Redd Counts

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Summary

The purpose of this protocol is to describe field methods for the consistent collection of salmonid redd abundance and subsequent estimation of adult salmonid breeding population size. We recommend surveys be conducted on predetermined, 3–5-km long stream reaches, using a spatially balanced rotating panel design. We suggest an annual draw of 10% of all reaches in the sampling universe as the target goal for monitoring; furthermore, to account for access problems and other barriers to sampling, we recommend that the initial sample draw should over-select reaches (sampling rate of 25%) to provide flexibility in the field. One field survey should occur prior to fish entering the spawning areas, with surveys thereafter conducted 7–14 d apart until new fish and redds are no longer observed. Surveyors will need to recognize that stream flows and/or weather conditions will have some bearing on the temporal aspects of surveys. All redds will be identified to species, measured, and georeferenced. Redd longevity and observer efficiency in redd detection will be estimated for each watershed by tracking the condition of individual redds measured during previous surveys. To document sex ratios, the sex of all live fish will be visually identified on behaviors at redds or other visual cues (dead fish will be identified, sexed, inspected for tags, and measured, per the carcass count protocol, page 59). In situations where multiple salmonid species overlap on a given spawning area, redd sizes will help differentiate the species involved.

Background and Objectives

Background

The family *Salmonidae* is characterized in part by most members being gravel nest spawners (Eddy and Underhill 1978). Female salmon and trout excavate a nest in gravel substrate, deposit eggs that are externally fertilized by one or more males, quickly cover these with gravel, and begin to dig another nest. A contiguous series of these nests is called a redd (Kuligowski et al. 2005). Nest or egg burial depth (DeVries 1997), redd size (Burner 1951; Orcutt et al. 1968), water depth, water velocity, and substrate preferences (Bjornn and Reiser 1991) vary among species. Burner (1951) divided redd building into three stages: prespawning, spawning, and postspawning. During prespawning, females excavate a nest pot and clear it of loose gravel and fine materials, leaving only larger cobbles with clean interstitial spaces for eggs to lodge. During spawning, the female alternately deposits eggs and digs to cover fertilized eggs with loose gravel as she moves upstream, digging more nests. The loose material dislodged and swept downstream is called the tail spill. During post-spawning, a female Pacific salmon has deposited all her eggs and, in what is termed "spent" condition, continues to dig gravels upstream of the nests until her death. Briggs (1953) wrote that both male and female steelhead *Oncorhynchys mykiss* drift downstream after spawning. Burner (1951) defines a mature redd as one in which all eggs have been deposited and some post-spawning digging has occurred. Thus, a mature redd consists of a pot on the upstream end and a tail spill of excavated gravels covering the incubating eggs, with the downstream end of the tail spill consisting of excavated fine material not covering eggs (see figures 1–3). The shape of a completed redd may influence water movement through egg pockets (Thurow and King 1994). Newly formed redds appear lighter in color than the undisturbed channel, except in gravel of basaltic origin (Bjornn and Reiser 1991), and may remain discernable for a period of days to weeks, depending on stream flow and periphyton accumulation (Susac and Jacobs 1999; Gallagher and Gallagher 2005; Isaak and Thurow 2006).

As the product only of reproductive adults, counts of salmon redds provide an index of effective population size (Meffe 1986). Redd counts are widely utilized to provide indirect estimates or indices of spawning escapement on rivers that lack counting facilities (Beland 1996; Maxell 1999). For example, Isaak et al. (2003) used a 45-year chinook salmon *O. tshawytscha* redd count data series to examine metapopulation characteristics in Idaho. Redd counts have been used to monitor chinook salmon since 1947 and Chum salmon *O. keta* since 1998 on the Columbia River (Dauble and Watson 1997; Geist et al. 2002). Bull trout *Salvelinus confluentus* populations have been monitored in Idaho and Montana for more than 20 years using redd counts (Maxell 1999; Dunham et al. 2001). Redd counts have been used in California, Oregon, and Washington to monitor coho salmon *O. kisutch* (Lestelle and Weller 2002) and steelhead populations *O. mykiss* (Maahs and Gilleard 1993; Jacobs et al. 2001; Boydstun and McDonald 2005). Redd counts are the primary metric for monitoring salmonids in Washington and Oregon and are proposed for monitoring coastal salmonids in California (Boydstun and McDonald 2005). Atlantic salmon *Salmo salar* populations have been monitored in Maine and other parts of North America for many years (Beland 1996 and references therein). Redd counts are used in evaluating population trends (Rieman and Myers 1997; Maxell 1999).

Population growth rate (e.g., the number of recruits-per-spawner) (Isaak and Thurow 2006) is typically derived from data sets in which robust estimates of escapement and recruits are available (Beland 1996). Although mark–recapture experiments have been shown to be accurate and precise for salmonid population estimation (Minta and Mangel 1989), they require capture programs that are expensive to operate and maintain, are subject to mechanical failure, require that fish be handled and tagged and their movements impeded, and often require specific geomorphic and hydrological features for placement and operation (Gallagher and Gallagher 2005). With due respect given to the inherent observation error rates involved, redd counts offer a less intrusive and less expensive alternative to mark–recapture programs.

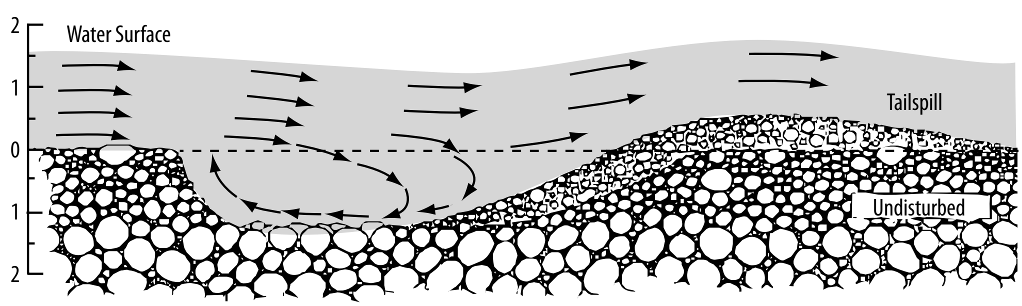

FIGURE 1.—Typical currents in a salmonid redd (Illustration: Andrew Fuller, from Burner 1951, 98)

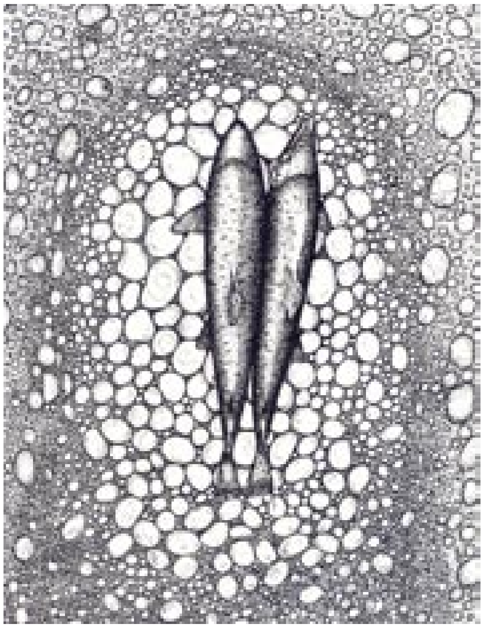

FIGURE 2. — A pair of spawning salmon on a redd (from Burner 1951, 99)

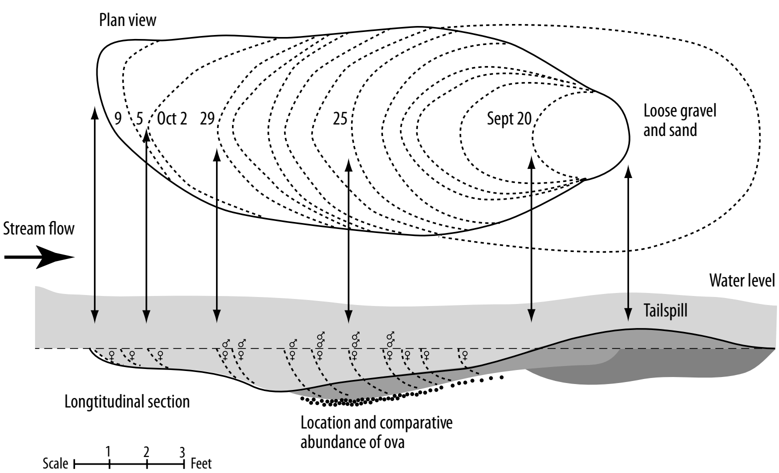

FIGURE 3. — Diagrammatic views of a fall chinook salmon redd measured daily (Illustration: Andrew Fuller from Burner 1951,101)

Rationale

Fish populations are an integral component of any aquatic system in which they exist. Intermittent streams as well as perennial rivers and streams are important for salmon spawning and contribute to aquatic ecosystem health (Everest 1973; Erman and Hawthorne 1976). In many instances, salmon act as keystone species, and, by their presence, absence, or trends in abundance, they provide an indication of the overall health of a watershed (Cederholm et al. 2001). Salmon presence, absence, or trends in abundance may also indicate the condition of specific components of watershed health, such as water quality, quantity, or temperature.

Dunham et al. (2001) state that redd counts are less intrusive and expensive than tagging, trapping, underwater observation, weirs, and genetics for inventorying bull trout populations, and that with limited resources, more populations can be inventoried over a longer period. Counting redds can be done with relative ease, and the counts may serve as an index of adult spawning escapement (Beland 1996; Dauble and Watson 1997; Rieman and Myers 1997; Maxell 1999; Muhlfeld et al. 2006). If a fishery manager could estimate the level of adults returning to spawn, as measured by redd counts, and identify areas where egg deposition was not apparent in otherwise suitable habitat (i.e., under-seeded), the opportunities for improving management targets would be greatly enhanced (Beland 1996). Redd counts coupled with information on population age structure can be used to calculate population growth rate (e.g., number of recruits per spawner) and examine metapopulation dynamics (Isaak and Thurow 2006).

Despite the potential effects of counting errors and species (and life history type) differences in contributions to redd abundances, redd counts have been shown to be significantly related to independent estimates of escapement for a number of salmon species. Redd counts for Atlantic salmon have been shown to be positively correlated with the numbers of adult spawners (Hay 1984; Heggberget et al. 1986; Madden et al. 1993; Semple et al. 1994; Beland 1996). Similar relationships between adult abundance and redd counts have been shown for brown trout *Salmo trutta* and brook trout *Salvelinus fontinalis* in North America (Benson 1953; Beard and Carline 1991) and brown trout in New Zealand (Hobbs 1937). Gallagher and Gallagher (2005) found significant relationships between chinook and coho salmon *O. kisutch* and steelhead redd counts and independent escapement estimates. Steelhead redd counts and females released above a counting structure on Snow Creek, Oregon were significantly positively related (Susac and Jacobs 2002). On the Columbia River from 1964 to 1992, chinook salmon escapement over McNary Dam was significantly positively correlated with redd counts (Dauble and Watson 1997). Bull trout escapement was significantly related to redd counts in Idaho (Dunham et al. 2001), and expanded redd counts and mark–recapture estimates were found to be similar among basins in Oregon (Al-Chokhachy et al. 2005). These studies support the notion that redd counts serve as reasonable indices of salmon escapement. It should be noted that, while most of the above studies tried to ensure the best redd counts possible, few applied measures to reduce counting errors or address observer efficiency. Nonetheless, significant relationships between redd counts and escapement were observed in these studies. This suggests that, while reducing errors in redd counts should be part of any monitoring plan, it may not be fundamental to establishing basic relationships between redd counts and escapement.

Objectives

The objectives of employing redd count surveys for salmonids are to

1) index temporal abundance of spawners;
2) estimate total abundance of spawning females or, when other data is available (e.g., carcass surveys), the total spawning population;
3) determine spatial spawning distribution; and
4) determine temporal spawning distribution.

Tasks necessary to achieving these objectives under this protocol include

- accurately counting spawning salmon redds by species;
- determining redd life (i.e., longevity of redds);
- consistently measuring redd sizes and dimensions (1) for species identification, (2) to compare redds made by hatchery and natural-origin fish, and (3) to distinguish redd characteristics of resident and migratory forms that spawn at similar times and places (e.g., *O. mykiss*).

Accurate estimates of the number of adult fish escaping harvest (escapement) to spawn are essential for effective management and conservation of salmonids (Busby et al. 1996; McElhany et al. 2000; Chilcote 2001). Trends in the reproductive portion of a population are often the most important characteristic for species recovery and conservation (Al-Chokhachy et al. 2005).

The validity of redd counts for population monitoring depends on two critical assumptions: (1) redds are counted with minimal error (no double, over-, or undercounting errors), and (2) redd numbers reflect population status (Dunham et al. 2001).

Redd counts can be used to estimate the number of female spawners in a given year by assuming one redd per female or by multiplying redd counts by a constant such as 1.2 to account for multiple redds per female (Duffy 2005). Redd counts have also been used to estimate total escapement by multiplying redd counts by estimates of the number of fish per redd (Al-Chokhachy et al. 2005; Gallagher 2005a) or by using redd areas and estimates of the female-to-male ratio (Gallagher and Gallagher 2005).

Redd counts, assuming that counting errors are sufficiently reduced, are usually employed because they provide a cost-effective index of adult salmon abundance useful for population monitoring and trend detection (Schwartzberg and Roger 1986; Rieman and Myers 1997; Maxell 1999; Isaak et al. 2003). The accuracy and precision of any salmonid population monitoring technique should be critically evaluated (Al-Chokhachy et al. 2005) and, if employing redd surveys, should include a pilot study to evaluate bias in redd counts for population monitoring prior to initiating a large-scale, long-term program.

Sampling Design

Redd counts for population monitoring should be conducted following a sampling design appropriate for estimating annual abundance and population trends for the species of interest. The spatial scale of such a monitoring program might range from the reach level to the watershed or regional level. The geographic scale of the monitoring program will influence sampling scheme selection. Isaak and Thurow (2006) suggest that conducting redd counts with a spatially continuous, temporally replicated sampling design will reduce errors associated with simple random designs and provide more accurate ecosystem views. Rotating panel designs (Firman and Jacobs 1999) incorporate the need for high precision in annual estimates of abundance at a broad spatial scale with the need for a large number of repeat visits necessary for trend detection (Boydstun and McDonald 2005). In coastal Oregon, salmonids are monitored by spawning ground surveys where 10% of all habitats are surveyed annually. For redd counts in Oregon, individual stream reaches are selected using generalized random tessellation stratified sampling (GRTS), a type of spatially balanced rotating panel design (Stevens 2002). This approach has recently been proposed for monitoring California's coastal salmonids (Boydstun and McDonald 2005).

When conducting redd counts, counts in nonrandomly selected index areas should not be used. Index areas may not represent population dynamics of salmonids at a regional scale (Rieman and McIntire 1996) and may miss redds due to annual variation in spatial distributions or spawning activity (Maxell 1999; Dunham et al. 2001). Lack of randomization in site selection and shifts in fish distribution may bias results from index site monitoring and mask population trends (Isaak and Thurow 2006).

A complete census requires that all stream reaches known to support the fish species of interest be surveyed for redds. If financially and logistically feasible, a census gives the best information for total redds (and female spawners), including spatial and temporal parameters. Care must be taken to ensure that all possible spawning areas are surveyed. Although the variance of the total redd estimate is zero, appropriately, it does not mean that the true number of redds is known. Krebs (1989) wrote that total counts are often of dubious reliability. This can be due to factors that prevent surveyors from seeing redds, overlapped redds counted as single redds, counting natural scour features as redds, and not including all spawning areas within the survey. However, these same factors operate identically in any statistically designed sampling program and are not included in their variance estimates. A census design should include explicit subdividing of the stream network so that the quality of the data can be described (such as clustering of redds). If possible, mapping each redd or using a global positioning system (GPS) to record each redd position is most desirable. Annual redd counts from index site monitoring generally consist of only a single point estimate and often are simple counts of visible redds. Such counts have no estimate of the associated statistical uncertainty (Maxell 1999) because they have not been randomly selected.

In many or most situations financial and logistic constraints force a sample design to be the best method of estimating total redds. Gallagher and Gallagher (2005) used a stratified index approach to estimate escapement from redd counts for several coastal rivers and streams in California. Their stratified random approach (Irvine et al. 1992) provided redd counts with associated statistical uncertainty for individual streams. This variance is the uncertainty of a sample expanded to nonsampled areas, not the uncertainty inherent in counting redds themselves. Other targeted research is needed to quantify the biases that cause redd counts to deviate from the truth. Random systematic and adaptive sampling designs should also be considered for redd surveys because of redd clustering. These should be compatible with a GRTS design. A stratified index approach, as well as large-scale regional approaches (Firman and Jacobs 1999), requires that the entire extent of spawning habitat within the sampling universe is known or established. The stratified index estimates employed by Gallagher and Gallagher (2005) were a specialized form of block sampling where the stream segments were blocks and the entire length of spawning habitat in a stream was the census zone. The mean and variance around redd density was calculated from the blocks and multiplied by the length of the census zone to estimate escapement for each stream. This approach can be used for estimating redd abundance in cases where the area of interest is a stream reach or a tributary and is fundamentally the same approach used in rotating panels designs (Boydstun and McDonald 2005).

The choice of the physical method used for counting redds will influence the sample design for redd counts surveys, site selection, sampling frequency, field and laboratory methods, and equipment needs. For smaller streams with reasonable accessibility, walking upstream and marking and counting redds is common (Gallagher and Gallagher 2005; ODFW 2005). For larger or more remote streams, rafting or aerial surveys by fixed-wing aircraft or helicopters can be used (Dauble and Watson 1997; ODFW 2005). The accuracy of aerial surveys may differ from walking surveys (Jones et al. 1998) and boat surveys. In some cases, a combination of methods may be used (Gallagher and Gallagher 2005; Isaak and Thurow 2006). In streams where spawning occurs in deep water, SCUBA diving or underwater cameras may be used to count redds (M. Gard, U.S. Fish and Wildlife Service, Sacramento, California, personal communication).

Survey designs and evaluation of bias in redd counts will likely vary depending on the field counting method. In instances where aerial surveys are used, it may be possible to calibrate observers by comparing repeat counts from multiple individuals, by using computer simulation (Jones et al. 1998), or from aerial photography (Neilson and Geen 1981). Bias in redd counts should be examined, reduced, and reported regardless of the physical method of counting and especially if counts are made from more than one field method.

Site Selection

Prior to selecting sampling sites, the study objectives, the size or distribution of the target population and the indicators that will be measured must be defined. Generally, a project area is defined in terms of the geographic range of a fish population, stock, or, in the case of threatened and endangered species monitoring in the United States, by evolutionarily significant units (ESU). If the objective is to obtain a complete census of the spawning population, stock, or ESU, then it is important to determine the distribution of the target population. In the case of redd counts for population monitoring, this would entail establishing the upstream and downstream limits of spawning habitat within streams in the study area. Criteria used for defining the population distribution must be clearly articulated (e.g., upper extent is < 20% gradient maintained for 100 m, gravel composition < 20% fines, water temperature < 20°C). Modeling approaches using combinations of geology, rainfall, land use, and other variables may be useful in delineating the extent of spawning habitat within a sample universe (Steel et al. 2004; Agrawal et al. 2005). Consultation with persons knowledgeable about areas within the sampling area or review of documents in agency or academic files may also assist with defining the spawning habitat in a sampling universe. A Delphi-type assessment might be employed to develop a rough cut at the extent of spawning habitat in the study area and then refined by field reconnaissance or as part of a pilot study. To determine the entire length of spawning habitat in streams where the extent of spawning habitat is not known, it should be determined by surveying the entire area of suspected habitat during the first year with foot survey efforts continuing for about 1 km above the last redd observed or to assumed barriers. In Figure 4 we offer an example map showing a stream with multiple sample reaches. Included on the map are the stream name (i.e., Pudding Creek), segment/reach name, stream segment number (under the GRTS sampling scheme), and locations of reach breaks.

Typically, sampling sites within a study area are selected probabilistically to reduce bias (Firman and Jacobs 1999; Stevens 2002; Boydstun and McDonald 2005). It is important to select a method or combination of methods that increases the degree to which the selected sample represents the population. The Oregon Department of Fish and Wildlife uses the Environmental Protection Agency's Environmental Monitoring and Assessment Program to draw a spatially balanced sample from the universe of all possible spawning habitat in its study area (Firman and Jacobs 1999). Boydstun and McDonald (2005) suggest an annual draw of 10% of all 3–5 km reaches in the sampling universe as the target goal for monitoring California's coastal salmonids; to account for access problems and other barriers to sampling, they suggest that the initial sample draw should over select reaches (sampling rate of 25%) to provide flexibility in the field. Some physical characteristics of the study area, such as snow melt–driven versus rainfall–driven systems, dams, or water diversions, and the life histories of species of interest may influence the sampling scheme and sample draws.

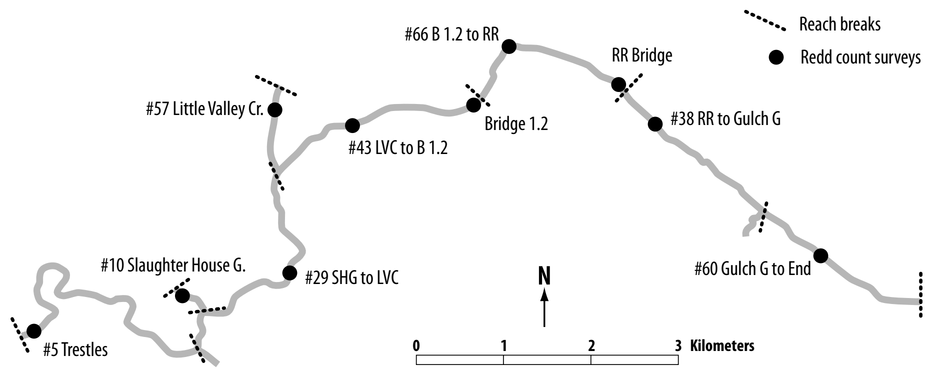

FIGURE 4. — Reach map for redd count surveys in Pudding Creek, California. Stream reach numbers reflect sample order under the generalized random tessellation stratified sampling (GRTS) scheme. (Note: Reach breaks are based on tributaries and other landscape features.)(Illustration: Andrew Fuller.)

Sampling Frequency

Redd counts for population monitoring should include a sampling design that is appropriate to the species of interest, should have sufficient replication for describing uncertainty, should have an established level of acceptable error, and should be conducted less than 14 d apart throughout the spawning run (ODFW 2004; Gallagher and Gallagher 2005). Surveys should begin prior to the onset of spawning of the species of interest and continue at least biweekly until spawning is complete. Redd count surveys should include marking newly made redds and recounting marked redds to estimate observer efficiency and reduce counting errors. If there is overlap in spawning among species, experiments and techniques should be established to differentiate between redd species. In some cases, and for some species, the duration of spawning may be short enough that one count at the end of spawning season can be used for an annual index, assuming that redds are not obscured by age, bedload movement, or scour, and therefore missed. In these instances, a pilot study should be conducted to determine if short duration of spawning activity exists and to examine potential bias in counts from one visit at the end of spawning. Muhlfeld et al. (2006) used statistical models of the error structure in redd counts to estimate observer efficiency for redd counts conducted once at the end of the spawning season. A redd count survey for such species, with timing of surveys dependent on some physical predictor of the onset of spawning, might employ the peak count method (Parken et al. 2003) to estimate redd abundance.

Error Rates and Reducing Observational Error

Counting errors may arise from redd species misidentification (Gallagher and Gallagher 2005), variation in habitat and redd characteristics (cover complexity, water depth and visibility, substrate composition, redd size, redd age, superimposition, or density), and if redds are obscured by periphyton or high discharge, spawning occurs outside the survey period, and spawning shifts from monitored to unmonitored reaches (Maxell 1999; Dunham et al. 2001). Redd counting errors may also occur due to variation in an individual observer's experience, training, energy, and enthusiasm (Dunham et al. 2001; Muhlfeld et al. 2006). Thus, counting errors may obscure important population trends (Beland 1996) and should be reduced to improve the power of redd counts for trend detection (Maxell 1999; Dunham et al. 2001).

The use of redd counts for population monitoring may be further complicated if female salmonids make more than one redd (Reingold 1965; Crisp and Carling 1989; Gallagher and Gallagher 2005; Kuligowski et al. 2005). The presence of "test" redds or false redds that are abandoned before eggs are deposited (Crisp and Carling 1989) may artificially inflate redd counts relative to escapement. The contributions of different life history forms of a species to redd abundance may influence redd count escapement relationships (Zimmerman and Reeves 2000, Al-Chokhachy et al. 2005). Overlap in spawning time and location among sympatric species (Fukushima and Smoker 1998; Geist et al. 2002; Gallagher and Gallagher 2005) may also confound redd count escapement relationships. An uneven sex ratio in the population of interest can complicate the use of redd counts for population monitoring.

A number of approaches for reducing redd counting errors due to species misidentification have been developed. Gallagher and Gallagher (2005) used logistic regression analysis to discriminate between chinook salmon, coho salmon, and steelhead redds in California and found that redd size (calculated from pot and tail spill measurements) and date were significant in predicting species. This approach reduced observer error in species identification from an average of 16% to 3.4%. In Alaska, sympatric sockeye salmon *O. nerka* and pink salmon *O. gorbusha* nests were classified by Fukushima and Smoker (1998) using discrimination analysis of depth, velocity, and stream gradient; however, their discrimination analysis misclassified more than 33% of the redds of these two species. Differences in chum and chinook salmon redd site selection within the same side channel of the Columbia River were attributed to differences in upwelling and downwelling of water in the hyporheic zone (Geist et al. 2002) and factors such as these might be important in differentiating redd species. Zimmerman and Reeves (2000) used stepwise discrimination to differentiate between redds of resident and anadromous steelhead, which correctly classified more than 64% of redds. Al-Chokhachy et al. (2005) attributed discrepancies between expanded redd counts and mark–recapture escapement estimates of bull trout to different contributions of migratory and resident forms, but they did not classify redds by life history type. Monitoring programs employing redd counts in systems in which sympatric species or different life history forms overlap should employ methods to reduce error in redd species identification. This should be examined in a pilot study as part of the development of a monitoring program.

Researchers have recently provided information relating to factors associated with errors in redd counts and improvements in survey design and data analysis methodologies that reduce counting errors in redd surveys. Dunham et al. (2001) did not find any relationship between habitat characteristics or observer experience level and redd count errors for bull trout redd counts in Idaho. They found that errors of both omission and misidentification were common among observers and that these errors tended to cancel each other out; furthermore, the researchers suggested that redd counts would be improved by better training of observers and use of more experienced personnel. Muhlfeld et al. (2006) also found that omission and false positive errors tended to cancel each other. They wrote that redd detection probabilities were high among observers, experienced observers made fewer mistakes, and redd counts can be used to accurately monitor bull trout populations. Muhlfeld et al. (2006) used models of observer error structure in redd counts to correct historic redd counts and thus improved their utility for population monitoring. Gallagher and Gallagher (2005) evaluated some of the bias in salmon and steelhead redd counts in California due to errors in redd species identification, detection of redds, and duration under variable survey conditions. They were able to reduce counting errors and produce reliable and precise redd counts by surveying biweekly, statistically differentiating redd species, uniquely marking redds and recounting all marked redds, calculating observer efficiency as the average of the percentage of known redds observed during each survey, having observers work in pairs, providing a "test" category for incomplete or questionable redds, and providing field and laboratory training. Gallagher and Gallagher (2005) presented models for predicting observer efficiency in redd counts from measurements of streamflow and water visibility. Monitoring programs using redd count surveys should investigate observer efficiency relative to the specific goals of the program and employ methodologies to reduce or eliminate errors in redd counts. This should include field and laboratory training of all observers, use of experienced observers whenever possible, pairing experienced and inexperienced observers, and providing specific written protocols to survey teams.

Field/Office Methods

Field season preparations

Depending on the species of interest, the geographic extent of the survey, and the desired precision in the data, the field season preparations for a redd count survey may require a few weeks or many months. In the case of a large-scale rotating panel survey design, defining the species of interest, the project goals and objectives, the sampling universe, and stream reach areas, creating a data matrix and conducting the sample draw, and identifying selected reaches on the ground might take several years. This process would likely need to include defining the extent of spawning habitat and access points, acquiring landowner permissions and necessary permits, and defining data flow and field survey logistics. Including issues such as the need to define the roles and responsibilities of the various entities involved, data needs, reporting requirements, and specialized permitting and compliance issues with endangered or threatened species or state collecting permits could further prolong field season preparations. A good example of the complexities and field season preparation needs for redd count surveys is the Oregon Plan experience (<www.oregon-plan.org>). Preparation of the ODFW (2005) Coastal Salmon Spawning Survey Procedures Manual drew upon the decades of cumulative experience of many individuals and took a number of months to complete.

Prior to the start of sampling, the species of interest, geographic extent of the survey, and specifics of the data to be collected in relation to the desired precision of the results should be defined. In general, preseason preparation includes defining and selecting sampling reaches, identifying access points, acquiring landowner permission, developing survey maps and data forms, developing a survey schedule, preparing databases for data storage, identifying personnel and equipment needs, hiring and training survey crew members, and purchasing necessary equipment. Locating and setting up housing for remote area crews might also occur as part of preseason preparations. Holding coordination meetings, if necessary, with other entities involved in conducting redd count surveys within the study area should be done prior to the field season. Training of field crews prior to survey start should also occur as part of the preseason activities.

Events sequence during field season

We recommend weekly to biweekly surveys in a rotating panel or stratified random design beginning prior to the onset of spawning of the species of interest and continuing until spawning is complete. Further, we recommend that surveys be combined with marking newly made redds and recounting marked redds, estimation of observer efficiency, and reduction of counting errors. Crews should work in pairs for safety and have communication devices in case of emergency. Walking upstream, crews can generally cover about 3 to 5 km in a day, depending on redd density and stream complexity. Floating downstream in rafts or kayaks, crews can cover 8 to 10 km per day, depending on redd density, stream size, side channel complexity, and logistics of access points. Surveying by aircraft can increase the area covered in a day, but this type of survey is affected by stream topography and vegetation and limited to midday periods when sun reflection glare is low and visibility is good. The sequence of surveys should be such that all reaches are resurveyed less than 14 d apart. With multiple crews, large geographic areas, and stream flow or visibility limitations, the logistics of daily survey schedules can be quite complicated.

On each survey, surveyors will look for new and old redds and record information for flagged and newly created redds. Before crews depart for the day, they should check to see they have all the necessary field and safety equipment, maps, and data forms and know which reaches are being surveyed by which crew. The destination reaches, crew members, satellite phone number, vehicle(s) taken, and estimated completion time for each crew should be recorded on a checkout board each day.

Measurement details

Measurements taken during redd count surveys will depend on the species of interest, study design, required precision of the data, presence of more than one species or life history form, and the overall goal(s) of the monitoring program. Sufficient data should be collected to meet the primary criteria of establishing the validity of redd counts for population monitoring; these criteria are (1) redds are counted with minimal error (no double, over-, or undercounting errors), and (2) redd numbers reflect population status. This second criterion will require independent escapement estimation or will have to be accepted as true based on prior study or on other publications of redd population relationships. In the field, data should be entered on prepared forms (using write-in-the-rain paper) or into preprogrammed handheld computers.

The date, climatic conditions, stream name and reach identifier, surveyors, streamflow, and water visibility (quantified as the maximum depth the stream substrate is visible) should be recorded for each survey. All redds observed should be counted, measured (only if redd is completed), and uniquely marked with labeled flagging tied to the nearest solid object directly upstream of the pot to avoid double counting. All newly constructed redds observed should be identified to species, treated as unknown, or denoted as "test" (i.e., redds that appear incomplete to observers) or under construction; they then should be marked with flagging and counted during each visit. Test redds and redds under construction should be reexamined on consecutive surveys and reclassified appropriately based on their apparent completion.

During redd count surveys, individual redds should be counted, marked, and uniquely labeled on data forms and in the field to avoid double counting and to allow estimation of observer efficiency (Gallagher and Gallagher 2005). At a minimum, the date each redd was first observed, fish species, unique identifier number, and location should be recorded on the data form. Redds can be marked in the field by tying survey flagging securely to the nearest solid object near or above each redd. For each redd, the unique identification number, date first observed, location relative to the flag (distance and compass direction), and species should be recorded on the flag and on the data form. Redd locations should also be marked on topographic maps or otherwise georeferenced. It is important to keep track of redds on which fish are still active and redds that do not appear to be completed. In these cases, redds should be reexamined on the next survey. An indication that a redd should be reexamined should be added to the flag for that redd and noted on the data form so that its date of completion can be established. In some instances, redds identified in the field as not yet complete at the time of first observation are actually either "test" redds or stream features that are not actually redds. By keeping track of them in the data, it is possible to remove them from the final redd counts at the end of the season and thus reduce this source of overcounting error.

Knowledge about redd size (including shape, substrate, position in river, and size of river) is most useful to spawner survey staff while assigning redds to species. Spawning time for each species is also critical. For differentiating redd species, examining fish length and redd relationships (Crisp and Carling 1989), determining fish life residence times, and reporting known species redd sizes, it may be necessary to keep track of redds on which known species of fish were observed.

Filling Out Data Forms in the Field

We offer the following as guidance for filling out data forms in the field; readers may have additional redd data needs beyond those noted here.

Header of Data Form

Fill in redd and fish data forms header information for each survey even if nothing is observed (see Appendix A for blank and example data forms); if needed, use extra space for detailed notes on the back of the data form. Use the stream name, segment or reach name, reach number, and map number from the map of the segment you are surveying. If you are surveying a stream that has multiple reaches (reach numbers), use a new data form for each segment and write the section number in the section space in the data form header, even if no redds are observed. It is very important to keep the data for each reach separate and identify the reach each redd came from. For surveys in streams with multiple reaches, redds at the lower end of the section that are on the boundary line are not counted; those at the upper end of the section that are on the boundary line are counted. Record the date of the survey. If a survey section takes more than 1 day, note the date of the second day in the notes. The week number is the survey week; the first survey of the season is week 1. Write the names of the people doing the survey in the surveyor's space. The map number is shown on the header information on the map page for each reach and is the same as the reach number; record that number here. Record the reach ID number in the appropriate space (this is the GRTS sample number). Record the air and water temperature in centigrade. Estimate the water visibility in meters with the survey rod as the visible depth to the stream substrate on every survey. Estimate the stream flow at the downstream end of each survey section on every survey and record the stage from the stage gauge, if present. A quick way to estimate the stream flow is to:

(1) measure the wetted width of the channel perpendicular to the flow (in meters) in a run area that lacks surface turbulence, under cut banks, and overhanging vegetation;

(2) measure the depth of the water (in meters) across the channel at three or four points and average these;

(3) multiply the width by the average depth;

(4) hold the wading staff parallel to the stream flow just above the water surface so that you have 1 m in view, drop a leaf at the top end of the 1-m mark on the wading staff while using the second hand of a watch or counting one-one thousand, and so forth, to estimate how long it takes the leaf to float 1 m;

(5) divide the number of seconds it took the leaf to float one meter by the result from step 3 above, which results in flow in cubic meters per second.

Record the drive time as the total drive time to and from the survey site. Record the start and end time of the survey as the time from leaving the vehicle until returning to it. Record the current weather conditions (e.g., sunny and cold, light wind). Note conditions of importance such as landslides, road conditions, or changes in stream visibility.

Redd Data

Record Number

Each redd and fish gets an unique individual record number. The record number is a seven-digit numeric code based on survey date that is linked to the stream and reach information in the header information. The first two numbers are the month (01 would be January and November would be 11). The second two numbers are the day of the month such that the second of the month would be 02 and the 15th would be 15. The following three numbers range from 001 to 999 and each redd and fish gets a consecutively higher number each day. For example, if you see a fish on a redd during a survey of reach 12 in the XYZ River on February 15, the redd number would be 0115001 and the fish number would be 0115002. Write the record number for each redd on the flagging (see Figure 5) and on the data form (see Appendix A). This number should be recorded on the maps and data forms (see Figure 6) for each redd observed.

1 ONMY REDD 0115001 CDFG 2003
Length = 2.4 Width = 1.4 Re-measure
Age 1

FIGURE 5. — Example of properly labeled flagging for a salmonid redd.

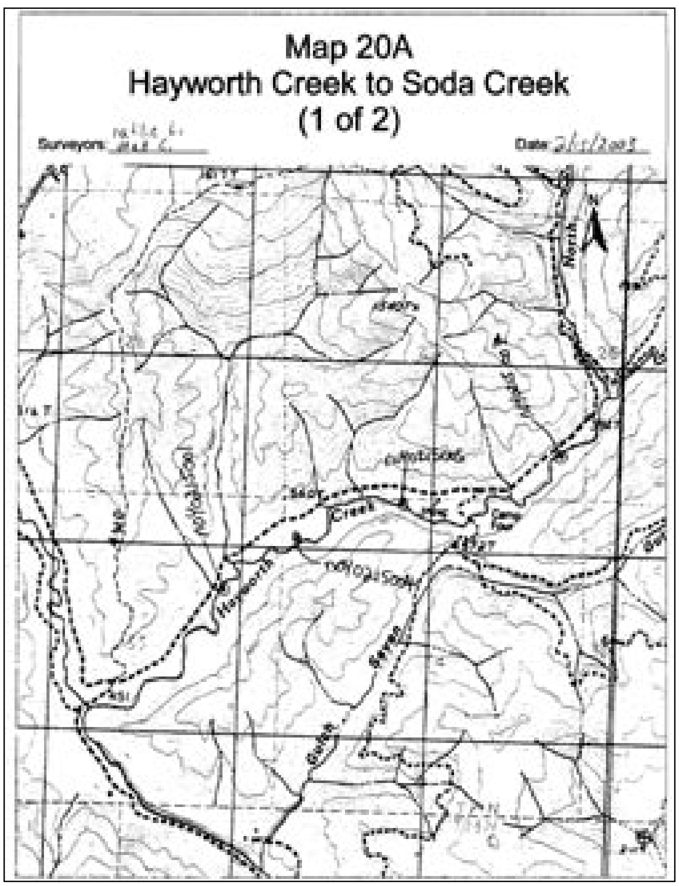

FIGURE 6. — Example of properly filled out map survey page with redd locations and record numbers tied to salmonid redd data form.

Species

Visually identify the species of each redd to the best of your abilities. Use the species code on the data form for fish and redds. Record this on the data form and on the flagging. If a redd is under construction and a fish is on the redd and you clearly identify it, use the species code—the first two letters of the genus and species of the study organisms (Onmy, Onki, Onts, Latr = Pacific lamprey, or Unkn for unknown)—record all data, and write "Remeasure" in the notes and on the flag. If the redd is classified as test or under construction (Fish on = yes), write this on the flagging and record the total length and width (sum of the pot and tail spill length and the maximum width) on the flagging with the word "remeasure". If you come across a flag with that instruction on it, remeasure it. If it is now clearly one species or another, use the species code with the previously used record number on the data form and record all appropriate data on the data form. If it has not changed, do not remeasure it. Do note the redd age (see Redd Age). If you remeasure a test redd and reclassify it, cross out the words "test" and "remeasure" on the flagging and write the species and date on the flag. Leave the original record number on the flag.

Fish on Redd

If you observe a fish on a redd (record "yes"), do your best to identify it to species. If there is not a fish on a redd, write "no".

Redd Age

To determine how long we are able to observe redds and estimate our ability to count all redds present (Gallagher and Gallagher 2005), estimate the redd age and record if and when it was previously measured. Record the redd age as

1 = new since last survey but still clear,

2 = still measurable but already measured,

3 = no longer measurable but still apparent,

4 = no redd apparent, only a flag, and

5 = poor conditions; cannot determine if present and measurable or not.

Note that all redds that have not previously been encountered (no flag present) are by definition age 1; if you come across an unflagged redd, it is age 1; if it looks older, write this in the notes column. On a subsequent survey, when a redd is no longer apparent and the flag is still there, record a 4 in this column and write 4 and circle it on the flag. Note that you did this in the notes. During surveys, when you find a redd flag with a circled 4 on it, just keep on going; there is no need to record any further information about this redd. If, however, a new redd has been constructed in this spot, do note the presence of the flag with a 4 on it in the notes and record all information for this new redd.

Remeasured?

This is a yes or no column. Yes if remeasured, no if not.

Distance to Flag

This is the distance in meters from the middle of the redds' tail spill to the flag that identifies this redd. Flagging must be tied to a solid object (see Figure 7). Record the distance from the tail spill to the flag in this column. Write this information on the flag as well.

Direction to Redd
This is the compass direction from the flag to the middle of the tail spill. Record this information in this column and on the flag (see Figure 5).

FIGURE 7. — Coho salmon on a flagged redd.

Notes
Record if the redd is irregularly shaped (not a circle, ellipsis, oval, square, or rhomboid) or if you suspect superimposition. What shape is it? Record the part of the stream where the redd is located (e.g., in the middle, on the side or edge, above or under a log.). Record other pertinent information. Use the back of the page with the record number followed by any additional information.

Page___ of___
The redd data form is page 1 to *n*, depending on how many redd data forms are used for each survey. If there are no redds, do not include the maps; otherwise, the map pages are the next numbers consecutively following the redd data page numbers. Fill out the entire data form for each survey, even if nothing is observed. Staple the sheets together and file them appropriately when you return to the office at the end of the day.

Flagging
For all redds, write the record number, species code, distance flag to redd, direction flag to mid tail spill, year, and redd age on the flag (see Figure 5). Tie the flag securely to the closest solid object directly above and perpendicular to the pot of the redd (see Figure 7). Do not step or walk on redds. Preferably, tie the flag so that it hangs right over the middle of the tail spill. Measure the distance from the middle of the tail spill to the flag location and write this distance on the flag and in the proper column on the data form. Measure the compass angle from the flag to the middle of the tail spill and write this number on the flag and record it on the data form. If the redd is a test redd or under construction (fish on), write REMEASURE on the flagging and in the notes. Examine all flags during each survey (See Redd Age). If the redd was identified as test during previous surveys and it has changed (e.g., is now larger) or is now clearly a redd of one species of another,

record the record number from the flagging on the data form and re-measure the redd. Cross out the words "test" and "remeasure" on the flagging and write the redd species and date on the flag. Leave the record number unchanged. Record all appropriate data. Record the location of the redd on the map and label it with its redd number.

Mapping

Mark the location of all new redds on the field maps. Pay attention to stream and landform features such as left (as you are looking downstream) and right bank tributaries, notable river bends, and other features to keep track of your location so that when you find a redd you can place its location on the map. Draw a dot on the map and connect it with a line to a place on the map away from the stream where you can write the record number for the redd. Do this for all redds observed. If there were no redds or fish observed for a survey, there is no need to include the map in the data packet at the end of the day. Reuse this map on a future survey.

Back at the Office

Put data forms in order and make sure every thing is filled out properly. Staple the forms together and file in a proper spot. Do not leave data forms in the data box or lying about the office, unless the forms are wet and need to dry. Store all equipment in the proper place. All data should be entered into the data base at the end of each day.

Determination of Redd Life

The length of time redds remain visible during spawning ground surveys is termed "redd life" (Smith and Castle 1991). More specifically, redd life reflects the length of time from the postspawning phase to the point that it is no longer discernable (this is a period of days to weeks, depending on stream flow and periphyton accumulation). It is an important aspect in redd counts and has a fundamental bearing on subsequent counts, count expansions, and population estimates. Redd life is variable among species and streams and over years (see Table 1) it is strongly influenced by streamflow, turbidity, periphyton growth, and redd superimposition. In Table 1, we offer summaries of redd life estimates for six species of Pacific salmon. To assess redd longevity, redds should be classified as new, measurable, no longer measurable, or no longer apparent, and recorded on data forms for each redd observed on each survey. Redd longevity (necessary for establishing survey durations and for use with the area-under-the-curve [AUC] population estimates) and observer efficiency (useful for expanding redd counts to account for redds present but not counted during surveys) require that all flagged and newly constructed redds be examined during each survey and that data be recorded regarding redd condition, date first observed, and unique identifier. Use of regional averages developed over a series of years in the AUC, coupled with observer efficiency, may prove reliable for salmon escapement monitoring.

TABLE 1. — Redd life estimates for Pacific salmon. Estimates are from foot surveys unless otherwise noted. Numbers in parentheses are the range of the estimates. (NR = not reported, NA = not applicable.)

Species	Run	Redd Life in Days			Years	River	Location	Source	Comments
		Estimate	Standard error	N					
Chinook Salmon	Fall	~ 42	nr	nr	1948–1992	Columbia	Washington	Dauble and Watson (1997)	Redds visible from air six weeks
		21	nr	nr	nr	Skagit	Washington	Smith and Castle (1991)	
		16	4.4	4	2003	Noyo	California	S. Gallagher (unpublished)	
		(7-28)							
	Summer and fall	19.1	2.6	nr	1998–2001	Stillaguamish	Washington	P. Hann (unpublished)	Multiyear average
		18.5	0.4	nr	1999–2002	Green	Washington	P. Hann (unpublished)	Multiyear average aerial survey
	Spring	40	nr	nr	nr	Yakima	Washington	Schwatzber and Roger (1986)	
		17.4 (7.3–30.6)	2.5	nr	1998–2001	Suiattle	Washington	P. Hann (unpublished)	Multiyear average
Chum Salmon *	nr	up to 60	nr	nr	2003	Columbia	Washington	Dehart (2004)	
Coho Salmon	na	24.8 (6–36)	0.9	147	2004	Mendocino Coast Streams	California	S. Gallagher (unpublished)	
	na	22.8 (6–84)	2.08	87	2003	Mendocino Coast Streams	California	S. Gallagher (unpublished)	
	na	14.3–25	nr	na	1986–1990	Hoko	Washington	Lestelle and Weller (2002)	Range of means 3 reaches and 4 years
	na	6.4–32.9	nr	na	1986–1989	Skokomish	Washington	Lestelle and Weller (2002)	Range of means 4 reaches and 3 years
Pink salmon*	Fall	< 15	nr	nr	1992–1994	Lake Creek	Alaska	Fukushima and Smoker (1998)	Redd life influenced by stream flow ^
Sockeye salmon*	Fall	< 15	nr	nr	1992–1994	Lake Creek	Alaska	Fukushima and Smoker (1998)	
Steelhead	Winter	40.7 (7–92)	1.39	148	2000	Smith	Oregon	Jacobs et al. (2001)	
	Winter	27.8 (2–88)	2.08	87	2003	Noyo	California	S. Gallagher (unpublished)	
	Winter	20.4 (11–42)	1.59	46	2004	Mendocino Coast Streams	California	S. Gallagher (unpublished)	

* Redd counts may not be applicable for population monitoring of these species due to group spawning behavior and lack of distinct individual redds (J. Haynes, Washington State Department of Fish and Wildlife, pers. comm.).
^ M. Fukushima National Institute for Environmental Studies, Tsukuba, Japan, pers. comm.

Measuring the surface area of redds

While it is not necessary to measure redds for most escapement estimation surveys, in systems with multiple species of salmonids that overlap in spawn timing and area, measurements and other characteristics of redds can aid in determining which species created the redds in question. Redd dimensions are being gathered in some locations to evaluate if hatchery and natural-origin fish make different sizes and shapes of redds (T. Pearsons, personal communication). Other researchers may want to distinguish redds constructed by resident and anadromous forms (e.g., *O. mykiss*) that spawn at similar locations and times.

Redd measurements (consisting of area, substrate, and depth) (see Figures 7–10) can be made to calculate the surface area of each redd for differentiating species, and report redd size, and for using redd areas to estimate escapement

(Gallagher and Gallagher 2005). Pot length (measured parallel to stream flow), pot width (perpendicular to the length axis), and pot depth (the maximum depth of the excavation relative to the undisturbed stream bed) (see Figure 9) should be measured and data recorded. The dominant pot and tail spill substrate should be visually estimated (or otherwise quantified) using a Brusven index (Platts et al. 1983). Tail spill length (longitudinally parallel to stream flow) and tail spill width at one-third and two-thirds from the downstream edge of the pot to the end of the tail spill (perpendicular to the length axis) should be measured. Redd areas can be calculated using the sum of pot and tail spill areas, which can be calculated by treating the pot as a circle or ellipse and the tail spill as square, rectangle, or triangle.

There are other methods for estimating redd surface area, and the specific method used (and precision needed in the data) will depend on study design and goals or the presence of more than one species or life history type. Probably the most precise method in estimating redd surface area was developed by Burner (1951), who estimated redd surface area by creating scale drawings of each redd, measured the maximum width and total length, and used a planimeter to estimate surface area. Estimating redd surface areas by simply multiplying total length by maximum or average width overestimated redd area and was not useful in differentiating chinook and coho salmon and steelhead redds (S. Gallagher, unpublished data). Other habitat-related variables such as gradient, water depth and velocity, distance to cover, stream shade, or channel complexity might also be collected in association with redd counts to address specific questions identified during development of the study plan.

Specific methods for measuring areas of redds in the field

The purpose of measuring redds is to estimate the area of the redd accurately so that these data can be used to differentiate species and estimate escapement. The pot area and tail spill area are calculated from the field measurements, treating the pot as a circle or ellipse and the tail spill as a circle, square, triangle, or rectangle, depending on the individual measurements. In most cases, redds will not conform to this idealized shape, so it is therefore quite important to remember that the focus should be on calculating the total area of the redd.

Pot Dimensions

Pot length (PL) is the total length of the pot parallel to the stream flow in meters to the nearest decimeter (see Figure 8). Measure in meters from the top to bottom edge. When the pot is irregularly shaped, estimate the total length to the best of one's abilities. Record this information on the data form. Pot width (PW) is maximum width of the pot perpendicular to the stream flow or pot length in meters to the nearest decimeter. Measure in meters from one edge to the other. When the pot is irregularly shaped, do estimate the maximum width as best as possible. Record this on the data form (see Figure 9). Pot depth (PD) is the maximum depth of the excavation relative to the undisturbed streambed in meters to the nearest centimeter. Use the staff to measure the depth. Record this on the data form in meters. Pot substrate (PS) is the size of the dominant substrate in the pot. Visually estimate, using the staff gauge to calibrate one's eye, the size of the dominant substrate in the pot in centimeters. The substrate size is the length of the diameter of the smallest axis that will pass through a sieve, in centimeters. Record this on the data form.

Tail Spill Dimensions

Tail spill length (TsL) is the total length of the tail spill parallel to the stream flow in meters to the nearest decimeter. Measure from the top edge of the middle of the pot to bottom edge of the tail spill. When the tail spill is irregularly shaped, do the best to estimate the total length. Record this on the data form.

Tail spill width 1 (TSw1) is the maximum width of the tail spill perpendicular to the stream flow or pot length in meters to the nearest decimeter. Measure from one edge to the other third of the distance down from the top of the tail spill. When the tail spill is irregularly shaped, do the best to estimate the maximum width. Record this on the data form.

Tail spill width 2 (TSw2) is the maximum width of the tail spill perpendicular to the stream flow or pot length in meters to the nearest decimeter. Measure from one edge to the other two-thirds of the distance down from the top of the tail spill. When the tail spill is irregularly shaped, do the best to estimate the maximum width. Record this on the data form.

Tail spill substrate (TS) is the size of the dominant substrate in the tail spill in centimeters. Visually estimate, using the staff gauge to calibrate the eye, the size of the dominant substrate in the tail spill. The substrate size is the length of the diameter of the smallest axis that will pass through a sieve. Record this on the data form.

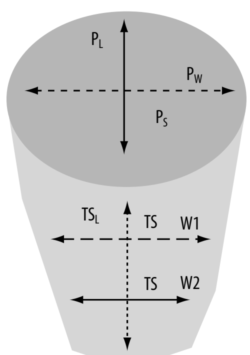

FIGURE 8. — General measurements for estimating surface area of a salmonid redd. P is pot; TS is tailspill; L is length; W is width; S is substrate (note location in mid-TS for substrate collection not denoted). (Illustration: Andrew Fuller.)

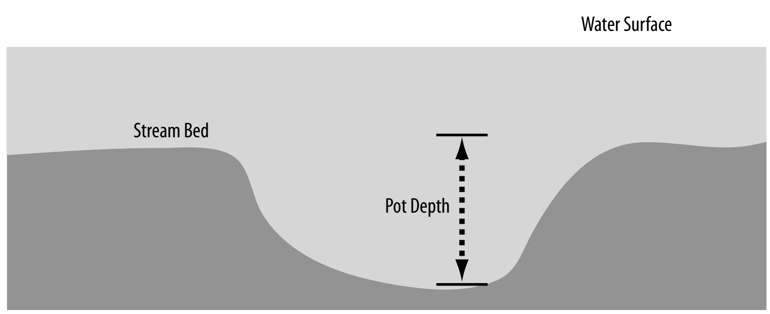

FIGURE 9. — Cross section of a salmonid redd pot. Pot depth is the distance from the bottom of the pot to the water surface minus the distance from the water surface to the streambed. (Illustration: Andrew Fuller.)

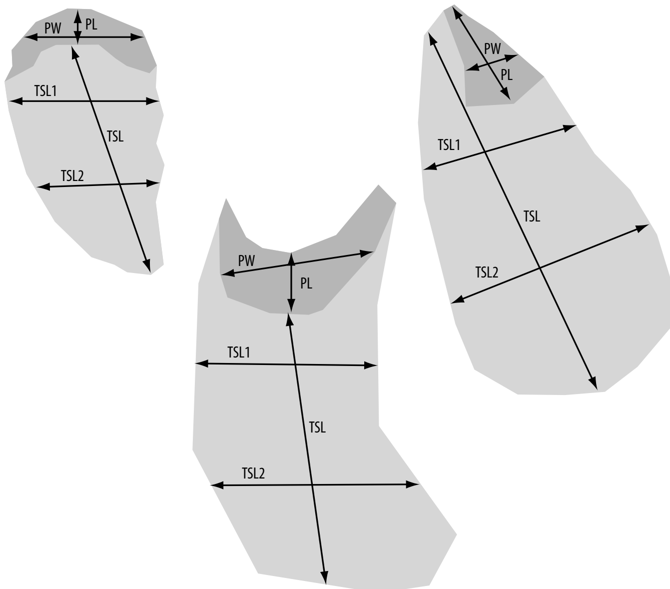

FIGURE 10. — Measurements for unusually shaped redds. (Illustration: Andrew Fuller.)

FIGURE 11. — Measuring a steelhead redd.

Data Handling, Analysis, and Reporting

Metadata procedures

Data common to all redd observations for each survey and survey reach should be linked with a one-to-many relationship to each individual redd observation (see Figure 12). These data should include the date, stream and section name, a unique stream reach identifier such as the latitude-longitude (LLID) number, survey number (1 is the first of the season), surveyors' names, climatic conditions, streamflow, water visibility, and so forth. The subject data discussed earlier could be included in separate data tables and have associated information connected by one-to-many relationships. For instance, the unique stream identifier table might contain the coordinates of the starting and stopping points for the stream reach, its name, general location, driving directions, and sample selection number. The stream section table might include the site description, land use, landowners' names(s) and contact information, and environmental descriptors.

Data specific to each redd would, by virtue of the one-to-many relationships above, contain all the above information needed to form a unique number. For instance, redd number 1 for each survey, coupled with the date the redd was first observed and a unique reach identifier, would serve as a unique number for each observation necessary to track redd longevity, and observer efficiency, and test redd counts. Other data fields specific to each redd should include redd species, fish presence, and specific redd data pertinent to the goals of the study. These fields might include information such as pot and tail spill measurements, substrate measurements, certainty of redd species identification, presence of fish, and general notes.

Quality assurance procedures for the metadata should include site verification, checking stream flow estimates against stream flow gauging stations (where available), and using paper records in conjunction with handheld computers. A series of queries should be designed to test if all redds were observed at least once, and to look for duplicate records and to sort individual redd observations by date to ensure that the date of the first observation exists in the database.

Data Fields

The following list below gives names and types of the data fields associated with redd survey and mapping efforts (adapted from Hahn et al. 1999), and is offered as a starting point for data sheets and database designs:

Field Name in Database	Print Field Name	Type	Size	Definition
River Name	River name			Name of river
River code	River code			
Species	Species			
ReddID	ReddID	I		Unique ID assigned by field biologists: • First 2–4 digits=river and section/reach code month+day when first observed • Next 4 digits=month+day when first observed (MMDD) • last 2–3 digitis=redd number within that section/reach on that date
Sid	Sid	S		Unique, sequential integer for digitizing & maps
Lat/Long	Lat/Long	N		Lat/Long location
ReddNum	RNum	A	2	Last 2 digits ReddID, # of redd found same date & in same river section/reach.
KM	KM	N		River km (or RM=River Mile)
Date1stOb	Date1stOb	D		Date when First Visible
Started	Started	S		Number days redd assumed started before FVDate (1st visible)
FVDate	FVDate	D		Date when judged First Visible (see rules)
FV.Julian	FV.Julian	I		Julian FV date
FV.DOY	FV.DOY	S		Integer day of year for FV date (1–365 —used in plotting by "date")
DateLastObs	DateLastObs	D		Date last observed
DateNotSeen	DateNotSeen	D		Next survey date when redd was no longer visible
LVDate	LVDate	D		Date when assumed Last Visible (see rules)
J.LVJulian	J.LVJulian	I		Julian LV date
SuprImp?	SI	A	1	Was the redd superimposed/overlapped? (Y=yes, P=partial, N=no, blank=unknown)

Field Name in Database	Print Field Name	Type	Size	Definition
SupSPP	SI-spp	A	2	Species which caused redd superimposition
RLife	RL	S		Redd life in days
FieldNote	FieldNote	A		Miscellaneous comments on summary sheets
ReddCat	Rcat	A	2	Code for redd category (A=active, S=start, C=complete...etc)
Comment	Comment	A	10	Comment during visibility assignment
DaysBetween	DaBtwn	S		Number of non-surveyed days between previous & current surveys
Page	Page	S		Page number in field notes
Observer	Obsvr	A	5	Initials of observer(s)

Database design

Figure 12 shows an example of database fields and relationships used for monitoring salmon escapement from spawning ground surveys in coastal California, following the methods of Gallagher and Gallagher (2005) and Gallagher and Knechtle (2005). In this layout, the *daily header* table is information that is included in the header portion of a data sheet, and the specifics for each individual observation are in the redd data and *fish on* tables (see Appendix A). The *fish on* table is for keeping track of fish on redds. The fields in the daily header table are self-explanatory, except for the *daily number* and *start/end mark*. The *daily number* is an automatic number the database uses as the primary key, and the *start/end mark* is for recording the beginning and ending location of the survey. In the redd data table, the first three fields are used to link handheld data recorders to the database. Handheld data recorders limit data transfer errors common when transcribing data from written field records to electronic databases. The *redd fish ID* is an automatic number for linking the *fish on* and redd data tables. The *redd record number* field is the unique number of each redd observation, and *rec date* is the date the redd was first observed. The *field stream marker* is the distance from the start of the reach to the location of the redd. The *fish on* table is the subform for tracking specific information regarding fish observed on redds. The first three data fields are similar to the redd subform, and the rest are self-explanatory. The *location* table is for information on specific reaches. The *field Loc ID* is the location code, the *LLID field* is the geographic coordinates of the starting point of each survey reach, and *HUC* (hydrologic unit code) is the hydrologic unit in which the reach is located.

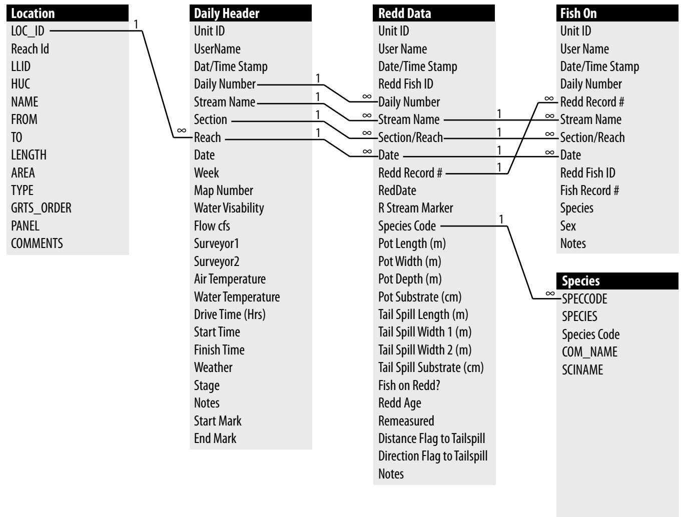

FIGURE 12. — Examples of database relationships for redd count surveys (modified with permission from database created by Dave Gibney, Institute for River Ecosystems, Humboldt State University, Arcata, California).

Data entry

Data should be entered from field data forms into a computer data system upon return to the office after each survey. All data entered from paper records into an electronic database should be rechecked for accuracy and corrected where necessary. A record of data entry errors should be kept and used to identify and alleviate common problems. If handheld data recorders are used, a paper backup should be made periodically in the field to check for errors. A series of queries should be designed to test if all redds were observed at least once, to look for duplicate records, and to sort individual redd observations by date to ensure that a date of first observation exists in the database. To reduce data entry errors, data fields can be given drop-down menus with limited choices such as yes or no, stream name lists, and species lists; some data fields can be set as required (e.g., numbers or text only, limits on decimal places, limits on descriptor length). All original data sheets or data files should be well organized, clearly labeled, and placed in an appropriate long-term storage location.

Data summaries

Gallagher and Gallagher (2005) used logistic regression to differentiate redd species using known redd data (i.e., known species of fish observed on a redd) to develop and check the predictive ability of their model. This technique may be useful in other situations where multiple species or life history forms overlap during spawning. The development of a method to differentiate redd species will likely require a pilot study to determine which, if any, variables might be useful in predicting redd species. Discrimination, principle components analysis, or other multivariate techniques may been useful for differentiating redd species (Fukushima and Smoker 1998; Zimmerman and Reeves 2000).

To assess redd longevity and observer efficiency, all flagged and newly constructed redds should be examined during each survey. To examine redd longevity, redds should be classified as new, measurable, no longer measurable, or no longer apparent. Weekly observer efficiency can be estimated as the percentage of known flagged redds (minus those classified as no longer apparent) observed during each survey (Gallagher and Gallagher 2005). Remember that the goal is to measure observer efficiency in seeing redds—not observer efficiency in seeing flagged redds. Weekly observer efficiency for each species is then averaged for each survey segment in each stream throughout the season to estimate total efficiency for the season (see Table 2). Observer efficiency calculated in this manner can then be used to expand redd counts to account for redds present but not observed. This expanded redd count number, taken along with the associated statistical uncertainty from replicate reaches (see sampling design, pages 203–208), can thereafter be expanded by the length of spawning habitat and presented as the annual redd index for the population of interest.

TABLE 2. — Example of observer efficiency estimate based on marked redds and expanded to account for redds present but not observed during redd surveys

Survey week	Number of redds observed				Observer efficiency			
	New redds	Previously counted	Removed	Known redds	Weekly	Average	Standard	Standard
1	0	0	0	0				
2	0	0	0	0				
3	5	0	0	0				
4	1	5	0	5	1.00	1.00		
5	2	6	0	6	1.00	1.00	0.00	0.00
6	2	6	0	8	0.75	0.92	0.14	0.07
7	1	6	0	10	0.60	0.84	0.14	0.06
8	6	7	0	11	0.64	0.80	0.20	0.08
9	4	7	1	17	0.41	0.73	0.19	0.07
10	6	8	2	20	0.40	0.69	0.25	0.09
11	0	8	0	24	0.33	0.64	0.26	0.09
Total count	27							
Season average	0.64							
Season SE	0.09							
Expanded count	37							
SE	2.43							

Observer efficiency can also be estimated by having several crews (of two people each) follow each other on one survey segment, with each crew recording newly constructed redds. Average field observer efficiency is then calculated by assuming that the largest number of redds observed by any one crew is the "known number," and the totals from each survey crew observing fewer redds can be divided by this number and then averaged. Another method to describe observer error compares "true" redd numbers established by an experienced observer counting redds periodically during the bull trout spawning season to single pass counts made by many observers at the end of the spawning season to model observer error structure and correct redd counts for observer bias (Muhlfeld et al. 2006).

Situations may arise when marking redds for estimating observer efficiency and avoiding double counts may not be practical. In these cases, redd numbers can be estimated from stream surveys using the area-under-the-curve method (Hilborn et al. 1999). This method employs periodic counts during the spawning season and calculates the AUC from the trapezoidal approximation, redd life, and estimates of observer efficiency. The trapezoidal approximation is calculated from the time, usually in days, between surveys and total redd counts on each survey. The trapezoidal approximation in units of redd/days is converted to AUC redd numbers by estimates of redd life (an estimate of the length of time redds remain visible in the stream). The resulting redd numbers are expanded to account for redds present but not counted using estimates of observer efficiency. This method requires that the length of time redds remain visible and observer efficiency estimates are known. Redd longevity is variable among streams (Susac and Jacobs 1999), may be variable among species (see Table 1), and will likely have to be estimated annually for individual streams. Estimates of observer efficiency require multiple passes by survey crews, marking and recounting redds, (Gallagher and Gallagher 2005), or estimates of "true" numbers from experienced observers (Dunham et al. 2001; Muhlfeld et al. 2006). One of the major shortcomings of the AUC is that it lacks a rigorous statistical method for calculating confidence bounds, which, when estimated, require intensive bootstrap computer simulation and independent mark–recapture estimates for their calculation (Korman et al. 2002; Parken et al. 2003).

Converting redd counts into escapement estimates

Number of redds per female

Specific data on the number of redds made by females is still needed. Detailed radio-telemetry efforts may be a useful approach to determine the number of redds a female salmonid constructs. Other options include getting detailed video recordings on the spawning activity of marked females, or by taking genetic samples from emerging fry as they leave the redd (captured via fry emergence traps). If the assumption of one redd per female can be validated, escapement estimates that assuming one redd per female can be made by multiplying the number of redds by the male-to-female ratio observed in each stream or river and summing this with the number of redds. Until the above research is conducted, interim estimates have been proposed. Duffy (2005) suggests multiplying redd counts by 1.2 to expand steelhead redd counts to female escapement. He further suggests that if the female-to-male ratio is known, it can be used to expand female estimates into total escapement. Generally, this approach will require independent escapement estimates to calculate the number of females per redd. There is little evidence to support or refute the idea that estimates of the number of females per redd is consistent among years or between streams. Studies requiring that redd numbers be converted to fish numbers in this manner should evaluate the transferability of this type of data.

Number of fish per redd

In Oregon, steelhead redd counts are significantly correlated with adult escapement, and an estimate of 1.54 females per redd was developed (Susac and Jacobs 2002). In Washington, redd counts are the principle method for monitoring salmonids, and cumulative redd counts are expanded by 2.5 fish per redd to estimate escapement (Boydstun and McDonald 2005). In California, Gallagher (2005b) found that the number of steelhead and coho salmon per redd differed slightly among streams and years, but the use of one value for all streams to convert redd counts to fish numbers for regional spawning ground surveys appeared reliable. Dunham et al. (2001) found considerable spatial and interannual variation in bull trout spawner-to-redd ratios and attributed it to either strong life history variation among populations or bias and imprecision in redd counts. Al-Chokhachy et al. (2005) estimated an average of 2.68 bull trout spawners per redd from a number of sources and attributed differences between redd counts and mark–recapture estimates to differences in life history forms.

Mark–recapture escapement estimates coupled with redd count surveys, in which the bias in redd counts following improvements to field and laboratory methods suggested in this document, should likely improve estimates of the number of fish per redd for expanding redd counts to escapement. Results of these types of experiments can be used to document redd count-escapement relationships and develop predictive models to estimate escapement from redd counts (Gallagher 2005b). The Bland-Altman method (Glantz 1997) is a useful statistical procedure for determining if two different measures of the same thing are significantly different and may be useful for assessing the transferability of redd counts to index escapement. The transferability of these types of estimates for converting redd abundance to escapement among years and streams needs further evaluation.

Redd area

Another approach to assessing escapement is through the measurement of redd sizes from known species (i.e., the redd area method). Further testing, based on radio-telemetry or other detailed observations of marked female fish, is needed to affirm or refute this approach. Differing water and substrate conditions or the size of the female are among the factors that can affect the size of the redds. Gallagher and Gallagher (2005) estimated salmon escapement using redd areas. Their redd area method assumes that the number of redds a female makes is related to the size of the redd. Coho salmon redd area escapement estimates were based on findings from releases above a counting structure, where it was estimated that females make between one and four redds. Here, redd areas greater than 5.1 m^2 represented one female, redds between 2.1 and 5.0 m^2 represented one-half a female, and redds less than 2.0 m^2 represented one-quarter of a female (Maahs and Gilleard 1993). Female coho redd area escapement estimates were multiplied by the male-per-female ratio observed in each stream and summed with female estimates to estimate total escapement. Observer efficiency estimates were then used to expand the redd area estimates as described earlier for redd counts.
To apply this method for estimating steelhead escapement from redd areas, Gallagher and Gallagher (2005) divided the area of the largest known steelhead redd observed over 2 years into quarters and estimated female numbers and escapement in the same manner as for coho salmon. The use of this method for other species will require documenting females making more than one redd and estimating redd surface areas.

Report format

Redd counts are a fundamentally important aspect in salmonid conservation and management, and consistency in the format of data and results will greatly aid our collective efforts. While we recognize slight variations in redd abundance survey reports (due to study plan, objectives, goals, audience, and species of interest), the overall report format should follow the "Introduction, Materials and Methods, Results, and Discussion" structure (Day 1988) and include sufficient details for evaluating the quality of the data for abundance and trend monitoring. The discussion section should include a section on recommendations for future monitoring based on evaluation of annual findings. At the very least, there should be tables of total redd counts, redd densities, observer efficiency, redd abundance, and associated statistical uncertainty for each survey reach and a total for the survey area. This table should also include reach segment lengths, total survey lengths, and total stream length in the sampling area. There should be a map of the survey area showing details of the survey sections and study area. If there is a multiyear data series, figures demonstrating trends with associated statistical evaluation of their significance should be presented. In the Methods section, details of all statistical analysis and hypotheses tested should be thoroughly documented.

Trend analysis

To examine a series of annual redd counts for evaluating population trends, the slope and intercept of the regression line must first be estimated . In some cases, it may be necessary to transform the data so that it fits the assumptions of normality or to use sophisticated multivariate models or nonparametric analysis; however, in general, the simplest method to examine time series data for trends is to use linear regression of adult abundance (e.g., redd counts) versus year to estimate the slope of the trend line. The slope of adult abundance versus year can be graphically examined and statistically tested to determine if it differs from zero (Glantz 1997).

Shea and Mangel (2001) presented models for coho salmon, suggesting that increasing time series and reducing observer uncertainty in juvenile estimates will improve statistical power for detecting trends (changes in long-term abundance) in adult populations from observations of juvenile abundance. To use redd counts for trend detection and population monitoring, Maxell (1999) recommended that errors in redd counts be identified and reduced, levels of significance that adequately balance the risks of committing type I and type II errors should be used, and one-tailed tests for identifying population declines should be used, especially during the first years of a monitoring program. Trend analyses should report the statistical power of tests for trend detection.

Archival procedures

All original data should be well organized, clearly labeled, and archived. Reports should be prepared annually and archived in the files of the primary agency in charge and sent to local or regional natural resource agency libraries. Digital versions of the data sets, as well as hardcopies of reports, should be submitted to international fisheries conservation organizations. Significant findings and new developments in monitoring techniques should be published in the primary literature.

Personnel Requirements and Training

Responsibilities

Redd count survey staff will be responsible for conducting redd counts per the field protocol and training manual. All survey staff will be expected to maintain complete survey field notes per the training manual or annual field protocol. In the field, experienced survey staff will train newly hired survey staff in redd counting techniques.

Qualifications

Redd survey staff should be in such physical shape as to allow for extended and at times strenuous hiking while carrying equipment and personal gear that may weigh 10 kg or more. Survey staff should expect to work extended daily hours as necessary. First-aid certification and swift water rescue training is required and should be provided by the employer during the preseason period. Education requirements for project leaders include a minimum undergraduate degree in fisheries management or related natural resource field or 2-year technical degree with a minimum of two seasons of experience in field survey techniques related to fish management.

Training

A field manual should be made available to all redd count survey staff to promote consistency among survey efforts and to address safety concerns. New hires should be scheduled to go on surveys with experienced redd survey staff and receive training in the field. Safety, aspects of landowner relations, trespassing regulations, and redd count protocol training for all survey crew members should be scheduled and conducted prior to initiating the field season. Safety training for field crews should include first aid, wilderness medicine, swift water rescue training, and wader safety training. Specialized training for using all-terrain vehicles, four-wheel drive vehicles, boats, or other equipment needed for conducting redd surveys should occur during the pre-field season period. Safety and data collection/equipment will require additional specialized training if aircraft, boats, or underwater video are used for redd count surveys. Redd count protocol training should include time for crew members to read and become familiar with the specifics of field procedures, redd identification, and data management.

Operational Requirements

Workload and field schedule

The field schedule should be developed so that all selected reaches can be surveyed less than 14 d apart (Gallagher and Gallagher 2005; ODFW 2005), with one survey occurring just prior to fish entering the stream and continuing until new redds and fish are no longer observed. Crews should work in pairs for safety and have communication devices in case of emergency. Walking upstream, crews can generally cover about 3–5 km in a day depending on redd density and stream complexity. Floating downstream in rafts or kayaks crews can cover 8–10 km per day, depending on redd density, stream size, side channel complexity, and logistics of access points. Surveying by aircraft can increase the area covered in a day but is limited to midday periods when glare is low and visibility is good.

Equipment needs

Equipment lists for survey vehicles and individual survey crew members should be developed and included in the training manual for redd count surveys (see Table 3). The survey vehicle should contain a first-aid kit (including a snakebite and bee sting kit), fire extinguisher, shovel, flat-tire repair kit, tools, flares, chain saw and safety gear, duct tape, bailing wire, rope, tow strap, WD-40 or other lubricant for stuck locks, rags, toilet paper, and a two-way radio. Cell or satellite phones and citizens' band (CB) radios should be included but may have limited reception in many field locations. Individual staff equipment for walking surveys should include items listed in Table 3. Specialized equipment for rafting or aerial surveys is not included herein.

TABLE 3. — Equipment list for field surveyors conducting redd counts

Spawning survey protocol
Data forms
Stream/river reach maps
Pencils, pens, permanent markers
Field notebook
Knife with sheath
Compass
Chest waders and rain gear or dry suit
Wading boots
Hat
Polarized sunglasses
Field vest or backpack
Flagging
Measuring tape (mm)
Watch
Cell or satellite phone
Contact and emergency phone numbers
GPS unit
Swift water safety gear
Machete
Brush axe
Chain saw
Food and water
Extra clothing

Budget considerations

Budget needs will reflect funding for equipment, overtime, travel, training, and administrative overhead. Included in this staff time is an allocation for data management, analysis, and report writing. Field crews should receive salaries equivalent to that of other technical survey crews in the area, a cost of living adjustment for expensive housing markets, medical coverage, and other benefits, including vacation, holiday, and sick-leave pay. The budget should incorporate costs of additional equipment such as all-terrain vehicles or rafts.

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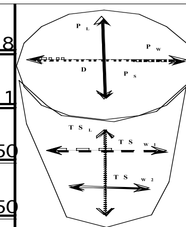
Appendix A: Example redd count data sheet

Fill out even if no redds were observed

Page_____1_____ Of ____3____

Stream Name: Caspar Creek	Week: 52	Water Temp. 8	
Section Name: Below Forks	Map # CAS 1	Air Temp. 11	
Reach ID: CAS 1	Water Visibility (m): 1.5	Start Time: 12:50	
Date: 12/12/2006	Stream Flow (m^3/s) 0.25	End Time: 13:50	
Surveyors: Mike Morrison, Scott Harris	Stage: 99.25	Drive Time: 0.75	



Species Codes: Onki = Coho Salmon
Onmy = Steelhead
Onts = Chinook Salmon
Latr = Pacific Lamprey
Unkn = Unknown Species

Weather: Ligth Rain

Notes: Steam Flow up at end of survey to Visibility down to 1.45

Directions: Visually identify each redd to species. Record the record number. Mark redd location with record number on the map. If a fish is on a redd record this on both fish and redd data forms, write fish number of redd form and redd number of fish form. If you can not measure a redd visually estimate the dimensions, record in appropriate spaces on data form, and write in the notes "estimated measurements." Flag all redds and write record number, species, year, and total length and width of redd on the flag. If test or under construction write "REMEASURE" and total length and maximum width on the flag. Remeasure all test and under construction redds on next survey. Redd age: 1 = New since last survey. 2 = Still measurable. 3 = Not measurable but still apparent. 4 = No longer there. 5 = poor conditions - can not measure or determine age.

Record Number	Species Code	Pot Length (m)	Pot Width (m)	Pot Depth (m)	Pot Substrate	Tail Spill Length (m)	Tail Spill Width 1 (m)	Tail Spill Width 2 (m)	Tail Spill Substrate	Fish on?	Fish #	Redd Age	Remeasured? Yes/No	Distance Flag to Tail Spill	Direction Flag to Tail Spill	Notes
1212001	onmy	1.2	2.2	0.15	4	1.5	1.4	1.1	5	yes	1212002	1	No	1.35m	230 degrees	fish spooked off
1212004	onki	2.3	3.2	0.2	6	3.3	2.5	1.5	2	yes	1212003	1	no	0.25 m	145 deg	flag above pot
1202105	test	1	1.2	0.1	5	1.6	1.4	1.2	4	no	na	2	yes			was test now is clearly onmy
1202106	onki	2.5	2.3	0.15	6	2.5	2.2	2	3	yes	1212005	2	yes			remeasure again fish still working
1212006	unkn	2.8	1.5	0.2	3	1.1	0.9	0.8	2	no	na	1	no	1.75 m	355 deg	redd perpendicul to stream flow
1202099	onki									no	na	5	no			flag syas remasu too turbid to
1202085	unkn									no		4	no			no longer present 4 on flag

Appendix B: Redd Counts Data Sheet

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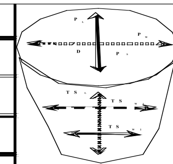
Stream Name:	Week:	Water Temp.		Species Codes: Onki = Coho Salmon
Section Name:	Map #	Air Temp.		Onmy = Steelhead
Reach ID:	Water Visibility (m):	Start Time:		Onts = Chinook Salmon
Date:	Stream Flow (m^3/s)	End Time:		Latr = Pacific Lamprey
Surveyors:	Stage:	Drive Time:		Unkn = Unknown Species

Weather:	Directions: Visually identify each redd to species. Record the record number. Mark redd location with record number on the map. If a fish is on a redd record this on both fish and redd data forms, write fish number of redd form and redd number of fish form. If you can not measure a redd visually estimate the dimensions, record in appropriate spaces on data form, and write in the notes "estimated measurements." Flag all redds and write record number, species, year, and total length and width of redd on the flag. If test or under construction write "REMEASURE" and total length and maximum width on the flag. Remeasure all test and under construction redds on next survey. Redd age: 1 = New since last survey. 2 = Still measurable. 3 = Not measurable but still apparent. 4 = No longer there. 5 = poor conditions - can not measure or determine age.
Notes:	

Record Number	Species Code	Pot Lengt (m)	Pot Width (m)	Pot Dept (m)	Pot Substrate	Tail Spill Length (	Tail Spill Width 1 (m)	Tail Spill Width 2 (m)	Tail Spill Substrate	Fish on?	Fish #	Redd Age	Remeasured? Yes/No	Distance Fla to Tail Spil	Direction Fla to Tail Spil	Notes