SHASTA RIVER HABITAT SUITABILITY CRITERIA

1.0 Study Goals and Objectives

Assessing the relationship between streamflow and habitat suitability for stream fishes using hydraulic habitat modeling requires both a hydraulic component and a habitat component. These two components contribute to a predicted flow-habitat index relationship, which is commonly referred to as Weighted Usable Area (but more accurately as Area Weighted Suitability or AWS). Hydraulic analysis, which can be done with 1-D, 2-D, or 3D models, provides the depth and velocity characteristics of the stream environment under different flow scenarios, while a habitat analysis requires a biological component, commonly referred to as Habitat Suitability Criteria (HSC). Many other instream flow methods that don't include a hydraulic model, such as Demonstration Flow Assessments, Direct Habitat Mapping, and MesoHABSIM, also require HSC. HSC (also known as habitat suitability indexes, habitat criteria curves, species preference curves, and probability-of-use curves), are indices that describe the relative suitability of specific habitat attributes for a specific species and life stage of aquatic organisms. An HSC scale ranges between 0.0, which represents totally unsuitable conditions, and 1.0, which represents optimal conditions). HSC can be developed for a wide variety of habitat attributes, but for application in a hydraulic habitat study the modeled habitat attributes must correspond to the hydraulic portion of the assessment.

HSC typically include the habitat attributes of water depth, water velocity (most often mean column velocity), substrate composition, and various types of instream or overhead cover. Depth and velocity are interactive with discharge, whereas substrate and cover are typically treated as fixed habitat attributes and are either available or unavailable based on modeled flow, wetted perimeter, and water surface elevation. HSC can take various forms depending on attribute type, such as continuous curve distributions for depth or velocity, stepped functions for categorical attributes such as substrate or cover, or binary criteria (e.g., an attribute is either fully suitable or fully unsuitable). Each type of HSC can be developed by collecting new site-specific data from the area being modeled, or by professional judgment, typically through discussions with species and modeling experts. In some applications, HSC developed from a previous study in a different location are applied in the study area, based on similarity of physical habitat conditions between the two sites, or by testing the transferability of the existing HSC using a sample of new data from the project location.

A wide variety of factors can influence habitat use and selectivity among stream fishes, including fish species and size, habitat availability, prey availability, water temperature, and densities of competitors or predators. Because each study area has a unique combination of such factors, most instream flow practitioners will agree that developing site-specific HSC, if collected in a manner to account for the site-specific attributes of each study area while also minimizing sampling and analytical biases, will produce the most biologically relevant and representative HSC for a given location. Consequently, site-specific HSC are preferred over judgment-based or out-of-basin HSC and should be developed wherever possible (CDFG 2008). However, developing site-specific HSC may not be feasible for certain locations or species/life-stages due to a variety of factors, such as species rarity, passage impediments, restricted access, where degraded physical habitat or marginal water quality would result in biased HSC, lack of funding or time, or other reasons. In such cases, development of judgment-based HSC or application of existing HSC from comparable sources may be the only realistic alternative.

This study plan describes the different methods of developing HSC for use in assessing the flow-habitat relationships in the Shasta River. Developing HSC as part of instream flow assessments has been identified as necessary steps in the effective management of water resources in California watersheds including the Shasta Basin (e.g., CDFG 2008, SVRCD and McBain and Trush 2013). The specific goal of this study plan is to develop a suite of HSC for each target species and life stage that can be combined with hydraulic models to predict the relationship between streamflow and fish habitat within each watershed and study reach.

Attaining this goal requires meeting several specific objectives:

1. Determine the target species and life stages by study reach
2. Determine appropriate study reach strata for HSC sampling
3. Determine the periodicity of each species/life stage by study reach
4. Determine the most appropriate methodology for developing HSC for a given species and life stage in a given study reach (or study reach strata)
5. Determine target sampling flows and for each study reach based upon unimpaired hydrology
6. Collect site-specific HSC data for each species and life stage in a given study reach (or study reach strata) or, if necessary, test out-of-basin HSC or develop Type I HSC in coordination with local fisheries experts and stakeholders
7. Analyze data and prepare report describing all developed HSC

Because the development of site-specific HSC requires many independent decisions, most of which can exert significant effects on the form of the resulting HSC curves (and hence on resulting flow:habitat relationships), it is vital that such decisions be made in consultation with the CDFW project manager. Consequently, decisions regarding each of the seven objectives listed above should be forwarded to CDFW for their input and approval prior to initiation of the specified task.

2.0 Existing Information/Literature Review

Significant effort has been expended over the years in the Shasta River Basin by CDFW, SVRCD, and university biologists to assess fish species periodicities, population sizes, juvenile distributions, and spawning locations. However, only one report of basin-specific HSC is known to be available. Interim instream flow assessments conducted in the Shasta River (McBain and Trush 2009, SVRCD and McBain and Trush 2013) utilized HSC derived by professional judgment to estimate the relationship between flows and fish habitat. Judgment-based binary HSC (suitable/non-suitable) were developed by a Technical Review Team (TRT) composed of CDFW, fisheries consultants, and NOAA Fisheries. These HSC were largely based on other HSC from the mainstem Klamath and Trinity rivers, and were created by selecting the range of depth or velocity where variable suitability equaled or exceeded 0.5. These suitability ranges were then evaluated and modified based on input from TRT members. Because no field work was conducted to verify the accuracy of the HSC, and because technical guidance from CDFW (CDFG 2008) recommends the use of site-specific HSC wherever possible, the existing HSC are not considered applicable to the current study plan effort.

3.0 Study Areas

During project scoping, the Shasta River was segmented into study reaches using criteria such as hydrology, length, geomorphology, and others (Normandeau Associates 2013; Figures 1 and 2). However, for the purposes of developing and applying HSC it is expected that study reaches will be arranged into reach strata having similar physical characteristics and species occupation. For example, reach strata may be developed based on attributes such as stream type (e.g., spring fed vs. snowmelt), channel size (e.g., mainstem vs. tributary), channel location (e.g., canyon vs. valley vs. headwater), gradient (e.g., low slope vs. high slope), etc. As noted in the above document, potential study reaches do not include reaches above permanent barriers, whether natural (e.g., falls) or anthropomorphic (e.g., Dwinnell Dam). Potential study reach strata are further discussed in Section 4.2.

4.0 Study Methods

4.1 Target Species and Life stages

The target species and life stages anticipated to be included for fish habitat modeling are listed in Table 1. Although lamprey are expected to occur in the study area, little is currently known about their distribution and abundance, and consequently it is unknown if their distribution and abundance will allow development of site-specific HSC. Additional life stages that may be considered during project scoping include adult steelhead holding, which may be an important habitat requirement in the typically small channels characteristic of steelhead spawning grounds. Adult holding habitat and associated cover elements should be collected incidentally during spawning HSC surveys or during winter/spring fry surveys. Because juvenile steelhead may rear for several years in tributaries prior to smolt outmigration, an additional juvenile life stage (e.g., 2++) may be considered for representing the habitat requirements for larger juvenile steelhead, which typically select deeper and faster water than smaller (older 0+ and 1+) juveniles. Assessing the relationships between individual fish size and selected microhabitat parameters should be conducted to determine if additional juvenile size classes are warranted.

Table 1. Target species and life stages for development of HSC.

Species	Life Stages
Oncorhynchus kisutch (Coho Salmon)	**spawning fry rearing juvenile rearing**
Oncorhynchus tshawytscha (Chinook Salmon)	**spawning fry rearing juvenile rearing**
Oncorhynchus mykiss (Steelhead)	**adult holding spawning fry rearing juvenile rearing**
Entosphenus tridentatus (Pacific lamprey)	**spawning ammocoete rearing**

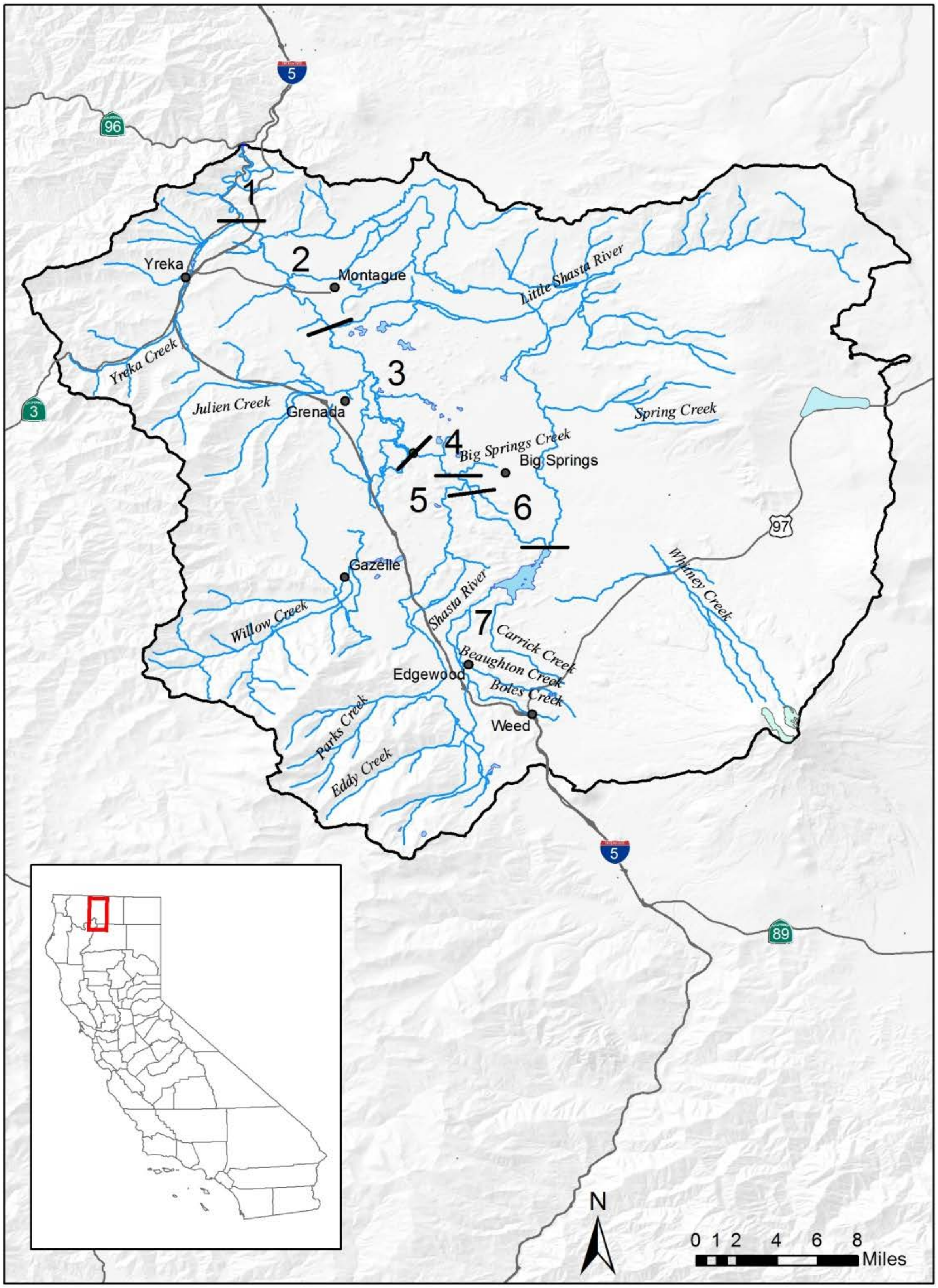


Figure 1. Shasta River Mainstem Reaches.

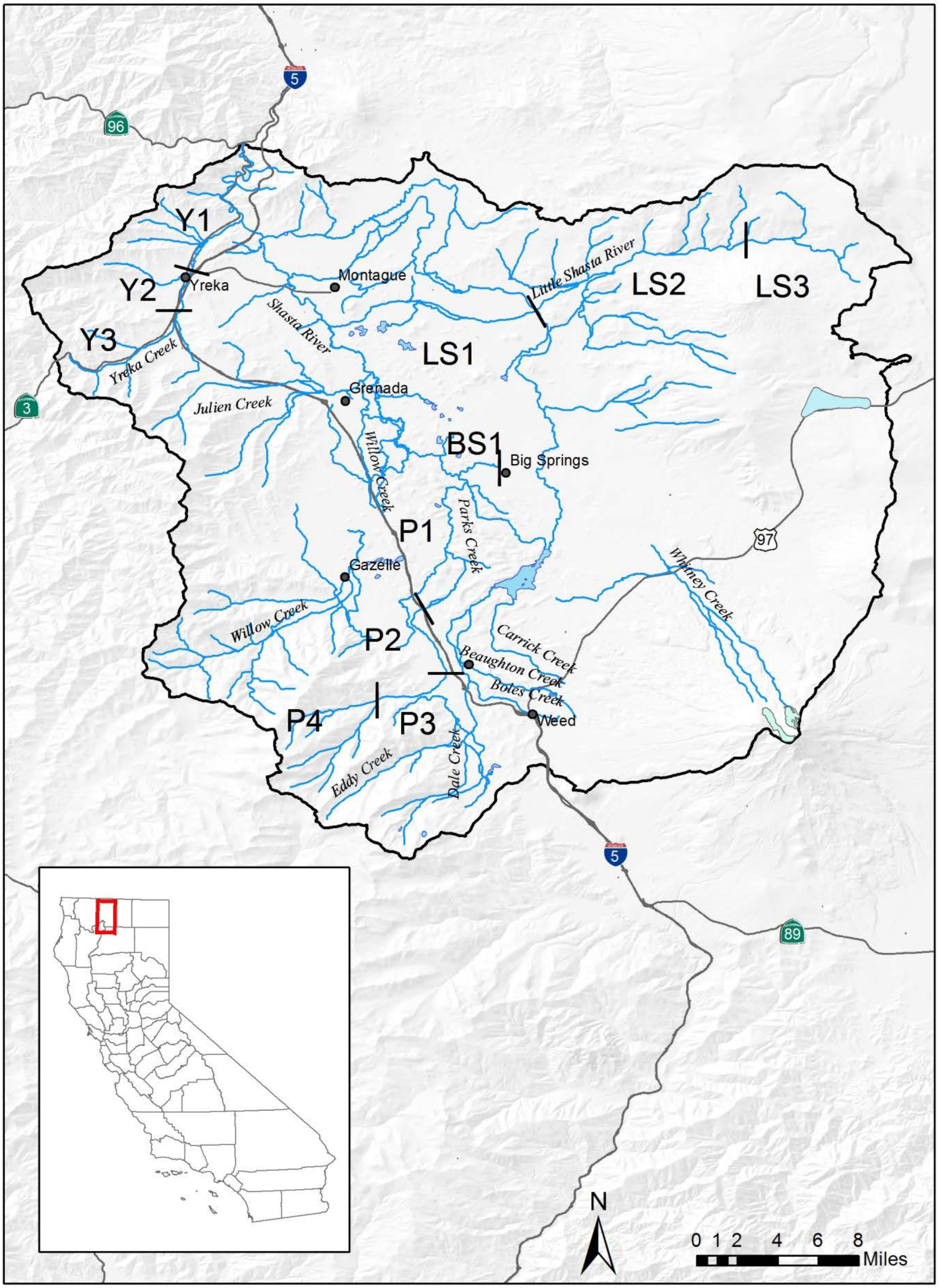


Figure 2. Shasta River Tributary Reaches. Little Springs Creek (Reach BS1a) is a tributary to Big Springs Creek and is not depicted due to its short relative length (0.7 miles).

The definitions of life stages should also be clearly stated, including the fish sizes used to collect site-specific HSC data. Most salmonids are well known to generally occupy faster and/or deeper microhabitats as they grow larger. This shift is particularly noteworthy as newly emerged fry (e.g., young 0+), which are closely associated with bank features, grow into small juveniles (older 0+) and progressively utilize deeper and faster focal positions that are less associated with the stream margins. The close association of small salmonid fry with the stream margins may also require specialized modeling procedures to accurately predict habitat suitability for these critical first weeks of life, particularly since habitat conditions in downstream reaches (e.g., mainstem Shasta or Klamath Rivers) may not be conducive to summer rearing. Consequently, definition of an appropriate size criterion is necessary to distinguish the relatively narrow tolerances of small fry and their rapid change in habitat selectivity as they grow.

4.2 Study Reach Strata

As described above, large differences in habitat and water quality characteristics exist between different locations within the basin, but sampling within each individual stream reach is not feasible given the size of the watershed. Consequently, appropriate reach strata should be developed based on expected species distributions, habitat characteristics, and access, which will then be used to allocate sampling effort to ensure that HSC are representative of strata characteristics. An example of a potential reach stratification scheme would include a mainstem canyon stratum, a mainstem valley stratum, and a headwater/tributary stratum. Specific reaches and sub-reaches organized by expected species and life stage characteristics are presented in Table 2. This potential study reach listing should be assessed prior to HSC site selection through correspondence with local biologists, review of updated studies, and/or site visits to verify species presence and relative abundance. Note that reach-specific information is not currently available for lamprey and will have to be determined prior to HSC site selection for this species.

4.3 Species Periodicities

A wealth of data currently exists describing the periodicity of upstream migration, spawning, juvenile rearing, and outmigration (whether smolt or pre-smolt) for anadromous salmonids in the Shasta River Basin. This periodicity data has been reviewed in various reports (Daniels et al. 2011, Chesney et al. 2007, Chesney & Knechtle 2011, SVRCD & McBain and Trush 2013), but should be reviewed and updated with recent information for selection of final periodicity tables. Table 2 lists general seasonal periods associated with each species and life stage. One aspect of species periodicity that is less well understood is the spring, summer, and fall redistribution of rearing juvenile salmonids from reaches experiencing excessive water temperatures into reaches possessing cold-water refuges, as observed by PIT-tagging studies in the Big Springs Complex area of the upper Shasta River (Chesney et al. 2009, Adams 2013). Consultation with CDFW, SVRCD, TNC-sponsored and other local watershed biologists should be conducted to ensure that the latest data are accounted for when associating species periodicities with specific stream reaches.

Table 2. Potential reach and sub-reach stratification for development and application of HSC in the Shasta River Basin. Seasons are F=fall, W=winter, Sp=spring, Su=summer.

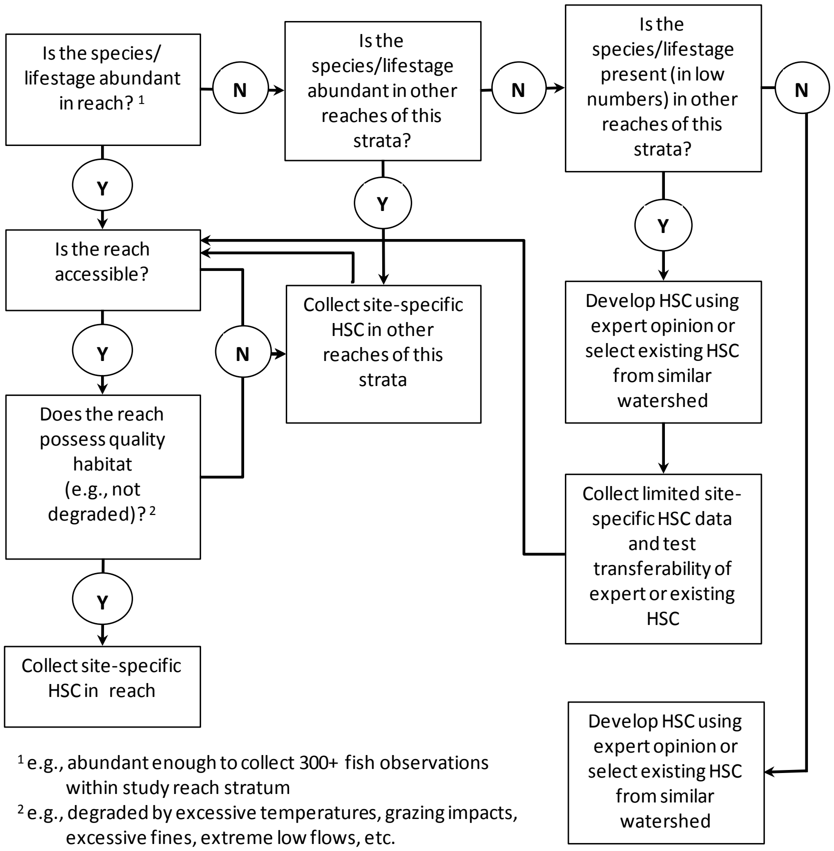
Basin Strata	Reach	Subreach	#	Miles	Species	Life-Stage	Seasonal Use
Mainstem Canyon	Shasta River	mouth-Yreka Cr	1	7.8	Chinook	spwn,rear	F,W,Sp
					Coho	spwn,rear	F,W,Sp
					Steelhead	spwn,rear	F,W,Sp,Su
Mainstem Valley	Shasta River	Yreka Cr-Lil Shasta R	2	8.5	Chinook	spwn,rear	F,W,Sp,
					Coho	spwn,rear	F,W,Sp,
					Steelhead	spwn,rear	F,W,Sp,Su
Mainstem Valley	Shasta River	Lil Shasta R-GID Div	3	14.3	Chinook	spwn,rear	F,W,Sp
					Coho	spwn,rear	F,W,Sp,Su
					Steelhead	spwn,rear	F,W,Sp,Su
Mainstem Valley	Shasta River	GID Div-Big Sprgs Cr	4	3.1	Chinook	spwn,rear	F,W,Sp
					Coho	spwn,rear	F,W,Sp,Su
					Steelhead	spwn,rear	F,W,Sp,Su
Headwater/Tributary	Shasta River	Big Sprgs Cr-Parks Cr	5	1.2	Chinook	spwn,rear	F,W,Sp
					Coho	spwn,rear	F,W,Sp
					Steelhead	spwn,rear	F,W,Sp,Su
Headwater/Tributary	Shasta River	Parks Cr-Dwinnell Dam	6	5.7	Chinook	spwn,rear	F,W,Sp,
					Coho	spwn,rear	F,W,Sp,Su
					Steelhead	spwn,rear	F,W,Sp,Su
Headwater/Tributary	Yreka Creek	mouth-Hwy 3	Y1	3.4	Chinook	spwn,rear	F,W,Sp,
					Coho	spwn,rear	F,W,Sp,Su
					Steelhead	spwn,rear	F,W,Sp,Su
Headwater/Tributary	Yreka Creek	Hwy 3-Greenhorn Cr	Y2	2.3	Chinook	?	?
					Coho	?	?
					Steelhead	spwn,rear	F,W,Sp,Su
Headwater/Tributary	Yreka Creek	Greenhorn Crk-headwtrs	Y3	6.8	Chinook	?	?
					Coho	?	?
					Steelhead	spwn,rear	F,W,Sp,Su
Headwater/Tributary	Little Shasta River	mouth-Low Shasta Rd	LS1	9.5	Chinook	spwn,rear	F,W,Sp
					Coho	spwn,rear	F,W,Sp
					Steelhead	spwn,rear	F,W,Sp,Su
Headwater/Tributary	Little Shasta River	Low Shasta -Cold Bottle Cr	LS2	8.8	Chinook	?	?
					Coho	?	?
					Steelhead	spwn,rear	F,W,Sp,Su
Headwater/Tributary	Little Shasta River	Cold Bottle Cr-headwtrs	LS3	9.2	Chinook	?	?
					Coho	?	?
					Steelhead	?	?
Headwater/Tributary	Big Springs Creek	Big Springs Creek	BS1	2.2	Chinook	spwn,rear	F,W,Sp,Su
					Coho	spwn,rear	F,W,Sp,Su
					Steelhead	spwn,rear	F,W,Sp,Su
Headwater/Tributary	Little Springs Creek	Little Springs Creek	BS1a	0.7	Chinook*	rear	F,W,Sp
					Coho*	rear	F,W,Sp
					Steelhead*	rear	F,W,Sp
Headwater/Tributary	Parks Creek	mouth-I-5	P1	8.2	Chinook	rear	F,W,Sp
					Coho	spwn,rear	F,W,Sp,Su
					Steelhead	spwn,rear	F,W,Sp,Su
Headwater/Tributary	Parks Creek	I-5-EF Parks	P2	3.7	Chinook	?	?
					Coho	spwn	F,W,Sp
					Steelhead	spwn	F,W,Sp
Headwater/Tributary	Parks Creek	EF Parks confl-headwtrs	P3	5.3	Chinook	?	?
					Coho	?	?
					Steelhead	?	?

* potential summer rearing ? potential spawning and/or rearing

4.4 Determine Type of HSC per Study Reach Strata

As previously stated, this study plan assumes that new site-specific HSC will be collected within the Shasta River Basin wherever feasible. Where not feasible due to insufficient fish abundance (or other pertinent reason), an alternative option is to collect a limited sample of site-specific data for testing the transferability of existing HSC from outside sources. This alternative should only be applied following agreement with CDFW and after collaborative selection of existing HSC for the particular species and life stage under consideration. The specific testing methodology used to assess transferability must also be developed under consultation with CDFW. If fish abundance is too low to test transferability (e.g., cannot achieve minimum sample sizes recommended by Thomas and Bovee 2002), or if habitat quality will not allow collection of unbiased HSC test data, the last alternative is to develop judgment-based HSC by a group of species and modeling experts in a series of meetings. Judgment-based HSC should be considered a method of last resort and should only be pursued with the concurrence of CDFW.

The type of HSC utilized for use in habitat modeling in each study reach or study reach strata will be dependent upon the feasibility of developing site-specific HSC in that reach strata. Feasibility will be dependent upon access to the study site, availability of quality physical habitat and non-limiting water quality parameters, and the presence and abundance of the target species and life-stage. Determining which process is most appropriate for a species and life stage in a study reach strata will thus depend on a number of factors, following a decision tree similar to Figure 3.



[1] e.g., abundant enough to collect 300+ fish observations within study reach stratum

[2] e.g., degraded by excessive temperatures, grazing impacts, excessive fines, extreme low flows, etc.

Figure 3. Potential decision-tree for selecting process of HSC development in study reaches for each species and life stage.

4.5 Determine Target Flows for Collecting HSC Data

It is important that site-specific HSC or HSC transferability data is not collected under conditions that impose significant limitations on habitat choice by the target species and life-stage. It is understood that all study sites do not contain a full and unlimited variety of potentially preferred habitat attributes, however it is expected that very high flows or very low flows will impose significant limitations on microhabitat choices, and thus should be avoided. Collection of HSC data should be directed towards intermediate flows that are less likely to restrict movement and position choice. The CDFW instream flow protocols suggests that robust HSC requires data collection under multiple flows, and recommends the use of site-specific flow exceedance curves to select the target flows for HSC data collection (CDFG 2008). Available hydrologic data should be reviewed to locate existing or to develop new flow exceedance curves for study reach strata. Flow exceedance curves are then evaluated to select the number and magnitude of target flows for HSC data collection. Specific flow targets will be specific to study reach strata, species, and life stage and should be determined in consultation with CDFW. Use of such flow criteria for the unique, spring-fed nature of Big Springs Creek and the Shasta River immediately downstream may not be appropriate and will require alternative target values.

4.6 Development of Site-Specific Habitat Suitability Criteria

As stated in Section 4.4, this study plan assumes that, wherever feasible, collection of new site-specific HSC is the preferred process, with the alternatives of testing already existing HSC or developing judgment-based HSC by expert opinion as methods only to be employed as a last resort (Figure 3).

Development of site-specific HSC is a complex process with a wide variety of alternative sampling designs, data collection methodologies, and analytical techniques. Differences in any of these processes can produce significant differences in the shape of HSC models, which can in turn exert significant effects on predicted flow-habitat relationships. Despite a 30+ year history of HSC development, standardized and universally accepted methodologies have not been established, due in part to the wide variation in species behavior and vast differences in the habitat characteristics of project locations, factors that each require adaptability in developing HSC. Despite these limitations, there are a number of factors that are widely recognized as being critical to the development of biologically realistic HSC, including biological stratification of species and fish size criteria, temporal stratification to represent differences in habitat selectivity due to diurnal, seasonal, or flow-related effects, and spatial stratification of habitat at reach and mesohabitat scales (CDFG 2008). Critical factors associated with field sampling and analysis of HSC data include the sampling design used to select study sites, the treatment of habitat availability effects on habitat use, choices related to the pooling of data from various spatial and temporal scales, the definition of substrate and cover attributes, the field procedures for assessing habitat utilization of individual or schooling fish, and data reduction or statistical models used to develop the HSC “curves”.

4.6.1 Biological Stratification

Biological stratifications such as target species and life stage definitions were discussed in Section 4.1. Some HSC studies have also utilized behavioral stratifications to differentiate habitat requirements for different activities, such as daytime vs. nighttime, feeding vs. resting, etc. In most studies involving salmonids, an assumption is made that habitat requirements for fish that are exhibiting daytime feeding activities are more rigorous and, therefore, more protective than are requirements for fish resting at nighttime or exhibiting a daytime, resting behavior. An exception to this rule may include the holding requirements for adult spawners when they are not actively building or defending a nest location. The suitability of spawning locations may, in part, be influenced by the nearby availability of cover sufficient to protect adult spawners, particularly in smaller tributary streams that lack deep water access. For this study plan and the associated budget, assume that HSC development will emphasize the collection of data on fish that are exhibiting undisturbed spawning or daytime feeding behavior.

4.6.2 Seasonal Stratification

In geographic regions where winter months produce cold water temperatures (e.g., <~8^{o}C), overwintering juvenile salmonids will exhibit a dramatic change in diurnal habitat utilization, by hiding within dense cover during the daylight hours and then emerging from the cover into the water column at night. This daytime hiding behavior requires instream cover that is dense enough to effectively block daylight, such as unembedded gravel and cobble substrate, undercut banks, dense root or woody debris structures, etc. In some stream systems such cover may be lacking and may result in a fall or early winter exodus of juveniles into other reaches (Bjornn 1971, Griffith & Smith 1995). For example, spring-fed rivers such as Big Springs Creek and the Shasta River below Big Springs may possess relatively little cover from substrate or bank-related features, but do provide abundant cover in the form of aquatic vegetation (Jeffres et al. 2008, 2010). If the aquatic vegetation dies back over the winter months the rearing juveniles may lack sufficient winter cover for daytime hiding (although the spring-fed water temperatures may not be cold-enough to elicit this behavior) and protection from periodic high flow events (Adams 2013). In contrast to the Big Springs Complex area, it is likely that most of the colder headwater and tributary reaches where juvenile coho and steelhead overwinter will have abundant overwintering cover in the form of large substrate or riparian-associated cover. Consequently, for the purposes of this study plan and associated budget, assume that the seasonal aspects of HSC development will be met by sampling during three seasonal periods for rearing life stages: spring, summer, and fall to capture the period of fry emergence as well as summer and fall periods for juvenile rearing. Spawning HSC will be collected during fall and early winter for Chinook salmon, coho salmon, and lamprey, with winter or spring sampling for steelhead spawning.

4.6.3 Spatial Stratification

The observed habitat selectivity of fish is significantly influenced by the habitat available to them, and such effects must be accounted for in the selection of sampling locations, and in the data collection methods. For example, collection of HSC data from the Scott River tributaries is unlikely to reveal selectivity for aquatic vegetation, while this source of instream cover is clearly a critical factor in focal point selection by juveniles in the Shasta River and Big Springs Creek (Jeffres et al. 2008, 2010). Stratification of sampling efforts by reach, such as that portrayed in Table 2, will help to ensure that all available reach-scale habitat characteristics will be represented in the HSC.

At a smaller spatial scale, different mesohabitat types possess different suites of microhabitat characteristics (see Table 2 in Shasta River Geomorphology Habitat Delineation Study Plan), and should be accounted for in the HSC sampling design. For example, riffles will typically possess a greater abundance of shallow/fast microhabitat types with a higher abundance of larger substrate particle sizes, than will pools which are more dominated by deep/slow microhabitats that are often associated with woody debris cover. Such differences are important to salmonids that show specific selectivity, but which are also distributed across a wide range of mesohabitat types. Although juvenile coho salmon are typically considered to prefer pool habitats with woody debris, an HSC study that over-emphasizes riffle habitats may produce HSC that suggest coho prefer shallow/fast habitats with cobble substrates. Because juvenile coho are closely associated with pool habitats, and juvenile steelhead are often associated with riffle habitats, a properly designed HSC study must be sure to include all mesohabitat types in a systematic and balanced manner. Additional allowance must be made for unique habitat features, such as Big Springs Creek and the mainstem Shasta River below the confluence, which possess mesohabitat characteristics significantly different from most other reaches in the Shasta River Basin (Jeffres et al. 2008, 2010).

Because of the important influence of physical features at the reach and mesohabitat scales on habitat availability and fish habitat selectivity, these influences must be clearly described and accounted for in the development of site-specific HSC.

4.6.4 Specific Factors in Developing HSC

In addition to the general stratification-based factors described above, numerous other factors can significantly influence the shape and character of site-specific HSC, and these factors should be specifically addressed in a logical and defensible manner.

Sampling Design

Wherever possible, random sampling (within study strata) should be employed in order to minimize potential biases introduced by individual pre-conceptions. For example, loose application of direct observation (snorkel) sampling methods will typically lead to a diver migrating towards “good” habitat and avoiding “poor” habitat, which may result in HSC that simply reflects the divers’ personal concept of good habitat. Randomization of sampling areas, whether at the mesohabitat scale or within-mesohabitat scale, will help ensure that all available habitat (e.g., both good and bad) is inspected. Truly poor habitat is unlikely to contain many fish and therefore will not be represented as suitable habitat in the HSC curves, yet the full range of habitat occupancy will be recorded.

This assumption may not be met if sampling is conducted under conditions of severe habitat limitation, where the present fish are capable of tolerating but may not have access to habitat affording opportunities for continued growth and survival. The sampling design and reach stratification process should clearly identify locations or time periods where such limitations exist, and should avoid sampling in such areas. Examples of habitat limitations in the Shasta River may include mainstem reaches during summer periods of high water temperature, habitats degraded or homogenized by past activities such as the reaches intensively grazed with excessive fines and little or no riparian or bank-related cover. The summer aggregation of juvenile coho into small areas of thermal refuge in the Shasta River above Big Springs may provide some opportunities to collect summer HSC data for this species and life stage (Adams 2013, Chesney et al. 2009), but care must be exercised to ensure that the juveniles have a range of suitable habitat from which to choose and express their selectivity.

Although random selection of sampling areas is desirable in most circumstances, random selection can be highly inefficient if the species shows narrow habitat tolerances. Spawning salmonids have very specific substrate requirements that make the majority of a stream channels unsuitable for redd construction; consequently, a purely random approach to development of spawning HSC may be highly inefficient. Instead, it is expected that independent redd survey crews will inform the HSC crews on what reaches are experiencing spawning activity in order to focus collection of spawning HSC data. Other potential examples of non-random or adaptive site selection may include focus on thermal refuges used by juvenile coho or steelhead in mainstem reaches. In a similar manner, the typically close association of small salmonid fry with the streambank may make sampling of midchannel areas ineffective and inefficient. In specialized cases such as these, it will be important to link the spatial scope of hydraulic analysis to the scope encompassed by the HSC; for example, by only modelling spawning within spawning riffles, or restricting modeling of fry rearing habitat to the stream margins.

Habitat Availability

The significant effects that habitat availability exerts on observed habitat selection by fish, whether in healthy habitat or in areas of habitat limitations such as that discussed above, must be accounted for in the sampling design and analysis of HSC data. There are numerous potential models that can be employed to account for the influence of habitat availability on habitat selection (c.f., Manly et al. 2002), but each have their strengths and weaknesses. Treatment of habitat availability in HSC studies have typically occurred either through sampling design (e.g., equal-area sampling), specific sampling protocols (e.g., presence-absence sampling with logistic regression, density sampling with poisson regression), or post-application of independently collected habitat use and habitat availability data (e.g., forage ratios).

The equal-area sampling approach (Bovee 1998) may be successful given careful habitat stratification to ensure that fish observations within depth, velocity, and substrate/cover strata will reveal actual selectivity for those attributes. Presence-absence and density protocols inherently include habitat availability effects by creation of HSC from data that include locations that are occupied by the target species/life stage as well as locations were the fish were absent. However, proper application of such methods should fall within a habitat-stratified approach to ensure that all available habitats are accounted for. Application of forage ratios in the development of HSC is commonly employed, but must be done with caution and with careful review of ratio results due to the frequent misapplication of extreme ratios that can severely over-emphasize the suitability of rare habitat and de-emphasize the suitability of commonly used habitat.

Factors that are frequently cited as promoting more robust HSC include achieving adequate sample sizes for both fish observation data and habitat availability data (if collected separately), sampling a wide variety of study sites (but avoiding degraded habitat), and sampling at different flows (but avoiding flows with habitat limitations). This study plan assumes that HSC and habitat availability data will be collected using an equal-area sampling design within an approved mesohabitat classification scheme that associates the CDFW Level III typing scheme with basic microhabitat characteristics (e.g., incorporates *at a minimum* a deep/slow, deep/fast, shallow/slow, and shallow/fast classification). Habitat availability may be measured independently within the HSC study sites using a random point sampling methodology, or measured within associated hydraulic habitat modeling reaches (e.g., 1D or 2D sites). In either case, the habitat availability data must be collected in the same locations where the HSC data is collected in order to ensure that both datasets (the habitat use and the habitat availability) are representing the same universe of habitat. Habitat availability data collected outside of an HSC study reach may encompass habitat not available to the observed fish, and will therefore suggest that such habitat is not suitable when it may in fact be highly suitable. An opposite artifact may occur if target species are observed in microhabitats that are not encompassed or are inadequately encompassed by the habitat availability data, which may result in an assumption that such habitat is not suitable (e.g., fish occurring where habitat is not available) or else may lead to overinflated suitability of that microhabitat (e.g., due to a few fish observed in a rare location).

Consequently, the habitat availability dataset must be sufficiently robust to ensure that the full range of habitat is assessed and that rare microhabitats are adequately represented. Habitat availability datasets with less than 500 data points may not be sufficient to characterize HSC sampling reaches, particularly if HSC data is collected from a large number of specific sampling reaches (as is expected). Care must also be taken to ensure that the proportional sampling of habitat use data is equivalent to the proportional sampling of habitat availability data. This study plan assumes that both habitat use and habitat availability data will be collected based on an equal-area sampling design. Consequently, if hydraulic modeling data is used to represent habitat availability for assessing that habitat use data, the availability may require re-weighing to ensure that the data does not over or under-emphasize specific mesohabitat types.

The influence of habitat availability on habitat selection and development of HSC is most strongly apparent on the rearing life-stages of target species. In contrast, assessing the effects of habitat availability on suitability for salmonid spawning may not require the same degree of effort, due to the highly restricted nature of spawning site selection. Salmonids have very rigorous substrate requirements for nest selection, which effectively restricts spawning to a relatively narrow range of utilized habitats. Consequently, this study plan assumes that habitat availability data collected during HSC spawning surveys will be limited to assessing the range (maxima and minima) in depths and velocities that are present in the patch of spawning substrate where the observed redd(s) occurred. This alleviates the strict necessity of collecting spawning habitat availability data in pools, high gradient riffles, or other habitats where substrate characteristics are not conducive to spawning.

Measured Microhabitat Variables and Data Collection Protocols

Most instream flow analyses utilize HSC that describe suitability for depth, mean column velocity, substrate type, and/or cover type, and this study plan assumes collection of at least these four variables. Spawning HSC is expected to emphasize substrate characteristics over cover elements, in contrast to juvenile rearing where substrate particles and other physical features (e.g., aquatic or terrestrial vegetation, woody debris, undercut banks, etc.) would be expected to function as cover from predation, high velocities, or other influences.

Although some studies have utilized additional variables, such as sub-gravel permeability and/or upwelling (for spawning), or distance to bank, distance to cover, adjacent velocities, etc. (for juvenile rearing), to be effective at refining the flow:habitat relationship such variables must be compatible with the hydraulic model that will be used to assess the availability and (for 2D models) the spatial characteristics of those variables. If non-traditional variables are proposed for use, these variables must be clearly described along with how they will be incorporated into the habitat modeling process. Traditional variables must also be clearly described, such as the particle sizes and areal extent of substrate classification (e.g., see Shasta River Hydraulic Habitat Study Plan), and thorough descriptions of cover classifications, including the spatial aspects of assessing those variables (e.g., distance or direction to cover). Note that the unique habitat features of the Big Springs Complex may suggest the use of non-traditional microhabitat variables and non-traditional flow:habitat models (Jeffries et al. 2008, McBain & Trush and HSU 2013).

If study scoping indicates that previously existing HSC may be tested for transferability within the study basin, site-specific data collection must include the same substrate and cover codes used in the source HSC study. Additional miscellaneous data collected at each sampling location will include mesohabitat unit and type, GPS coordinates of sampling areas, time of day, water visibility (measured using a consistent and repeatable protocol), and water temperature.

Water temperatures may need to be measured throughout the sampling unit and at each fish focal position if thermal heterogeneity is present (e.g., at spring outflows).

All site-specific data should be collected at the finest scale that is appropriate to the target organism. Rearing juvenile salmonids typically select focal positions from which they intercept drift, and it is assumed those feeding positions (rather than resting or hiding positions) will be the focus of the rearing HSC data collection. Snorkeling is the preferred methodology for identifying undisturbed focal positions, and given the clarity of the streams in the study basin it is assumed that snorkeling will be the primary methodology for collecting rearing HSC data. Data should not be collected on any individual fish thought to have been disturbed or displaced by the diver before its selected focal position was identified. Consequently, smaller sampling areas should be surveyed by a single diver to avoid confusion over previously marked and/or disturbed fish. Multiple divers may be employed in mainstem study sites if they are adequately separated to minimize movement of fish between divers.

Divers must enter each sampling area carefully to minimize displacement of target fish, and must move slowly to ensure identification of species, fish size (to nearest cm fork length), fish behavior, and focal position. Noting behavior as feeding, holding, hiding, or disturbed will serve as a quality control mechanism as fish that are actively feeding can be reasonably assumed to be undisturbed. Disturbed or hiding fish will not be measured, although the structure used by hiding fish may be noted to help assess what cover types are utilized. Divers will place a numbered marker immediately beneath the fish’s focal position for subsequent relocation and measurement of focal microhabitat parameters (depth, velocity, substrate or cover).

Juveniles that occur in tight aggregations, such as newly emerged fry or (in some cases) schooled juvenile coho or chinook salmon, may require characterization of group areas rather than of individual focal positions. In such cases multiple microhabitat measurements should be made to adequately characterize the group location. The number of measurements made at each group location should be based on a set protocol that is dependent on the spatial area encompassed by the group, such as (for example) one measurement per two square feet. Group areas having high complexity may require more dense measurements, whereas a large, homogenous area may require fewer measurements. It is strongly recommended that each separate microhabitat measurement for grouped fish should be considered a single habitat observation, regardless of the number of fish present. In other words, individual measurements should not be utilized multiple times when assessing frequency of use, which can lead to multimodal distributions of habitat use and can confound assessment of selectivity. For fish that commonly occur in groups but are otherwise uncommon in the study area (e.g., coho juveniles), it may be necessary to collect microhabitat measurements in a higher density than for more common species where an adequate number of locations can be measured to represent a habitat use observation.

The basic microhabitat parameters (depth, velocity, substrate or cover) will also be collected at each habitat availability location. In addition, each availability location will be assessed for the nearby presence (or absence) of any fish focal positions, utilizing a fixed distance criteria of, for example, two feet. If a fish focal position (as indicated by the deployed markers) occurs within the specified distance of the availability location, it will be designated as an “occupied” position by the species and life stage represented by the nearby marker. Availability locations not in proximity to an existing marker will be classified as “unoccupied” locations. This occupied/unoccupied dataset may be used for assessing transferability of existing HSC in the event that site-specific HSC data is too limited to create new HSC (Thomas and Bovee 2003, Groshens and Orth 1994). Alternatively, the data can be used as presence/absence data in a logistic regression model to develop new HSC (Thielke 1985, USFWS 2005). Note that this occupied/unoccupied data can only be recorded if the availability data is collected in concert with the habitat use data, e.g., not based on independent availability measurements from 1D or 2D hydraulic modeling sites collected at a different time.

In contrast to rearing juvenile salmonids, adult anadromous salmonids will utilize a much larger spatial area for redd construction (e.g., square meters vs. square feet). Although the redd is a visible indication of the fish's site selectivity, redd microhabitat data will only be collected where the adult fish are present and positively identified to species by the HSC crew or by a previous redd survey crew. If redd surveys have verified that a specific stream reach is only utilized by a single species (whether by spatial or temporal separation), and if recent flow history strongly suggests that a non-occupied redd was constructed under similar flow conditions, redd HSC data can be collected at redds absent of adult spawners. Application of statistical models to distinguish species of unoccupied redds where spawning periodicities overlap (e.g., coho and chinook or coho and steelhead), such as that used by Gallagher and Gallagher (2005), should only be applied following consultation with CDFW.

Redd microhabitat characteristics will include, at a minimum, depth, mean column velocity, and substrate characteristics at three locations per redd: immediately upstream of the redd pit, and immediately to each site of the redd pit. These measurements are intended to represent, as best as possible, the microhabitat conditions that existed prior to redd excavation. Mesohabitat type or sub-type (e.g., pool tail) or other physical feature associated with the gravel deposit and redd location should be noted. Additional redd habitat parameters, such as pit and tailspill dimensions, tailspill substrate characteristics, substrate embeddedness, distance to nearest hiding cover for adult spawners, etc., may also be collected; however only those parameters that are incorporated into the hydraulic model will be used to assess the spawning flow:habitat relationship. As stated above, assessing habitat availability associated with redds may be limited to measurements of the minimum and maximum depths and velocities available at each gravel deposit, in order to qualitatively assess if the redds are being limited by the availability of microhabitats within potential spawning areas.

Although direct observation methodologies should be used for assessing spawning and rearing of adult and juvenile salmonids, alternative methodologies, such as electrofishing for lamprey ammocoete rearing, may be necessary and should be discussed with CDFW prior to application.

Pooling HSC Data from Various Strata

Collecting HSC data from a variety of reaches, habitat types, seasons, flows, etc., is generally considered to produce more robust and representative HSC, but it raises issues associated with pooling data from different sampling strata. It is not feasible to develop and apply different HSC for a large number of study strata, thus HSC data are typically pooled into appropriate levels of application, e.g., summer vs. winter, mainstem vs. tributary, etc. However, pooling HSC data can contribute artifacts that may not be desirable. For example, in most studies involving data collection over several reaches, higher juvenile densities in a reach may produce a larger number of fish observations in that reach. HSC data directly pooled from all reaches will result in a final HSC curve that is most representative of the reach having the most fish. If the higher fish densities in a given reach were due to greater habitat quality rather than simply due to greater sampling effort or restricted escapement of adult spawners, direct pooling of data between reaches may be desirable. If, on the other hand, higher sample sizes occurred in a specific reach simply due to greater effort or greater adult escapement, direct pooling may generate HSC that unintentionally emphasizes specific reaches. In the latter case, re-weighting of the HSC data by reach may be necessary prior to pooling the data. Weighting the HSC data to equalize samples sizes from multiple reaches may also introduce artifacts if low sample sizes in one or more reaches produce spurious distributions, and such effects should be avoided.

Creation of HSC Models

As noted above, the development of site-specific HSC can follow many paths, including the procedures used to reduce the collected habitat data into an HSC model. Methods can vary from a simple histogram analysis to a complex multivariate analysis; however most traditional instream flow studies utilize each microhabitat component (depth, velocity, substrate, cover) as an independent variable that is combined to estimate suitability of a specific location at a specific flow. For the purposes of this study plan, it is assumed that HSC development will involve a frequency analysis of pooled habitat use (by species and life stage) and habitat availability data derived from an equal area sampling design. The pooled habitat use data HSC will be compared to HSC curves based on habitat use data adjusted by habitat availability data (e.g., normalized use/availability ratios). The final decision to select use-only HSC, use-to-availability HSC, or HSC developed by alternative methods that account for availability (e.g. logistic regression, presence-absence) will be made in consultation with CDFW. Frequency smoothing methods (if used), including identification and correction of spurious ratio results, must be clearly described. Any judgmental decisions on HSC curves, such as treatment of suitability at zero velocity or suitability at depths or velocities beyond measured values, should also be clearly described. Any use of non-traditional HSC variables or HSC development procedures, must be shown to be compatible with the hydraulic model and should be adequately justified and approved for use prior to application. Note that CDFW, at its discretion, may choose to obtain and develop the final HSC in place of or independently of the contractor.

5.0 Deliverables

Study products will include a study report that encompasses a summary of HSC meeting results, field methods, data analysis, and resulting HSC curves for each species and life stage, with comparison of final HSC with data from other studies. All raw HSC or transferability data, including GIS and imagery data, will be made available on CD.

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