AN OVERVIEW OF THE COLUMBIA HABITAT MONITORING PROGRAM'S (CHaMP) SPATIAL-TEMPORAL DESIGN FRAMEWORK

David P. Larsen[1], Carol J. Volk[2], Don L. Stevens Jr.[3], Anthony R. Olsen[4], and Chris E. Jordan[5]

[1]South Fork Research
c/o U.S. Environmental Protection Agency
200 SW 35th St.
Corvallis, OR 97330

[2]South Fork Research
44842 SE 145th St
North Bend, WA 98045

[3]Stevens Environmental Statistics
6200 W. Starr Road
Wasilla, AK 99654

[4] Western Ecology Division
U.S. Environmental Protection Agency
200 SW 35th St.
Corvallis, OR 97330

[5]Northwest Fisheries Science Center
NOAA Fisheries
2725 Montlake Blvd E.
Seattle, WA 98112

Introduction

In 2011, the Bonneville Power Administration (BPA) initiated a coordinated tributary habitat monitoring program in the Interior Columbia River Basin in response to the Federal Columbia River Power System (FCRPS) Action Agencies (2010) prescriptions for habitat monitoring (FCRPS BiOp RPA 56.3). The 2008 Biological Opinion (BiOp) identified tributary habitat restoration as an important part of the FCRPS' collection of approaches to mitigate potential anadromous salmonid mortality resulting from the FCRPS power system. As a result, BPA and the National Oceanographic and Atmospheric Administration, along with a variety of other federal, state, tribal and private sector partners, initiated the Columbia Habitat Monitoring Program (CHaMP) in 2011 with standardized habitat surveys in eight Interior Columbia River Basin (ICRB) watersheds. (Figure 1)(Ward et al. 2012).

CHaMP's primary objectives were to describe the status and trends of habitat attributes that are important for Endangered Species Act listed (ESA-Listed) Chinook salmon *Oncorhynchus tshawytscha* and anadromous steelhead *Oncorhynchus mykiss* growth and survival. To efficiently meet the data collection and analysis needs of the program, CHaMP applied a common spatial-temporal design framework to the selection of monitoring sites in each CHaMP watershed, standardized habitat monitoring methods across the subbasins, employed an integrated, web-based system for documenting methods and designs, implemented a web-based system for data management, and collaborated with other agencies conducting habitat monitoring in these subbasins to leverage existing designs and locations.

At the outset, CHaMP recognized, within the broad status and trends objectives, a variety of sub-objectives, some of which were posed in developing CHaMP's spatial-temporal design, and some developed after the basic surveys had been implemented. For example:

- Additional watersheds might be selected, or originally selected watersheds (or parts of watersheds) might be deleted;
- Multiple differing sub-objectives might be specified for individual watersheds;
- Sites within watersheds might be dropped and/or new sites added;
- Project funding would change over duration of the project;

- Design changes were likely as experience was gained in implementation of the original design;
- Sites with previous monitoring (legacy sites) would be incorporated as appropriate;
- Designs would integrate collaborating agency objectives as feasible;
- Multiple habitat attributes would monitored so targeting design to optimize a single attribute's estimate was impractical;
- Designs would take into account that a web-based data management system would be integral to documentation and data storage and retrieval.

This report's primary objective is an overarching documentation of the design framework and process underlying CHaMP's selection of monitoring sites. Details about each watershed's specific design, relevant code, and yearly changes are described in separate watershed specific design documentation (e.g. Lemhi Status and Trend Design). To meet the multiple objectives, coordination, communication, data base management, aggregation of data across subbasins and the inevitable design changes, CHaMP used a master sample (Larsen, et al., 2008) along with the Stevens and Olsen GRTS (generalized randomized tessellation stratification, Stevens and Olsen 2004; Olsen et al. 2012) site selection algorithm as the foundation for each watershed's design. The first section of this report contains a description of the master sample concept and its integration with GRTS along with some features of master samples that were particularly useful for developing CHaMP's designs. Two CHaMP watershed specific case study sections follow that exemplify the varying details that emerge when faced with balancing achieving multiple sub-objectives embedded within a basic status and trends objective. We then discuss some of the features of the combination of the master sample and the use of the GRTS algorithm that allowed us to meet the varying and changing objectives and maintain the statistical integrity of the basic attribute status and trends objectives. A final section describes a web based system developed under the Pacific Northwest Aquatic Monitoring Partnership's (PNAMP) guidance that facilitated CHaMP's implementation of the various steps in setting up and implementing each watershed's design, including storage of the master sample, initial specific watershed design documentation and subsequent changes, and tracking the status of each candidate monitoring site.

The Master Sample Concept and CHaMP's implementation of it

Kish (1965) and Dodge et al. (2006) define a master sample as a large sample from which subsamples can be selected as needed to meet objectives of particular projects, "to avoid ad hoc sampling on each occasion". The concept of a master sample is not a new one and appears to have originated in the early 1940's when the U.S. Department of Agriculture, the U.S. Bureau of the Census and the Statistical Laboratory at Iowa State College collaborated to create a national area sample of agriculture. One of the primary objectives was to develop efficient sampling methods for taking economic surveys of American agriculture. Fuller (undated) describes a multi-year collaboration among the three agencies in the development of what became known as the Master Sample of Agriculture (King 1945; Jessen 1945) consisting of a sample of 300,000 farms from which subsamples of farms could be selected for specific projects.

Olsen and staff generated a Columbia Basin wide (CBW) stream (linear) network master sample from the NHD Plus 1:100,000 digital hydrography dataset using the *grtslin* function in the R package *spsurvey* (R Development Core Team 2012; Kincaid and Olsen 2012). Using the GRTS algorithm is particularly suited for selecting stream locations because the candidate sites are provided in an order that has the property of being *sequentially spatially balanced*. This property ensures that any consecutive sequence of sites in the design order will be spatially balanced. Thus, a sparse design consisting of the first several sites in sequence can be supplemented by additional sites taken in consecutive order. Creating a GRTS-based stream network master sample takes advantage of this sequentially spatially balanced property by selecting a dense list of sites that could be considered permanent. For example, a master sample could be generated whose list of sites is, on average, 1 km, or 0.5 km apart. Then sites for particular designs could be selected from this permanent pool. Designs might specify distributing sampling effort by stratification and/or assignment of sites to temporal panels (e.g., a sampling schedule). The CBW sample consists of 551,046 sites at an average density of one site/km, covering the NHD Plus stream networks in OR, WA, and ID.

As a brief background, GRTS based survey designs fall into one of three broad approaches for selecting a sample of 'population units' to gather information about 'populations':

1. Judgmental or convenience selection by which populations units are selected based on a judgement about their representativeness of a larger population. The fundamental problem with judgmental selection is that there is no way of objectively evaluating the 'representativeness' of the sample unit selection process, consequently, uncertainties and biases in the resulting statistical summaries cannot be determined.
2. Probability selection by which randomization is used in the selection of population units from a population allowing for evaluation of sampling uncertainties; and
3. Model-based selection of population units in which a model of the population is specified and population units are selected by which to 'calibrate' the model. Model based selection depends upon the validity of the assumptions underlying the chosen model(s), often difficult to evaluate. For surveys, like CHaMP's, that collect data on a variety of attributes comprising the surveys, it would be impossible to establish a model appropriate for all the attributes.

Reynolds (2012) contrasts these three approaches for sample (site) selection, their assumptions, inference methods and potential for biased results. Lohr (2010) and Gitzen et al. (2012) also discuss strengths and weaknesses of each approach.

The GRTS algorithm meets the basic randomization requirement of probability sampling in that each site has a positive probability of inclusion in a sample. The reciprocal of the inclusion probability is the sample weight which is used to describe the portion of the target population that a site represents. Simple random selection yields constant weights among sites; stratified (or other variable probability) designs yield variable weights depending on the particular design choices. Weights are used in making design based inferences about the target population's attribute properties, such as frequency distributions, summary statistics (e.g., mean, median (or other quantiles), variance), or other properties (e.g., relationships among variables). Initial design weights aimed at achieving target sample sizes often require adjustments because sites selected in the initial design phase might not be sampled for a variety of logistical reasons such as: denial of site access; site inaccessibility; site is not a part of the population of interest; or the inability to complete assigned sites within budget. Careful evaluation of the status of each site initially selected and replacement sites allows proper adjustment of weights. Adjusted weights are then used in making design based population inferences. Not taking into account variable weights in the analysis of data generated by probability-based surveys very likely will yield biased summary results. See Valliant, et al. (2013) for a detailed discussion of the weight assignment and adjustment process and potential consequences of not taking weights into account and Nahorniak et al. (2015) for an illustration of the biases that can be introduced if appropriate weights are not included when making model based inferences from probability based sampling.

A feature not currently incorporated in the GRTS site selection code is the ability to include sites with a monitoring history (legacy sites), either to prioritize sites from the same design's master sample or sites from other designs. Designers of monitoring programs are often faced with a desire to incorporate legacy sites into the new design whose objectives might differ from those for which the legacy sites were selected. The core of the GRTS design strategy is a random ordering of two-dimensional space that preserves much of the two-dimensional proximity relationships. Thus, two sites that are near to one another in two-dimensional space will tend to be near one another in the random ordering. Stevens modified the basic GRTS algorithm utilizing this property to incorporate legacy sites into a GRTS sample. Conceptually, the GRTS modification recognizes the spatial organization of the legacy sites, and then selects additional sites such that the resulting merged collection of sites will be sequentially spatially balanced. Sites might have come from earlier applications of the CBW master sample, or from other sources. The resultant design will be a randomized design to the extent that the legacy sites were a probability sample, or a reasonable approximation of a probability sample. This feature was important for the designs of several of CHaMP's watersheds that had monitored GRTS selected sites for many years.

A feature of master samples that proved useful for CHaMP is the ability to develop a data base covering all sites in the master sample. The data base can contain all the NHD Plus segment information where each site occurs (e.g., flow path, elevation, Strahler stream order) in addition to the obvious site identifier and geographic coordinates of the site (e.g., latitude/longitude, UTM coordinates). Furthermore, any digital geographic coverage information that is available can be transferred to each site; for example, the USGS hydrologic codes and names, Omernik ecoregions codes and names, or land use/land cover files can be incorporated into the master sample file. For some studies, specific information about subsets of sites can be useful; for CHaMP, assignment of master sample sites to specific Chinook or anadromous steelhead populations was important because it allowed extraction of only those sites that are part of specific population domains. Table 1 contains a list of the attributes contained in the Interior Columbia River Basin (ICRB) portion of the CBW master sample covering the listed anadromous steelhead and Chinook domains.

Another strength of a master sample file is that it can also be useful for making spatially explicit site predictions from models that relate monitored sites' attributes (dependent variables) to spatial data available at all sites (independent variables). Some recent examples of such models that relate channel and riparian attributes to watershed/landscape attributes include: Cao et al., 2015; DeWeber and Wagner, 2015; Hough-Snee, et al., 2015; and Meredith, et al., 2014. CHaMP has been developing two types of spatially explicit models along these lines: models that interpolate site specific attributes at non-monitored sites within each of CHaMP's monitored watersheds based on models relating measured attributes to the landscape data in CHaMP's master sample file and similar models that extrapolate from monitored watersheds to unmonitored watersheds. Having landscape data available at all master sample sites obviously facilitates such interpolation or extrapolation.

As illustrated in the following sections, the combination of a GRTS generated master sample with a broad list of site attributes, the ability to incorporate legacy sites, and the use of the GRTS algorithm to select subsets of the master sample gave CHaMP the ability to achieve watershed specific design objectives in a statistically sound manner.

CHaMP's implementation of the CBW master sample:

CHaMP's spatial-temporal design template was a nine-year plan consisting of three rotating panels (each on a three-year cycle) and one annual panel. Each year, 25 sites were selected in each watershed with 15 and 10 sites assigned to the annual and rotating panels, respectively. A total of 45 unique sites were selected across three years and this three year cycle repeats three times over the nine years, providing the potential for trend detection at each of the 45 sites, as well as yearly status estimates, or moving average status estimates such as "three year" snapshots. CHaMP also recognized three geomorphic strata (source, transport, and depositional valley classes) based on Montgomery and Buffington's (1997), and Beechie and colleagues (2006) geomorphic classification of rivers and streams and public/private ownership. As described in various parts of this report, this design template could be modified in a variety of ways. Once the set of objectives for each watershed was specified, CHaMP's design process then included the following steps:

1. Identification of each watersheds specific anadromous domain and portion of the CBW master sample set within that domain;
2. Incorporation of any legacy sites;
3. Incorporation of collaborating agency contributions (such as additional funding, collaborative participation, or legacy sites from other designs);
4. Specification of desired strata and sample sizes per stratum;
5. Specification of the temporal pattern (standard was an annual panel and 3 panels each on a 3 year cycle);

Implementation of the modified GRTS algorithm produced an ordered list of sites by stratum and panel, along with an extra ordered set of substitute sites should any of the initial set of sites be rejected (i.e., access denied; site is 'non-target'). Watershed specific crews evaluated the candidate list of sites to determine which sites were to be field sampled.

The following sections illustrate how the master sample concept has been applied in two of CHaMP's watersheds. The case studies intend to provide some detail illustrating the complexity and flavor of what developing and implementing monitoring designs face in addressing complex sets of multiple objectives that have a tendency to change over time. These are issues that managers and technicians often confront when designing long term monitoring plans. The combination of the properties and flexibility of the GRTS algorithm, the master samples derived using it, and modifications to the basic *spsurvey* GRTS code to allow for incorporation of legacy sites provided us the ability to adjust the spatial designs to meet the variety of objectives and their changes. CHaMP's Grande Ronde design involved coordination among three programs (CHaMP, Oregon Department of Fish and Wildlife's (ODFW) steelhead spawning surveys, and the Columbia River Intertribal Fisheries Commission's (CRITFC) Chinook habitat surveys) and incorporation of both ODFW and CRITFC legacy sites. CHaMP's Tucannon design illustrates how local 'action effectiveness' monitoring can be embedded in a broader scale status and trends design. Both of these watersheds modified CHaMP's design template and made changes between 2011 and 2012. Table 2 summarizes the types of design changes in each of the CHaMP watersheds.

The Grande Ronde watershed: Incorporating multiple design objectives and legacy sites

Within the Grande Ronde watershed, ODFW and CRITFC monitor endangered steelhead and Chinook, respectively. Steelhead are broadly distributed across the Grande Ronde basin and ODFW had been monitoring steelhead spawner abundance, but not habitat, at GRTS selected sites within the domain since 2008. The two Grande Ronde Chinook populations occupy a much smaller portion of the watershed than steelhead (Justice et al. 2010). CRITFC began surveying both Chinook habitat and spawner abundance in 2010 based on a self-generated digital hydrography on which they selected sites using GRTS (Justice et al. 2010). In 2011, as CHaMP's objectives and design developed, CRITFC and ODFW decided to collaborate with CHaMP to increase the overall sampling effort and data integration.

Due to the disparate spatial domains of the two species and the need to devote adequate sampling effort to the smaller Chinook domain, CHaMP, ODFW and CRITFC decided to split the Grande Ronde target domain into three spatial strata: a stratum for each of the two Chinook populations (CRITFC Upper Grande Ronde and Catherine Creek) and a third for the steelhead-only domain (ODFW)(Figure 2). Splitting the domain into three separate areas facilitated logistical considerations for ODFW and CRITFC by ensuring that crews would visit distinct areas of the watershed, cutting travel costs. Additionally, it simplified the final habitat summary process for steelhead; since the full steelhead domain included the three distinct strata, the habitat estimates of each domain could be added together to estimate the entire steelhead domain. For the steelhead-only stratum, the basic CHaMP valley class and ownership stratification was used to select the four panel sets of sites from the master sample. The two Chinook domains were not stratified in 2011 due to the small spatial domain and geomorphic similarity, and CRITFC's history in the region indicated that denied access to sites posed minimal problems. However, CRITFC's Chinook design had legacy sites monitored in 2010 that CRITFC wished to carry over into the new CHaMP design for the Grande Ronde. These sites were transferred to the closest location on CHaMP's hydrography (NHD Plus) and were combined as legacy sites with the master sample sites to generate the four panel structure in each Chinook stratum (Grande Ronde Chinook design 2014).

After the 2011 field season, both ODFW and CRITFC requested design changes for the steelhead-only and Chinook domains, respectively. For steelhead, the 2011 CHaMP habitat survey sites were not co-located with the ODFW's steelhead spawner survey sites. Since the original 2011 CHaMP design and the ODFW spawner survey design were both GRTS selected samples from a master sample and used the same four panel rotational design (annual sites and sites on a three year rotation), CHaMP was able to integrate the two designs into a single spatially-balanced design that incorporated both ODFW spawning survey sites and 2011 CHaMP habitat sampled sites with minimal disturbance to the spatial balance and random nature of the 2011 sample. To combine designs, CHaMP's annual (15 sites) and rotating panel one (10 sites) were retained and ODFW's spawner panel two and three sites were assigned to CHaMP's rotating panels 2 and 3. ODFW's spawner annual sites were split into two groups, and each group added to CHaMP's rotating panel two and three habitat sites. This pool of spawner sites was sorted by CHaMP strata (valley class and ownership), keeping the original use order set up in the spawner surveys. These legacy sites were selected for each panel and stratum and supplemented with CHaMP's master sample as needed to fill in blocks and meet the sample quota. There may have been some loss of spatial balance in combining the designs in this way compared with the spatial balance that might have been achieved if surveys had been designed together from scratch, but retaining specific panel rotations and sites was an important objective of the recombined design.

The Chinook design change in 2012 addressed CRITFC's desire to expand the target domain to include both the Chinook spawning and rearing domains, as the 2011 domain included only Chinook spawning areas (Figure 2). This request was accommodated by reducing the annual sample size from 15 to 10 and assigning the five 'released' annual sites to rotating panel one since these sites had already been sampled in 2011. Rotating panels two and three were reselected within each expanded Chinook stratum, allocating 10 sites to each panel. This process both expanded the Chinook sampling domain and increased the total number of unique sites from 60 to 70.

The Tucannon Watershed: Integrating local 'action effectiveness' monitoring within a broader scale status and trends design

The Tucannon watershed supports a population of Chinook along the mainstem and within a few of its contributing tributaries. Substantial habitat and riparian restoration projects have been implemented and are planned that include additions of large wood, removal of levees and riparian tree planting (Anchor QEA 2011). A need to monitor and evaluate the effectiveness of these habitat improvement projects was recognized and there was a desire to embed the restoration effectiveness monitoring effort within the broader status and trends monitoring context across the entire Chinook domain. The nested nature of this design would provide important contextual status and trend reference information at a watershed-scale for the action effectiveness monitoring occurring at the treatment scale. To accomplish this, the Tucannon target domain was divided into two major strata (tributary and mainstem), and then a series of treatment and control strata were embedded within the mainstem (Figure 3).

Ninety eight master sample sites occur within the target population, with 50 mainstem, 21 tributary, and 27 to treatment/control groups.

The initial CHaMP design for the Tucannon allocated seven annual and six rotating panel sites to the two major strata, and eight annual and four rotating panel sites to treatment/control sets. During 2011-2013, typical changes to the design included shifting some treatment/control strata to the mainstem stratum because the treatment was cancelled, or shifting some mainstem sites into a treatment/control group because new treatment areas and timelines were established. Embedding treatment/control sets within a broader status and trend monitoring domain allows evaluation of the full domain response to the collection of treatments over time, while simultaneously allowing treatment specific effectiveness monitoring.

Discussion

Through the use of a master sample along with the GRTS algorithm, CHaMP successfully maintained statistical goals while accommodating objectives, budget, and logistical changes to the basic design framework either during the original design phase when working with collaborators, or after initial implementation of the design. The changes are all based on recognizing some basic properties of statistical sampling: The target population remains definable (even though it might have been changed); strata are unambiguously defined; randomization is used in the site selection process; and sample weights remain calculable from the evaluation of the status of each site to allow for design based statistical inferences (attribute frequency distributions, summary statistics). The following are typical of the kinds of modifications that CHaMP made to the basic design structure; the examples refer to both the CHaMP case watersheds as well as several of the other six identified in Figure 1 and Table 2:

Stratification: typically involved stratifying along different attributes (e.g., the Lemhi status and trend design stratified along subbasins, but not by valley class), or no stratification (target domain was small enough that valley class/public private stratification was unnecessary); in some cases special studies were embedded within the broader status and trends, such that a separate probability design was set up within a portion of the broader domain.

Sample size or sample allocation to temporal panels: Sample size was often increased because collaborating agencies added resources to CHaMP's sampling budget or was decreased because budgets were reduced. The sequential ordering of sites within strata allowed straightforward changes in sample sizes (along with calculation of changed sample weights) by adding or deleting sites from the tails of the ordered stratum lists. Flexibility in allocating sites to annual or rotating panels allowed Grande Ronde to reduce annual site allocation to increase sample size among the rotating panels.

Target domain: In some cases, the target domains were changed as more information was gained. Deleting newly reclassified master sample sites as non-target easily translates into a revised ordered list of sites for sampling and consequent frame and weight adjustments. Revisions to the target domains was especially important in the Wenatchee status and trend and Entiat status and trend designs.

Incorporation of legacy sites: Continued monitoring of sites with previous monitoring is important for detecting long term changes and consequently incorporating these sites into future monitoring programs is often desired. Changes to the GRTS algorithm allowed CHaMP to take advantage of incorporation of legacy sites in several of the CHaMP watersheds. For example, Wenatchee, Grande Ronde, John Day, and Entiat basins had ongoing sampling programs based on probabilistic designs. Integrating the relevant sites into CHaMP's design for each basin preserved these sites' monitoring history.

Master sample intensification: There was no technical reason preventing the selection of higher density of sites for the CBW master sample at the time that it was generated. Most status and trends monitoring programs covered relatively broad spatial domains such that the 1 site/km average density was more than sufficient. As the principles of probability site selection became more desirable at finer spatial scales, it became apparent that finer master site densities were relevant. At this stage, these studies are relatively spatially sparse, and local intensification was adequate. However, as interest increases in finer scale surveys, it might be reasonable to increase the CBW master sample density. A permanent high density list of sites could be an attractive pool of sites from which all (or most) monitoring programs could obtain monitoring sites. The CBW master sample was intensified in several watersheds that adopted

CHaMP's approach and whose target domain was relatively limited. For example, the original CBW 1 site/km density was increased to 1 site/200 m in CHaMP based surveys in the Yankee Fork, a tributary to the Upper Salmon River, Idaho, where intensive restoration was planned (YFT00001 User Sample), and in a portion of the Minam basin, Oregon, that CRITFC planned to use as a Chinook habitat reference watershed for comparison both Upper Grande Ronde and Catherine Creek Chinook domains.

The ability to intensify master samples might be especially useful to address objectives at spatial scales that are finer than that used for the master sample. For example, in the northwest, monitoring the effectiveness of site specific restoration actions (often called Action Effectiveness Monitoring or AEM) occurs through local agencies such as watershed or tribal councils, statewide agencies like ODFW or Washington's Salmon Recovery Funding Board (SRFB) (Crawford and Arnett 2011; Tetra Tech Inc. 2013) or at regional scales such as BPA's regional effort to evaluate restoration effectiveness of projects it has funded (Roni et al. 2013). AEM often follows an MBACI (Multiple Before After Control Impact) design (Roni et al. 2013) requiring sites at relatively close spacing covering the reach extent that matches the restoration extent, as well as matching control sites. If the master sample is dense enough to meet AEM needs, the subset of relevant control and impact sites can be selected from the master list, as we illustrated with the CHaMP-Tucannon example. If the master sample's density is too low, then additional sites can be selected in the vicinity of the restoration to meet the local scale designs via the intensification process. In either case, the use of a master sample allows embedding the restoration (or other local scale) monitoring within broader scale monitoring that can allow statistical integration of the local scale results within the broader scale results.

Frame extension: In some cases, the NHD Plus digital stream network might exclude portions of networks that are important for particular surveys. This situation arose in CHaMP's Lemhi watershed domain where two small streams important for Chinook were not part of NHD Plus, consequently, no pool of master sample sites was available. CHaMP applied the *grtsln* function to select sites at the CBW density on digital representations of the two small streams excluded from NHD Plus. This set of sites could have been merged with the Lemhi master sample list. However, Lemhi CHaMP stratified on the small basins so it was unnecessary to merge this list with the full Lemhi list; the relevant target sample for these two 'strata' was selected from their respective stratum lists. If the valley class stratification were used for Lemhi, these additional sites could be merged with the full master Lemhi list to generate a new valley class specific ordered list of candidate sampling sites.

Other potential modifications to survey designs can be expected. Whether these changes can be accommodated within the requirements for probability designs (and sound design based inferences) will depend on the investigator's ability to identify the target population, population units, stratification and temporal panels, target sample sizes, and randomization in the sample selection process such that each sample unit's inclusion probability (or weight) can be determined during the analytical phase of the study. In the end, after data are collected on the sample units, can the inclusion probability or weight be calculated for each sample unit? If not, design based inferences can be called into question.

Online implementation of master samples

In concert and coordinated with the development and implementation of CHaMP's designs, PNAMP initiated a Monitoring Resources website (https://www.monitoringresources.org/) whose interactive, on line web based tools facilitated a variety of steps in CHaMP's design process. PNAMP's monitoringresoruces.org supports a suite of information and tools to meet a variety of monitoring needs for the environmental monitoring community, including educational materials, a community forum, a place to document and share monitoring resources. The site allows practitioners the ability to describe relevant monitoring projects, implement GRTS based site selection from master samples, and document the design process and history of site selection. The site provides guidance and support from the design stage through implementation to generation of descriptive statistics based on the implemented design. Monitoring Resources' Glossary of monitoring terms helps ensure consistent use of terms and concepts. Monitoring Resources contains several components including:

- *Methods and Protocols* that provides a framework for and stores specific methods and protocols that a monitoring program uses
- *Sample designer* that allows users to develop and document specific GRTS based survey designs
- *Site Manager* that tracks the status of each site selected during the design phase
- *Monitoring Explorer*-the Map Viewer that allows users to visually explore the spatial distribution and status of sites that have been monitored by others in the users area of interest

With the tools available in monitoringresources.org, practitioners can plan and implement effective, efficient monitoring projects, share information, and coordinate and integrate monitoring efforts. Resource managers, funders, and policy makers benefit from comprehensive views of existing and proposed monitoring projects, providing a better understanding of how priorities are being met and where gaps or redundancies among monitoring programs may exist. This set of tools helps meet a need practitioners have expressed to know the 'who, what, when, where, and how' of monitoring activities.

Summary

We briefly review the concept of a master sample applied to stream networks in which a randomized set of stream sites is selected across a broad region to serve as a list of sites from which a subset of sites is selected to achieve multiple objectives of specific designs. CHaMP selected sites from a regional master sample to develop physical habitat surveys in eight Upper Columbia watersheds focusing on the stream habitat domains of anadromous salmonids and steelhead. Details of two case studies illustrate how CHaMP applied the concept to generate sampling designs that could meet both a set of comprehensive status and trends objectives across all basins as well as differing specific objectives in each of the basins. The case studies illustrate the flexibility offered by using master samples including meeting multiple objectives and their changes; covering a variety of spatial scales; incorporation of previously monitored sites (preferably coming from earlier randomized surveys); and increasing the site density at local scales. We also describe PNAMP's web-based system that allows users to develop designs from master samples, document those designs and store information about site histories. The system allows users to evaluate sites that others have selected to determine relevance for incorporation into their designs facilitating coordination and integration of monitoring designs.

References

Anchor QEA. 2011. Tucannon river geomorphic assessment and habitat restoration study. Anchor QEA, Bellingham, Washington. Available: http://snakeriverboard.org/wpi/wp-content/uploads/2013/01/Tucannon-River-Geomorphic-Assessment-Habitat-Restoration-Study-April-2011-Report.pdf. (April 2015).

Beechie, T. J., M. Liermann, M. M. Pollock, S. Baker, and J. Davies. 2006. Channel pattern and river-floodplain dynamics in forested mountain river systems. Geomorphology 78(1-2): 124-141.

Cao, Y, L. Hinz, B. Betzke, J. Stein, and A. Holtrop. 2015. Modeling and mapping fish abundance across wadeable streams of Illinois, USA based on landscape-level environmental variables. Journal of the Fisheries Research Board of Canada.

Crawford, B. A., and J. Arnett. 2011. Protocol for monitoring effectiveness of habitat protection projects. Report MC-10, Washington Salmon Recovery Funding Board, Olympia, Washington. Available: http://www.rco.wa.gov/documents/monitoring/MC-10_Habitat_Protection_Projects.pdf. (April 2015).

DeWeber, J. T., and T. Wagner. 2015. Predicting Brook Trout occurrence in stream reaches throughout their native range in the Eastern United States. Transactions of the American Fisheries Society 144: 11-24.

Dodge, Y., D. Cox, D. Commentes, A. Davison, P. Solomon, and S. Wilson. 2006. The Oxford dictionary of statistical terms. The International Statistical Institute, Sixth Edition. Oxford University Press. Oxford, United Kingdom.

Fuller, W. A. 1938-1944. The Master Sample of Agriculture. Iowa State University RS 13/24/0/5. Available: http://www.add.lib.iastate.edu/spcl/arch/rgrp/13-24-00-05_report.html. (March 2015).

Gitzen, R. A., J .J. Millspaugh, A. B. Cooper, and D.S. Licht. 2012. Design and analysis of long-term ecological monitoring studies. Cambridge University Press, Cambridge, United Kingdom.

Hough-Snee, N., B.B. Roper, J.M. Wheaton, and R.L. Lokteff. 2015. Riparian vegetation communities of the American Pacific Northwest are tied to multi-scale environmental filters. River Res. Applic. 31: 1151-1165.

Jessen, R. J. 1945. The master sample of agriculture: II. Design. Journal of the American Statistical Association 40: 46-56.

Justice, C., S. White, D. McCullough. 2010. Stream habitat monitoring protocol for the upper Grande Ronde River and Catherine Creek. Version 1.0. A Component of Monitoring Recovery Trends in Key Spring Chinook Habitat Variables and Validation of Population Viability Indicators. Columbia River Inter-Tribal Fish Commission. Portland, Oregon.

Kincaid, T.M., and A. R. Olsen. 2012. Spsurvey: spatial survey design and analysis. R package version 2.3. Available: http://www.epa.gov/nheerl/arm/. (April 2015).

King, A. J. 1945. The master sample of agriculture: I. development and use. Journal of the American Statistical Association 40: 38-45.

Kish, L. 1965. Survey sampling. John Wiley & Sons, Inc. New York.

Larsen, D. P., A. R. Olsen, and D. L. Stevens, Jr. 2008. Using a master sample to integrate stream monitoring programs. Journal of Agricultural, Biological, and Environmental Statistics 13: 243-254.

Lohr, S. L. 2010. Sampling: design and analysis, Second Edition. Brooks/Cole. USA.

Montgomery, D. R. and J. M. Buffington. 1997. Channel-reach morphology in mountain drainage basins. Geological Society of America Bulletin 109(5): 596-611.

Meredith, C. B. Roper, and E Archer. 2014. Reductions in instream wood in streams near roads in the Interior Columbia River Basin. North American Journal of Fisheries Management 34: 493-506.

Nahorniak, M., D. P. Larsen, C. Volk, and C. E. Jordan. 2015. Using inverse probability bootstrap sampling to eliminate sample induced biased in model based analysis of unequal probability samples. PLoS ONE 10(6): e0131765. doi:10.1371/journal.pone.0131765.

Olsen A. R., T. M. Kincaid, and Q. Payton. 2012. Spatially balanced survey designs for natural resources. Pages 126-150 *in* R. A. Gitzen, J. J. Millspaugh, A. B. Cooper, and D. S. Licht, editors. Design and Analysis of Long-Term Ecological Monitoring Studies. Cambridge University Press, Cambridge, United Kingdom.

R Development Core Team. 2012. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. Available: www.R-project.org/. (March 2015).

Reynolds, J.H. 2012. An overview of statistical considerations in long-term monitoring. Pages 23-53 *in* R. A. Gitzen, J. J. Millspaugh, A. B. Cooper, and D. S. Licht, editors. Design and Analysis of Long-Term Ecological Monitoring Studies. Cambridge University Press, Cambridge, United Kingdom.

Roni, P., R. Scranton, and J. O'Neal. 2013. Action effectiveness monitoring of tributary habitat improvement: a programmatic approach for the Columbia Basin Fish and Wildlife Program. Available: https://salishsearestoration.org/wiki/File:Roni_et_al_2013. (March 2015).

Stevens, D. L., Jr. and A. R. Olsen. 2004. Spatially-balanced sampling of natural resources. Journal of American Statistical Association 99(465): 262-278.

Tetra Tech Inc. 2013. Reach-scale effectiveness monitoring program. 2012 Annual Progress Report. Available: http://www.rco.wa.gov/documents/monitoring/2012Report.pdf. (March 2015).

Valliant, R., J.A. Dever, and F. Kreuter. 2013. Practical Tools for Designing and Weighting Survey Samples. Springer New York.

Ward, M. B., P. Nelle and S. M. Walker. (editors). 2012. CHaMP: 2011 pilot year lessons learned project synthesis report. Prepared for the Bonneville Power Administration by CHaMP. Bonneville Power Administration, Portland, Oregon.

Tables

Table 1. A list of the attributes currently part of CHaMP's master sample file.

Attribute Type	Attributes
Topography	Elevation Valley Class Channel Type Slope Confinement Bankfull width (modeled)
Watershed identification	CHaMP Watershed HUC4 Code HUC3 Code CHaMP Target Domain
Landscape Characteristics	Geology Type Erodibility Class Omernik Ecoregion % National Land Cover Composition by Class HUC 6 Disturbance Class Disturbance Class PCA 1 HUC 6 Natural Class Natural Class PCA 1 Natural Class PCA 2 Land Ownership
Fish Characteristics	Steelhead Population Spring/Summer Population Intrinsic Potential (area weighted)
Climate	Temperature Range Growing Degree Day Precipitation
Hydrology	Mean Annual Flow Mean Annual Velocity Channel Forming Flow (1.5 years) Mean Annual Summer Flow 7 Day Low Flow Mean Annual Flow Strahler Order Stream Junction Density

Table 2. Summary of the changes to the Columbia Habitat Monitoring Program's (CHaMP) design template in each of the eight CHaMP watersheds from 2011 - 2013.

Watershed	Organizations	Project Designs	Legacy sites	Stratification level 1	Stratification level 2	Design changes 2011 to 2012	Design changes 2012 to 2013
Entiat, WA	Terraqua	Status and Trends, Entiat IMW	Yes	Status and Trend vs. IMW	Valley Class and Ownership (within Status and Trend only)	Reduced frame handled by site evaluation rejections	None
Grande Ronde, OR	CRITFC	Monitoring Recovery Trends for Spring Chinook	Yes	Upper Grande Ronde Chinook, Catherine Creek Chinook,		Expansion of Upper Grande Ronde Chinook domain; updated sample allocation	None
	ODFW	Steelhead Spawning Surveys	Yes	Steelhead	Valley Class and Ownership (within Steelhead only)		
John Day, OR	ODFW, EcoLogical Research	Steelhead Monitoring Program for Middle Fork John Day; South Fork John Day	Yes	Greater John Day, Greater South Fork John Day, Bridge Creek IMW, ISW watersheds	Valley Class and Ownership (Greater SFJD, Greater JD); Gradient class (ISW watersheds)	Change ISWs to Middle Fork John Day and South Fork John Day and utilize mainstem and valley class strata	Reduce sampling to only Middle Fork John Day and South Fork John Day
Lemhi, ID	Quantitative Consultants, Inc.	Status and Trends	Yes	19 priority watersheds		None	None
Methow, WA	Terraqua	Status and Trends	No	Valley Class and Ownership		None	None
South Fork Salmon, ID	Quantitative Consultants, Inc.	Status and Trends	No	Secesh, Greater South Fork Salmon	Stream Order (within Greater SF Salmon)	Reduce sampling to Secesh	None
Tucannon, WA	EcoLogical Research	Status and Trends	No	Mainstem, Tributary, and Treatment/Control Restoration groups		Incorporate additional restoration and control groups	Incorporate additional restoration and control groups
Wenatchee, WA	Terraqua	Status and Trends	Yes	Valley Class and Ownership		Reduce target frame	None

Figures

Figure 1. The Columbia Habitat Monitoring Program's (CHaMP) set of watersheds used in CHaMP's core pilot habitat surveys.

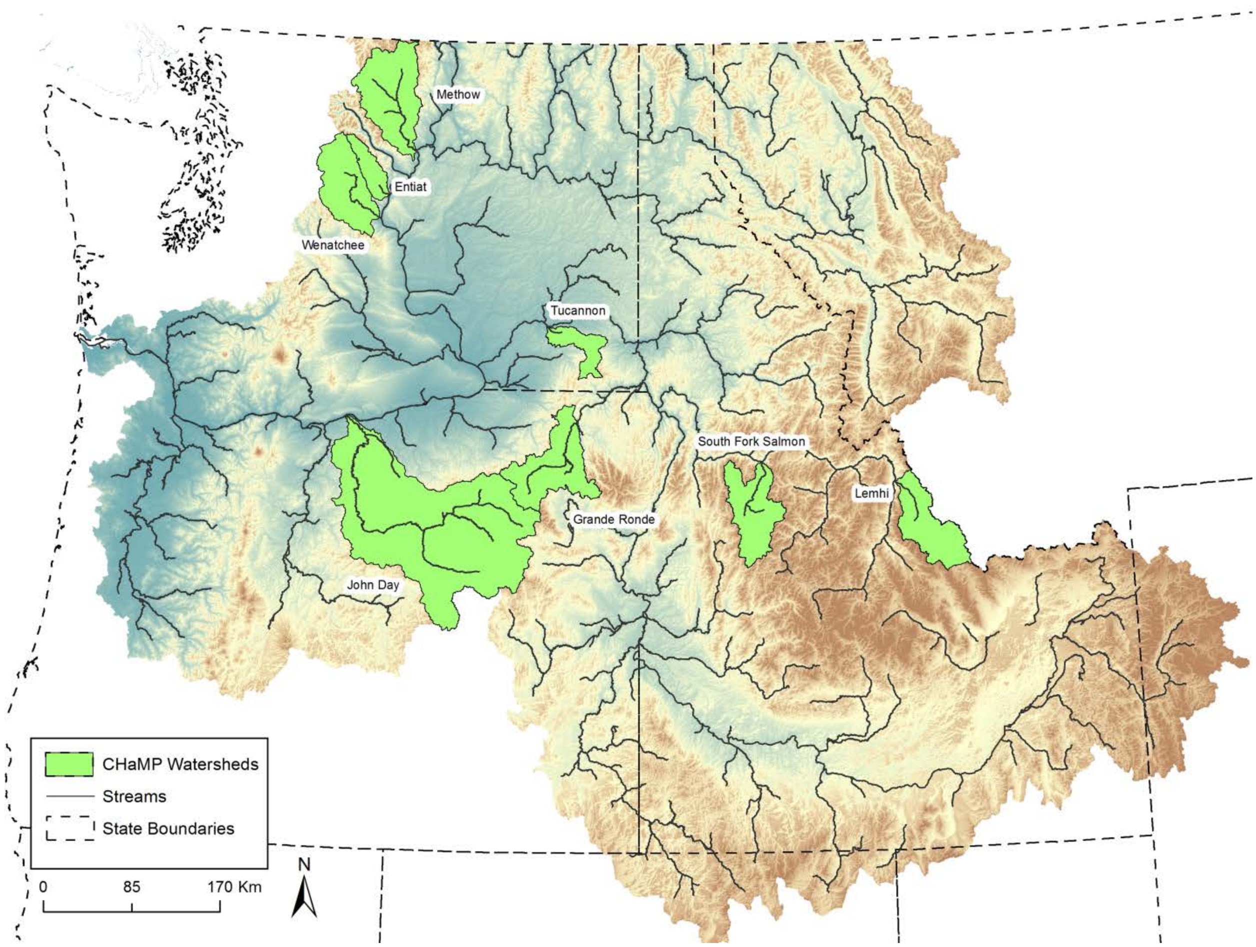

Figure 2. The extent of the Upper Grande Ronde watershed's stream network where sites were selected for the habitat surveys, coded by the major strata.

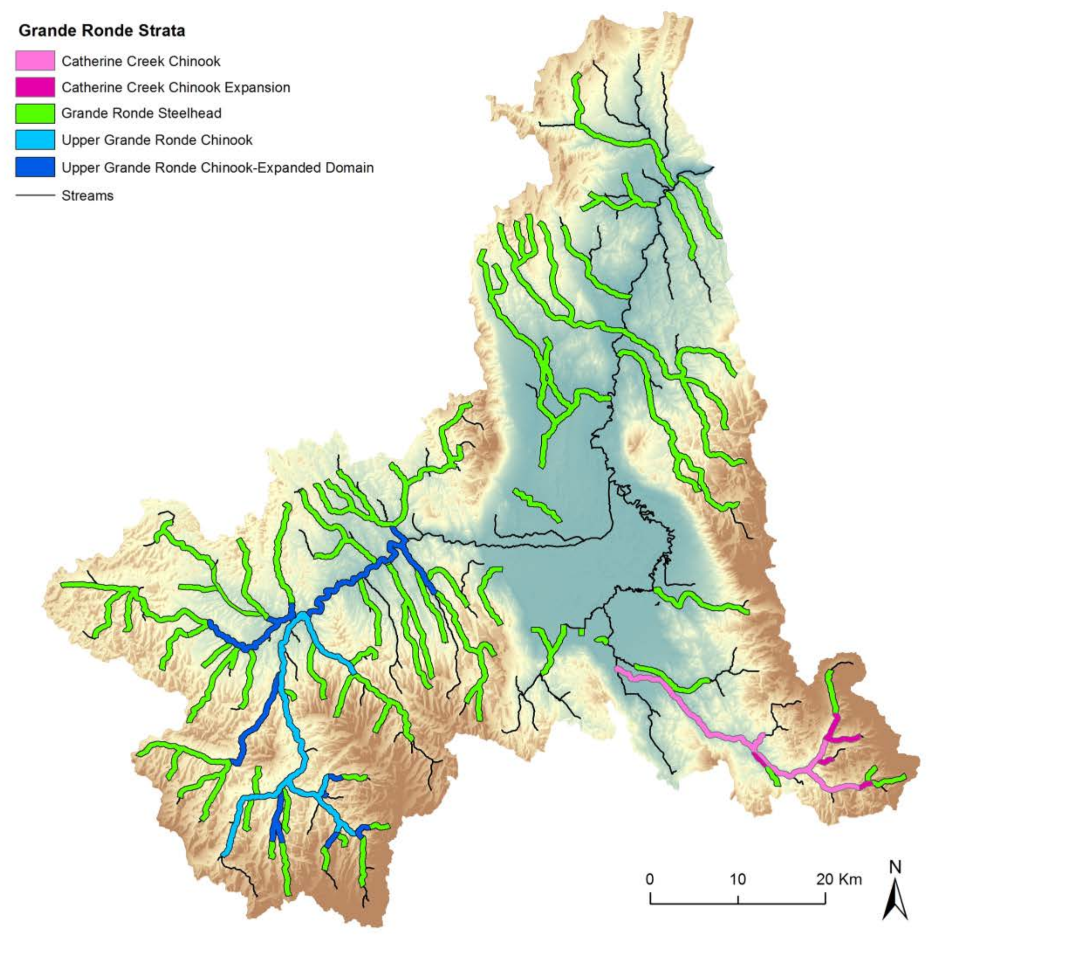

Figure 3. The extent of the Tucannon watershed's stream network where sites were selected, illustrating two major strata (mainstem and tributary), along with finer scale treatment-control strata.