determined using existing or new data, specific and detailed records of metadata should be maintained. In all cases, data sources, sampling and analytical approaches as well as the rationale for any inference about patch occupancy should be thoroughly documented and peer-reviewed for scientific consistency.

3.9 Conclusions and recommendations for distribution metrics

RMEG Recommendations	Further Work Required
Methods described in Chapter 3 should be used for defining the probability of detecting bull trout in patches. Field sampling should focus on determining how bull trout site and patch detection probabilities may vary based on habitat conditions in the different core areas. Determine the proportion of occupied patches (based on detected redds or juveniles as described in Chapter 3) within a Core Area, as an initial metric of distribution.	Use existing information from pilot studies (e.g. Boise, Lewis, and John Day) to assess how Pr(detection) at the site and patch scale varies with easily estimated habitat variables (e.g., stream order, stream size, gradients, conductivity, etc.). Work with local fisheries biologists to determine what size classes of bull trout are indicative of multiple age classes in different core areas. Determine how the ability to detect bull trout varies in different bull trout core areas, so as to fully inform the appropriate monitoring effort required to track change in bull trout patch occupancy. Explore the effects of different definitions of bull trout occupancy (e.g., simple presence of juveniles vs. multiple age classes of juveniles). Determine metrics describing the size and spatial pattern of potential and occupied patches.

Chapter 4: Connectivity - Assessing Changes Over Time in Connectivity Within Core Areas

4.1 Why determine connectivity? Purpose (background)

Connectivity can influence the occurrence and persistence of local bull trout populations through dispersal from surrounding populations (Rieman and McIntyre 1993). Patterns of occurrence have been associated with the estimated size of habitat patches and the relative isolation of patches (i.e., the distance to the nearest occupied patches) (Rieman and McIntyre 1995; Dunham and Rieman 1999). Rieman and Allendorf (2001) concluded that few local bull trout populations are large enough to maintain genetic variation indefinitely without gene flow from other sources. Genetic analyses have similarly shown patterns of "isolation by distance", which suggest gene flow is higher among local populations in close proximity to one another (Costello et al. 2003; Whiteley et al. 2003). Other work shows that populations of bull trout or related species isolated behind impassable barriers face increased risks of local extinction (Morita and Yamamoto 2002), loss of genetic variation Yamamoto et al. (2006), and accelerated genetic drift (Costello et al. 2003; Whiteley et al. (2006); Taylor et al. 2003). In addition, connectivity may play a similarly important role in maintaining life histories. Physical barriers or other impediments in a migratory corridor will constrain the expression of migratory life history types. The loss of migratory life histories may increase the risk of extinction for local populations and possibly metapopulations (Rieman and Dunham 2000). As discussed in chapter 2, we will use patches as a biologically relevant surrogate for potential local populations because of the limited information available on population structure at that scale and the inconsistencies in how local populations have been delineated.

Measures of connectivity can be used to assess the current status of bull trout and are required to meet recovery criteria. One of several measures used to assess the current status of bull trout was a measure of connectivity represented by the migratory life history and its functional habitat. The presence of the migratory life history of bull trout was used as an indicator of the functional connectivity of a core area. In addition, the goal of the bull trout recovery plan 'is to ensure the long-term persistence of self-sustaining, complex interacting groups of bull trout distributed across the species native range, so that ultimately the species can be delisted.' To that end, two of the recovery criteria established in the USFWS draft bull trout recovery plan (USFWS 2002) relate directly to measures of connectivity: 1) Restore and maintain suitable habitat conditions for all life histories and strategies; and 2) Conserve genetic diversity and provide the opportunity for genetic exchange. Abundance may also relate to connectivity, if populations are too small to moderate the effects of environmental variation on survival. Further, in terms of spatial and temporal scale, the recovery plan refers to connectivity from two perspectives:
1) connectivity among patches (local populations) to facilitate genetic exchange within a core area (metapopulation); and 2) connectivity of a riverscape to allow for the migratory life history types to fully express their potential behaviors.

Measures of connectivity, then, should be considered in two categories: 1) connectivity among patches; and 2) connectivity through migratory corridors to alternative river or lake environments that will allow the full expression of migratory life history types among local populations. Extending the patch concept identified in chapter 2, connectivity could be estimated as both 'realized' connectivity and 'potential' connectivity. The term "realized" refers to current environmental conditions and existing connectivity among bull trout habitats. In the past, connectivity may have been very different when conditions were more favorable for bull trout (e.g., during wetter and colder climate regimes, or prior to widespread human disruption of watershed processes). Potential connectivity then may refer to either historically likely conditions, or conditions possible with remediation of migratory barriers, restoration of migratory habitats, or restoration of enough habitat patches close enough together for local populations to interact through dispersal. The contrast of 'potential' and 'realized' bull trout connectivity (in concert with 'potential' and 'realized' bull trout patches) may be an important step in guiding the recovery process.

In concept it may be difficult to discriminate between patch size and connectivity among patches as distinct effects on bull trout populations. Larger patches presumably support larger populations while connectivity may increases effective size of any local population through dispersal from other sources. Connectivity may be lost through barriers to movement (i.e., physical isolation), but also through loss of habitat area and decline of potentially interbreeding individuals in the local or surrounding patches. Most bull trout populations occupy habitats vulnerable to change through both anthropogenic and natural (e.g., wildfire or large storms) effects. The result may be a simultaneous loss of connectivity and habitat area. The implication for modeling or prediction of the effects of habitat loss and fragmentation on bull trout is that the effects of patch size and isolation should be considered simultaneously in a measure(s) of connectivity.

We have argued in Chapter 2 that patches of suitable spawning and early rearing habitats can be used as a basis for delineating landscape units for monitoring (i.e. the distribution and proportion of occupied patches; Dunham et al. 2002, Peterson et al. 2002). The concept of patch-based analysis of fish distribution was explored previously by Rieman and McIntyre (1995), Dunham and Rieman (1999) and Dunham et al. (2002) for bull trout from the Boise River basin (see Appendix A.1 for a detailed summary). Potential components of connectivity that emerged from that analysis included: 1) the size of, and distances among habitat patches suitable for spawning and rearing, and 2) isolation (the inverse of connectivity), measured as the distance along the stream network from the patch in question to the nearest occupied patch (Dunham and Rieman 1999). More recent measures of connectivity also incorporate assumptions about patch size and distribution (Moilanen and Nieminen 2002; Isaak et al. 2007); however these metrics require estimates of dispersal characteristics for the populations in question. Although dispersal has rarely been measured directly for any salmonids, genetic analyses (e.g., Tallman and Healey 1994; Isaak et al. 2007), or empirical analyses of the patterns of species occurrences might provide a starting point. Here, the RMEG proposes that inter-patch connectivity could be used to guide monitoring through a sample allocation that weights high probability habitats differently than low probability habitats (e.g., Peterson and Dunham 2003). This metric of connectivity could also be used in post sampling analysis to test hypotheses regarding the role of inter-patch connectivity. Connectivity expressed as the distribution of patch sizes and inter-patch distances could also be used as a response variable to be monitored itself. Finally, from a practical standpoint, criteria for defining patches of suitable habitat that are developed in a GIS framework will allow the use of the existing hydrography to define a variety of connectivity metrics from the matrices of between patch distances or aggregations of nearby areas (i.e., a "network" procedure).

In Appendix C.1A and B, we explore several possible metrics of connectivity through data available for the Boise and Lewis river basins in detail. Here we define connectivity and show some simple examples of how connectivity could be applied as part of recovery criteria. We also briefly describe potential options for measuring connectivity of bull trout populations through measures of genetic variation and diversity, a concept the RMEG is in the preliminary stages of evaluating.

4.2 The approach

Based on a GIS analysis (see Chapter 2), we first identify bull trout patches for a core area. These patches can range in size, for example (e.g., Lewis River) from 515 to 32,722 hectares (see Figure A.3) with inter-patch stream distances ranging from < 1km to 82km and averaged 35 km. Next, following the methods of Moilanen and Nieminen (2002) with a slight modification to address barriers, we calculate a GIS based index of connectivity using the following formula:

$$S_i = \sum (p_j\ b_i \exp(-\alpha d_{ij}) A^e_j)$$

where p_i is the occurrence of bull trout in the potential source (i) patch (0/1), b the occurrence of a barrier restricting movement from a downstream potential source patch to the focal (j) patch (0/1), ά is a dispersal scalar for bull trout and 1/ ά = the average dispersal distance (assumed 10 km for bull trout), d is the distance in km between the focal and potential source patch, A is the area in hectares of a potential source patch, and e is emigration rate. We calculate S_i for current conditions versus historic potential connectivity. Based on distance and occupancy for the Lewis River patches, there was a significant reduction in connectivity values from the historic potential period to the current period (Figure 4.1A and 4.1B).

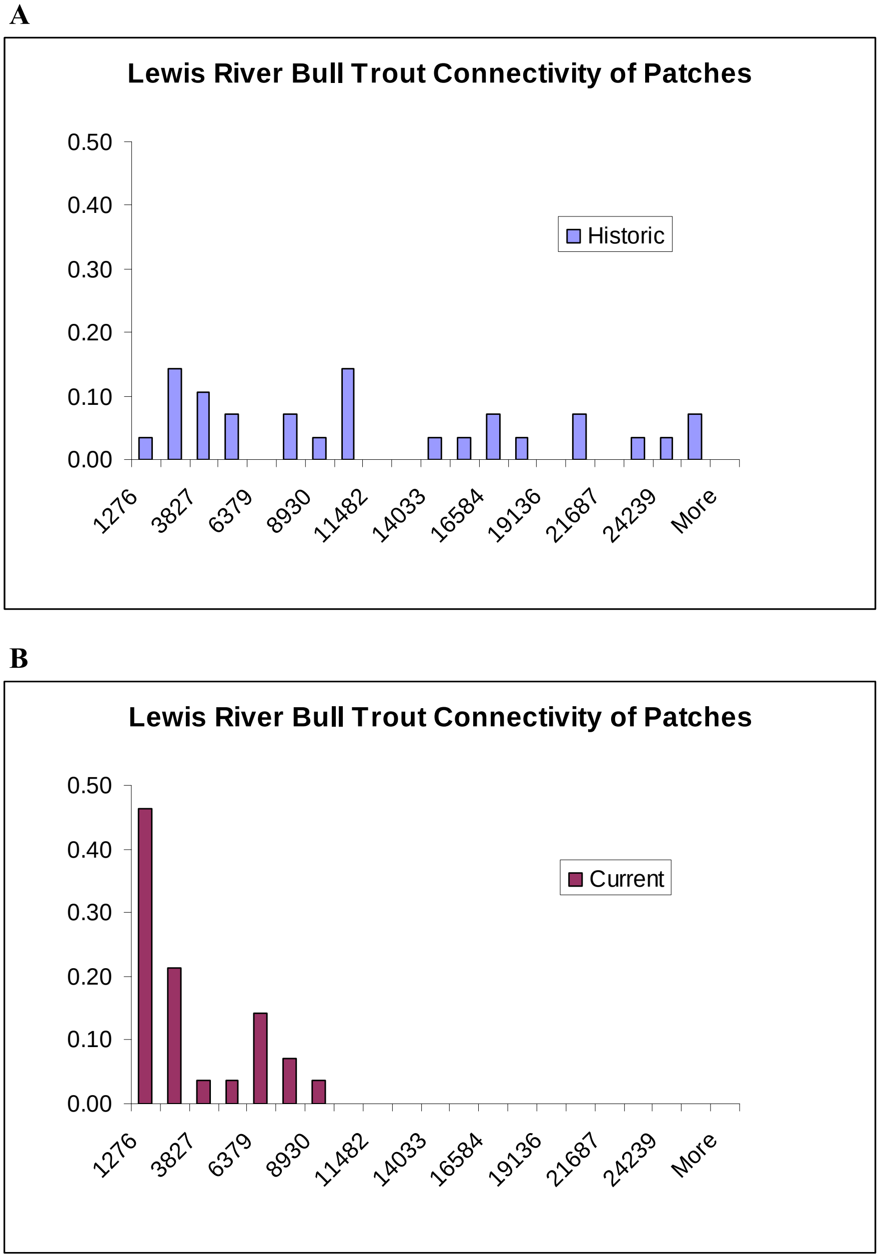


Figure 4.1. The proportion of patches contained in each connectivity index bin for the Lewis River core area during the current period and the historic potential period.

The Lewis River analysis was not sensitive to assumptions for dispersal distance and emigration rates. In a separate analysis of connectivity for the Boise River we observed that connectivity and patch size are essentially complementary. Small patches may persist if they have high connectivity (30km), while patches with limited connectivity may persist if they are large. Using this metric of connectivity, we could explore hypothetical patterns of barriers and occurrence of bull trout that might closer reflect pre-development conditions.

As an example we plotted a frequency distribution of the connectivity current scores for the Boise first under hypothetical distributions assuming that bull trout occurred in every patch, and second, that bull trout occurred in every patch and no barriers existed throughout the system. Under the most optimistic case most patches had a potential connectivity greater than 15, under current fish distribution and no barriers few patches have connectivity greater than 15, but none are isolated (connectivity = 0). In contrast, under current conditions most patches have connectivity less than 10 and many are isolated (Figure 4.2).

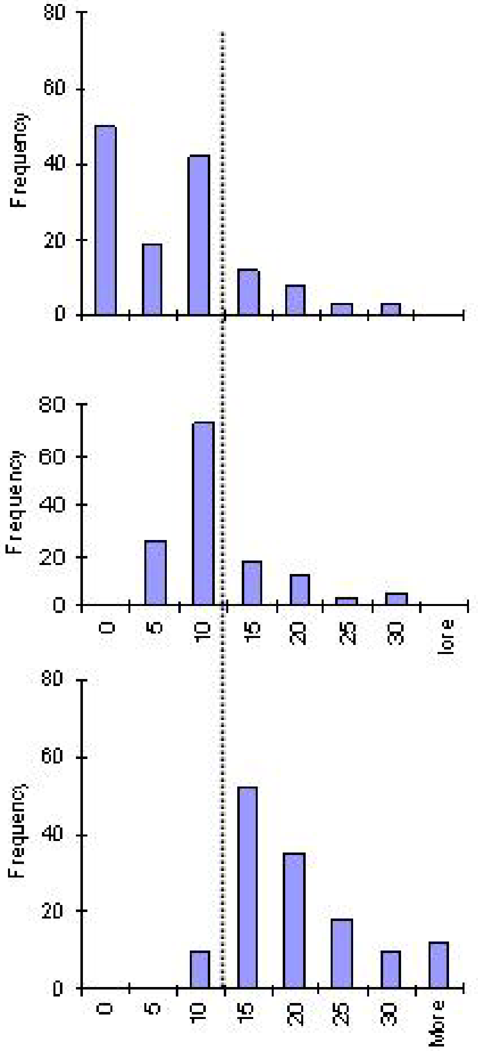


Figure 4.2. Distributions of current and potential connectivity for all patches in the Boise River basin. The top panel is the current condition. The middle panel assumes no barriers exist. The bottom panel assumes bull trout occur in every patch and no barriers exist. The vertical line is for reference only.

Comparisons of different metrics of connectivity for the Boise River demonstrated that measures of focal patch size and connectivity together produced the best models overall. Connectivity and patch size appear to compensate for each other suggesting that local populations could be buffered from extinction through either or both. The best fitting models for the Boise also suggest that dispersal distances are relatively limited (<10km), so the effective size of available habitat might be estimated from habitat networks with a minimum distance of less than 5 to 10 km. The pattern of dispersal with distance between patches is largely speculative, however, and needs focused research to resolve the issue.

Connection to the migratory corridor

Connectivity to the migratory corridor has not been evaluated in RMEG analyses to date. Loss of connectivity through physical barriers can also impact the migratory corridors and impede full expression of the migratory life history types for a population of bull trout. The first level of assessment of connectivity, as it relates to expression of the migratory life history form, can be a simple reconnaissance of whether the migratory form is present in a bull trout core area. The extent, number, and distribution of populations known to support migratory individuals would determine the level of risk associated with the loss of corridor connectivity in a core area. This is similar to the approach in the Draft bull trout Recovery Plan of assessing population risk due to functional connectivity of the system (USFWS 2002). Another approach would be to compile information on factors influencing connectivity between patches and the migratory corridors. The GIS coverages and compilation of the local knowledge of barriers could be completed for each of the patches and their likely migration corridors within a core area. Depending on the quality of the information either a quantitative or qualitative assessment of connectivity to the migratory corridors could be estimated (i.e. the number of isolated patches vs. the number of potential barriers respectively, within the core area) (USFWS 2002). The information used in the corridor connectivity assessments could be ground-truthed by establishing some intensively surveyed pilot core areas for bull trout through monitoring and evaluation protocols focused on two types of barriers.

Natural barriers and human-caused barriers

In addition to fragmentation and isolation (or connectivity) resulting from patch structuring, patterns of connectivity also arise from natural passage barriers. Natural barriers such as waterfalls and desiccated stream reaches are rarely included in existing GIS coverages, and, as yet, are difficult to predict. As a result, any knowledge of natural barriers typically requires on-the-ground surveys. A common protocol for assessing natural barriers still needs to be developed for any general application.

Human-caused barriers, such as dams, diversions, road crossings or other coverages have been assessed using a variety of fish passage protocols (e.g., Clarkin et al. 2003). Most fish passage protocols are based on hydrologic simulations of flow conditions through a potential barrier (e.g., a culvert), and assumptions about critical swimming speeds and jump heights of fish. The latter are not well known for bull trout, and anecdotal field observations indicate that bull trout often pass through barriers predicted to be impassable by commonly used protocols for similar species. Thus, the complete suite of characteristics of human-caused barriers that disrupt passage are still poorly understood. In lieu of better information about conditions controlling passage, it may be reasonable to use a standard fish passage protocol (e.g., FishXing) to identify potential passage barriers. A conservative assessment would assume any structure identified as a barrier through such an analysis to be a barrier until passage is actually demonstrated in the field under the range of conditions bull trout are likely to encounter.

The potential for genetic metrics of connectivity

Relative to bull trout recovery, it is appropriate to view connectivity from two perspectives. In general, these perspectives correlate with geographic scale. Within population connectivity (WPC) refers to bull trout within a population being connected (or having access) to various habitats. This connectivity allows for the potential expression of various life history characteristics. An example of disrupted WPC would be if a thermal barrier prevented fluvial bull trout from using a migratory corridor and they were unable to express a migratory life history. For WPC, an evaluation should consider the spatial and temporal structure of a population as well as the life histories expressed by bull trout in a population. Between population connectivity (BPC) refers to bull trout from different populations being connected (or having gene flow) with each other. This connectivity allows for, in particular, the mixing of genetic material from different populations. An example of disrupted BPC would be if a physical barrier prevented the immigration of any bull trout into a population, effectively isolating the population.

The degree of BPC may influence the viability of a population. Population genetic theory suggests that effective population sizes (Ne) ≥ 50 are necessary to prevent inbreeding depression, and Ne ≥ 500 are necessary for viability over ecological time scales (Franklin 1980, Soulé 1980, Rieman and Allendorf 2001). If populations are connected, they have an opportunity to achieve (or exceed) these numbers through spawners from multiple areas (Rieman and Allendorf 2001). If a population is not connected to any other, it must be large enough to achieve (or exceed) these numbers independently. While these are general guidelines, genetic modeling suggests that this theory should hold true for bull trout. However, little empirical data exists to corroborate the 50/500 concept specifically for bull trout and exceptions to this concept may exist (Rieman et al. 1997). More specific information on the effective size of viable bull trout populations would be valuable toward defining minimum viable population criteria for recovery.

The RMEG is currently attempting to engage a geneticist to explore how to measure and evaluate BPC. For BPC, this evaluation should consider the utility of patches to define population units and also address how much gene flow is necessary, how often a gene flow event is necessary and the benefits of episodic gene flow events. RMEG plans to undertake model simulations to evaluate these genetic issues. In these simulations genetic parameters would be controlled to establish reasonable bounds around a genetic signal. Connectivity questions could then be pursued such as:

- How well can genetic techniques measure connectivity and gene flow?
- How much genetic connectivity is required to maintain bull trout populations?
- How often do you need a gene flow event to maintain population structure?
- What are the benefits of episodic events?

These simulation results can be contrasted with existing empirical data for river basins (e.g. Boise, Pend Oreille, John Day, Kootenay, Oldman and others) that have extensive bull trout genetic samples) to help refine the model's assumptions about maintenance of gene flow.

4.3 Conclusions and recommendations for connectivity metrics

The RMEG analysis of connectivity metrics in the Boise and the Lewis rivers focused on fragmentation and isolation resulting from patch structuring. Based on these two examples, the connectivity indices, calculated through a GIS, are relatively easy to compile once bull trout patches have been identified for a core area (Chapter 2). These data provide a first approximation that could be used to interpret the importance of habitat loss and fragmentation in other systems. Habitat fragmentation has reduced connectivity in the Lewis and Boise. Clearly, isolation of individual patches has been an important factor. The loss of potential contributing patches was probably important (e.g. Figure 4.2), but without empirical information on the distribution of bull trout before human disruption of these systems it is difficult to directly quantify the magnitude of that effect.

Metrics of connectivity, along with focal patch size, appear to be important factors explaining the occurrence or persistence of bull trout within patches of a core area. The evaluation of GIS based connectivity indices like these can be used to help guide recovery measures for bull trout core area populations. Robust measures of connectivity, however, will depend on measures of presence/absence that minimize the effects of sampling error. In other words reliable measures of bull trout occurrence will be necessary to get reliable estimates of actual connectivity. The development of probabilistic measures of bull trout occurrence outlined in Chapter 3 will be important to this process. In addition, better knowledge of dispersal distances for bull trout would help refine, measures of connectivity, and connection to the migratory corridor (not yet evaluated) will need to be included in future analyses.

Lastly, the RMEG is pursuing the evaluation of connectivity through population genetics and measures of population structure. It may be possible to evaluate the genetic structure of bull trout populations at multiple levels: among individuals within local populations, among local populations within core areas, and more broadly across the species range. The immediate focus of RMEG will be on evaluating methods to determine population structure of core area populations and measures of connectivity among local populations within a core area.

RMEG Recommendations	**Further Work Required**
Use connectivity indices that incorporate the distances between focal and donor patches, patch sizes and barriers, using a GIS-based approach similar to those evaluated by RMEG and described in Chapter 4.	Develop a robust and parsimonious index that explains observed patterns of patch occupancy. Test candidate indices in strategically selected areas through detailed studies that employ occupancy data, tagging/telemetry studies that record actual movement patterns of tagged fish, and molecular markers for assessment of “effective” dispersal (measurements of actual biological response to connectivity). Simulation models should be developed to determine how much connectivity is required to maintain bull trout populations, and how often gene flow events are necessary to maintain population structure.

Chapter 5: Sampling Techniques and Survey Design for Estimating Bull Trout Abundance and Trend

5.1 Introduction

An accurate and precise assessment of the abundance of populations is necessary for the conservation and management of imperiled species (Gibbs et al. 1998; Williams et al. 2002). This abundance information is essential for evaluating trend, viability and extinction risk, identify limiting factors, and to assess the response of the population to proposed and implemented management actions (Ham and Pearsons 2000; Holmes and York 2003; Bradford et al. 2005; Al-Chokhachy and Budy *in review a*).

Bull trout (*Salvelinus confluentus*) is an imperiled species of char native to the Pacific Northwest. Combinations of habitat degradation (e.g., Fraley and Shepard 1989), barriers to migration (e.g., Rieman and McIntyre 1995), and the introduction of non-natives (e.g., Leary et al. 1993) have led to the decline of bull trout populations across their native range (Rieman et al. 1997). Bull trout are currently listed as Threatened under the Endangered Species Act in the United States (64 FR 58909 58933) and ‘Of Special Concern’ in Canada. The U.S. Fish and Wildlife Service (FWS) is responsible for developing recovery plans for the listed species under their jurisdiction including threatened bull trout.

The draft recovery plan for bull trout outlines criteria to gauge achievement of recovery objectives and assess whether actions have resulted in the recovery of bull trout. With respect to the abundance criteria, the metric of interest is the number of spawning fish present in a core area. The FWS defines the core area as the combination of core habitat (all elements) and core populations of bull trout, forming a biologically functioning unit (i.e., a set of local populations). The general guidelines for satisfying the abundance criteria suggest a minimum of 1000 adult reproductive fish per core area and no fewer than 100 fish per local population to minimize the risk of inbreeding depression and genetic drift. Specific numeric abundance objectives by core area were also proposed (USFWS 2002). Thus, one key component of recovery planning for bull trout is the development of an effective monitoring and evaluation program that allows, among other things, estimation of abundance and trends in abundance, ultimately at the level of the core area (USFWS 2002; Chapter 1, this document).

A sub-committee of the RMEG is evaluating options for sampling population abundance of bull trout and assessing population trend. Here, we discuss challenges associated with assessing abundance for bull trout, synthesize lessons learned with regard to different sampling techniques and approaches, and provide an annotated flow chart summarizing the pros and cons of each technique, given the ultimate sampling goal. Our discussion necessarily considers two hierarchical population groupings, the local population and the core area. Abundance sampling has typically been implemented at the local population level; however, recovery criteria for abundance are assessed at the core area level. Thus, survey design should generate population-level estimates that can ultimately be expanded to the core area level. Therefore we close with a brief and preliminary discussion of potential survey designs for sample allocation and replication within and among core areas (USFWS 2002), recognizing both the need for flexibility in the sampling strategy applied across different regions and the realities of implementation costs. The information we have summarized is also broadly applicable to the monitoring and evaluation of many other inland freshwater trout species (e.g., cutthroat trout; *Oncorhynchus clarki*).

Bull trout present some distinctive sampling challenges for assessing abundance and trend. Within a population or core area, bull trout can exhibit several different complex life-history strategies. These forms include resident and migratory forms (resident, fluvial, and adfluvial), which occupy a diversity of habitat types (small streams, large rivers, and lakes) across time (seasons and years) (Rieman and McIntyre 1993; Nelson et al. 2002; Homel et al. *in review*). Bull trout typically demonstrate cryptic behavior (Thurow et al. 2006), occupy cold-water habitats usually in remote locations (Rieman et al. 1997; Selong et al. 2001), and often naturally occur at low densities (Rieman and McIntyre 1993). These characteristics make sampling and monitoring bull trout populations especially challenging (Al-Chokhachy et al. *in review*) and require long time commitments to evaluate population trends through time.

Past efforts to assess bull trout abundance have varied considerably across regions, depending on funding and regional priorities and a variety of sampling techniques have been used. Abundance may be estimated from redd counts, spawning counts, snorkeling, single and multiple pass electrofishing estimates, and mark-recapture techniques. Estimates of adult abundance usually provide more complete information about population health because adults have successfully transitioned through all life-stages and the habitats that support each life stage (Dunham et al. 2001; Taper et al. 2006). Some techniques are more useful for making inferences about trends in abundance (e.g., redd counts), while others are more effective at providing more direct estimates of absolute abundance (e.g., mark-recapture). The sampling techniques tend to become more complex, expensive, and effort-intensive as they move from indices of relative abundance to estimates of absolute abundance and population growth rates (λ).

The sampling technique and survey design used for measuring abundance will likely be different for different regions, given variation in bull trout life history, habitat type, logistical issues, and resources available. While it would be desirable to employ the same sample technique and survey design within and across different populations and core areas to provide consistency for comparisons of abundances and trends, we acknowledge that monitoring and evaluation programs will need room for local and regional flexibility. Ideally, a range of sampling techniques and survey designs should be evaluated *a priori* to development of any monitoring program so trade-offs between cost and statistical reliability can be evaluated, and estimation bias and precision can be assessed across techniques and areas. The RMEG will be evaluating these trade-offs in the future through field and analytical assessments carefully planned to facilitate cost-effective bull trout monitoring (new and on-going) while simultaneously increasing our understanding of bias and sampling errors.

5.2 Lessons learned: sampling techniques

Redd counts (RC)

Redd counts provide a feasible and relatively inexpensive estimate of reproductive adult abundance (Table 5.1). In addition, redd counts have been performed across the greatest number of bull trout populations and for some of the longest time periods. Bull trout usually spawn in specific areas of natal headwater systems over a concentrated time period (late-summer to early-fall). Redd surveyors typically visit the spawning grounds several times over the duration of the spawning event and count redds based on conditions such as the presence of spawning fish, disturbance of gravel, and nest structure (Dunham et al. *in review*). The number of redds in a local population or core area may be estimated by a census (i.e., a complete count of all redds throughout the spawning distribution and period), or a sub-sample at index sites or a random sample of potential sites (e.g., spatially balanced EMAP design, *see below*; Sankovich et al. 2003).

In terms of assessing abundance and ultimately trends, redd count accuracy is frequently limited by some combination of: 1) strong observer variability (Maxell 1999; Dunham et al. 2001; Hemmingsen et al. 2001; *but see* Muhlfeld et al. 2006), 2) redd superimposition, 3) delineation between test digs and redds (Maxell 1999; Dunham et al. 2001), and 4) a high proportion of fine substrate (Hemmingsen et al. 2001). In addition, when multiple life-history forms coexist within a single population, both redd and spawner counts are limited by the potential for a positive bias towards large (likely migratory) bull trout and a corresponding negative bias towards small (likely resident) bull trout (Moore et al. 2005), a bias that varies in magnitude substantially across core areas (Al-Chokhachy et. al. 2005). Ultimately, if these types of surveys are used to assess abundance, it will be necessary to evaluate different sources of variability and uncertainty and correct for observer error or bias (Dunham et al. 2001; Muhlfeld et al. 2006) as well as which portion of the population (migratory, resident) is primarily represented by redd count data (Al-Chokhachy et al. 2005). This latter issue can be especially critical for assessing status relative to recovery goals; those goals currently require a threshold number of reproductive (but not necessarily migratory) adults. In addition, if the ultimate goal is to expand redd counts out to estimates of reproductive adult abundance, estimates of adults/redd will also be needed, which requires either information on sex ratio and maturity or the number of adults entering a particular spawning area (Sankovich et al. 2003). Comparisons to date indicate that, while variable, the relationship between redd counts and population estimates may be similar within some populations, but is rarely similar across populations or core areas (Al-Chokhachy et al. 2005; Moore et al. 2005). Ultimately, if redd counts are complemented with a more robust and comprehensive sampling technique for at least a sub-set of the populations within a core area, this sampling technique may provide a reliable and cost effective monitoring tool for providing an estimate of abundance and trend.

Trap counts (TC)

Migratory adults can be counted using a trap in conjunction with a weir or fish ladder as they are moving upstream prior to spawning. This technique is labor intensive, as it requires frequent inspection over several months while fish are migrating. Weirs can also be difficult to maintain during higher flows and periods of heavy litter accumulations. In addition, trap counts do not account for adults that do not migrate below the trap (e.g., Sankovich et al. 2003). A more complete count of adult abundance can be estimated by marking fish captured in the trap and subsequently making mark-recapture estimates (see below) (Sankovich et al. 2003; Dunham et al. 2001). Since bull trout often occupy low-productivity watersheds of relatively good water clarity, the use of video techniques to count concentrations of adults has promise (Haro and Kynard 1997; Heibert el al. 2000).

Snorkel counts (SN)

Snorkel counts can provide a relatively inexpensive, non-invasive technique estimate of bull trout population abundance, the abundance of fish by size class, and the relative abundance of other species (Table 5.1). Bull trout snorkel surveys should generally occur during the summer months when migratory adults are present (Hemmingsen et al. 2001; Homel and Budy *in press*). Recent research has demonstrated several limitations of this approach for monitoring bull trout abundance including: 1) a consistent negative bias (i.e., underestimate), which varies across size class and habitat (Thurow et al. 2006); 2) low precision due to the frequent low densities of fish present and high spatial variability in fish distribution within streams (Al-Chokhachy et al. *in review*; Al-Chokhachy and Budy *in review a)* and 3) in response to 1–2, a long temporal commitment required to detect modest changes in abundance (Al-Chokhachy et al. *in review*). In addition, snorkeling may be physically infeasible in small, shallow streams and can be extremely biased at low temperatures, when fish are using interstitial spaces. Despite these limitations, snorkel surveys can be an effective means for monitoring adult bull trout abundance if formal evaluations of bias are conducted across size classes, habitat types, and across diel periods (e.g., Thurow et al. 2006).

However, further research may be necessary to evaluate the consistency of documented biases across large spatial scales (i.e., local populations within core areas/subbasins etc.).

Electrofishing-based estimates

Relative to other species, electrofishing has been used less frequently to monitor adult bull trout because of concerns about potential injury and mortality associated with the technique; some populations may be at low abundance and the species is listed under ESA. Because larger fish, such as migratory adult bull trout, are more responsive to the electric field, they have been expected to be more susceptible to electrofishing-induced injury or mortality. However, laboratory and field data relating the incidence of electrofishing injury and fish size have been equivocal (Snyder 2004). Regardless, the use of electrofishing should be limited to periods prior to spawning because of the potential for significant damage to gametes in ripe fish and developing embryos (Snyder 2003). In addition, electrofishing can be relatively ineffective in some of the extremely low conductivity waters bull trout inhabit. Nevertheless, despite the higher potential for injury compared to other techniques, electrofishing does permit the collection of other important monitoring data that requires having the fish in-hand (e.g., precise lengths, sex, maturity, genetic tissue samples, etc.) and may be preferable for sampling mixed populations of bull trout, brook trout, and hybrids.

Single-pass electrofishing (SP): Single-pass electrofishing provides an estimate of bull trout abundance that is less biased than snorkel surveys due to higher sampling efficiency, but it is also more invasive (Table 5.1; Thurow and Schill 1996; Peterson et al. 2004). Single-pass removal estimates are usually conducted during summer, base-flow conditions with backpack electroshocker units, with or without block nets, to avoid upstream migrating adults and downstream migrating juveniles. Although single-pass removal techniques are more efficient than snorkeling surveys, similar issues also apply, including: 1) a tendency to be negatively biased (e.g., Rosenberger and Dunham 2005), 2) high variance across reaches within a population (Al-Chokhachy et al. *in review*), 3) higher relative cost and effort, and 4) limited feasibility in large rivers, small populations, or where densities are very low, and/or water temperatures exceed 16°C. Nevertheless, like snorkel surveys, single-pass removal techniques may offer an effective technique for monitoring bull trout populations across large spatial scales, if the bias between these indices of abundance and population abundance is evaluated *a priori* or simultaneously as part of the same effort (e.g., Rosenberger and Dunham 2005) and relative to habitat characteristics (Peterson et al. 2002; Peterson et al. 2004) and fish size (Peterson et al. 2004).

Depletion estimates (DE): In contrast to the techniques discussed above, depletion estimates provide an absolute estimate of bull trout population abundance (Table 5.1). Depletion techniques are generally conducted with multiple personnel and require the use of block nets, thus necessitating a considerably greater degree of effort and a higher cost. The precision of depletion techniques generally increases with an increasing number of passes (e.g., Rosenberger and Dunham 2005), and can vary substantially across size classes of fish (Peterson et al. 2004). Timing considerations are the same as described for snorkel and single-pass techniques. While depletion techniques can provide fairly accurate and precise estimates of abundance, relative to snorkeling or single pass techniques (Thurow and Schill 1996), this technique is sensitive to a similar list of limitations as described above for single-pass techniques, albeit usually not to as great of a degree. The commitment of personnel (typically a minimum crew of three must complete at least three passes and process fish) presents a potential limitation for many monitoring and evaluation programs. As with snorkel or single-pass removal estimates, there is a potential for a negative bias as a function of fish distribution (and factors affecting fish distribution behavior) (Peterson and Thurow 2004). Limitations discussed above for single-pass removal estimates associated with river size, population size and handling/stress effects, and water temperature all apply to depletion estimates.

Mark-recapture

Mark-recapture techniques provide one of the most efficient techniques for estimating bull trout abundance and trend; however, this technique is also typically the most costly and requires a high degree of effort and handling of fish (Table 5.1; Al-Chokhachy et al. *in review*). Nevertheless, in addition to increased accuracy and precision relative to the other techniques, mark-recapture techniques can simultaneously provide additional information critical for identifying limiting factors and monitoring population status including vital rates (e.g., survival; Al-Chokhachy and Budy *in review a*), movement patterns (Homel and Budy *in press*), population structure (Al-Chokhachy 2006), and ultimately population trend (see below). A mark-recapture estimate of population abundance can be accomplished via a range of analytical estimators. Simple closed-capture population abundance estimates (e.g., Lincoln-Petersen type models) are based on an initial marking event (e.g., single-pass removal) and a subsequent recapture or resight event (e.g., snorkeling) in a closed population (i.e., no immigration or emigration over time interval), whereas more elaborate "robust sampling designs" use multi-year trapping periods with a set of closely spaced sampling occasions within each year (Pollock 1982; White et al. 1982; Pollock et al. 1990; Burnham et al. 1995a). Alternatively, population trend can be estimated based on individual recapture information (e.g., PIT tags) from active or passive (antennae) recaptures using open estimator, temporal symmetry models (e.g., Al-Chokhachy and Budy *in review b*). Temporal symmetry models can account for the reduced capture probabilities generally associated with cryptic species and potential differences in capture probabilities across groups within populations (e.g., Peterson et al. 2004). Further, recaptures obtained via passive PIT-tag antennae can provide a means for additional recaptures of previously PIT-tagged individuals without further harassment and continuous sampling within and across years.

Despite these advantages of mark-recapture data for assessing bull trout abundance and trend, the information provided by mark-recapture techniques (abundance or trend) can be limited by: 1) low capture and/or recapture rates which affect precision (Al-Chokhachy et al. *in review*); 2) the patchy distribution and low-densities of bull trout (Al-Chokhachy and Budy *in review a*); 3) high costs associated with mark-recapture techniques (including expensive passive antennae); and 4) feasibility issues in large rivers, as block nets not possible resulting in violations of model assumptions (Burnham et al. 1995b). Nevertheless, mark-recapture techniques allow the simultaneous estimation of key vital rates like growth and survival, as well as relatively accurate and precise estimates of abundance or trend.

Table 5.1. Summary of the relative advantages (pros), disadvantages (cons), and degree of effort of the primary sampling techniques used for sampling bull trout abundance, relative to the sampling goal at the local population scale (sample unit). BT refers to bull trout. Recommendations are preliminary.

Mark-Recapture (MR)

PROS:	CONS:
• Estimate of population abundance (migratory and resident BT)	• Cost and effort: extremely high
• Flexibility in field sample design (e.g., active or passive recapture, trap, resight)	• Field implementation difficulty: high
• Ability to account variable recapture rates	• Fish handling and stress: medium-high
• Multiple analytical models available (open and closed)	• Use limited in large or warm (>16 °C) rivers and small populations (e.g., handling stress)
• Allows direct estimation of population growth rate independent of abundance estimate (e.g., temporal symmetry model)	• Precision sensitive to low capture and recapture rates
• Provides size structure and potential for population structure	
• Allows other measurements (e.g., length, vital rates, hybridization)	

Recommendation: Evaluate violation of assumptions and model sensitivity analytically. Couple a comprehensive mark-recapture program in key indicator populations with a simpler, more cost-effective technique in other populations within core area.

Depletion Estimation (DE)

PROS:	CONS:
• Estimate of abundance of juveniles and resident adults	• Not appropriate for migratory adults
• Estimate of abundance of other species	• Cost and effort: high
• Allows other measurements (e.g., length, vital rates, hybridization)	• Field implementation difficulty: medium-high
	• Fish handling and stress: potentially high
	• Precision varies with fish size and number of passes
	• Negative bias possible
	• Use limited in large or warm (>16 C) rivers and small populations (e.g., handling stress)

Recommendation: Do a minimum of 3 passes and test for variable detection probability. Evaluate bias across size classes and habitat types in a sub-set of local populations within core areas.

Single-pass Removal (SP)

PROS:	CONS:
• Index of abundance of juveniles and resident adults	• Not appropriate for migratory adults
• Cost and effort: medium	• Variable and negative bias
• Field implementation difficulty: medium	• Low precision
• Provides index of abundance of other species	• Use limited in large or warm (>16 C) rivers and small populations (e.g., handling stress)
• Allows other measurements (e.g., length, vital rates, hybridization)	

Recommendation: Evaluate bias across size classes and habitat types, and couple with a more precise and accurate technique in a sub-set of local populations within core areas.

Snorkel Counts (SN)

PROS:	CONS:
•Includes migratory and resident BT	•May miss migratory fish depending on timing of sampling
•Cost and effort: low	•Strong and variable negative bias
•Fish handling and stress: low	•Low precision
•Field implementation difficulty: medium	•Does not allow tagging or other measurements
•Provides size structure	
•Provides index of abundance of other species	

Recommendation: Evaluate bias across size classes, habitat types, and time periods (diel) couple with a more precise and accurate technique in a sub-set of local populations within core areas.

Redd Counts (RC)

PROS:	CONS:
•Cost and effort: low	•Positive bias for larger, migratory fish
•Field implementation difficulty: low	•Negative bias for small, likely resident fish
•Fish handling and stress: low	•Potentially high observer error
•Long time series available for some populations	•Effects of superimposition and test digs
•Allows estimation of population trend	•Expansion to an estimate of abundance requires an estimate of adults/redd

Recommendation: Use trained observers and couple with a more precise and accurate technique in a sub-set of populations within core areas.

Weir – Trap Counts (TC)

PROS:	CONS:
•Fish handling and stress: low – medium	•Field implementation difficulty: high
•Allows tagging or other measurements (e.g., length)	•Cost and effort: high
•Provides information on migration timing	•Positive bias for larger, migratory fish
	•Negative bias for small, likely resident fish

Recommendation: Couple with a technique (e.g., MR) for quantifying non-migratory adults.

5.3 Survey designs

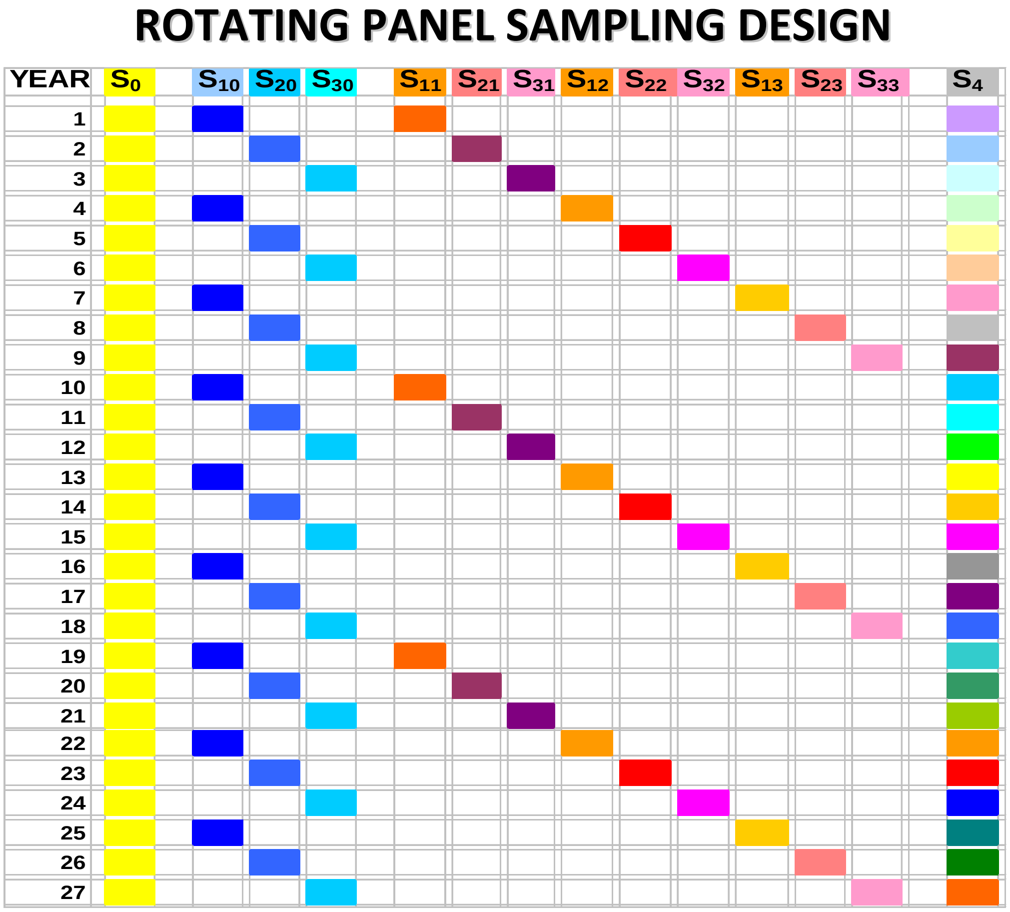
Beyond deliberations over the advantages and disadvantages of sample technique used, designing surveys to estimate abundances and changes over time (trend) requires the parsimonious allocation of field sampling across space (core area) and time (usually years). Knowledge of spatial and temporal variation of the technique and indicator of choice (redds versus adult fish) is critical for the efficient allocation of visits to new sites, or to revisits to existing sites. For example, given a fixed total sampling effort, should more sample sites be visited during an annual index window (e.g., the spawning season), or should a sub-set of sites be re-sampled? For evaluating trend, should all sites be revisited annually, or would a revisit pattern across years (in which not all sites are sampled every year) be more efficient? Unfortunately, the most efficient design for one type of question is not necessarily the most efficient for another type of question. Sampling more sites, at the expense of revisits to sites, improves the precision for estimating abundances or spatial distribution, whereas revisiting sites across years generally improves change or trend detection capability. Given these complexities, the large spatial scale over which bull trout abundance must be sampled, and variability in resources available, we recognize the need for some degree of flexibility in sample design. Panel designs offer both flexibility and potentially satisfactory statistical power.

5.4 Panel designs

To meet differing needs for site-visits, statisticians have proposed sample designs that allow balancing the need for more sites for status estimation with the need for revisits to sites for change/trend detection. These designs consist of panels of sites, each panel with a particular pattern of visits across years. A simple design consists of one panel in which all sites are visited every year. A slightly more complex design consists of an annual panel (sites are visited each year), panels that are visited on a specified cycle, and a panel of randomly selected sites each year (Figure 5.1). For example, a five panel design could consist of: an annual panel, a year 1 panel of sites visited every third year, starting with year 1, a year 2 panel of sites visited every third year, starting in year 2, a year 3 panel of sites visited every third year, starting in year 3, and a panel of new, randomly selected sites each year. These are sometimes called rotating panel designs. Urquhart and Kincaid (1999) and MacDonald (2003) give examples of a variety of panel designs, and MacDonald (2003) proposes a nomenclature for panel designs.

Why might panel designs be a preferred choice? Revisiting sites for change or trend detection eliminates site-to-site differences in the same manner that pairing in experimental studies eliminates the subject-to-subject differences (i.e., paired t-tests). Site-to-site variation is often a major component of variation in stream surveys across a wide variety of indicators (Kincaid, et al. 2004; Larsen, et al. 2004), and consequently eliminating its effect on change/trend detection is desirable. If trend/change detection were the only objective, then setting up a single panel annual visit design would generally be most efficient. What might be lost if rotating panel designs are used instead? The answer is: not much. Urquhart et al. (1993, 1998) and Urquhart and Kincaid (1999) have shown that trend detection capability for panel designs “catches up” with an annual panel design after the passage of three cycles, achieving essentially the same power as an annual panel design. Given that many of the kinds of change or trends of interest are relatively long term (decadal), rotating panel designs allow considerable flexibility in the allocation of field sampling within and among sites.

Rotating panel designs implemented for several years also allow the estimation of spatial and temporal variation, critical to the continued evaluation, and potential modification of initial sample designs. Urquhart, et al. (1998), Kincaid et al. (2004), and Larsen, et al. (2004) describe these variance components and their effects on design choices for status and trend estimation. Stevens (2002) describes a rotating panel design that has been implemented by the Oregon’s Department of Fish and Wildlife and Department of Environmental Quality that consists of an annual panel, a three year cycle (three panels), a 9 year cycle (9 panels), and a random panel, yielding a total of 14 panels Figure 5.1). The surveys are used to estimate the numbers of adult coho spawners in Oregon’s coastal streams in several monitoring areas, number of juveniles, habitat and water quality conditions.



ROTATING PANEL SAMPLING DESIGN

YEAR	S_0		S_{10}	S_{20}	S_{30}		S_{11}	S_{21}	S_{31}	S_{12}	S_{22}	S_{32}	S_{13}	S_{23}	S_{33}		S_4
1	■		■				■										■
2	■			■				■									■
3	■				■				■								■
4	■		■							■							■
5	■			■							■						■
6	■				■							■					■
7	■		■										■				■
8	■			■										■			■
9	■				■										■		■
10	■		■				■										■
11	■			■				■									■
12	■				■				■								■
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24	■				■							■					■
25	■		■										■				■
26	■			■										■			■
27	■				■										■		■

Figure 5.1. Conceptual diagram of an EMAP rotating panel design developed for coho salmon (3-year life cycle). This design balances status assessment with trend detection and requires less effort after initial sampling investment. The panels are: annual, 3-yr, 9 yr, and 27 yr, with a 25% split per year. For example: Sites S0 are sampled every year; S10, S20, S30 are sampled every four years; S4 are sites sampled every 27 years.

5.5 Assessing trend: Analytical considerations

The bull trout recovery criterion for trend in abundance calls for a stable or increasing trend of adults. Although this criterion is subject to biological interpretation, it corresponds in statistical terms to a finite population growth rate (λ) that is not less than one. Thus a rigorous assessment of the statistical power of proposed survey designs and protocols to detect meaningful departures from a positive growth rate is an important component of designing the monitoring and evaluation program. There are a number of analytical approaches that might be used to estimate trends in abundance which range from simple log-linear regression to much more complex analyses (e.g., Morris and Doak 2002). Rotating panel survey designs may be used with a variety of metrics of abundance and are designed to estimate a regional trend from multiple-site sampling. The panel design typically uses some variation of linear or log-linear regression to analytically estimate trend and has been shown to be superior to independent surveys for detecting trend (Urquhart and Kincaid 1999). Multi-phase regression analyses are recommended for estimating the distribution of trend statistics (Diaz-Ramos et al. 1996; Stevens 2002). Methods that include the option of testing and adjusting for autocorrelation between abundance data from adjacent years are preferable, since the nature of population growth means deviation from the long term growth rate at one time period will be correlated with deviation at the preceding time period (Staples et al. 2004b).

Estimating population trend or growth rate can also be done with the use of a range of PVA (population viability assessment) models. Our purpose is not to review those approaches here. More specific to bull trout, however, there are emerging PVA approaches that can be tailored to generate metrics for use in monitoring 'signals' (Staples et al. 2004b; Staples et al. 2005). The Viable Population Monitoring (VPM) approach focuses on identifying relative "risk" of population decline before a decrease in population abundance can be detected statistically (Staples et al. 2005; Taper et al. *in press*). This approach therefore represents a proactive approach for examining future scenarios (i.e., what is the chance of having less than a target abundance within a specified time period) rather than trying to establish whether a past decline has been significant. VPM is focused on predicting short-term population trajectories (2–5 generations on average) that can are used for evaluating short-term security in terms of population recovery. Another approach potentially applicable to bull trout relies on analytical estimates of growth rates using diffusion approximation (DA) based models (Dennis et al. 1991). In recent years DA models have been developed that allow separate estimation of process and observation error from sparse or messy data (Holmes 2001; Holmes and Fagan 2002; Staples et al. 2004a).

Finally, as discussed briefly above, mark-recapture techniques may be useful for estimating trends in abundance, either through providing estimates of abundance that are then separately analyzed for trend (e.g., Pollock et al. 1990), or through open population mark-recapture studies which integrate abundance and trend estimation objectives directly (temporal symmetry models; Pradel 1996). Trend based on estimates of abundance from mark-recapture can be biased by heterogeneity (see Pollock et al 1990; Burnham et al. 1995b; Link 2004), a problem that can be overcome only with long time series and high capture rates. In contrast, several examples have recently emerged which demonstrate that population growth can be effectively measured using temporal symmetry models of mark-recapture data (Schwarz 2001; Nichols and Hines; 2002; Al-Chokhachy and Budy, *in review* b). These temporal symmetry models are advantageous as they use individual encounter histories of mark-recapture data to develop an autonomous estimate of population trend (Pradel 1996) that is less affected by the precision of abundance estimates compared to other methods (e.g., Dennis et al. 1991) and avoids some of the key pit-falls associated with projection matrix estimates (Nichols and Hines 2002). These direct estimates of population growth (λ) are also more robust to heterogeneity and assumptions of closure (Schwarz 2001; Hines and Nichols 2002).

5.6 Considerations for implementation: Issues of scale, cost, and effects on populations

Previous sections of this chapter describe a variety of protocols (and their respective abundance metrics) by which estimates of bull trout abundance could be made at either a reach scale (e.g., redds, juveniles, or spawner counts), or at a small watershed scale (e.g., mark-recapture, or counting weirs), scales that generally apply to a local population. However, as recovery objectives for abundance are stated in terms of the number of reproductive adults in a core area, practitioners are faced with the challenge of scaling up from measurements made at these smaller scales to the scale of the core area. In addition, it would be impractical to attempt to implement some techniques across all populations in a management unit due to the high cost and considerable effort required. A robust, yet economically feasible approach for estimating bull trout abundance across larger spatial scales (core area/subbasin) could include a combination of techniques distributed across different types of habitat and population structure within a nested sampling design (a sub-set of a panel design). With a nested survey design, many sites across the core area (potentially stratified by key populations) are sampled using the inexpensive sampling techniques, while a subset of these sites could also be sampled with the more expensive methods, to estimate bias associated with the less expensive methods. Non-invasive techniques (e.g. redd counts, snorkeling) have an advantage in that they do not directly contact individual fish, which is important for populations that are doing poorly. A potential method for dealing with these multiple objectives is to have a well designed mark-recapture program implemented in key index populations (that are comparatively healthy) to provide estimates of bias relative to simpler, more cost-effective techniques (e.g., redd counts). Less invasive techniques that are evaluated for bias via mark-recapture could then be implemented broadly across the other populations within the core area (see Table 5.1). Over time, potential site covariates that might be associated with variation could be measured at the full set of sites. Then the development of empirical models incorporating the covariates could be applied to the full set of sites to correct them for estimated bias. The use of nested designs could then be used to “scale up” the site-specific bias corrections to the core area abundance estimates.

In terms of the allocation of sample effort of the less expensive technique across a potentially large core area, the patch concept (Chapter 2 this document) can be useful to help guide the development of specific survey designs. Stratified or variable probability designs can be developed based on knowledge about which patches are occupied or likely to be occupied in a given core area, or which patches are likely to have higher abundances than others (Staples et al. *in prep.).* In addition, knowledge about patch specific life histories can help guide the selection of the most efficient/effective measurement or combination of measurement protocols.

Finally, the accuracy needed to evaluate proximity to the criterion is related to (or is a function of) how far the current condition is from the criterion. Recovery criteria for bull trout are explicit, quantitative statements above or below which the target taxon might be deemed safe from extinction. As such, if abundances are several orders of magnitude away from the criterion (either above or below), relatively inaccurate abundance indicators would suffice. However, as the abundance criterion is approached from either direction, improved accuracy would be needed to evaluate difference from the criterion. A coarse evaluation of the accuracy needed as related to target criteria can be incorporated into the development of cost effective survey designs.

5.7 Conclusions and recommendations for monitoring abundance

RMEG Recommendations	Further Work Required
At a patch and site scale: Focus on estimating adult abundance using appropriate methods for each region, accounting for the variation in bull trout life history, habitat type, logistical considerations and the resources available.	Quantify biases inherent in different abundance sampling techniques under different conditions. Explore whether better methods could be developed for extrapolating from juvenile to adult bull trout abundances.
At a core area scale: Use a probabilistic panel survey design (e.g., GRTS) for sample allocation to estimate abundance. Such designs offers both flexibility and potentially satisfactory statistical power, while providing an economically feasible approach for estimating bull trout abundance across larger spatial scales (e.g., core area/subbasin). Use a nested survey design potentially stratified by key populations and habitats, and using a combination of abundance sampling techniques. Most sites would be sampled using inexpensive, non-invasive sampling techniques (e.g., redds, snorkeling), while a subset of these sites would also be sampled with more invasive but more informative techniques (e.g., mark-recapture, weirs). This subset would be used to estimate the bias associated with the less intensive methods. Then one would “scale up” to core area abundance estimates, using bias corrections to the less intensive, non-invasive methods.	Panel designs may not be appropriate for all abundance measurement techniques (e.g., weirs). In small core areas, a census may be less expensive to undertake than a panel design.

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Appendix 2.1
Bull Trout Patch Analysis: The Lewis River Core Area

Approach

The approach to describing bull trout patches in the Lewis River Core Area, Washington, follows a modified approach from Dunham and Rieman (1999). The resulting patches were identified using temperature:elevation relationships and determining catchment areas for subwatersheds that fall within the acceptable temperature threshold.

DEM and Stream Layer Acquisition

DEMs (10 m resolution) were acquired for each quadrangle in the Lewis River subbasin from the University of Washington (GIS at Earth Space and Science, duff.ess.washington.edu/data). The quadrangles were appended to one another to construct a single Lewis River subbasin DEM. A high resolution stream layer for the Lewis River subbasin was acquired from the National Hydrography Dataset web site (nhd.usgs.gov).

Temperature:elevation relationships

A maximum annual stream temperature of 16^{o}C was identified as the threshold for supporting bull trout populations. Temperature data was acquired from water quality monitoring reports generated from 1996-2003 (GPNF 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003). The maximum annual stream temperature for a given stream location in the Lewis River subbasin was determined for the overall time period. In other words, if one year of monitoring occurred at a location, then the maximum temperature from that year was used. If several years of monitoring occurred at a location, then the highest maximum temperature achieved over all years was used. No consideration was given to the duration of the highest annual maximum temperature (e.g., one v. several days). Geographic coordinates (UTM NAD 83) were determined for all stream locations used and elevation was determined using the constructed Lewis River subbasin DEM. Temperature:elevation relationships were investigated using regression analysis (SigmaStat, SPSS Inc.) and resulted in a determination of elevation above which the maximum annual stream temperature never exceeded 16^{o}C.

GIS analysis

GIS analyses were conducted using ArcGIS 8.3 and Arc Hydro Tools. The constructed Lewis River subbasin DEM and the stream layer are used with Arc Hydro Tools to conduct a two series of analyses: terrain preprocessing and watershed processing. All of these steps must be conducted in the order prescribed by the Arc Hydro Tools manual to result in the final patches.

There are two key parts to this process that should be highlighted. In terrain preprocessing, the ‘Fill Sinks’ analysis results in a DEM layer that contains the streams of the subbasin. Those streams also have related elevations and orders. This layer was filtered according to the temperature:elevation relationships that were developed and stream orders. In doing so, a DEM layer was created that contains all stream segments above the threshold elevation and stream order. In watershed processing, this filtered DEM layer was then used to identify each subwatershed terminus above the threshold elevation and stream order. For example, a subwatershed terminus represented a point above which the stream network had no streams larger than 3rd order and was expected to be no warmer than 16ºC over the course of a year. Each subwatershed terminus then resulted in a potential patch corresponding to the subwatershed above it. The next step was to filter the potential patches so that only those greater than or equal to 400 hectares were identified as bull trout patches in the Lewis River subbasin.

Results

Temperature:elevation relationships

Temperature:elevation relationships were initially investigated in four separate drainages of the Lewis River subbasin based on qualitative analysis of the dataset (Upper Lewis, Clear, Muddy and East Fork/Canyon/Siouxon). Linear regression provided the best fit for each drainage dataset, however the Upper Lewis provided the only statistically significant relationship (Figure A2.1-1). The results indicated similar temperature:elevation relationships for three of the drainages (Upper Lewis, Clear and East Fork/Canyon/Siouxon). Therefore, these three drainages were combined to yield a statistically significant linear relationship (Figure A2.1-2). The temperature:elevation relationship in the Muddy drainage was drastically different and this drainage was considered separately through the remainder of the exercise. The resulting relationship to maintain an annual maximum stream temperature no greater than 16°C for the Lewis River (no Muddy) drainage yielded an elevation of 570 m or greater and for the Muddy River drainage yielded an elevation of 1230 m or greater.

GIS analysis

GIS analysis resulted in 33 potential patches in the Lewis River subbasin. These patches ranged in size from 515 to 12,476 ha (Figure A2.1-3).

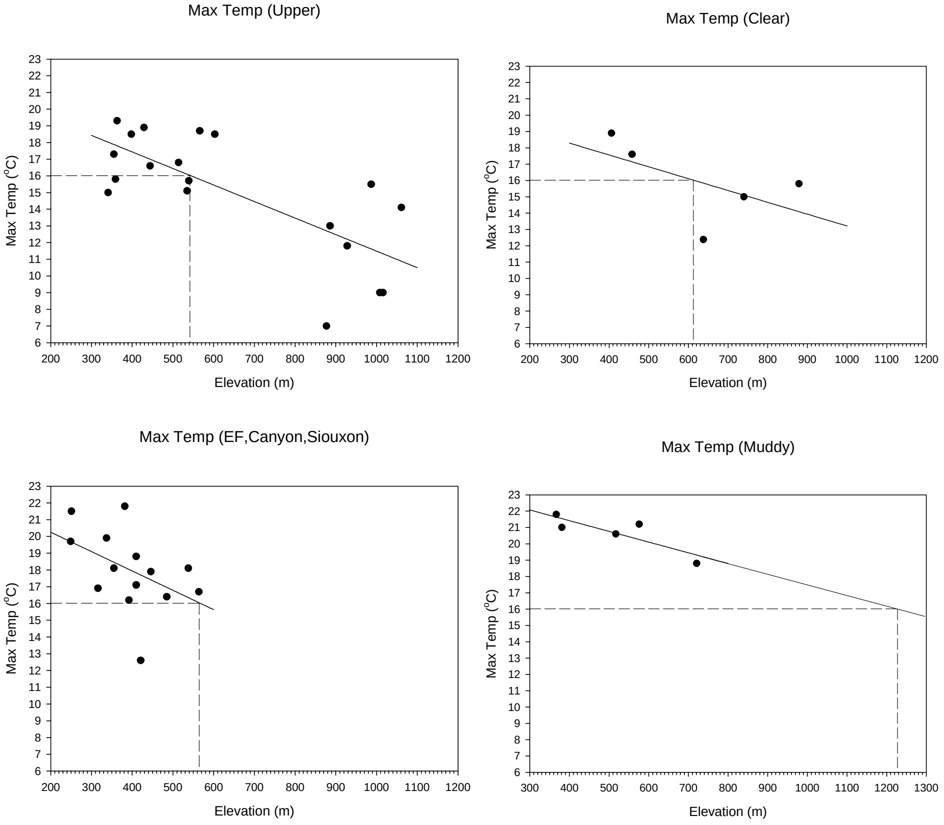

Figure A2.1-1. Linear regression analysis results for four drainage areas in the Lewis River subbasin.

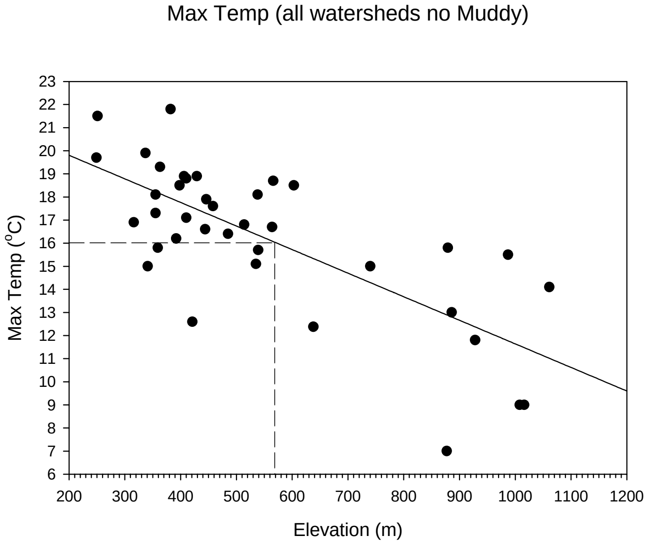

Figure A2.1-2. Linear regression analysis results for Lewis River (no Muddy) drainage in Lewis River subbasin.

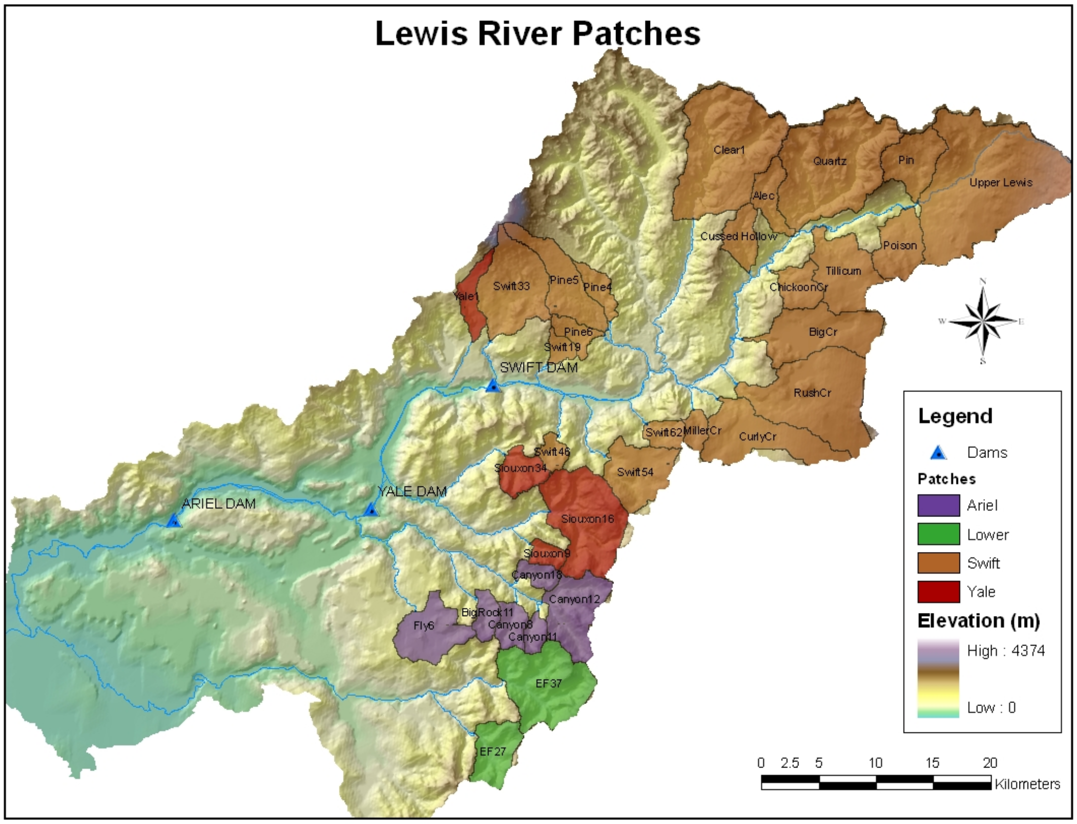

Figure A2.1-3. Lewis River subbasin potential bull trout patches (N=33) identified by temperature:elevation, stream order and catchment area.

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Appendix 3.1
Identifying Sample Sites within a Patch: A Survey Design for the John Day River

Created 7/7/2006 Created by Barbara Rosenbaum

John Day Basin 500m Master Stream Sample Survey Design

Contact: Phil Larsen in conjunction with mporter@essa.com (Marc Porter) and howard_schaller@fws.org

Description of Sample Design

Target population: Lewis River Subbasin – USGS HU 17080002.

Sample Frame: NHD Plus - NHD Flowline layer.

Survey Design: A Generalized Random Tessellation Stratified (GRTS) survey design for a linear resource was used. The GRTS design includes reverse hierarchical ordering of the selected sites.

Multi-density categories: None.

Stratification: None.

Panels: No panels – master sample set.

Expected sample size: Expected sample size 31260 sites – one site approximately every 500m where the total stream length is 15,630 km.

Over sample: None.

Site Use: Sites are listed in siteID order and must be used in that order within the basin. All sites that occur prior to the last site used must have been evaluated for use and then either sampled or reason documented why that site was not used.

Sample Frame Summary: Total Length of the Resource is 15,630 km.

Site Selection Summary: Number of sites in sample: 31,260.

Description of Sample Design Output:

The dbf file for the shapefile (“JohnDay500mSites”) has the following variable definitions:

Variable Name Description

SiteID: Unique site identification (character)

Xcoord: x-coordinate from map projection (see below)

Ycoord: y-coordinate from map projection (see below)

Mdcaty: Multi-density categories used for unequal probability selection

Weight: Weight (in km), inverse of inclusion probability, to be used in statistical analyses

Stratum: Strata used in the survey design

Panel: Identifies base sample by panel name and Oversample by OverSamp

EvalStatus: Site evaluation decision for site: TS: target and sampled, LD: landowner denied access, etc (see below)

EvalReason: Site evaluation text comment

auxiliary variables

Remaining columns are from the sample frame provided.

NHD Plus is the sample frame. The attached documentation describes the additional attributes.

Projection Information

```
PROJCS["USA_Contiguous_Albers_Equal_Area_Conic_USGS_version"
GEOGCS["GCS_North_American_1983"
DATUM["D_North_American_1983"
SPHEROID["GRS_1980",6378137.0,298.257222101]]
PRIMEM["Greenwich",0.0],
UNIT["Degree",0.0174532925199433]],
PROJECTION["Albers"],
PARAMETER["False_Easting",0.0],
PARAMETER["False_Northing",0.0],
PARAMETER["Central_Meridian",-96.0],
PARAMETER["Standard_Parallel_1",29.5],
PARAMETER["Standard_Parallel_2",45.5],
PARAMETER["Latitude_Of_Origin",23.0],
UNIT["Meter",1.0]]
```

Evaluation Process

The survey design weights that are given in the design file assume that the survey design is implemented as designed. Typically, users prefer to replace sites that can not be sampled with other sites to achieve the sample size planned. The site replacement process is described above. When sites are replaced, the survey design weights are no longer correct and must be adjusted. The weight adjustment requires knowing what happened to each site in the base design and the over sample sites. EvalStatus is initially set to “NotEval” to indicate that the site has yet to be evaluated for sampling. When a site is evaluated for sampling, then the EvalStatus for the site must be changed.

Recommended codes are:

EvalStatus:

Code Name:

Meaning:

TS Target Sampled site is a member of the target population and was sampled

LD Landowner Denial landowner denied access to the site

PB Physical Barrier physical barrier prevented access to the site

NT Non-Target site is not a member of the target population

NN Not Needed site is a member of the over sample and was not evaluated for sampling

Other codes

Many times it is useful to have other codes. For example, rather than use NT, may use specific codes indicating why the site was non-target.

Statistical Analysis

Any statistical analysis of data must incorporate information about the monitoring survey design. In particular, when estimates of characteristics for the entire target population are computed, the statistical analysis must account for any stratification or unequal probability selection in the design. Procedures for doing this are available from the Aquatic Resource Monitoring web page given in the bibliography. A statistical analysis library of functions is available from the web page to do common population estimates in the statistical software environment R.

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NHD web page http://nhd.usgs/gov NHDPlus web page (July 2006) http://www.horizon-systems.com/nhdplus

Aquatic Research Monitoring Web Page: http://www.epa.gov/nheerl/arm

Appendix 3.2
Assessing Bull Trout Patch Occupancy: The Baldy Creek Patch

Approach

The study evaluated the occupancy of bull trout patches in BCP. At the 1:100,000 scale (USGS stream layer database), Baldy Creek is a third order tributary of the North Fork John Day River (Oregon). The BCP includes Baldy, Bull and Limber creeks and extends to near the mouth of Baldy Creek. Based on previous surveys, bull trout were known to occupy the BCP, presumably at relatively high densities (ODFW 2005). This study occurred during July and August, 2006. The primary objective was to 1) evaluate the occupancy of this patch. This was accomplished sampling four sites. Secondary objectives were to provide 2) an additional empirical estimate of the power to detect patch occupancy and 3) guidance on the minimum number of sites that must be sampled to evaluate patch occupancy. These objectives were accomplished by sampling 21 sites in the BCP.

Sample sites

To achieve all the objectives of the study it was necessary to sample 21 sites in the BCP. Using GRTS, a random set of spatially-balanced sample sites were identified (Fig. 3.2) and UTM coordinates were generated. Across the BCP there was an average of one site every 0.5 km. GRTS provides a set of sites in spatially balanced order, with a sequential site identifier. To maintain the spatial balance, the first 21 sites on the GRTS list should be sampled, if viable. Reconnaissance surveys were conducted to evaluate whether sites were viable. Sites could be determined non-viable for a variety of reasons, including being dry, too narrow (< 1 m in width), too steep (> 18% gradient) or inaccessible (for example, private ownership access denied). Non-viable sites should be coded with the reason. Additional sites from the GRTS ordered list are evaluated to achieve the desired target of 21 viable sites. At each viable site, the reach to be sampled was the stream segment between the points 25 m upstream and downstream of the UTM point identified for the site. The area between these points provided 50 m reaches at each site.

Fish Sampling

Snorkeling was conducted at each site between 25 July and 6 August. Snorkeling was conducted during daylight hours (between 10:00 H and 17:00 H). Block nets were not be used in this exercise. Prior to sampling, snorkel surveyors were trained in techniques to identify species and estimate the size of fish underwater. Based, in part, on the information from Thurow and Schill (1996) and Thurow et al. (2001), one or two surveyors were used in each unit. Briefly, surveyors made one, upstream pass using flashlights to increase visibility under piles of large wood (LWD) and other shaded areas. All species that were observed were recorded by 50 mm size classes. Since bull trout may mature at lengths as short as 150 mm (Earle and MacKenzie 2001), juveniles were considered bull trout shorter than 150 mm. Underwater visibility was measured using a salmonid silhouette (Peterson et al. 2002). In three locations at each site, the distance to where the silhouette could be clearly identified (i.e., Secchi disk), both leaving the silhouette and approaching the silhouette, was recorded. Whether a snorkel surveyor could see underwater from bank to bank was also recorded.

One-pass, backpack electrofishing was conducted at each of the sites from 15-27 August. Electrofishing was also conducted during daylight hours (between 10:00 H and 17:00 H). Block nets were not be used in this exercise. Crews consisted of one person carrying the electrofishing unit and one or two people netting fish. Prior to sampling, crews were trained in electrofishing protocols. Electrofishing was conducted using a Smith-Root LR-24 backpack electrofisher. Settings were initially set at 350-500 V, depending on the size of the channel, 16% duty cycle, and a frequency of 28 Hz. Adjustments were left to the discretion of the crew leader and made in response to conditions (i.e., temperature and conductivity) and fish behavior (i.e., tetanus v. taxis). Electrofishing was conducted working upstream. Sampling was conducted in a manner that would draw fish out of optimum habitat to be captured (i.e., the electrofisher was not continuously engaged as the crew moved upstream). When possible, the entire channel was sampled in a zigzag manner. In reaches where the entire channel could not be sampled as the crew moved upstream, one bank was completely sampled through the reach, and then the other bank was sampled. All fish encountered were captured. After the entire reach had been sampled, captured fish were anesthetized using approximately 25 ppm clove oil. All fish were then identified to species, measured (fork length), weighed (g), and allowed to recover before releasing them back into the sampling reach.

Habitat Sampling

For each reach, the following habitat parameters were collected: water temperature, conductivity, gradient, channel dimensions, woody debris, and undercut banks. Elevation for each unit was obtained via Digital Elevation Model data or via topographic maps. At the start of fish sampling, water temperature was measured and conductivity was recorded. The gradient of each sampling reach was measured using a hand-held transit and stadia rod. The elevation at the water surface was measured at the bottom and top of each reach and the change in elevation was used to estimate gradient. Gradient was measured twice, each time by a separate crew member. Transects were established and flagged every ten meters in each reach and measured along the thalweg. Wetted width, mean depth, and maximum depth were measured along each transect. Mean depth was estimated from measurements at ¼, ½, and ¾ wetted width. Total length, which was equal to or larger than 50 m, was recorded as an index of sinuosity. Within each reach, the number of pieces of wood > 10 cm in diameter and > 3 m in length were counted. Only pieces of wood directly within the channel or within 1 m of water surface were quantified. The number of LWD piles, aggregates of > 4 pieces of wood together, and the number of root wads were also quantified in each reach. The amount of undercut banks was measured for each sampling unit. Undercuts were defined as areas under boulders, banks, wood, or bedrock along a stream bank that are >5 cm deep, > 10 cm in length, and > 5 cm in height (Kershner et al. 2004); only undercuts within 0.5 m of stream surface (both above and below) were considered. Prior to sampling, crews were trained in all aspects of habitat measurements. To minimize variability between crew members, one person was used for all sampling and habitat data collection.

Results

Sample sites

In the BCP, 39 sample sites were identified (Figure A3.2-1). Of the first 21 sites that were identified, reconnaissance surveys indicated that all were viable. Thus, the first 21 sites identified (00059-18367) were selected for sampling. The first four sites were used to evaluate whether the patch was occupied and all 21 sites were used to assess detection probabilities in the patch.

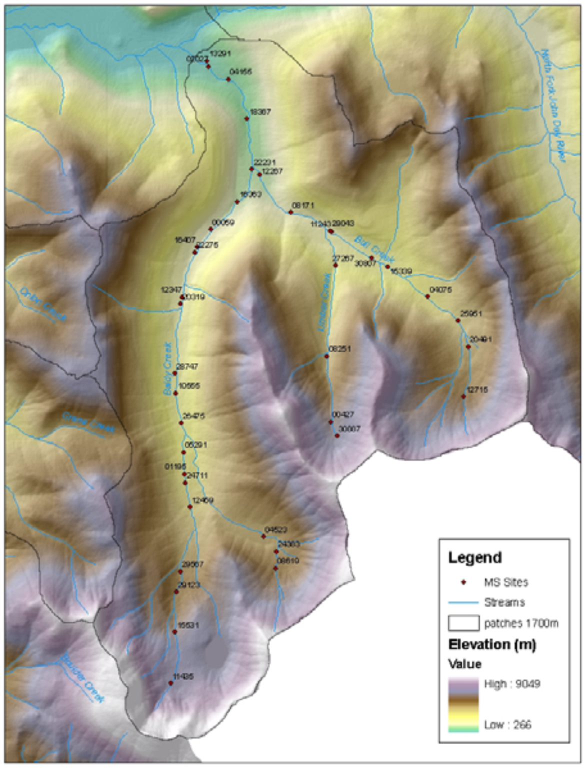

Figure A3.2-1. Potential sample sites in the Baldy Creek Patch. Sites were generated using a probabilistic approach (GRTS). Each site was numbered. Sites numbers were ordered from low to high. A sample framework was developed selecting the lowest numbered sites first. For example, site 00059 was the first to be targeted for sampling.

Fish

During snorkel surveys, visibility ranged from 1.9-5 m and surveyors could see from bank to bank at all reaches. We observed bull trout, brook trout, bull trout/brook trout hybrids, juvenile *O. mykiss* and juvenile Chinook salmon. Bull trout that were 50 -150 mm in fork length were observed in 15 of the 21 sample sites (71.4%). Bull trout > 150 mm in fork length were observed in 12 of the 21 sample sites (57.1%). Young of the year (YOY) bull trout (those < 50 mm in fork length) were observed in eight of the 21 sample sites (38.1%). Overall, some size class of juvenile bull trout was observed in 14 of the 21 sample sites (66.7%). Whenever YOY bull trout were observed, another size class of juvenile bull trout was also observed.

During electrofishing surveys, conductivity ranged from 20-80 µSiemens with an average of 37 µSiemens. We observed bull trout, brook trout, bull trout/brook trout hybrids, and juvenile *O. mykiss*. Bull trout between 50-150 mm were observed in 15 of the 21 sample sites (71.4%). Bull trout > 150 mm were observed in 10 of the 21 sample sites (47.6%). Young of the year bull trout were observed in two of the 21 sample sites (9.5%). Overall, some size class of juvenile bull trout was observed in 14 of the 21 sample sites (66.7%). Whenever YOY bull trout were observed, another size class of juvenile bull trout was also observed.

Habitat

Habitat data was collected but not thoroughly analyzed.

Analysis and discussion

As expected, the BCP was occupied by bull trout. Based on the sample design used in this study, the patch would have been judged to be occupied by bull trout after the first site (00059) was sampled. Site 00059 was in Baldy Creek and located in the lower portion of the patch. At this site, snorkel and electrofishing surveyors observed multiple size classes of juvenile bull trout while bull trout longer than 150 mm were only observed by snorkel surveyors. The patch would not have been determined to be occupied from either survey method at sites 2 and 3. However, snorkel surveyors would also have concluded the patch was occupied after sampling site 4 (and electrofishing surveyors would also have concluded the patch was occupied after sampling site 5).

The SSDP in the BCP resulted in relatively high power to detect whether bull trout occupied the patch. The SSDP for juvenile bull trout in the BCP (71.4%) was substantially greater than the highest probability used to bracket the hypothetical model (50%) (Figure A3.2-2). In addition, 0.30 is the lowest SSDP we have observed in any test case. Applying the SSDP that was derived from the BCP, if 14 sites were sampled (as originally proposed from the model) the probability that bull trout would be present if they were not detected is extremely low (P = 2.45-8). In the BCP, at least two sites must be sampled for the power to detect whether bull trout occupy a patch to exceed 80%. If two sites are sampled, the resulting power is 92.5%.

It may be possible to optimize the probability of detecting bull trout (Rich et al. 2003) by sampling sites that are at the most upstream extremes of the patch (Rieman and McIntyre 1995). We evaluated whether we could minimize the effort necessary to evaluate patch occupancy by sampling upstream sites prior to downstream sites. The BCP would not have been judged to be occupied by bull trout after sampling any of the five most upstream sites. Thus, although this study was not specifically designed to examine this relationship, sampling effort would not have been minimized using this strategy in the BCP.

Methods to survey for bull trout have been well discussed in the literature (see Thurow et al. 2001, Peterson et al. 2002). Snorkeling at night is commonly suggested for bull trout surveys (e.g. Bonneau et al. 1995, Jakober et al. 1995, but see Thurow and Schill 1996). However, given the quantity and remote location of potential sites that may need to be sampled to evaluate bull trout patch occupancy and recovery, night snorkeling may not be feasible in many cases. Thus, we focused on snorkeling and electrofishing during daylight. In the BCP, sampling during daylight hours proved sufficiently powerful to detect bull trout. In addition, in the BCP example, snorkeling and electrofishing during the daylight hours provided similar probabilities of detecting bull trout.

Detection probabilities may be related to the habitat being sampled. Once sufficient habitat data is collected and analyzed it may be possible to predict how detection probability varies with habitat type. Ultimately, to achieve a given detection probability, this relationship may permit the required number of sample sites per patch to be adjusted based on the habitat being sampled. In lieu of this relationship being fully developed, it is possible to use a conservative estimate of SSDP to determine the maximum number of sites necessary to sample. We anticipated that BCP would have a relatively high SSDP, so this patch does not provide a conservative estimate. However, to date, we have not observed a SSDP lower than 0.30 in any patch we have sampled.

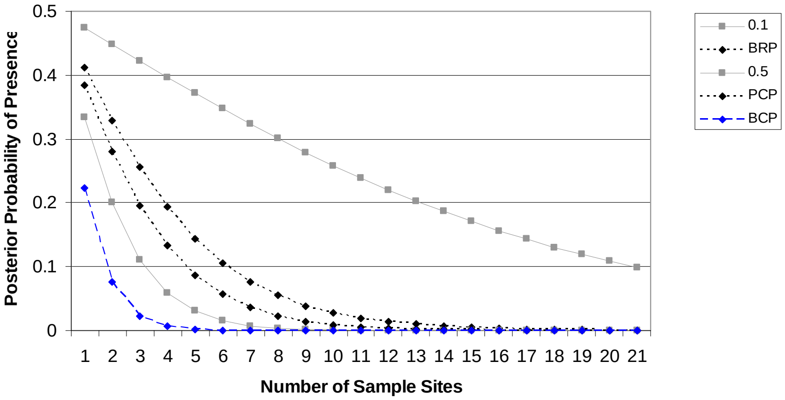

Figure A3.2-2. Estimating the probability of the BCP being occupied (bull trout being present) if no bull trout were detected during sampling. The prior probability of presence was set at 0.50 (uninformed). Hypothetical SSDPs were set at 0.1 and 0.5. The BCP SSDP for juvenile bull trout was 0.71. SSDPs for patch sampling in the Boise River (BRP, 0.30) and Lewis River (PCP, 0.38) are shown for comparison.

Appendix 4.1

(A) Connectivity Index Example for the Lewis River

GIS analysis identified 29 bull trout patches for the Lewis River core area. These patches ranged in size from 515 to 32,722 hectares. The inter-patch stream distances ranged from <1km to 82km and averaged 35 km.

Following the methods of Moilanen and Nieminen (2002) with a slight modification to address barriers, we calculated a GIS based index of connectivity using the following formula:

$$S_i = \sum (p_j \, b_i \exp(-\alpha d_{ij}) A^e_j)$$

where p_i is the occurrence of bull trout in the potential source (i) patch (0/1), b the occurrence of a barrier restricting movement from a downstream potential source patch to the focal (j) patch (0/1), ά is a dispersal scalar for bull trout and 1/ ά = the average dispersal distance (assumed 10 km for bull trout), d is the distance in km between the focal and potential source patch, A is the area in hectares of a potential source patch, and e is emigration rate. We calculated S_i for current conditions versus historic potential connectivity. Based on distance and occupancy, there was a significant reduction in connectivity values for the Lewis River patches from the historic potential period to the current period. However, this was a relatively data poor area for standardized information on bull trout occupancy data across the identified patches. The proportion of Lewis River bull trout patches with Si values greater than 5000 was greatly reduced from the historic period to the current period (Figures 4.1-1A and 4.1-1B).

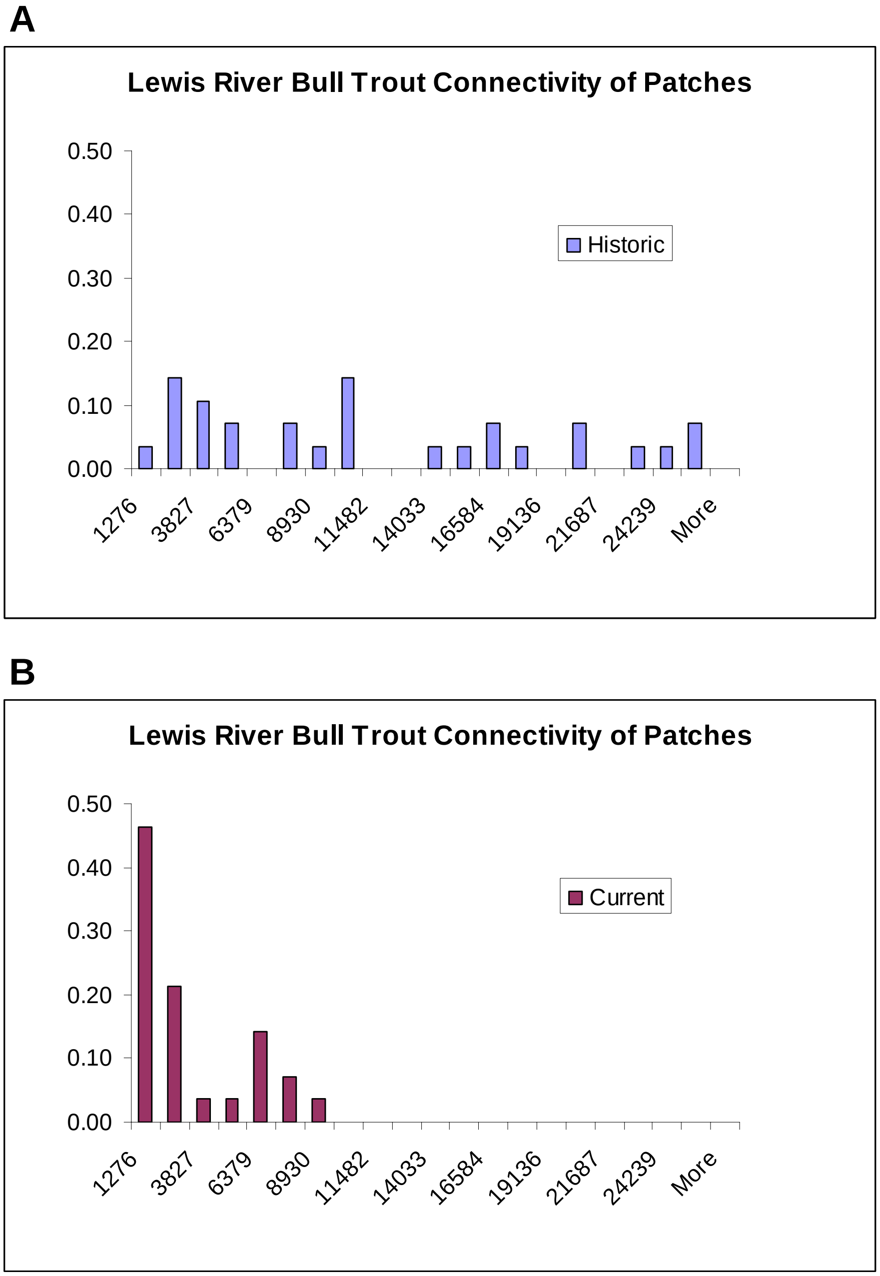

Figure A4.1-1. The proportion of patches contained in each connectivity index bin for the Lewis River core area during the current period and the historic potential period.

The analysis was not sensitive to assumptions for dispersal distance and emigration rates. We also evaluated the addition of mainstem barriers; however, the connectivity index results were not very sensitive to the addition of mainstem barriers. However, in a relative sense the driving inputs for indices of connectivity for the Lewis River example are the distance from focal patch to all potential donor patches, donor patch areas, and donor patch probability of presence.

(B) Connectivity Index Example for the Boise River

Rieman and McIntyre (1995), Dunham and Rieman (1999) and Dunham et al. (2002) proposed the concept of patch based analysis of fish distribution and used data for bull trout from the Boise River basin to explore the concept. The results suggested that the geometry (size and distance) of habitats suitable for spawning and rearing define the structure and influence the persistence and dynamics of populations (i.e., metapopulation processes). Whiteley et al. (2006) found evidence isolation by distance in the Boise bull trout populations that indicated past dispersal was influenced by distance among occupied habitats in some parts of the basin. Isaak et al. (2007) has shown that geometry of habitats and particularly "connectivity" defined by a distance weighted sum of the size of potential source patches (following Moilanen and Nieminen 2002) can explain the occurrence and dynamics of Chinook populations in the Middle Fork Salmon. In this case size of the local patch and connectivity of potential source patches were more important predictors than local patch quality.

We reanalyzed the Boise bull trout occurrence data to explore the utility of alternative connectivity metrics. The Boise patch structure (Figure A4.1-2) was defined and mapped following Dunham and Rieman 1999. Some patch boundaries have been refined based on the distribution of known barriers and more complete temperature data. We have mapped 137 patches considered to be thermally suitable habitat for bull trout in the system. We did not include patches with contributing areas smaller than 500 ha in our analysis because smaller watersheds rarely support permanent streams larger than 2 m in this basin. Patches were first inventoried as described by Rieman and McIntyre 1995, but the occurrence of bull trout has been revised with additional data collected through studies that have continued in the basin. Of 137 potential patches 97 have been inventoried for bull trout occurrence in the last 10 years. "Presence" was restricted to patches with evidence of successful reproduction based on the occurrence of pre-migratory individuals (<150mm) or spawning adults. Absence was based on the failure to find bull trout with repeated sampling (effort generally high enough to leave a probability of occurrence given no fish in the sample less than 0.15).

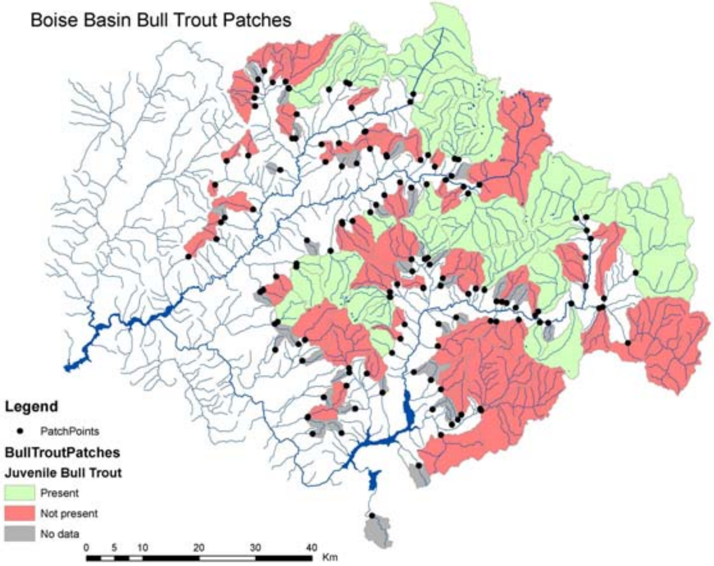

Figure A4.1-2. Thermally suitable habitat patches for bull trout in the Boise River basin. Patches delineated following Rieman and Dunham 1999 with some updates. Green are occupied, orange are not.

We used two measures of local patch size: contributing area of the watershed above the lower patch boundary and length of stream suitable for bull trout within the patch. We defined suitable stream segments within a patch as those with contributing areas larger than 400 ha and valley bottom gradients less than 15% (scatter plots of the original data from Rieman and McIntyre [1995] suggest few bull trout are found in segments steeper than this or smaller than this).

ToArea= area in ha of the focal patch
ToLenKM= length in km of suitable stream segments in the focal patch from modeled hydrography based on the 30m DEM.

We considered connectivity to be the amount of potential source habitat that could supply immigrants to any focal patch (Dunham and Rieman 1999 considered only the distance from the nearest occupied patch). We used two connectivity formulae each estimated with area and suitable stream length in potential source patches (four different metrics). The two formulae weighted the distance between the focal patch of interest and a potential source patch differently. The distance between all pairs of patches was estimated by the distance along the stream line between the lowest points in the two patches. For patches with an impassable upstream migration barrier between them the downstream patch could be excluded as a potential source for the upstream patch, but the upstream patch was included as potential source for the downstream patch. Patches were mapped based on connectivity and a simple rule set was used to filter and establish all potential sources for every patch in the basin (Figure A4.1-3). We manipulated the estimates of connectivity to consider hypothetical patterns of barriers and occurrence of bull trout that might closer reflect pre-development conditions.

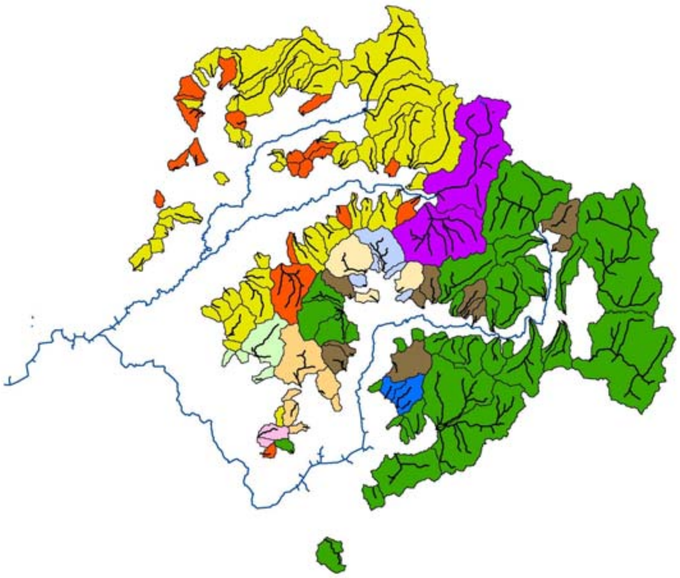

Figure A4.1-3. Patches color coded by connectivity. All patches of a common color are interconnected among themselves with the exception of the brown and orange patches which are completely isolated.

The first two connectivity metrics were weighted by dividing the area or stream length of the potential source patches for every focal patch.

Conn1= $\sum (a_i/d_i * b_i * p_i)$

Conn2= $\sum (l_i/d_i * b_i * p_i)$

Where a is the area in hectares of a potential source patch i, d is the distance in km between the focal and potential source patch i, b_i is the occurrence of a barrier restricting movement from a downstream potential source patch i to the focal patch (0/1), p_i is the occurrence of bull trout in the potential source patch (0/1), and li is the length of suitable stream segments in the potential source patch.

The second two connectivity metrics were based on Isaak et al (2007) after Moilanen and Nieminen (2002). Although connectivity based on the original work was intended to approximate the number of dispersing individuals by incorporating a term for dispersal rate, we dropped that term so that our metric simply weights the potential contributing area as a function of distance. In this case the potential contribution of a patch immediately adjacent to the focal patch is essentially equal to the entire area.

Conn3= $\sum a_i * b_i * p_i * \exp(-\acute{\alpha} * d_i)$

Conn4= $\sum l_i * b_i * p_i * \exp(-\acute{\alpha} * d_i)$

Where $\acute{\alpha}$ is a dispersal scalar for bull trout and $1/ \acute{\alpha}$ = the average dispersal distance (assumed for bull trout). Based on the IBD summarized in Whiteley et al. 2006 we initially assumed an average dispersal distance of 10km. All of the connectivity metrics produce an exponential decline in effective patch size with distance from the focal patch (Figure A4.1-4). In hindsight conn1 and conn2 approximate conn 3 and conn 4 with a smaller dispersal distance (i.e. ~ 4 km rather than 10). Further analyses could be based on a single metric and simply vary the dispersal scalar to consider that influence directly.

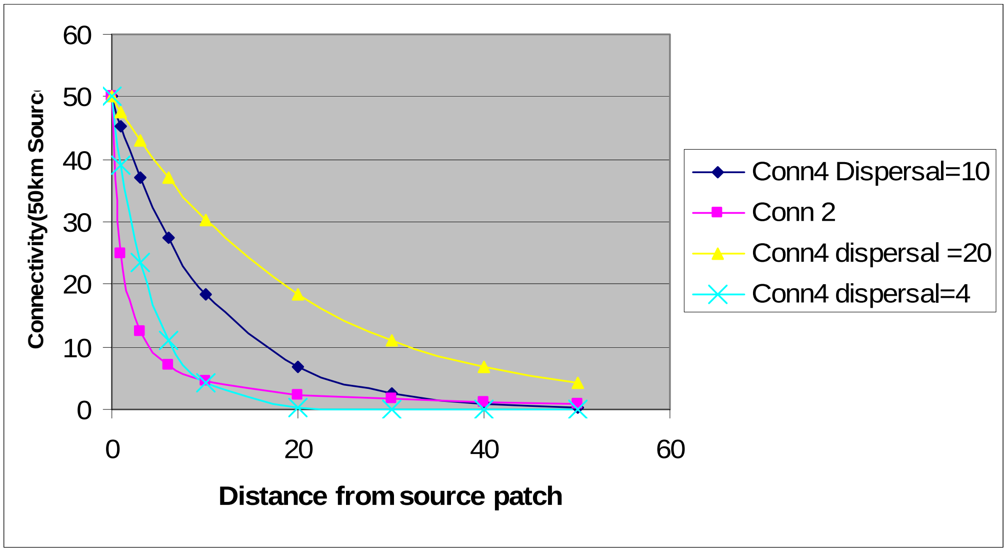

Figure A4.1-4. Connectivity (km/km) for a potential source patch with 50 km of suitable stream habitat for bull trout as a function of distance from the focal patch.

The four connectivity measures were intercorrelated suggesting they provide similar information although correlations were strongest for metrics based on the same mathematical expression (Table A4.1-1; Figure A4.1-5).

Table A4.1-1. Pearson correlation coefficients between four measures of connectivity

	Conn1	*Conn2*	*Conn3*
Conn1			
Conn2	0.98		
Conn3	0.81	0.82	
Conn4	0.78	0.82	0.99

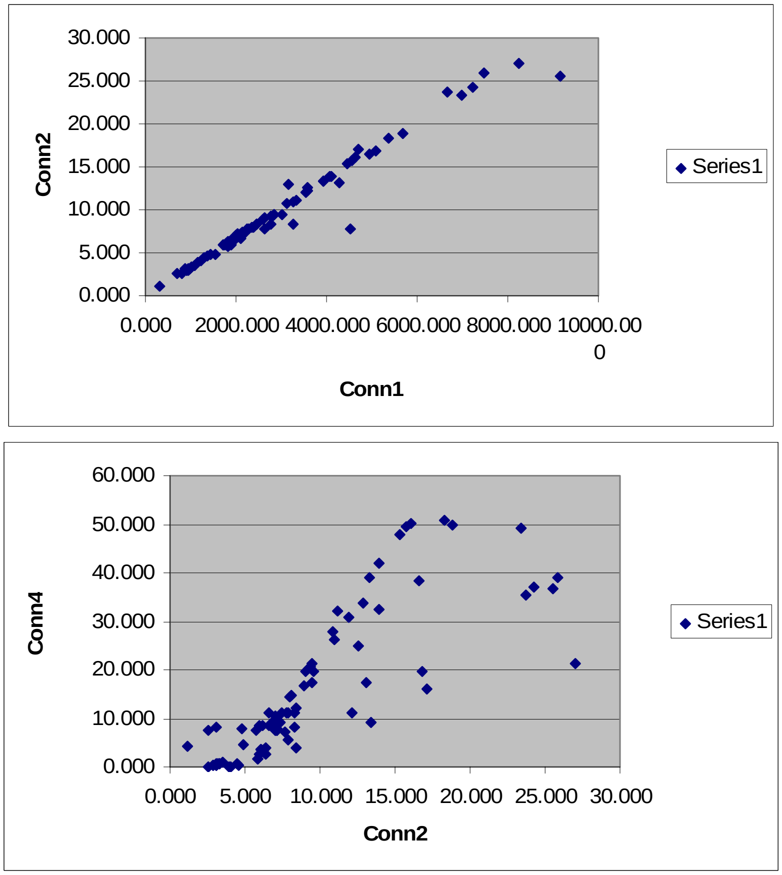

Figure A4.1-5. Scatter plots showing the associations between three different measures of connectivity. Plots based on the same mathematical expression were more closely associated than those based on different expressions.

We also included four composite variables where we summed local patch size and connectivity.

Conn5a= ToArea+Conn1
Conn5L=ToLenkm+Conn2
Conn6a=ToArea+Conn3
Conn6L=ToLenkm+Conn4

Our reasoning was that focal patch size and connectivity are essentially measures of a continuum of the potential demographic size of any local population based on the habitat available to support it. In other words a small patch with a lot of potential contributing habitat nearby may be just as likely to persist as a large patch isolated from any adjacent populations because it may draw on a similarly large number of adults. The further contributing patches are from the focal patch the more contributing habitat required because fewer individuals will disperse over larger distances.

Regression Analysis

We used logistic regression analysis of bull trout occurrence as a function of patch area or length and the different measures of connectivity. The alternative models included each of the patch size variables paired with its appropriate connectivity estimate (i.e. based on length or area), the composite variables alone, and each measure of patch size or connectivity alone. After plotting the results we also used a log e transformation of the predictors and reanalyzed the data.

The log transformed predictors fit much better than the non- transformed predictors so we present only those results. The most plausible models included measures of both patch size and connectivity or their sum (i.e. *conn2 and conn5l;* Table A4.1-2*)*. The measures of connectivity using a short dispersal distance (*conn2*) provided a better fit than those approximating a longer dispersal distance (*conn4*). The measures of connectivity and patch size based on stream length generally fit better than those based on area. All of the of the models that included some measure of focal patch size fit much better than models based on connectivity alone.

Table A4.1-2. Results of the logistic regression exploring the relationship of bull trout occurrence to patch size and connectivity. Including models with the same patch size and connectivity metrics, combined in different ways, seemed redundant (e.g., conn5l; conn2 Tolength).

Predictors	AICc	AIC wt	Evidence Ratio	Likelihood Ratio X^2
conn5l	90.48	0.24	1.00	<0.0001
conn2 Tolength	90.83	0.20	1.19	<0.0001
Tolength	91.66	0.13	1.80	<0.0001
conn5a	91.69	0.13	1.83	<0.0001
conn4 Tolength	92.27	0.10	2.45	<0.0001
conn1 Toarea	92.55	0.09	2.82	<0.0001
conn3 to area	93.07	0.07	3.65	<0.0001
Toarea	94.77	0.03	8.54	<0.0001
conn6l	98.02	0.01	43.38	<0.0001
conn6a	99.43	0.00	87.79	<0.0001
conn2	109.77	0.00	15444.37	0.0014
conn1	111.00	0.00	28566.79	0.0026
conn3	112.14	0.00	50513.71	0.0049
conn4	112.83	0.00	71324.84	0.0073

Plots of the two best model predictions provide some context for interpreting the range of connectivity estimates (Figures 4.1-6 and 4.1-7). Connectivity could be interpreted as a direct compliment to local patch size. Small patches are expected to persist if they have high connectivity (30km), where as connectivity may be less important to large patches.

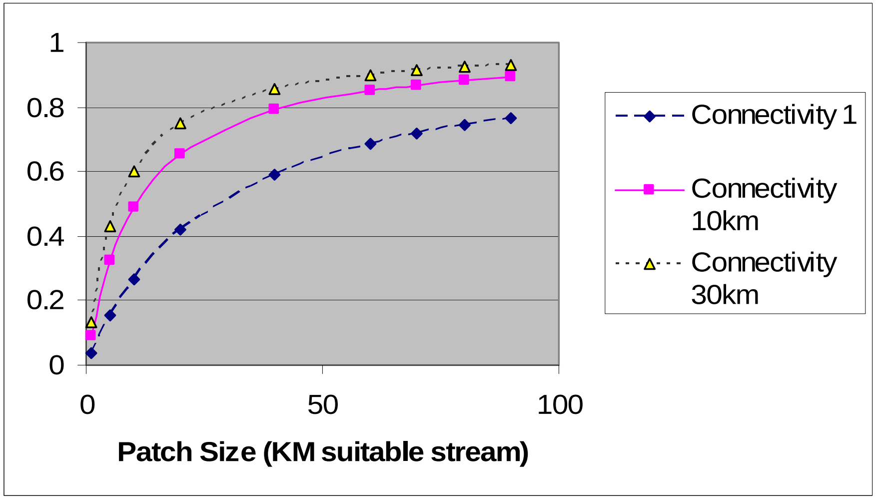

Figure A4.1-6. Predictions of probability of occurrence as a function of patch size (km) and connectivity using the best fitting two variable model (i.e. P= *conn2+tolength*)

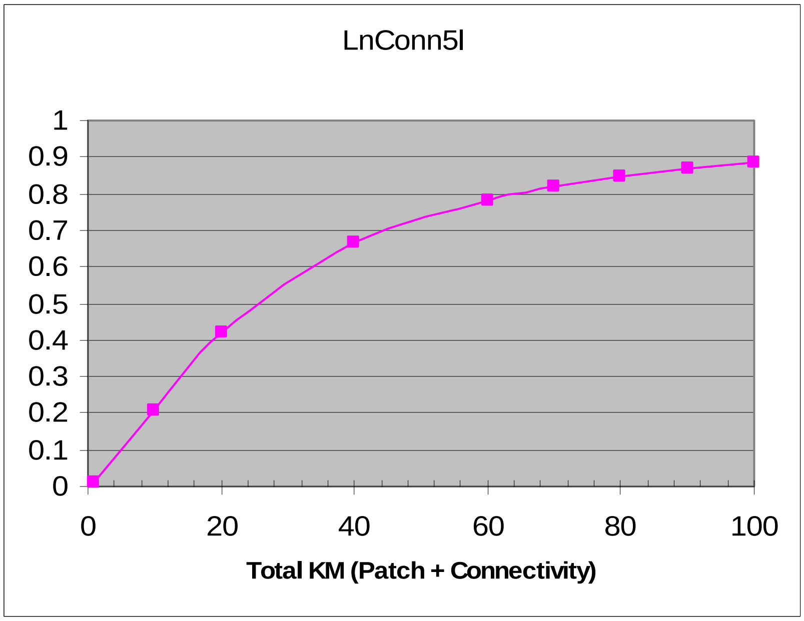

Figure A4.1-7. Predictions of probability of occurrence as a function of the composite variable *conn5l* (i.e., sum *conn2* and *tolength*) which was the overall best fitting model

Changes in connectivity in the Boise River Basin

We explored the changes in connectivity that might have occurred in the Boise by plotting a frequency distribution of the current scores for *Conn2* and hypothetical distributions assuming that bull trout occurred in every patch, and where bull trout occurred in every patch and no barriers existed throughout the system. Under pre development conditions most patches had a potential connectivity greater 15 under current conditions most patches have a connectivity less than 10 and many are isolated.
(Figure A4.1-8).

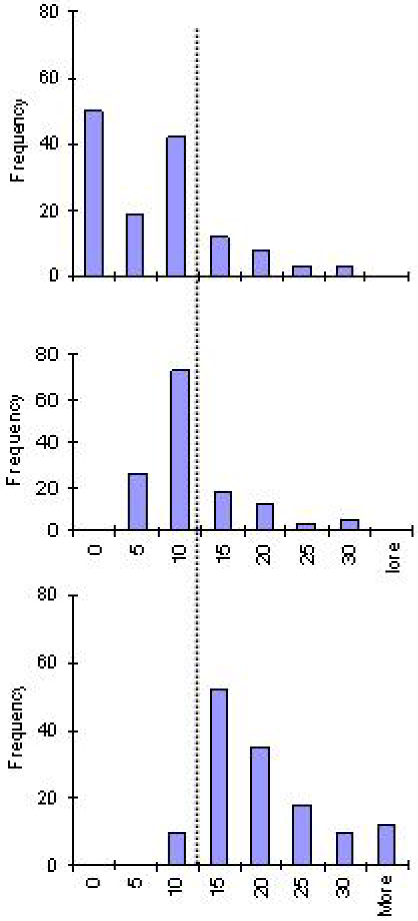

Figure A4.1-8. Hypothetical distribution of connectivity (*conn2*) for all patches in the Boise basin. The top panel is the current condition. The middle panel assumes no existing barriers. The bottom panel assumes bull trout occur in every patch. The vertical line is for reference only.

Conclusions

Focal patch size was the most important measure of habitat geometry explaining the occurrence of bull trout in the Boise Basin, but measures of focal patch size and connectivity together produced the best models. There are a variety of connectivity metrics that could be explored in efforts to explain the distribution and persistence of bull trout. Connectivity and patch size appear to compensate for each other suggesting that local populations could be buffered from extinction through either or both. The best fitting models suggest that dispersal distances are relatively limited (<10km) so the effective size of available habitat might be estimated from habitat networks with a minimum distance of less than 5 to 10 km. The patterns of dispersal with distance between patches is largely speculative, however, and needs more focused process based work to resolve. These data provide a first approximation that could be used to interpret the importance of habitat loss and fragmentation in other systems. Habitat fragmentation has reduced connectivity in the Boise, but primarily through complete isolation of individual patches and not through loss of potential contributing patches.

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