USING NETWORK MODELS TO PREDICT STEELHEAD ABUNDANCE,
MIDDLE FORK JOHN DAY, OR

by

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ABSTRACT

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by

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In the management of threatened and endangered species, informed population estimates are essential to gage whether or not recovery goals are being met. In the case of Pacific salmonids, this evaluation often involves sampling a small subset of the population and scaling up to estimate larger distinct populations segments. This is made complicated by the fact that fish populations are not evenly distributed along riverscapes but respond to physical and biological stream properties at varying spatial extents. We used rapid assessment survey methods and the River Styles classification to explore fish-habitat relationships at a continuous network scale. Semi-continuous surveys were conducted across nine streams in the upper Middle Fork John Day River watershed and increased the number of sites surveyed eight-fold over other monitoring methods within the watershed. Using this increased sample size and continuous habitat metrics we improved watershed-wide steelhead (*Oncorhynchus mykiss*) abundance models.
We first validated the distinctions among River Styles through a classification analysis using physical metrics measured at the rapid assessment sites. Overall classification accuracy, using a combination of reach and landscape scale metrics, was 88.3% and suggested that River Style classification was identifying variations in physical morphology within the watershed that was quantifiable at the reach scale. Leveraging the continuous River Styles classification of physical habitat and a continuous model of primary production improved the prediction of steelhead abundance across the network. Using random forest regressions, a model that included only habitat metrics resulted in $R^2 = 0.34$, while using the continuous variables improved the model accuracy greatly to $R^2 = 0.65$. Random forest allowed for further investigation into the predictor variables through the analysis of the partial dependence plots and identified a gross primary production threshold, below which production might be limiting steelhead populations. This method also identified the rarest River Style surveyed within the watershed, Confined-Valley Step Cascade, as the morphology that had the largest marginal effect on steelhead. The inherent physical properties and boundary conditions unique to each River Style has the potential to inform fish-habitat relationships across riverscapes and improve abundance estimates on a continuous spatial scale.
PUBLIC ABSTRACT

Using Network Models to Predict Steelhead Abundance, 

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It is important in the management of threatened and endangered species to have informed population estimates. Population estimates are used to gage whether or not recovery goals are being met. When assessing Pacific salmonids this assessment involves sampling a small subset of the population and then scaling up to estimate larger populations units. This is complicated by the fact that fish populations are not evenly distributed along river systems but respond to fluctuating physical and biological stream properties. We used rapid assessment survey methods and the River Styles classification to explore fish-habitat relationships. River Styles is a classification system that uses the stream characteristics and the landscape setting to define different river types. We preformed surveys in nine streams in the upper Middle Fork John Day River watershed. Using rapid assessment methods we increased the number of sites surveyed eight-fold over other monitoring methods used in the watershed. Using this increased sample size and continuous habitat metrics we improved watershed-wide steelhead abundance models. We concluded that the physical properties unique to each River Style had the potential to inform fish-habitat relationships and improve abundance estimates across networks of streams.
I would like to thank Bonneville Power Administration (BPA) and the Integrated Status and Effectiveness Monitoring Program (ISEMP) for funding for this research. I would also like to thank Nick Bouwes for his mentorship during this project and for the opportunity to be a part of the research being conducted in the Columbia River Basin. I am grateful for the support and collaboration of Joe Wheaton, Tom Edwards, Carl Saunders, and Gary O’Brien along with the many researchers involved with the Columbia Habitat Monitoring Program. I am also very thankful for the support I received from Utah State University and the Watershed Sciences Department.

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Monica R. Blanchard
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INTRODUCTION

It is recognized that fish populations are not spatially balanced across river networks, but in fact exhibit heterogeneity that reflect the spatially variability of habitat characteristics (Schlosser 1991, Schlosser 1995, Fausch et al. 2002, Torgersen et al. 2006). Channel morphology in conjunction with biological factors, such as temperature and productivity, determine the distribution and abundance of salmonid populations. Physical heterogeneity in channel morphology is scale dependent (Wiens 2001) and is in part driven by large scale factors such as climate, lithology, and topography, which are expressed at smaller scales as assemblages of geomorphic units (Montgomery 1999, Ganio et al. 2005, Leopold et al. 1995, Brierley and Fryirs 2005). Disturbance events and river processes maintain patch variations and system connectivity at different scales (Ward 1989, Wiens 2002). Salmonids, in turn, interact with the physical environment at numerous scales, from seeking flow refugia in a low velocity hydraulic unit, to foraging for drifting macroinvertebrates in a geomorphic unit, to migrating many kilometers to find suitable temperature regimes. This natural heterogeneity in both physical form and fish distributions encourages continuous stream surveys of fish populations and their habitat in order to understand their variability at multiple spatial scales (Fausch et al. 2002).

The analysis of the fluvial processes at intermediate spatial scales, in conjunction with continuous fish population surveys, identifies spatial patterns and heterogeneity that exists within individual drainages (Ganio et al. 2005). When juvenile Chinook Salmon (Oncorhynchus tshawytscha) were observed in warmer sections, either lower in the
watershed or in an overall warmer system, they were associated with relatively higher gradient sections of stream (Torgersen et al. 2006). By contrast, in the colder, upper watershed reaches, Chinook juveniles were associated with lower gradient sections.

Landscape context changed the relationship of a species and its habitat indicating that the use of the same type of habitat can vary along the continuum of the riverscape. Landscape setting likewise dictates the distribution patterns of Cutthroat Trout abundance (*Oncorhynchus clarkii clarkii*) due to differences in underlying lithology (Ganio et al 2005, Gresswell et al. 2006). The bedrock resistance, and therefore susceptibility to erosional disturbances, explained the variations observed in cutthroat abundance patterns among different drainage networks. Continuous species censuses reveal not only that habitat characteristics and species abundances were variable at larger spatial scales but that the species-habitat associations were not constant and change across the network.

In studying spatial heterogeneity across stream networks, fluvial geomorphic classification have been used to links biological responses to stream physical form and pattern. Numerous habitat monitoring protocols have been implemented in the Pacific Northwest, particularly to assess habitat quality and quantity for Endangered Species Act (ESA) listed salmonids: PACFISH/INFISH Biological Opinion Effectiveness Monitoring Program (PIBO, Heitke et al. 2006), Channel Type user’s guide for the Tongass National Forest (Paustian 1992, 2010), Oregon Department of Fish and Wildlife Aquatic Inventory Project (Moore et al. 2014), and Columbia Habitat Monitoring Program (Bouwes et al. 2011).
The key assumption of these protocols is that fish populations are responding to stream physical habitat attributes at multiple scales. These management tools are built off \textit{a priori} knowledge of species habitat associations and limitations at different life stages. Surveying the physical morphology is used to inform habitat availability as well as to continue to evaluate fish-habitat relations at varying spatial scales. Hierarchical fluvial geomorphic classifications provide a process-based approach to assessing river characteristics, which has the potential to be integrated with biological organisms to facilitate understanding of fish-habitat links at multiple spatial scales. Extrapolating fish populations based on these relationships could provide a powerful way to scale up analysis of fish abundances throughout a watershed, while limiting the need for extensive on the ground survey efforts.

The River Styles Framework (Brierley and Fryirs 2005) is a geomorphic classification that describes fluvial processes and resultant form and has the potential to be used to correlate salmonid-habitat relations at multiple scales. The framework delineates reach types and produces a watershed wide classification of these different reaches called River Styles, which reflect distinctions in stream character and behavior. The classification emphasizes the importance of understanding the hierarchical nature of stream network within the context of the landscape setting. Watershed and basin scale landscape controls, such as connectivity, position with the watershed, elevation, geology, relief, and slope, drive river behavior which in turn shapes river characteristics across the network. These controls result in spatial variations in the channel planform, channel geometry, and assemblages of geomorphic units present within stream segments. These
reach scale attributes define differences in River Styles, or reach type, classification. The power of this particular classification lies in the fact that it is developed based on fluvial processes, which in turn control channel patterns of characteristics. This classification allows for both the flexibility of incorporating the diversity of river types in a watershed while maintaining the capability to be transferred to other watersheds due to the foundation in process driven delineation. Unlike other stream geomorphic classifications that look to group channel form for broad use (Hawkins et al. 1993, Montgomery and Buffington 1997, Rosgen 1994), the River Styles approach reflects the diversity of a specific region as well as strives to define geomorphic condition in the context of historical impacts, both natural and anthropogenic. Reach assessment is not based on a presupposed reference condition but on the condition of the presently defined by controlling factors.

Initial studies linking River Styles to biologic response have shown variable success and have been species dependent. Chessman et al. (2006) examined diatom, macrophytes, macroinvertebrate, and fish assemblages within the Berga River basin in Australia. All four biotic groups displayed significant differences in assemblages among River Styles. Further analysis to isolate the influences of the River Style from the independent factors of altitude, catchment area, and geographical distance, found that only macrophyte and macroinvertebrate assemblages were significantly correlated to River Style, while fish and diatom assemblages were more responsive to the physical factors that were not inherently defined by River Style. However, for paired sites at a given distance, all groups of biota, except for diatoms, displayed a larger biological
dissimilarity in the different River Style than in the same style. Another study in Australia found when comparing macroinvertebrate assemblages between pairs of River Styles, two of the three pairs showed community structure differences and significant relationships were also found at the geomorphic unit level and smaller (Thomson et al. 2004). Both studies highlight the prospect of leveraging River Styles classifications as a method of understanding species distributions and geomorphic associations, and suggest species dependent variations in classification usage. The investigation into salmonid-River Styles relationships in the Pacific Northwest offer a good opportunity to further explore the biological applications of River Styles.

In addition to stream morphology, temperature regimes and prey resources effect salmonid distributions, growth, and survival (Warren et al. 1964, Chapman 1966). These factors can be particularly influential in the arid inter-mountain west where summer stream temperatures can be very warm. Dieterman et al. (2004) found brown trout (Salmo solar) had higher growth rates in streams with higher summer temperatures even if stream temperature exceeded the species thermal optima. When predicting trout growth, they found that a consumption rate (P-value) based model predicted trout weight gain better than a temperature effects based model. These findings suggest that indirect temperature influences on the quality and quantity of available prey can play a stronger role in influencing trout growth than the direct influence of temperature. Kiffney and Roni (2007) found a positive relationship between streams basal productivity (primary production and detritus) and invertebrate taxa richness. They also found that the most important covariates for explaining all trout fry biomass and all rainbow trout biomass
were basal productivity and stream physical habitat characteristics. The combination of assessing stream production and morphology offer a powerful way to assess fish populations.

The intention of our research was to expand on the foundations that prey resources, temperature, and physical habitat vary continuously and thus influence fish population to varying degrees. We investigated these continuous relationships using network models of habitat characteristics to predict juvenile steelhead abundance across nine of streams. We conducted rapid assessment, semi-continuous surveys of steelhead populations and of geomorphic and habitat characteristics in the Middle Fork John Day River watershed in north-central Oregon. From this extensive survey effort, we validated the use of River Styles as a classification system that defines differences in reach geomorphic attributes through a classification analysis. After validating the use of River Styles classification, we utilized continuous models of physical habitat, temperature, and primary production to predict steelhead abundance. By utilizing these network models of River Styles, to describe the habitat characteristics present in unique stream reaches, along with continuous stream production estimates, we predicted fish abundance across a wide variety of streams with in the Middle Fork John Day River watershed.

METHODS

Study watershed

The Middle Fork John Day River (MFJD) is a 117 kilometer long tributary that drains the Blue Mountains in Northeastern Oregon before joining the North Fork John
Day River (Fig. 2). The MFJD, and its encompassing John Day River watershed, are rare examples of free flowing rivers not only in the Columbia River Basin, but the entire United States. The MFJD is differentiated into upper and lower sections of the watershed; the upper watershed is predominantly public land while the lower watershed consists of mostly private land. The upper watershed is managed as an Intensely Monitored Watershed (IMW) with the goal of evaluating the effectiveness of restoration projects and promoting collaboration in the effort to monitor threatened and endangered salmonid species. As part of this collaboration, Columbia Habitat Monitoring Program (CHaMP) crews conduct high resolution topographic surveys of stream channels and collect salmonid habitat data. Surveys were completed at randomly selected sites across the IMW based on generalized random tessellation stratified (GRTS) survey design that distributes spatially balanced points across the stream network (Stevens Jr. and Olsen 2004, Dobbie et al. 2008). The rapid assessment habitat and fish survey efforts conducted for this research were coordinated with CHaMP crews to allow for exchange and communication of data and included seventeen overlapping survey sites. Within the upper watershed, rapid assessment surveys were conducted on eight tributaries in addition to the mainstem MFJD: Bridge Creek, Clear Creek, Dry Fork Clear Creek, Vinegar Creek, Granite Boulder Creek, Big Boulder Creek, Camp Creek, and Lick Creek (Fig. 2).

The upper MFJD drains an area of 826 km$^2$ and ranges in elevation from 2478m in the Blue Mountains to 1058m in the mainstem valley bottom. The watershed receives mean annual precipitation of 53 cm/year and has a hydrologic regime that follows the
spring snowmelt runoff pattern common to the interior west; the largest pulse in discharge occurs in the spring months due to snow melt and spring storms, followed by dry, hot summers.

Stream temperatures in the MFJD watershed can exceed optimal thermal tolerances for salmonid species, particularly in the mainstem MFJD where temperatures over 18°C are common in the summer months. There have also been instances of extreme temperature resulting in mass die offs, including a mass die off of holding adult Chinook Salmon in the summer of 2013.

Over the past century, a boom bust cycle of logging and mining operations, along with heavy cattle grazing, left a large impact on streams throughout the watershed. Although much of this activity has been reduced or stopped altogether, the influences of the past century’s anthropomorphic changes are still evident on the river channels of the MFJD and have left segments of river in poor geomorphic condition (O’Brien and Wheaton 2014). Cattle grazing still occurs on private and public land throughout the watershed but has been reduced through conservation efforts.

The upper MFJD watershed supports anadromous populations of ESA threatened steelhead as well as Chinook Salmon. Additionally, there are Bull Trout (Salvelinus confluentus) in some of the colder headwater streams. Dace (Rhinichthys sp.) and sculpins (Cottus sp.) are found throughout the system. Mountain Whitefish (Prosopium williamsoni), Redsided Shiners (Richardsonius balteatus), suckers (Catostomus sp), and Northern Pikeminnow (Ptychocheilus oregonensis) are more prevalent in the mainstream and lower in some tributaries.
FIG. 1. Map of the upper Middle Fork John Day River watershed. Steelhead abundance at rapid assessment survey sites are displayed by white bars (fish/100m). River Styles delineated on the anadromous streams that were assessed in this study. Anadromous streams that were intermittent or too small to survey are displayed but River Styles are not delineated. Inset map of Oregon delineates the John Day River watershed and the upper Middle Fork John Day watershed.
Data collection

Snorkel and electrofishing surveys

Snorkel surveys were conducted at 197 rapid assessment sites from late June to late August of 2013 when stream flows were low and close-to or at baseflow conditions. Surveys were conducted following protocols detailed in O’Neal (2007). Fish abundances were assessed in every unit that was deep enough to survey, >0.15m, except for units where turbulent water made viewing fish impossible or ineffectual. All salmonids were counted and categorized based on length estimates into four size classes: Young of Year (YOY) < 60mm, 60≥99mm, 100≤149mm, ≥150mm. For non-salmonids, rough visual counts were taken but no size specifications were detailed.

The snorkel survey fish counts were calibrated with 12 mark-recapture or depletion surveys between July 1st and July 8th (Eco Logical Research 2013, unpublished data). Unit snorkel counts were summarized at the site scale and mark-recapture surveys conducted within four days of snorkel surveys. Salmonids above 60mm were tagged with Passive Integrated Transponder tags (PIT tags) and YOY counts were not included in snorkel site abundance estimates. Mark-recapture surveys provide the most accurate population abundance estimate with which snorkel surveys can be calibrated (Hankin and Reeves 1988, Rosenberger and Dunham 2005). Population data for mark-recapture estimates was calculated using the Lincoln-Peterson mark-recapture model (White et al. 1982) and depletion estimates were calculated using a jackknife estimator (Pollock and Otto 1983, Hankin and Mohr 2008). Seasonal growth data was collected at two sites on the mainstem MFJD, two sites on Vinegar Creek, and one site each on three other
tributaries (Granite Boulder Creek, Bridge Creek, and Clear Creek) form July 4th to September 14th 2013 (N=158). The number of recaptured fish varied from 4 to 51 across the seven sites.

*Geomorphology and habitat surveys*

The River Styles Framework consists of a four stage process that was completed by Utah State University and Eco Logical Research, Inc. for the Middle Fork John Day watershed (O’Brien and Wheaton 2014). The initial step, Stage One, consists of a catchment-wide classifying the riverscape characteristics, behavior, and boundary conditions; this stage produces a watershed wide classification of River Styles, or reach types, which for the purposes of this research will be the aspects of the framework that will be utilized to correlate habitat characteristics to steelhead populations. Stage Two in the River Styles Framework assesses the catchments river evolution and geomorphic condition. This stage identifies the degrees to which anthropogenic influences have impacted the natural evolutional trajectory of a river and the capacity of adjustment in each River Style. This stage also determines the present day geomorphic condition of the river, relative to what would be expected of an intact segment of each River Styles. The degradation of conditions within specific River Styles results is the loss or alteration of identifying geomorphic properties. Stage Three and Stage Four build on the catchment specific knowledge from the previous two stages and begin to look to the future and possible management decisions. Stage Three addresses the future trajectory of the River Styles under each condition and the recovery potential of those degraded segments. Stage
Four produces a catchment-wide prioritization of management efforts and target conditions.

River Styles field surveys were conducted in summer 2013 at representative sites across the MFJD. Fourteen unique River Styles were identified within the entire watershed. Twelve of the fourteen were accessible to anadromous salmonid species; of these, eight River Styles were the focus of more intensive surveying due to their importance to steelhead trout (Table 1). The four River Styles that were not sampled each made up a very small proportion of the steelhead extent and were either intermittent or too small to survey effectively. Full assessment following procedures detailed by Brierley and Fryirs (2005) were conducted at eight representative sites within the watershed, along with a general census of the watershed (O’Brien and Wheaton 2014). Further analysis to define boundaries and classifications utilized remote sensed data before and after the field surveys were completed.

In addition to the full River Styles validation, 197 spatially explicit sites were surveyed at the geomorphic unit resolution across 30.5 kilometers within nine different anadromous fish bearing streams (Table 1). These rapid assessment sites were distributed across the eight focus River Styles. Within this network, sample order was based on the GRTS sample designed for the CHaMP program, which placed survey points at roughly one kilometer intervals. At each sample location that was surveyed, three to six sites, each roughly the length of 20 times the bankfull widths, were assessed back to back in order to capture larger segments of stream. In addition to the random sites, surveys were conducted at five tributary junctions. Confluences are explicitly excluded from CHaMP
survey protocol but can be areas of ecological significance (Benda et al. 2004). Using rapid assessment methods allowed for the surveying of these geomorphically complicated sites. At these locations, two back to back sites were surveyed downstream and upstream of the junctions on both the tributary and the mainstem. Boundaries between sites were delineated at the ends of units not mid-way through a unit at a pre-defined length and resulted in variable lengths. Sites ranged from 67m to 317m in length.

**TABLE 1.** Table of the eight River Styles surveyed in the Middle Fork John Day watershed using rapid assessment surveys. River Styles grouped by valley confinement; unconfined, confined, and partly confined River Styles. Distance surveyed in each River Style is roughly proportional to the total stream distance of each River Style within the target streams in the MFJD watershed.

<table>
<thead>
<tr>
<th>River Style (Abbreviation)</th>
<th>Valley Confinement</th>
<th>Number of Sites</th>
<th>Distance Surveyed (km)</th>
<th>Total Stream Distance (km)</th>
</tr>
</thead>
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<tr>
<td>Alluvial fan (AF)</td>
<td>Unconfined</td>
<td>15</td>
<td>2.2</td>
<td>17.5</td>
</tr>
<tr>
<td>Low-moderate sinuosity gravel bed (LMS GB)</td>
<td>Unconfined</td>
<td>19</td>
<td>3.7</td>
<td>23.9</td>
</tr>
<tr>
<td>Confined-valley w/ occasional floodplain pockets (CV OFP)</td>
<td>Confined</td>
<td>30</td>
<td>4.1</td>
<td>29.2</td>
</tr>
<tr>
<td>Confined-valley step cascade (CV SC)</td>
<td>Confined</td>
<td>6</td>
<td>0.8</td>
<td>6.9</td>
</tr>
<tr>
<td>Bedrock-controlled elongate discontinuous floodplains (BC EDF)</td>
<td>Partly Confined</td>
<td>30</td>
<td>7.2</td>
<td>23.8</td>
</tr>
<tr>
<td>Low-moderate planform-controlled discontinuous floodplain (LM PC DF)</td>
<td>Partly Confined</td>
<td>51</td>
<td>6.5</td>
<td>41.4</td>
</tr>
<tr>
<td>Low sinuosity planform-controlled anabranch (LS PCA)</td>
<td>Partly Confined</td>
<td>33</td>
<td>4.2</td>
<td>15.9</td>
</tr>
<tr>
<td>Meandering planform-controlled discontinuous floodplain (M PC DF)</td>
<td>Partly Confined</td>
<td>13</td>
<td>1.8</td>
<td>11.7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>197</td>
<td>30.5</td>
<td>170.3</td>
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</table>
Geomorphic characteristics were measured and evaluated at several scales. Rapid assessment sites surveyed reach scale and geomorphic unit scale attributes using a simplified version of the CHaMP protocol (Bouwes et al. 2011) and unit classification based on Geomorphic Unit Classification (Wheaton et al. 2015, in press). All units within the bankfull channel were surveyed (N= 2934). Unit width and length (meters) was measured in a quarter of the units and visually estimated at the rest of the units. Average depth and substrate roughness were measured at three locations and averaged for bar and planar units; max depth and pool tail depth were measured in all pool units. The number of qualifying pieces of large woody debris and number of log jams were counted, and ocular estimates of substrate and fish cover were assessed in each unit based on the methods detailed in the CHaMP protocol. The only deviation from the protocol was combining fine and course gravel into one category for ocular substrate estimates. Unit scale ocular estimates were averaged over a site used to construct grain size distribution curves. Conductivity measurements (μS/cm) and temperature (C˚) were sampled at every other site using Extech EC400 Waterproof Exstik Conductivity Meter.

We used ArcGIS (ESRI 2012) to estimate reach and landscape scales metrics, including slope, lithology, sinuosity, valley width, and valley confinement. Slope (cm/cm) was derived at the 200m reach scale (Beechie and Imakie 2013) and elevations (meters) were extracted from a 10m Digital Elevation Model (DEM). The underlining lithology of the MFJD watershed is fairly complex; an erodibility index was used to categorize variations in rock type (Integrated Status and Effectiveness Monitoring Program 2013). The index ranged from one to eight, where one indicates highly erodible
alluvial sediments and eight identifies resistant bedrock. Erodibility of the underlining lithology is an indicator of variations in sediment caliber and volume available in different sections of stream. Sinuosity was classified using Google Earth™ imagery and was categorized based on three levels as defined by Schumm (1985): straight (1.0-1.05), low sinuosity (1.06-1.30), and sinuous (>1.31). The degree of channel confinement within the valley was classified by the amount of its course that a channel abuts the valley margin, as defined in the River Styles. Confinement levels are defined as unconfined (the channel abuts the valley <10% over the reach length), partly confined (10-90%), and confined (>90%). This metric was analyzed using Google Earth™ imagery and was corroborated with field observations.

Temperature data was logged hourly using TidbiT v2 Water Temperature Data Logger by HOBO® Data Loggers at all mark-recapture sites. A regional water temperature model was used to extrapolate continuous temperatures across the entire stream network. This regional model was based on remotely-sensed land temperature data from MODIS satellite imagery and calibrated with in stream temperature TidbiT loggers (McNyset 2013, unpublished). Continuous temperatures were modeled for stream segments ranging from 40m to 6.7km in length, averaging about 2km. Temperatures were modeled for eight day mean and maximums for the entire year of 2013.

**Continuous metric development**

Continuous network models of physical stream characteristics, River Styles, and gross primary production were used to predict steelhead abundance at the 197 rapid
assessment sites. These models were developed in collaboration with colleagues at Utah State University. Detailed methods can be found in the cited sources.

FIG. 2. Data sources that were network model inputs that were used to predict steelhead abundance at the 197 rapid assessment sites in the MFJD.

River Styles classification

To investigate whether River Styles reflected distinctions in river morphologies, site measurements and landscape metrics were used to validate classification accuracy of River Styles. Statistical classification analysis was conducted using the randomForest package (Liaw and Wiener 2002) in the statistical program R (R Core Team 2013). Random forest is a tree based, machine learning, statistical technique used for classification and regression analysis. The tree based classifications are useful in the
analysis of ecological data because they can handle non-normal distributions, non-linear relationships, categorical variables, and complex interactions, which are prevalent in natural settings (De’Ath and Fabricius 2000). Random forest provides an even more robust method by aggregating trees and has been shown to be a powerful classification tool in ecological studies (Cutler et al. 2007).

The classification data was from the 197 rapid assessment sites sampled across nine streams and eight River Styles. Initially, fourteen morphological predictor, both field based and GIS based variables, were selected for the baseline model. From this initial model, we wanted to find the model that resulted in the lowest classification error, while reducing the number of predictor variables and simplify the model. Using random forest classification, variable reduction was conducted with backwards stepwise elimination of variables based on the variable importance, which was calculated as the mean decrease in classification accuracy. Comparisons of overall model classification error rates guided final variable reduction. Due to bias inherent when using continuous variables in conjunction with categorical data (Strobl et al. 2007), the variable importance was used to guide variable reduction, but the ultimate removal of a variable was based on changes in model error rates. The final model was validated using 10-fold cross validation.

**Gross primary production**

A model of gross primary production (GPP, g 0.2 L−1 D−1) in the John Day was developed by Utah State University and Eco Logical Research, Inc. from data collected in the summer of 2013 (Saunders 2014, unpublished data). The GPP model used average summer temperatures temperature, conductivity, and solar input to estimate gross primary
production at the 48 survey locations where back to back rapid assessment sites were surveyed. Observed dissolved oxygen measurements were captured at sixteen locations within the MFJD watershed and at eight locations in the nearby Murderers Creek Watershed using PME MiniDOT loggers. Loggers were deployed for 2-3 days periods between July 14th and July 31st. The diel dissolved oxygen variations were used to estimate GPP (Grace and Imberger 2006). Average summer temperatures were calculated from the 8 day average temperatures from the continuous regional temperature model over an 80 day period from June 26th to September 13th. This timeframe encompasses the warmest months of year and the primary growing season for salmonids. Solar input was calculated in ArcGIS using the Point Solar Radiation Point tool using a 10m DEM, 30m LandFire vegetation data, and a 10m buffer along the stream channel. This method of estimating solar radiation can be applied at any spatial scale across the entirety of the watershed for continuous predictions. Conductivity measurements from each site were calibrated to a 25°C standard to account for temperature dependent differences in stream conductivity readings. A continuous model of conductivity is currently being calibrated at USU and will provide the final continuous variable for extended GPP prediction (Saunders 2015, personal communications). These three variables were used to predict the observed GPP (R² = 0.58) and used to extrapolate GPP values to the rapid assessment sites surveyed across the MFJD watershed. Average GPP values are summarized by stream (Table 2) and by River Style (Table 3). The variation in GPP values was much higher across different River Styles than across individual streams.
TABLE 2: Modeled average gross primary production (GPP), number of sites (n), and standard deviations (SD) at the 197 rapid assessment sites across the eight tributaries and mainstem MFJD River.

<table>
<thead>
<tr>
<th>Stream</th>
<th>n</th>
<th>Average GPP (gO$_2$L$^{-1}$D$^{-1}$)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bridge Creek</td>
<td>15</td>
<td>3.31</td>
<td>1.42</td>
</tr>
<tr>
<td>Big Boulder Creek</td>
<td>4</td>
<td>10.52</td>
<td>1.32</td>
</tr>
<tr>
<td>Camp Creek</td>
<td>33</td>
<td>4.52</td>
<td>1.23</td>
</tr>
<tr>
<td>Clear Creek</td>
<td>27</td>
<td>2.88</td>
<td>1.69</td>
</tr>
<tr>
<td>Dry Fork Clear Creek</td>
<td>9</td>
<td>2.74</td>
<td>0.08</td>
</tr>
<tr>
<td>Granite Boulder Creek</td>
<td>15</td>
<td>0.76</td>
<td>1.11</td>
</tr>
<tr>
<td>Lick Creek</td>
<td>8</td>
<td>4.42</td>
<td>1.07</td>
</tr>
<tr>
<td>Middle Fork John Day River</td>
<td>57</td>
<td>6.02</td>
<td>1.77</td>
</tr>
<tr>
<td>Vinegar Creek</td>
<td>29</td>
<td>4.20</td>
<td>1.40</td>
</tr>
</tbody>
</table>

TABLE 3: Modeled average gross primary production (GPP), number of sites (n), and standard deviations (SN) at the 197 rapid assessment sites across the eight River Styles.

<table>
<thead>
<tr>
<th>River Style</th>
<th>n</th>
<th>Average GPP (gO$_2$L$^{-1}$D$^{-1}$)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>AF</td>
<td>15</td>
<td>4.02</td>
<td>2.84</td>
</tr>
<tr>
<td>LM S GB</td>
<td>19</td>
<td>6.07</td>
<td>1.93</td>
</tr>
<tr>
<td>CV OFP</td>
<td>30</td>
<td>2.65</td>
<td>1.25</td>
</tr>
<tr>
<td>CV SC</td>
<td>6</td>
<td>6.89</td>
<td>4.70</td>
</tr>
<tr>
<td>BC EDF</td>
<td>30</td>
<td>6.08</td>
<td>1.95</td>
</tr>
<tr>
<td>LM PC DF</td>
<td>51</td>
<td>3.77</td>
<td>1.39</td>
</tr>
<tr>
<td>LS PCA</td>
<td>33</td>
<td>3.50</td>
<td>2.06</td>
</tr>
<tr>
<td>M PC DF</td>
<td>13</td>
<td>5.39</td>
<td>0.91</td>
</tr>
</tbody>
</table>

*Steelhead abundance*

Abundance of juvenile steelhead (fish/100m) was modeled using random forest regression (Liaw and Wiener 2002). Three models were compared to evaluate the use of continuous components of physical habitat and measurements of stream production in estimating abundance. The first model, the Habitat model, acts as a baseline for modeling
steelhead abundance. This model used the eight habitat metrics identified in the River Styles classification to describe the physical habitat setting along with the Julian date on which the site was sampled; Julian day was included as a covariate in all three models in order to account for variations that occurred over the course of the summer sampling effort. The Habitat model is not necessarily using the physical habitat metrics that would best model fish abundance, but is attempting to assess how well the physical metrics that define the differences among River Styles also explain variations in fish populations. The second model, the Habitat-Production model, contained the same variables as the Habitat model with the addition of stream production component to the model, the gross primary production (GPP) calculated from the continuous production model. The third model, the River Styles-Production model, replaced the eight physical attributes with the River Styles classification while retaining Julian date and GPP. Random forest was selected for this regression model due to the capacity of this method to assess both numerical and categorical data, as well as the ability to fit non-normal distributions and handle complex interactions between variables (De’Ath 2007, Cutler et al. 2007). The \( R^2 \) values and root mean squared errors were compared across the three models.

RESULTS

**River Styles classification**

The River Styles classification analysis resulted in utilizing eight of the initial fourteen habitat metrics, five reach scale measurements and three landscape controls (Table 4) to classify the eight River Styles in the MFJD watershed. Reach characteristics
included in the reduced model were bankfull width, sinuosity, pools per 100m, pieces of qualifying LWD per 100m, and average roughness. The landscape control values were erodibility, channel slope, and valley setting. Six variables were removed from the model: bedrock presences (site average percent), side channel ratio (side channel length (m)/ total site length (m)), site average percent undercuts, bars units/100m, planar units/100m and site average residual pool depth (m).

Random forest classification resulted in a strong classification accuracy of 88.3% percent correctly classified (PCC) using ten-fold cross validation (Table 5). Classification was particularly strong for the three River Styles resulting in 100% PCC: bedrock-controlled elongate discontinuous floodplains (BC EDF), confined-valley with occasional floodplain pockets (CV OFP), and alluvial fan (AF) River Style. Additionally, no sites were misclassified as BC EDF or AF. The lowest classification accuracy was observed with the confined-valley step cascade River Style (CV SC), at 16.7% PCC. This River Style also had the least number of sites surveyed and was uncommon within the basin. All the misclassified sites were identified as the CV OFP, the only other confined-valley River Style. Both confined-valley River Styles had similar average characteristics and only demonstrated larger distinction in substrate roughness and LWD frequency, though the later was highly variable (Table 6). This high degree of overlap in reach characteristics with CV OFP, in addition to the small sample size of the CV SC River Style caused its low classification accuracy.
TABLE 4. Variables used in the River Styles classification model. Landscape controls were derived off 10m DEM and reach characteristics were measured in the field.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Type</th>
<th>Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Landscape Controls</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Erodibility</td>
<td>Factor</td>
<td>1,7,8</td>
<td>Degrees of erodibility, scale 1-8, 1 highly erodible and 8 least erodible (^a)</td>
</tr>
<tr>
<td>Channel Slope</td>
<td>Integer</td>
<td>Cm/cm</td>
<td>Slope extracted every 200m from NHDplus stream layer (^b)</td>
</tr>
<tr>
<td>Valley Setting</td>
<td>Factor</td>
<td>Confined, Partly Confined, Unconfined</td>
<td>Degree to which the river is confined against the valley margin as defined in River Styles (^c)</td>
</tr>
<tr>
<td><strong>Reach Characteristics</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bankfull Width</td>
<td>Integer</td>
<td>m</td>
<td>Average bankfull width over site length</td>
</tr>
<tr>
<td>Sinuosity</td>
<td>Factor</td>
<td>Straight (1.0-1.05), Low Sinuosity (1.06-1.30), Sinuous (&gt;1.31)</td>
<td>Classification of stream sinuosity over a site based on aerial imagery and measurements in ArcGIS (^d)</td>
</tr>
<tr>
<td>Average Roughness</td>
<td>Integer</td>
<td>cm</td>
<td>Average roughness of substrate. Measured three times within each non-pool unit and average for a unit value Units average together for a site value</td>
</tr>
<tr>
<td>LWD/100m</td>
<td>Integer</td>
<td>Count</td>
<td>Number of qualifying pieces of large woody debris per 100m of stream (^e)</td>
</tr>
<tr>
<td>Pools/100m</td>
<td>Integer</td>
<td>Count</td>
<td>Number of pools per 100 m of stream</td>
</tr>
</tbody>
</table>

\(^a\) ISEMP (2013)  
\(^b\) Beechie and Imaki (2013)  
\(^c\) Brierley and Fryirs (2005)  
\(^d\) Schumm (1985)  
\(^e\) CHaMP (2013)
TABLE 5. Results from 10-fold cross validation classification of River Styles using random forest. River Style results are grouped by valley confinement categories; unconfined, confined, and partly confined. PCC = percent correctly classified. Overall PCC across all River Styles was 88.3%.

<table>
<thead>
<tr>
<th>River Style</th>
<th>AF</th>
<th>LM SGB</th>
<th>CV OFP</th>
<th>CV SC</th>
<th>BV EDF</th>
<th>LM PC DF</th>
<th>LS PC A</th>
<th>M PC DF</th>
<th>PCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>AF</td>
<td>15</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>LM SGB</td>
<td>0</td>
<td>18</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>94.7</td>
</tr>
<tr>
<td>CV OFP</td>
<td>0</td>
<td>0</td>
<td>30</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>CV SC</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>16.7</td>
</tr>
<tr>
<td>BC EDF</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>30</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>LM PC DF</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>48</td>
<td>4</td>
<td>0</td>
<td>92.3</td>
</tr>
<tr>
<td>LS PC A</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>27</td>
<td>0</td>
<td>81.8</td>
</tr>
<tr>
<td>M PC DF</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>1</td>
<td>5</td>
<td>41.7</td>
<td></td>
</tr>
<tr>
<td>Overall PCC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>88.3</td>
</tr>
</tbody>
</table>

The three partly confined, planform-controlled River Styles, which were found in the tributaries and upper segments of the mainstem MFJD, displayed the most overlap in classification. The sites surveyed in these three River Styles had similar average characteristics, notably they had partly confined valley settings, low sinuosity, erosion resistant lithology, and similar substrate roughness; however distinctions in average values were present in slope, LWD frequency, pool frequency, and bankfull width (Table 6). The two most common of these River Styles, low sinuosity planform-controlled anabranch (LS PCA) and low-moderate planform-controlled discontinuous floodplain (LM PC DF) had strong classification accuracies of 81.8% and 92.3% PCC respectively. The only misclassification occurred between these two River Styles, six LS PCA sites were classified as LM PC DF and four LM PC DF sites were identified as LS PCA. Meandering planform-controlled discontinuous floodplain River Style (M PC DF) was
uncommon within the watershed and had the second fewest sites surveyed. The PPC for this River Style was 41.4%, the second lowest accuracy. The majority of the misclassified sites were placed in the LM PC DF River Style category and one site identified as LS PCA.

The low-moderate sinuosity gravel bed (LMS GB) River Style displayed a high PCC, 94.7%. This River Styles is unconfined and present along the mainstem MFJD and the lower and upper reaches of Camp Creek. A significant proportion of the stream segments within this River Style were inaccessible for surveying due to landowners denying access and the segments overall have been heavily altered by anthropomorphic influences. As a result, these sections of river are often in moderate or poor geomorphic conditions.

**TABLE 6.** Summary of site characteristics of the eight River Styles. River Styles are grouped by valley setting, unconfined (U), confined (C), and partly confined (PC). The number of sites in each class of sinuosity and erodibility is noted next to the class (n). Mean and standard deviation values are summarized for all non-categorical variables.
condition (O’Brien and Wheaton 2014); however, the measured geomorphic characteristics along with the landscape controls still successfully distinguished it as a unique river type.

The variable importance plot (Fig. 3) displays variables ranked by the influence exerted on the model through the decrease in classification error. Valley setting was the most influential variable for classifying River Styles, followed by bankfull width and slope. Overall, landscape control metrics played the larger role in defining differences among River Styles, ranked 1\textsuperscript{st}, 3\textsuperscript{rd}, and 5\textsuperscript{th} in variable importance. The reach measurements of pool/100, roughness, LWD/100m increased the MSE by smaller increments. However, these reach measurements likely helped define differences between River Styles that are positioned in similar landscape setting, such as the three partly confined, planform-controlled River Styles.

**Continuous steelhead abundance**

Significant improvements in model strength were made through the consecutive steps moving from the Habitat model to the River Styles-Production model; the initial Habitat model performed the weakest ($R^2 = 0.34$, RMSE = 43.6), while the River Style-Production model performed the strongest ($R^2 = 0.65$, RMSE = 31.4) (Fig. 4). There was a significant improvement between the habitat only model when GPP was added ($R^2 = 0.49$, RMSE = 38.4); however, the largest increase in model strength was made when River Styles replaced the fluvial geomorphic characteristics. This suggests that the River
FIG. 3. Variable importance plot for the classification model for River Styles. Variables with higher mean decreased accuracy values have greater influences on the models classification accuracy.

Styles delineation is capturing differences in physical habitat that significantly influence fish distributions.

Variable importance plots based on increase in the mean squared error (MSE) for the three models are shown in Fig. 5. In the Habitat model, the two variables that exerted the strongest influence on steelhead abundance were bankfull width and survey date (Fig. 5A). Slope, LWD frequency, pool frequency, substrate roughness, and sinuosity were group together roughly in the middle of the plot. Valley setting followed by erodibility had smallest influences on model error. Of the three landscape characteristics, slope had largest influences on model accuracy.

When GPP was added to the second model it became the most influential variable and maintained that position in the River Styles-Production model (Fig. 5B-C). GPP was
strongly correlated to and driven by average temperature ($R^2 = 0.71, p<0.0001$); GPP additionally incorporates measurements of stream productivity (conductivity and solar input), and reflects both temperature and food resource influences on fish. In the River Styles-Production model, River Styles and Julian date had similar degrees of influence on the model accuracy (Fig. 5C).

FIG. 4. Results for three models of steelhead abundance using 10-fold cross validated random forest regression: Habitat model (A), $R^2 = 0.34$, rmse = 43.6; Habitat-Production model (B), $R^2 = 0.49$, rmse = 38.4; River Styles-Production model (C), $R^2 = 0.65$, rmse = 31.4. The solid black line is the 1:1 line.
FIG. 5. Variable Importance plots for Habitat model (A), Habitat-Production model (B), and River Styles-Production model (C). Plot ranks influence of variables on the strength of the model based on the percent increase to the mean squared error (MSE). The higher the percent increase in the MSE the greater the influence the variable has on model accuracy.

Partial dependence plots for the River Style-Production model (Fig. 6) display a graphical depiction of the marginal effect of each predictor variable on the response variable. Fig. 6A shows the highly non-linear relationship between GPP and steelhead abundance. The strongest pattern shows low GPP rates, roughly under 3 g O₂ L⁻¹ D⁻¹, resulted in low marginal effects on steelhead abundance, while above that threshold, GPP had a much higher marginal effect. For the River Styles partial dependence plot (Fig. 6B), LM S GB and M PC DF River Styles stood out as resulting in lowest marginal effect on abundance rates, while CV SC resulted in the highest marginal effect on steelhead abundance. The Julian day partial dependence plot (Fig. 6C) showed an overall trend of increased steelhead as the summer progressed. Possible explanations for this trend may
FIG. 6. Partial dependence plots showing the marginal effect of the three variables in the River Styles-Production model on the response variable of steelhead abundance: (A) gross primary product, (B) River Styles, and (C) survey date in Julian days. Tick marks along x-axis in plots A and C represent 25 sites and display the distribution of sites across the range of sampled measurements. River Styles are grouped by valley confinement, unconfined, confined, and partly confined River Styles separated by vertical line.

be a result of the more efficient snorkeling due to falling water levels as well as fish growing over the summer to exceed the 60mm threshold needed to be counted.

DISCUSSION

The overall high classification accuracy of River Styles is a strong indicator that River Styles is distinguishing physical morphological characteristics that are detectable with measured and derived variables at the reach scale. The hierarchical nature of rivers is emphasized in the process of classifying and distinguishing River Styles, and both reach scale metrics and landscape controls within the upper MFJD watershed were found to be important in differentiating distinctions among river morphologies. In five of the
eight River Styles the classification accuracy was over 90%. These River Styles had highly distinguishable characteristics and unique landscape settings that were discernable in the classification analysis. However, two of the eight River Styles had low classification accuracy likely due to fewer surveyed site and similarities to other more dominant River Styles. CV SC (PCC = 16.7%) and M PC DF (PCC = 41.7%) highlight the fact a small sample size of rare River Styles may not be enough to be able to identify distinct characteristics; however, these River Styles can be important to fish (see below) and may warrant more explicit investigation into distinguishing attributes.

The inclusion of River Styles in steelhead abundance models resulted in an increase in model power over using the eight measured physical metrics. This suggests that the differences among these river types encapsulate physical properties that fish respond to in addition to the characteristics that were used to distinguish individual river classes. The eight characteristics included in the classification effectively distinguish different River Styles with a high degree of accuracy; however, the added strength derived when using River Styles classes to model steelhead suggests that there are additional characteristics and interactions among the physical properties that are incorporated when using River Style. These distinctions can provide an avenue to explore the differences in habitat use across the watershed.

Investigating the influence of geomorphic characteristics on fish abundances is particularly evident when comparing the differing fish responses to the three partly-confined, planform control River Styles. The most overlap in classification error was observed among these three River Styles. The characteristics that had greater range in
mean values among the three were slope, LWD frequency, pool frequency, and bankfull width (Table 6), which were also the morphological characteristics that exerted the strongest influence on steelhead abundance (Fig. 5). LS PCA and LM PC DF had overall similar average values and varied significantly only in pool frequency, where LM PC DF had on average higher pool frequency. When compared with those two River Styles, M PC DF sites were wider, lower in slope, and had less LWD. M PC DF sites also had higher average GPP than the other two River Styles (Table 3). Overall, LS PCA and LM PC DF had high classification accuracy, with some overlap with each other, and M PC DF had low classification accuracy and was most often mis-classified as LM PC DF. However, in the partial dependence plots for steelhead abundance, these three River Styles exert different levels of influences on steelhead. LS PCA has the third highest marginal effect of all River Styles on steelhead abundance, behind the two confined-valley setting River Styles, while M PC DF had the lowest overall marginal effect; LM PC DF was in between, with a marginal effect closer to that of LS PCA. The variations in habitat, though not clearly distinguished by the River Styles classification, appear to be influencing steelhead abundance and emphasize the importance of accurately classifying reaches types. The wider, lower complexity and lower gradient M PC DF sites may support higher GPP values; however, the lower fish abundances could have been responding to an interaction of these characteristics that led to a reduced frequency of prey encounters as compare with the steeper, more complex River Styles. Stream salmonids typically feed by facing upstream and wait for drifting macroinvertebrates to be carried within the reactive distance, the range where the fish can capture its prey.
(Hughes and Dill 1990). Higher velocity locations deliver more prey; however, higher velocity locations requires great swimming effort and are energy intensive. The most energy efficient location for stream salmonids would therefore be areas of low velocities adjacent to locations with higher velocities (Hughes 1998, Hughes et al. 2003). The LS PCA and LM PC DF sites, with steeper gradients and higher frequency of structure (i.e. LWD) to breakup flow and provide low velocity hydraulic units, could be providing stream reaches where increased prey delivery and flow complexity can support higher abundances of steelheads. In comparison, the M PC DF sites may not be providing the same beneficial process and characteristics. The low sample size of the relatively rare M PC DF likely led to the low classification accuracy. However, the difference in the marginal effect on steelhead abundances demonstrates the importance of identifying this River Styles and distinguishing this reach type from the other partly confined, planform-controlled reaches if efforts to extrapolate fish populations are to be successful. Future modeling efforts to convert the categorical variables of sinuosity and confinement into continuous variables may help refine our ability to differentiate among these three River Styles.

The three partly-confined, planform control River Styles were found in the tributaries and in the upper reaches of the mainstem MFJD where the river is more akin to a head water stream. In the lower reaches of the mainstem MFJD, below the confluences of Bridge Creek, Clear Creek, and Dry Fork Clear Creek, there are two dominant River Styles that provide another juxtaposition of stream characteristics and fish response. BC DEF and LM SGB are the two dominate River Styles in the mainstem
MFJD and they alternate back and forth in the upper watershed. These two classes differ across most of the River Styles characteristics, though they had very similar estimates of GPP. The BC DEF River Style had lowest frequency of LWD and lowest frequency of pools of all the River Styles, both characteristics that indicate habitat complexity and that are commonly positively correlated to fish populations. This pattern was observed in this research with the River Styles that had the largest marginal effect on steelhead populations also had the highest frequencies of LWD and high pool frequency. The outlier in this pattern was the BC DEF River Style, which interestingly exerted a much higher positive effect on steelhead populations than its mainstem counterpart LM SGB River Style. It is possible that this variation in steelhead abundance is due to differences in the geomorphic condition of these two River Styles. Condition is assessed in Stage 2 of the River Styles Framework and not explicitly accounted for in this research. However, all sixteen LM SGB sites on the mainstem MFJD were found to be in moderate condition, while the BC DEF sites were all in good condition (O’Brien and Wheaton 2014). The moderate condition of the LM SGB sites and associated riparian communities resulted from decades of cattle grazing among other activity. This degradation led to large scale restoration efforts along many kilometers of the river. These restoration projects included supplementation of woody debris and construct pools. However, even in the sections where restoration projects have occurred there were few native riparian plants, and the geomorphic processes that would create and maintain habitat still remain altered. The degraded condition of the LM SGB reaches could have negatively influenced steelheads ability to persist even though attempts to restore habitat have been made. In the less
impacted BC DEF reaches, fish could be utilizing the larger substrate roughness to provide habitat complexity in the absence of LWD. Ignoring local stream segment conditions or assuming watershed wide fish-habitat relationships would suggest that LM SGB River Styles would support higher abundances of steelhead. By including River Styles we dissect the watershed into more informative sections that provide information on fish-habitat relationships at a smaller scale.

In addition to the variety in the physical morphologies, the MFJD watershed contains streams that have a large diversity of thermal regimes, stream conductivity, and canopy cover, resulting in a wide range in stream productivity (Table 2 and 3). GPP exerted the largest influence on model accuracy and based on the partial dependence plots there appears to be a threshold below which steelhead populations were limited by primary production, roughly 3 g O\textsubscript{2} L\textsuperscript{-1} D\textsuperscript{-1}. Within the MFJD watershed there were, three tributaries whose GPP measurements falls below the modeled threshold, Granite Boulder Creek, Clear Creek, and Dry Fork Creek. Granite Boulder and Clear Creeks both maintain cooler summer temperatures than any of the other streams measured in the basin, with daily maximum temperatures rarely exceeding 18°C (Columbia Habitat Monitoring Program 2013). The other five tributaries and mainstem MFJD maintain higher summer temperatures and all had GPP modeled values over the 3 g O\textsubscript{2} L\textsuperscript{-1} D\textsuperscript{-1} threshold. The mainstem MFJD, Camp Creek, and Vinegar Creek often experience daily maximum temperatures that exceed 22°C (Columbia Habitat Monitoring Program 2013). Warmer stream temperatures influence primary production and invertebrate production (Bilby and Bisson 1987, Li et al 1994, Morin and Dumont 1994). The higher abundance
of steelhead in these warmer streams suggests the higher GPP, and a resultant increase in
trophic production makes it metabolically worthwhile for fish to reside in those streams
rather than in the two tributaries, which maintain cooler, more thermally optimal
temperatures during the summer. Dieterman et al. (2004) found similarly results where if
production is high enough in warm streams, it is beneficially for salmonids to occupy
reaches where temperatures exceed thermal optima. Conversely, in a study in several
tributaries of the mainstem John Day River and South Fork John Day River found
temperature, primary production, and invertebrate biomass to be negatively correlation to
steelhead densities (Tait et al. 1994, Li et al 1994). As a whole this study included sites
with considerable warmer daily temperatures than those measured in the upper MFJD.
However, there are reaches in the upper and lower segments of the mainstem MFJD that
are approaching high extreme daily temperatures similar to those observed in other parts
of the John Day River watershed. These two studies suggest that at extreme temperatures
above a certain threshold the benefits of high stream productivity, as a result of higher
temperatures, will be outweighed by metabolic costs of those extreme temperatures on
salmonids. At this point, the high stream temperatures observed in the MFJD watershed
promoted high stream primary production and likewise supported higher numbers of
juvenile steelhead than streams with lower temperatures and lower production.

The strong influence of production on steelhead abundance could be particularly
important for fish populations in the arid west in the face of future climate change.
Surveys were conducted in 2013 in which there was lower than average snow packs in
the winter and consequently lower than average summer discharge based on a 83 year
record (USGS gage 14044000 Middle Fork John day River at Ritter, OR). Regional climate projections suggest that summers are expected to be warmer and drier and snow melt is predicted to occur earlier (Mote and Salathe Jr. 2010, Elsner 2010). These predictions will likely result in lower summer stream flow and higher stream temperatures than observed averages over the past century; therefore, conditions in 2013 may be more representative of future stream environments in the upper MFJD watershed. The balance of high productivity and high temperatures that was observed in the upper MFJD suggests that high production streams might be able to provide enough food for salmonids to buffer against the some of the adverse metabolic impacts of increased water temperatures, at least initially. Additionally, the diversity of thermal regimes present within the upper MFJD watershed may provide additional defense for salmonids. As temperatures increase, stream like Granite Boulder and Clear Creek may see increases in production and would be able to support higher numbers of fish.

The large range of temperature regimes, production, and physical properties captured in the upper MFJD watershed highlights the benefit of using rapid assessment surveys in addition to high resolution, lower density surveys methods. When fewer sites are distributed across a basin it is possible that rare river morphologies or entire tributaries do not contain a single survey point. However, uncommon river morphologies or different tributaries can be significant to fish and warrant surveying. By using rapid assessment methods to densify sites across the landscape we were able to investigate the diversity of the network more thoroughly. The CV SC River Style provided an example of the benefit of higher density surveys. CV SC segments comprised the smallest
proportion of river kilometers accessible to anadromous fish and were not surveyed by the CHaMP crews. In the River Styles classification, CV SC was highly mis-classified with only one site correctly identified as CV SC, while the other five were classified as CV OFP. However, the physical morphology of this River Styles seems to be of consequence to fish. Steelhead populations were far denser within the CV SC sites (mean = 167 fish/100m, SD ± 69) as compared to the watershed wide average of 105 fish/100m (SD ± 54) or the CV OFP mean of 109 fish/100m (SD ± 60). By investigating this rare morphology we identified these reaches as potentially advantageous to steelhead populations and as distinct from even the most directly similar River Style. This emphasizes the necessity of surveying these uncommon river types.

In addition to the investigation of rare River Styles, diversity among tributaries can be better understood through the expansion of survey sites. Big Boulder Creek is a fairly short tributary due to a fish passage barrier, which only allows anadromous fish access to the lower 3.2 kilometers of the stream. A significant portion of this section of stream flows over private land where access to survey crews was denied, resulting in a limited number of sites available for monitoring. Based on the GRTS site draw used by CHaMP crews, this stream is not surveyed. However, rapid assessment surveys were conducted in two sections across five sites. At all sites high numbers of fish were observed, identifying Big Boulder Creek as a tributary that sustains some of the highest numbers of steelhead within the basin. Modeled GPP also revealed the highest values within the Upper MFJD watershed were found in Big Boulder Creek (Table 2). Rapid assessment surveys allowed for the investigation of this tributary and the CV SC River
Style, otherwise missed with randomly selected sampling locations. As a result, this increased our understanding of the physical and biological diversity present within the watershed. This expansion of the range in watershed characteristics will allow us to model watershed fish populations more accurately and guides future monitoring efforts.

Conclusions

There are some limitations and possible confounding factors that warrant future consideration as we expand rapid assessment surveys. For example, within the MFJD watershed there were large variations in steelhead populations among different tributaries. Using Spatial Stream Networks Models (SSNM) to model spatial relationships along the river network throughout the upper MFJD, we found strong evidence for spatial autocorrelation in steelhead abundances across the MFJD watershed (Ver Hoef et al. 2014). Modeled autocorrelation of steelhead abundance using a Torgegram, which uses network distances rather than Euclidian distances to measure spatial autocorrelation, indicated that flow-connected sites demonstrated spatial autocorrelation for roughly 12 kilometers. This spatial dependence of steelhead populations over many kilometers indicates that populations were not independent and that factors influences populations were acting over a large distance. This may be due to environmental factors, such as GPP and temperature, which display strong spatial patterns. Alternatively, biological properties, such as spawning densities, could be contributing to this spatial pattern. Spawner surveys were conducted in the MFJD watershed by Oregon Department of Fish and Wildlife (ODFW); however, three of the streams surveyed by rapid assessment were not part of the spawner survey study design.
(Clear Creek, Dry Fork Clear Creek, and Bridge Creek). We therefore did not include a metric for spawner or redd density. However, heterogeneity in juvenile abundance has been correlated with redd heterogeneity, both at the stream scale (10km) and at the local reach scale (100m) (Beland 1996, Foldvik et al. 2010). When available, spawner data could add further strength to models of juvenile abundance. More in depth investigation into spatial relationships and biological properties would be useful avenues of future research. Additionally, surveying streams outside of the MFJD would help to distinguish between factors that drive steelhead abundance and properties that are dependent on the networks spatial configuration.

The model improvement that was achieved by including River Styles to model steelhead abundance highlight the potential for using the continuous classification to extrapolate prediction of steelhead populations to un-surveyed areas along the network. The distinctions among the River Style geomorphic characteristics and the distinctions in steelhead abundance among the River Styles allow for the examination of fish-habitat relationships at a finer scale than the watershed. This segment approach to modeling could refine our estimates of fish populations as well as our understanding of how the influences of habitat properties vary across a riverscape. Furthermore, as we begin to understand how different River Styles influence fish populations we can start to leverage the other aspects of the River Styles Framework, not just the classifications. River Styles classification based on fluvial process allows for transferability across watersheds but also permits the identification of a greater collection in reach types. A reference condition is not enforced and assessment it based on the streams current status. The understanding
of geomorphic condition and the capacity for change that is derived through the full implementation of the River Styles Framework help identify areas where restoration is needed and where those efforts could affect the most change. River Styles provides a tool with which to identify reaches where improvements in geomorphic condition and potential fish abundance can be paired.

Using rapid assessment surveys to complement a more intensive, dispersed survey effort added to the understanding of the diversity present within the MFJD watershed. By expanding the number of sites visited within the basin, rare and unique habitats were identified that were important to fish but had gone unmonitored through random selection. This increased number of sites also allow for the use of a greater array of analyses approaches, including machine learning techniques (i.e. random forest) and spatial analysis (i.e. SSNM). Future research will be geared towards deriving continuous, non-categorical variables for sinuosity and valley confinement to enhance our distinction of River Styles that have similar broad categorical landscape controls and reach characteristics. We plan on testing watershed population estimates based on random forest in comparison with those derived by the GRTS method. The effort to estimate endangered steelhead abundances at the population scale is complex and warrants continual investigation into enhancements. Using continuous variables may improve our ability to model populations more accurately and examine how fish-habitat relationships change over space. The explicit inclusion of River Styles as a continuous factor describing habitat demonstrates a potentially useful method for extrapolation but
necessitates the expansion into other watersheds to understand how these relationships maintain or change in different settings.
LITERATURE CITED

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