Estimating Potential Stream Carrying Capacity with an Assessment of Anadromous Salmonid Habitat in the Upper Mainstem Eel River, California, USA

Emily Cooper
Humboldt State University
Internship Time Period: June 2016 – October 2016

Advisor: Dr. Alison O'Dowd
Humboldt State University

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Executive Summary

Large flood control and hydroelectric dams have contributed to freshwater habitat degradation and species decline through watershed fragmentation, disruption of natural flow regimes, blockage from historical salmonid spawning and rearing habitat, and interference of nutrient distribution. Anadromous salmonid populations in northern California's Eel River watershed have been impacted by two dams that are part of the Potter Valley Project, and current populations of Coho, Chinook, and steelhead are estimated between 1-3% of their historic populations. In response to the need for addressing the upcoming FERC relicensing of Scott Dam beginning in 2017, this project provides an assessment of salmonid habitat and an estimation of potential stream carrying capacity for steelhead trout (*Oncorhynchus mykiss*) and Chinook salmon (*O. tshawytscha*) in the Upper Mainstem Eel River sub-watershed above Scott Dam's reservoir to inform the relicensing decision and recovery management for anadromous salmonid populations.

In addition to using the Intrinsic Potential (IP) Model from the National Marine Fisheries Service (NMFS), fish passage barriers upstream of Scott Dam were verified for identifying potential distribution for each species of interest. Streams within the designated study site were then stratified into reach types that were then subsampled for implementing habitat assessment field surveys. These habitat data are currently being summarized among survey reaches to estimate potential juvenile capacity for steelhead and Chinook salmon, and the habitat summaries and capacity estimates will then be extrapolated from survey reaches onto corresponding reach type strata. The capacity estimates will be scaled up from the habitat unit to the reach scale, and ultimately to the watershed scale for the entire study site.

Two methods for modeling potential capacity for each species of interest are being used. The Unit Characteristic Method uses fish density values specific to habitat units (i.e. pools, riffles, glides), and the density values are then adjusted according to other habitat parameters (i.e. fish cover, depth, substrate, etc.) and how they deviate from average conditions within the study site. Ripple, a GIS-based capacity estimation model, estimates specific capacity for a given species for each life stage at simulated seasonal flow events using a 10 m resolution digital elevation model. The results from these two approaches to estimating potential carrying capacity will be compared not only to each other but also to estimates from past reports including the IP Model. Implications of this research have the potential to inform the dam relicensing process as well as recovery management actions for native salmonid populations in the Eel River.

Project Objectives

This project is an assessment of salmonid habitat in the Upper Mainstem Eel River sub-watershed above Scott Dam to inform recovery needs for anadromous salmonid populations. The Potter Valley Project is an inter-basin water transfer project that consists of Cape Horn Dam and Scott Dam, a hydroelectric plant, and an eight-foot diameter diversion tunnel that pumps water from the Upper Mainstem Eel River to the headwaters of the Russian River in the Potter Valley (NMFS, 2002). Although a fish ladder allows passage at the downstream dam, Cape Horn Dam, fish are unable to pass upstream of Scott Dam. The waterways upstream of Scott Dam were historically used by anadromous salmonids, but Scott Dam has been blocking access to the area now for almost 100 years (Langridge, 2002; Yoshiyama & Moyle, 2010; NMFS, 2012). These two dams have contributed to the impact on anadromous salmonid populations in Northern California's coastal Eel River watershed, and current populations for coho, Chinook, and steelhead are estimated between 1-3% of their historic populations (USFS & BLM, 1995; Yoshiyama & Moyle, 2010; NMFS, 2012). Scott Dam's current 50-year license through the Federal Energy Regulatory Commission expires in 2022, and the process for relicensing begins in 2017. A crucial part of the FERC relicensing process will be to understand the impacts associated with the Potter Valley Project on the recovery of anadromous fish populations.

There are discrepancies among past assessments in estimates of the amount of potential salmonid habitat and carrying capacity upstream of Scott Dam (VTN, 1982; USFS & BLM, 1995). A study conducted by Venture Tech Network (VTN) in 1982 quantified a total of 35.7 miles of major channel habitat and an additional 22.7 miles (totaling 58.4 miles, or ~94 km) of minor channel habitat being blocked above Scott Dam. The assessment methods for the VTN (1982) study consisted of reconnaissance level air surveys along with ground-level surveys in select locations, and its results include several barriers to anadromy in the waterways upstream of Lake Pillsbury along both the mainstem Eel River as well as the Rice Fork tributary. Several years later, in 1995, the US Forest Service (USFS) and Bureau of Land Mangement (BLM) released a "Watershed Analysis Report for the Upper Main Eel River Watershed," in which they estimated about 100 miles (160 km) of anadromous fish habitat being blocked by Scott Dam, but methods for this estimate were not elaborated upon. In 1999, the Center for Ecosystem Management and Restoration (CEMAR) provided a synthesis of information on historical distribution and current status of both anadromous and resident *O. mykiss* in the upper mainstem Eel River both up and downstream of the Potter Valley Project (Becker and Reining). The CEMAR study reports distribution and use of almost all streams by *O. mykiss* both historically and currently above Lake Pillsbury, beyond those barriers to migration classified by the VTN (1982) report. VTN (1982) estimates potential abundance from density values derived from spawner surveys in other streams of the Eel River, resulting in an historical estimate of 3356 steelhead spawners and 2499 Chinook spawners and a current estimate of 1499 steelhead spawners and 1250 Chinook spawners. Some unpublished data from California Department of Fish and Game (1979) estimates historical abundance in the watershed area above Scott Dam to be 2500 steelhead and 2300 Chinook. Finally, another approach for estimating potential habitat and abundance comes from the IP Model developed by NMFS. The IP Model maps potential stream habitat in a GIS and estimates potential abundance from other data containing spawners per linear unit, similar to abundance estimate methods used by VTN. The disparities described among estimates from each of the aforementioned sources are too large to overlook, therefore imploring the necessity for clarification.

In response to the need for addressing the upcoming FERC relicensing of Scott Dam with current, sound scientific data, this project's goals are to: 1) quantify anadromous salmonid spawning and rearing habitat and 2) estimate potential stream carrying capacity in the mainstem Eel River watershed upstream of Lake Pillsbury for Chinook salmon and steelhead trout if access to the area upstream of the Scott Dam were restored.

Original project goals also included Coho salmon as a species of interest; however, based on historic distribution data and fish counts from the past 20 years at the California Department of Fish and Wildlife (CDFW) Van Arsdale Fisheries station at Cape Horn Dam, Coho salmon are not believed to use interior streams as far inland as those upstream of the Potter Valley Project. Thus, the species of interest for this project include fall-run Chinook salmon and winter-run steelhead trout. The goals for the amount of ground-based habitat assessments also changed as the project developed. Specifically, after field reconnaissance in the study site during Spring of 2016, it was made clear how limited the access to streams is in the study site and that there would have to be some bias in survey site selection as a result. Original goals for survey length per day were estimated at about 3 km/day, but were adjusted to 0.5-1 km/day after reconnaissance and protocol training. Originally, specific project tasks included the following:

• Conduct field reconnaissance and observe high flows at project site in January of 2016.

• Conduct watershed characterization through geospatial analysis of elevational data and areal imagery using an Intrinsic Potential (IP) fish model. This will be used to identify potential migratory barriers for salmonids based on slope for determining possible portions of stream reaches that are inaccessible to spawning adults.

• Compile identified potential natural barriers for fish passage from geospatial analysis and from past Upper Eel River assessments including VTN (1982), and CEMAR (2009) onto one map for ground-truthing field surveys by March 2016.

• Correspond with Forest Service employee Hilda Kwan, West Zone Hydrologist, at Mendocino National Forest for accessing areas of the project site from National Forest roads.

• Ground check potential known migratory barriers with National Marine Fisheries Service (NFMS) and other collaborators by May 2016.

• Stratify identified potential stream habitat into reach types.

• Identify feasibly accessible and ecologically representative areas of reach types for habitat field surveys on a map.

• Conduct habitat field surveys with a two-four person crew in identified areas from May-June 2016 using methods from CDFW's California Salmonid Stream Habitat Restoration Manual, Part III (2004).

• Validate IP model by comparing it to field data where there is overlap.

• Analyze all data to quantify salmonid habitat and potential carrying capacity.

Thus far, all but the final two listed project tasks were conducted as planned, and the final two tasks are currently underway. Data analysis should be complete and results reported by May of 2017.

All field work was conducted in the Mendocino National Forest, so collaboration from Forest Service employees in both the Upper Lake Ranger District and the Grindstone Ranger District was necessary for approval to conduct field work and for pertinent information on area access and other related work being done by the Forest Service in the area. This exposure to professionals in the USDA Forest Service provided useful insight for potentially incorporating a USDA agency position in my career path. Upon completion of a Master of Science in Natural Resources at Humboldt State University, I aim to work professionally in a salmonid habitat and watershed management position such as Fisheries Biologist or Stream Ecologist.

Project Approach

This project used geospatial analyses followed by on-the-ground verification of salmonid habitat. Initial watershed characterization for identifying limits to salmonid extent within the Eel River watershed was evaluated by NMFS with an Intrinsic Potential (IP) Model using a 10m resolution Digital Elevation Model (DEM) in a Geographic Information System (GIS). Essentially, IP modeling determines potential range of accessible habitat for salmonids based on slope, valley constraint, and annual discharge for determining possible portions of stream reaches that are inaccessible to spawning adults and unsuitable for rearing juveniles based on suitability curves (Figure 1) (NMFS, 2005; Burnett et al., 2007). Habitat requirements for each salmonid species are evaluated using IP parameters, and areas upstream of identified barriers for migration are omitted.

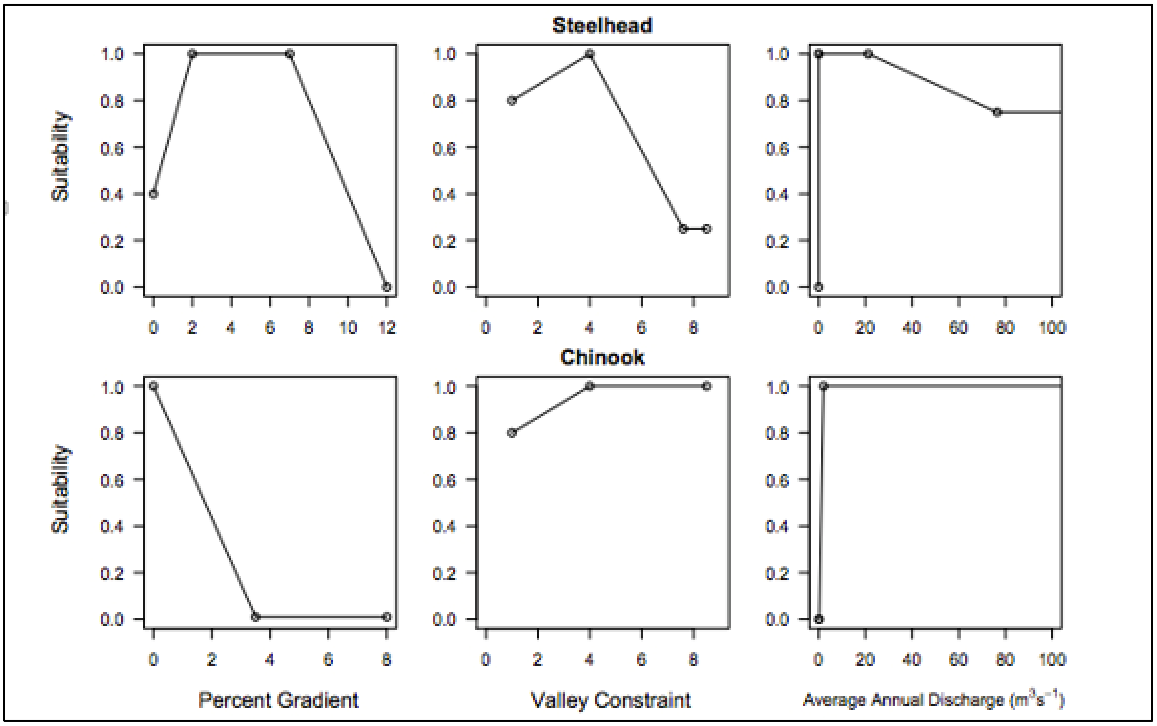

Figure 1. Suitability curves for each of the three IP components (gradient, valley constraint and discharge) for steelhead and Chinook. Note the scale change (abscissa) across each species for the gradient attribute (NMFS, 2005).

The IP model assigns a score from 0 – 1 to each segment of stream within the model stream network, and the IP score scales the actual stream segment length to a weighted length. For Central California Chinook ESU (CC Chinook), NMFS originally mapped a total stream length of 97 km in the upper mainstem Eel River watershed above Scott Dam with an IP weighted value of 60 IP-km; for Northern California Steelhead DPS (NC Steelhead), a total stream length of 318 km was originally mapped in the upper mainstem Eel River watershed above Scott Dam with a weighted IP-km value of 218 IP-km. However, because the IP Model has relatively coarse resolution at about 100 m^2, it was known that potential passage barriers could be misclassified. The area in Figure 2 marked by a star was originally classified by the IP Model (as well as other past reports) as a passage barrier for both Chinook and steelhead, yet there were mixed reviews from other sources on whether this site is a true barrier to anadromy.

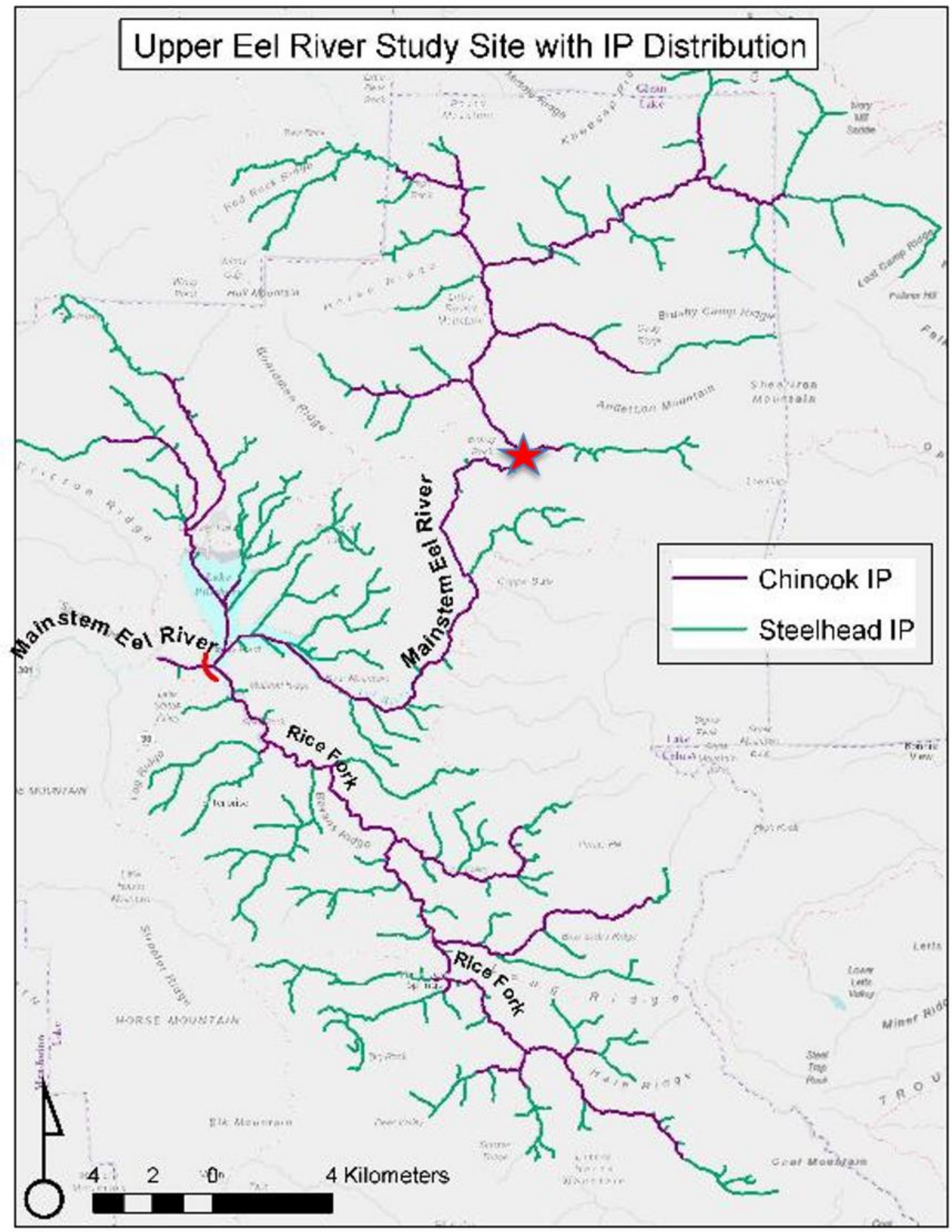

Figure 2. Intrinsic Potential Model with potential distribution of Chinook salmon and steelhead trout upstream of Scott Dam in the upper mainstem Eel River, CA. The star on the map designates a barrier site that was reclassified as a partial barrier after ground-based assessments conducted in May 2016. (NMFS, 2016).

This potential barrier was observed by myself and another HSU student on 20 February, 2016 during high winter flows (11.5 cubic m/s about 0.5 km downstream of the falls) with photo documentation and field measurements including vertical height, horizontal width, and depth of staging pool, using methods adapted from Gunther et al. (2000) in the *Assessment of Fish Upstream Migration at Natural Barriers in the Upper Alameda Creek Sub-Watershed* (SFPUC, 2010) (Figures 3-4).

Figure 3. Standing at river left of Bloody Rock roughs on 2/20/2016 at ~400 CFS. Stadia rod is in meters.

Figure 4. View of Bloody Rock roughs from downstream on 2/20/2016 at ~400 CFS. Red arrow indicates approximate position of individual in Figure 3. Red circle marks a 6’ man in the picture for scale.

The site was again assessed by myself and other expert fisheries biologists from NFMS and fish passage expert Ross Taylor on 17 May, 2016 during lower flows (~58 CFS). Bloody Rock roughs was reclassified as a partial barrier for both steelhead and Chinook during seasonal low flows, but that it should not be a barrier during high flows typical of spawning run times. Therefore, the potential range of distribution for potential habitat was extended beyond this site, closer to the headwaters of the mainstem Eel River. This resulted in an increase in the total stream length for potential distribution for both steelhead and Chinook, and the reclassified distribution in the IP Model was considered part of the study site for this project's field-based surveying of suitable salmonid habitat (Table 1).

Table 1. Total mapped km and weighted km in the NMFS Intrinsic Potential Model for Chinook salmon and steelhead trout in the upper mainstem Eel River upstream of Scott Dam. The table shows a comparison of potential habitat values before and after a ground-based natural barrier assessment and their respective percent increase in length of stream habitat.

	Chinook		Steelhead	
	Total km	IP km	Total km	IP km
Pre-Barrier Assessment	97	60	318	218
Post-Barrier Assessment	144	83	463	333
% Increase in Habitat	48%	38%	46%	53%

Once potential distribution was identified in the study area for each species of interest, the next step in the research process was to develop a field survey design that would capture ecologically representative and spatially distributed areas of the streams in the study site. Stream characteristics pertaining to both geomorphological processes and fish habitat were identified for stratifying the stream network into different reach types. Stream gradient is included as a stratification variable due to its correlation with flow velocity, substrate composition, channel morphology, and stream habitat types; stream size measured in drainage area is included due to its correlation with channel morphology, habitat types, habitat stability, and flow volume (Higgins et al., 2005). Stream gradient and drainage area data were associated with the streams in the IP Model, and the reach type strata represent a set of ranges for both gradient and drainage area (Table 2).

Table 2. Reach Type strata and their descriptions for streams in the upper mainstem Eel River upstream of Scott Dam.

Reach Type	Reach Type Description	
	Gradient	**Drainage Area**
1.2	0 - 2%	2 - 10 sq. km
1.3	0 - 2%	10 - 100 sq. km
1.4	0 - 2%	>100 sq. km
2.1	2 - 7%	0 - 2 sq. km
2.2	2 - 7%	2 - 10 sq. km
2.3	2 - 7%	10 - 100 sq. km
3.1	7 - 12%	0 - 2 sq. km
3.2	7 - 12%	2 - 10 sq. km
3.3	7 - 12%	10 - 100 sq. km
4.1	> 12%	0 - 2 sq. km
4.2	> 12%	2 - 10 sq. km

After the streams were stratified into reach types, a randomized subsample of 25 survey locations proportional to the frequency of each reach type by length was generated using the Generalized Random Tessellation Stratified (GRTS) method for a linear resource (Kincaid, 2015). Five times the number of survey locations within each reach type stratum were also assigned as oversample sites for backup (Figure 5).

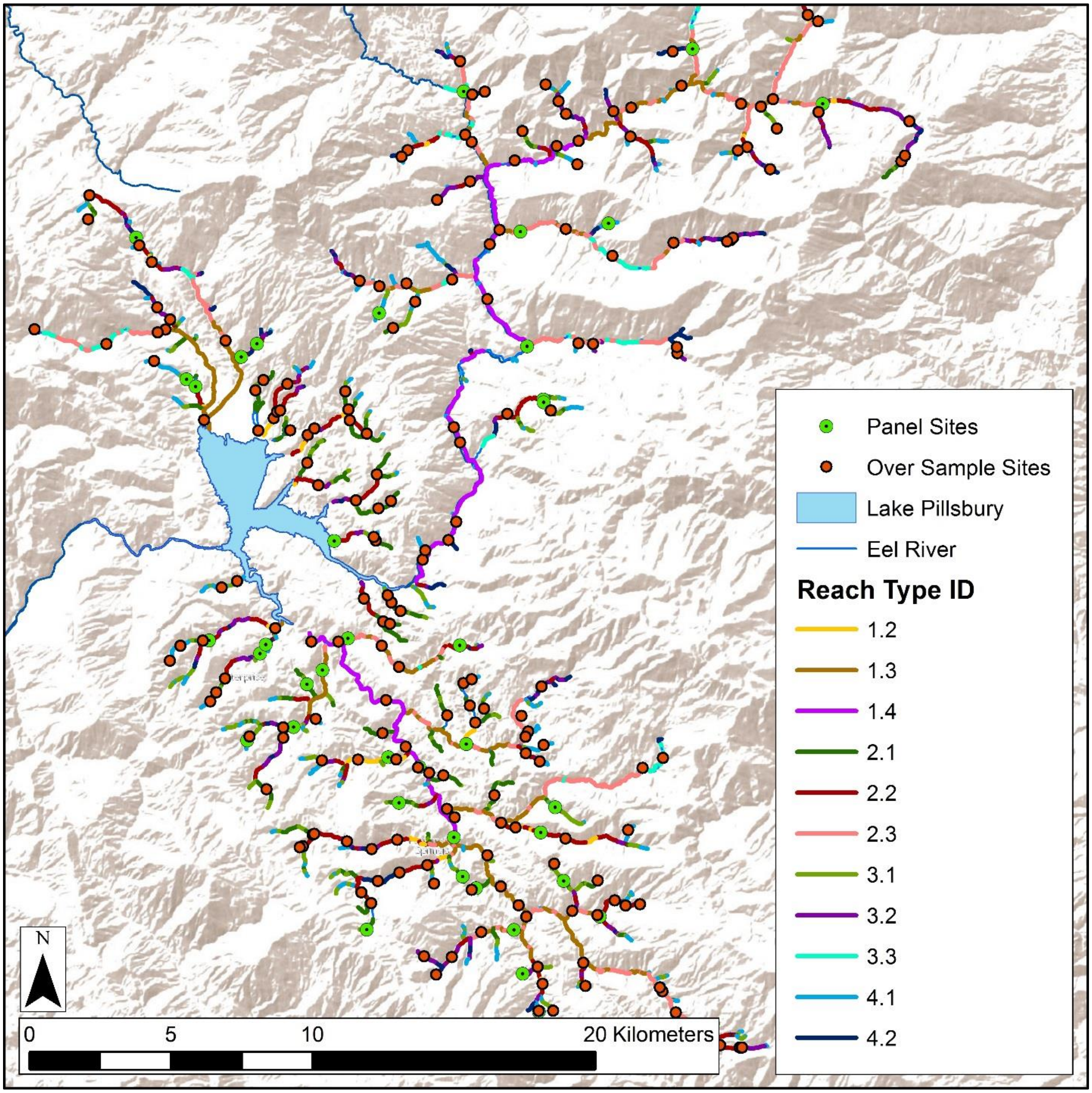

Figure 5. Study site stream network with stratified reach types and GRTS subsample of survey locations in the upper mainstem Eel River, CA, showing both panel and oversample sites.

Once a subsample of survey locations was generated, field surveys were conducted during the months of late June – early August 2016. Habitat inventory surveys were conducted in the field with methods from California Department of Fish and Wildlife's *California Salmonid Stream Habitat Restoration Manual, Part III*. Salmonid habitat was classified by area and depth of habitat unit composition as it relates to fish habitat use. Other habitat conditions related to fish density were measured including instream large woody debris, fish cover, streambed substrate composition, canopy cover, discharge, and water quality variables such as temperature, alkalinity, and turbidity.

Project Outcomes

A total of 20 wetted stream reaches totaling 13.2 stream km and 11 dry stream reaches totaling 6.3 stream km were surveyed. Survey sites were visited in order according to their proportion by reach type length, spatial distribution within the study site, and access (Figure 6). Access to streams in the study site was a limiting factor, and all routes used for field surveys were recorded in detail and compiled into one document for any future field work in the area.

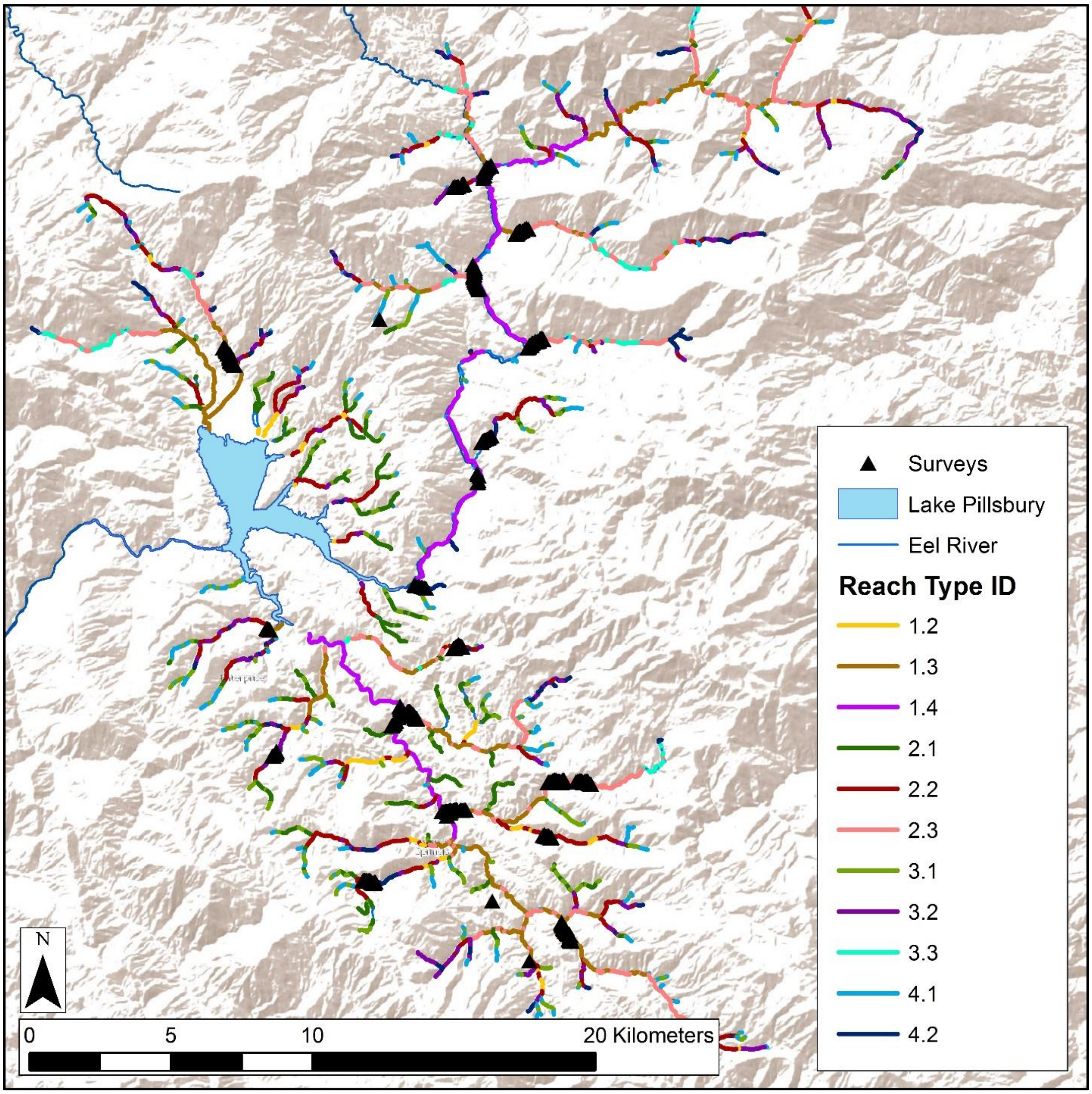

Figure 6. Study site stream network with stratified reach types and conducted field survey locations (black triangles) from summer 2016 in the upper mainstem Eel River, CA.

These habitat data are currently being summarized among survey reaches to estimate potential juvenile capacity for steelhead and Chinook salmon, and the habitat summaries and capacity estimates will then be extrapolated from survey reaches onto corresponding reach type strata. The capacity estimates will be scaled up from the habitat unit to the reach scale, and ultimately to the watershed scale for the entire study site. Results for habitat characterization of the study site will include box plots representing the distribution of habitat attributes measurements per reach type strata including: channel width, flow (cubic meters per second), riffle depth, pool depth, cover complexity, proportion of pools and fastwater habiat, canopy cover, proportion of fine substrates, proportion of boulders in fastwater habitat, and temperature. Any reach type strata whose habitat data are not significantly different will be lumped together for extrapolation.

One approach to estimating potential capacity involves a stream carrying capacity model known as the Unit Characteristic Method that uses fish density values specific to habitat units (i.e. pools, riffles, glides) (Cramer and Ackerman, 2009; Cramer et al., 2012). The core of the model multiplies fish density by a measured habitat unit area, and the density values are then adjusted according to other habitat parameters (i.e. fish cover, depth, substrate, etc.) and how they deviate from average conditions within a habitat survey reach. There are standardized fish density values specific to habitat unit types built into this model derived from a previous study that observed juvenile salmonid densities in six Oregon streams over several years that were believed to be at fully seeded capacity (Johnson et al., 1993). The condensed model is as follows in equation 1.

$$\textbf{Parr Capacity}_i = \left(\sum area_k \cdot den_j \cdot chnl_{jk} \cdot dep_{jk} \cdot cvr_{jk}\right) \cdot prod_i \qquad (1)$$

Where;

i = stream reach. "Reach" is a sequence of channel units that compose a geomorphically homogenous segment of the stream network,
j = channel unit type,
k = individual channel unit,
area = area (m^2) of channel unit *k*,
den = standard fish density (fish/ m^2) for a given species in unit type *j*,
dep = depth scalar with expected value of 1.0,
cvr = cover scalar with expected value of 1.0,
chnl = discount scalar for unproductive portions of large channels with expected value of 1.0, and
prod = productivity scalar for the reach, with expected value of 1.0. This scalar combines the separate effects from four additional factors defined in equation 2:

$$prod_i = turb_i \cdot drift_i \cdot fines_i \cdot alk_i \qquad (2)$$

Where;

turb = turbidity during summer low flow (measured in NTUs),
drift = percentage of reach area in fastwater habitat types that produce invertebrates,
fines = percentage of substrate in riffles composed by fines, and
alk = alkalinity during summer low flow (measured as mg/l $CaCO_3$).

Uncertainty will be incorporated into the UCM model by including standard deviations for each parameter and running a Monte Carlo simulation for a random subsample representing the minimum and maximum range of error among the model parameters. A spatial representation of the Monte Carlo simulations with uncertainty maps for survey reaches will be developed.

Another approach to estimating capacity involves using a GIS-based model known as Ripple, developed by Stillwater Sciences (2008). This model estimates specific capacity for a given species for each life stage at simulated seasonal flow events. This method requires habitat unit composition data and local fish density data, and its output provides two density scenarios: one density estimate representative of local fish densities, and another density estimate representative of full capacity. The results from these two approaches to estimating potential carrying capacity will be compared not only to each other but also to estimates from past reports including the IP Model.

Conclusions

The population declines in native salmonid populations in the Eel River must be addressed with appropriate management and policy action in response to the call for salmonid population recovery and sustained ecological health. The relicensing of Scott Dam and adaptive management of the Potter Valley Project are important decision making processes that affect those native salmonid populations of the Eel River. Sound scientific research is needed to inform those decisions, and the results of this project aim to do so in the FERC relicensing process of Scott Dam. With both GIS and ground-based habitat assessments of the historic anadromous salmonid habitat upstream of Scott Dam, the amount of habitat will be quantified so potential stream carrying capacity can be estimated using two methods. Results will be compared between carrying capacity estimation methods used in this project as well as to results from past estimates. What these results may mean for the future of native salmonids in the Eel River watershed will be discussed. This project aims to shed some light on answering whether restoring access to the area above Scott Dam will aid in the recovery of the Eel River salmonid populations as a whole. Finally, ways to improve these research endeavors will be identified and recommendations for future research will be given. A final thesis paper will be completed and a thesis defense is set to take place by May 2017.

This experiential learning internship has held true to its name by providing essential hands-on experience in environmental science and watershed resource management, including requirements such as project design, implementation of field work, collaboration with people from other organizations, and data management. This internship has furthered my career opportunities as well as my career goals by providing skills specific to watershed management, fisheries biology, and applied stream ecology. I strongly feel that this opportunity has further prepared me for a potential career with the USDA.

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Appendix

A. Methods for reach stratification for a GRTS survey design.

1. Designate range categories in excel. For this, the only attribute collumns needed include: object ID, mean gradient, area (km2), gradient category, area category, and reach type ID
    a. Gradient:
        i. 0-2%
        ii. 2-7%
        iii. 7-12%
        iv. >12%

    =IF(B2<0.02,1,IF(B2<0.07,2,IF(B2<0.12,3, IF(B2<20,4))))

    b. Drainage Area (km^2):
        i. 0-2
        ii. 2-10
        iii. 10-100
        iv. >100

    =IF(C2<10,1, IF(C2<100,2, IF(C2<250, 3, IF(C2<100000,4))))

    c. Combine gradient and area categories into one column of values:

    =CONCATENATE(D2,".", E2)

    d. IP score Category
        i. 0-0.33 low
        ii. 0.33-0.66 medium
        iii. 0.66-1 high

    =IF(E2<0.33,1,IF(E2<0.66,2,IF(E2<1,3)))

    e. Convert concatenated values into numbers, make new file with ObjectID, Reach Type ID, and IP Cat collumns for joining to attribute table in ArcMap

2. Join excel file to attribute table of shapefile in Arc
    a. Open Arc, right click IP streams layer, click joins and relates
    b. Join attributes from a table, choose field as "OBJECTID"
    c. Browse for appropriate excel file (StrataJoinTable.xls)
    d. Double check attribute table to make sure it worked

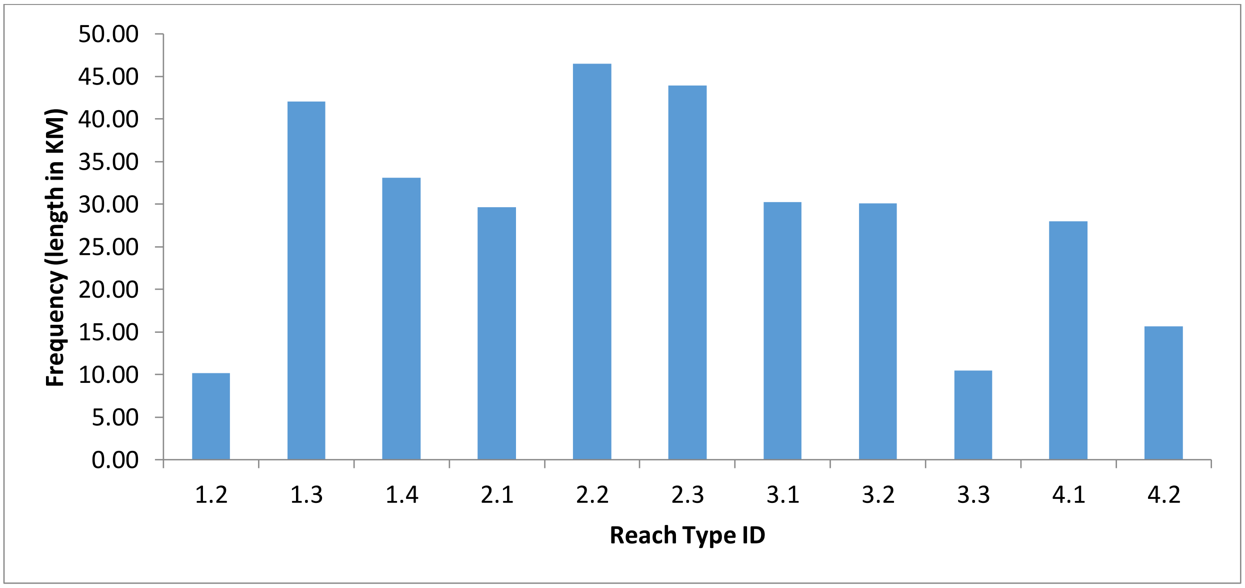
3. Add XY coordinates to attribute table
    a. Open attribute table
    b. Top left icon drop down
    c. Add field > Name: Start_X,
    d. Type: Double > click OK

e. Rt click new column in att. Table > Calculate Geometry > yes
f. Property: Y (or X) coordinate of line start
g. Use coordinate system of data source
h. Repeat starting from c. for Start_Y coordinate

4. Export into new shapefile
   a. "U:\ejc485\Master's Thesis\GRTS\GRTS_Streams_1"
   b. "U:/ejc485/Master's Thesis/GRTS/GRTS_Streams_1"

5. Translate spatial data into R
   a. Open .R code in RStudio
   b. Use proper file path and file name for code
      i. To copy file path: shift + rt click folder with shapefiles in it and click "copy as path" – Then you can paste wherever you want
   c. Change backslashes to forward slashes for R code
   d. Run the code after installing all packages

6. Run GRTS
   a. Generate lengths table, which will give you output of lengths of each Reach Type
      i. Copy the output, save to .txt or .csv file, convert to .xlsx file
      ii. Identify proportion of Reach Type occurrence in stream data frame



   b. Assign number of survey sites proportional to Reach Type lengths

Reach Type ID	1.2	1.3	1.4	2.1	2.2	2.3	3.1	3.2	3.3	4.1	4.2	**Total**
No. Survey KM	0.8	3.3	2.6	2.3	3.6	3.4	2.4	2.4	0.8	2.2	1.2	**25**

No. Survey Reaches	2	3	3	5	7	3	5	5	1	4	2	**40**
Length of Each Survey Reach	0.4	1.1	0.9	0.5	0.5	1.2	0.5	0.5	0.8	0.6	0.6	

c. Create the Design List: multiply number of survey reaches by 5 for oversample value

```
stratdsgn<-list(
    "1.1"=list(panel=c(PanelOne=1), seltype="Equal", over=0),
    "1.2"=list(panel=c(PanelOne=2), seltype="Equal", over=10),
    "1.3"=list(panel=c(PanelOne=3), seltype="Equal", over=15),
    "1.4"=list(panel=c(PanelOne=3), seltype="Equal", over=15),
    "2.1"=list(panel=c(PanelOne=5), seltype="Equal", over=25),
    "2.2"=list(panel=c(PanelOne=7), seltype="Equal", over=35),
    "2.3"=list(panel=c(PanelOne=3), seltype="Equal", over=15),
    "2.4"=list(panel=c(PanelOne=1), seltype="Equal", over=0),
    "3.1"=list(panel=c(PanelOne=5), seltype="Equal", over=25),
    "3.2"=list(panel=c(PanelOne=5), seltype="Equal", over=25),
    "3.3"=list(panel=c(PanelOne=1), seltype="Equal", over=5),
    "3.4"=list(panel=c(PanelOne=1), seltype="Equal", over=0),
    "4.1"=list(panel=c(PanelOne=4), seltype="Equal", over=20),
    "4.2"=list(panel=c(PanelOne=2), seltype="Equal", over=10),
    "4.3"=list(panel=c(PanelOne=1), seltype="Equal", over=0),
    "4.4"=list(panel=c(PanelOne=1), seltype="Equal", over=0))
```

*Zero Survey Reach Types: 1.1, 2.4, 4.3; Reach Types not present: 3.4, 4.4 ➔ GRTS required a minimum of 1 panel site, but none of these are included in survey

d. Convert SurveySites R output into a shapefile (in R code)

7. Import new shapefile from SurveySites output into study site map in ArcMap
    a. Export att table to excel
    b. Create list of panel sites and list of oversample sites as 2 separate .xlsx files
    c. Import each file into ArcMap
    d. Save layers as shapefiles

8. Evaluate Access to Sites via remote sensing and Cost Distance Analysis
9. Assign Walking Order to Survey Site List
    a. Plan Survey Sites for first 2 weeks of field work
10. Import SurveySites onto GPS unit

B. R code for GRTS developed in the computer program RStudio.

```
install.packages("rgdal")
install.packages("rgeos")
install.packages("geosphere")
install.packages("raster")
install.packages("spdep")
install.packages("spsurvey")


library(sp)
library(rgdal)

# The first argument is the name of the directory where the data is
# stored. If your data is already in the R working directory, just use
# '.'. The second argument is the name of the shapefile without the
# extension (.shp)
pts <- readOGR("U:/ejc485/Master's Thesis/GRTS/GRTS_Streams_1_1", "GRTS_Streams_1_1", verbose
= FALSE)
lin <- readOGR("U:/ejc485/Master's Thesis/GRTS/GRTS_Streams_1_1", "GRTS_Streams_1_1", verbose
= FALSE)

#not sure if this is needed
pol <- readOGR("U:/ejc485/Master's Thesis/GRTS/GRTS_Streams_1_1", "GRTS_Streams_1_1", verbose
= FALSE)

#Plotting spatial data

maxXY<- pmax(bbox(pts)[,2], bbox(lin)[,2], bbox(pol)[,2])
minXY<- pmin(bbox(pts)[,1], bbox(lin)[,1], bbox(pol)[,1])
plot(pol, xlim = c(minXY[1], maxXY[1]), ylim = c(minXY[2], maxXY[2]))
plot(lin, add = TRUE)
plot(pts, add = TRUE)


library(spsurvey)


########################################

##View data frame
View(lin)
View(pts)


sp2shape(sp.obj=lin, shpfilename="GRTS_Streams_1")

att=read.dbf("GRTS_Streams_1")   #read attribute table from shapefile
head(att)  #display initial six lines in attribute data frame

#display number of stream segments cross-classified by the strata (combos) and
```

```
#multidensity (IP) categories
TypeVsIPTable=addmargins(table("Reach Type"=att$REACH_TYPE_ID, "IP score"=att$IP_CAT))
TypeVsIPTable

#display sum of lengths among each Reach Type
ReachTypeLengths=tapply(att$LENGTH, list(att$REACH_TYPE_ID), sum)
ReachTypeLengths


#summarize frame stream length by stratum and multidensity category
lengths<-tapply(att$LENGTH, list(att$REACH_TYPE_ID, att$IP_CAT), sum)
lengths

lengths=lengths[,c("1","2","3")]
lengths

lengths=na.omit(lengths)
lengths

lengths=addmargins(lengths)
lengths

lengths<-round(lengths,2)
lengths

names(dimnames(lengths))<-list("Reach Type", "IP score")
lengths


##############################
#Stratified, equal probability GRTS survey design with an oversample

?set.seed

#create the design list
stratdsgn<-list(
                "1.1"=list(panel=c(PanelOne=0), seltype="Equal", over=0),
                "1.2"=list(panel=c(PanelOne=2), seltype="Equal", over=10),
                "1.3"=list(panel=c(PanelOne=3), seltype="Equal", over=15),
                "1.4"=list(panel=c(PanelOne=3), seltype="Equal", over=15),
                "2.1"=list(panel=c(PanelOne=5), seltype="Equal", over=25),
                "2.2"=list(panel=c(PanelOne=7), seltype="Equal", over=35),
                "2.3"=list(panel=c(PanelOne=3), seltype="Equal", over=15),
                "2.4"=list(panel=c(PanelOne=0), seltype="Equal", over=0),
                "3.1"=list(panel=c(PanelOne=5), seltype="Equal", over=25),
                "3.2"=list(panel=c(PanelOne=5), seltype="Equal", over=25),
                "3.3"=list(panel=c(PanelOne=1), seltype="Equal", over=5),
                "3.4"=list(panel=c(PanelOne=0), seltype="Equal", over=0),
                "4.1"=list(panel=c(PanelOne=4), seltype="Equal", over=20),
                "4.2"=list(panel=c(PanelOne=2), seltype="Equal", over=10),
                "4.3"=list(panel=c(PanelOne=0), seltype="Equal", over=0),
                "4.4"=list(panel=c(PanelOne=0), seltype="Equal", over=0))
```

```
att=na.omit(att)

#select the sample
SurveySites<-grts(design = stratdsgn,
              DesignID = "STRATIFIED",
              type.frame = "linear",
              src.frame = "shapefile",
              in.shape = "GRTS_Streams_1",
              att.frame = att,
              stratum = "REACH_TYPE_ID",
              shapefile = FALSE)

head(SurveySites@data)
summary(SurveySites)
plot(SurveySites)

# write out a new shapefile (including .prj component)
writeOGR(lin, ".", "GRTS_Streams_4Survey", driver="ESRI Shapefile")

##########################################

shp=read.shape("IP_SteelheadStreams_Strat")

NamedSampleSizesForPanels=c(PanelOne=64) # creates a vector

NamedSampleSizesForEachCategory=c("1.1"=4,"1.2"=4,"1.3"=4, "1.4"=4, "2.1"=4, "2.2"=4, "2.3"=4,
"2.4"=4, "3.1"=4, "3.2"=4, "3.3"=4, "3.4"=4,
                           "4.1"=4, "4.2"=4, "4.3"=4, "4.4"=4)

# list entry for stream reach types, with no oversample for streams with a gradient more than 12%

GradientLessThan12Entry=list(panel=NamedSampleSizesForPanels, seltype="Unequal",
caty.n=NamedSampleSizesForEachCategory, over=36) # oversample

GradientMoreThan12Entry=list(panel=NamedSampleSizesForPanels,
                    seltype="Unequal",
                    caty.n=c("4.1"=4, "4.2"=4, "4.3"=4, "4.4"=4),
                    over=0)

Design=list(Perennial=PerennialEntry,Intermittent=IntermittentEntry)
Unequalsites<-grts(design=Design,
              DesignID="UNEQUAL",
              type.frame="linear",
              src.frame="sp.object",
              sp.object=shp,
              att.frame=att,
              stratum="Per_Int",
              mdcaty="Strah_Cat",
              shapefile=FALSE)

head(Unequalsites@data)
```

C. Formulas, definitions, and values of parameters of the UCM model (Cramer and Ackerman, 2009).

UNIT SCALE PARAMETERS

den (fish/m2)

		Steelhead Juveniles	
Unit Name	Unit ID	Density	SD
Backwaters	6	0.05	
Cascades	2	0.03	
Glides	3	0.08	0.04
Pools	4, 5	0.17	0.02
Riffles	1	0.03	0.02

chnl

Glides	If W > 24: (W - 24)*.35/W + 24/W
Pools	if W > 24: (W - 24)*.75/W + 24/W
	if L > 4*W: L = 4*W
Riffles	if W > 24: (W-24)*.15/W + 24/W
	where W = wetted width of unit in meters

dep

Pools & Glides	If D is < 0.10: 0.0*D
	If D is 0.10 - 0.80: (0.30* D - 0.027)/0.17
	if D is >0.8: 0.22/0.17
Riffles	If D is < 0.1: 0.0 * D
	If D is 0.10 - 0.16: (0.5*D - 0.5)/0.03
	If D is 0.16 - 0.30: (0.29*D - 0.017)/0.03
	If D is 0.30 - 0.80: (0.25*D - 0.003)/0.03
	If D is 0.80 - 0.90: 0.20/0.03
	If D is 0.90 - 1.50: (-0.32*D + 0.485)/0.03
	If D is >1.50: 0
	where D = depth in meters

cvr

Pools & Glides	If wood complexity = 1: 0.58

If wood complexity = 2: 1.00
If wood complexity = 3: 1.42
if wood complexity = 4 or 5: 1.84

Riffles — If Bpr < 0.25: 1.0
If Bpr is 0.25 - 0.75: 1 + 12*(Bpr = 0.25)
If Bpr is > 0.75: 7.0

where Bpr = proportion of substrate in riffles comprised of boulders

REACH SCALE PARAMETERS: multiply by unit-scale capacity adjustment
prod = (turb*drift*fines*alk)

turb

if Dr is < 0.3m: 10^(2-(1+0.024*N)*0.1)/10^2-0.1
If Dr is 0.3-0.5m: 10^(2-(1+0.024*N)*0.3))/10^2-0.3
If Dr is > 0.5m: 10^(2-(1+0.024*N)*0.5))/10^2-0.5

where Dr = mean depth of riffles within the reach
whre N = NTU

drift

If Rp > 0.5: 1.0
If Rp is ≤ 0.5: 0.1+1.8*Rp

where Rp = proportion of reach surface area that is riffle or cascade

fines

If Fp is <0.1: 1.0
If Fp is ≥0.1: 1.11 - 1.1*Fp

where Fp = proportion of substrate in riffles that is comprised of fines

alk

(mgCaCO3/l)^0.45/4.48

winter

If Cp < 0.15: 0.20 + (Cp)/0.15*0.8
If Cp > 0.15: 1.0

where Cp = Proportion of substrate in the stream comprised of cobbles

temp

Tsi = 1/(1+e^-a-bTi)

where
Tsi = Temp scalar for capacity for reach i in a given week
a = intercept of logit(Tsi) = 19.63
b = slope of logit(Tsi) = -0.98
T = weekly average temperature (WAT) for reach i in a given week