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IN THIS ISSUE

- Thermal Networks – Do You Really Mean It?
- Notices and Technical Tips
- Tools for Understanding Riparian Vegetation Distribution using a Plant Guilds Approach

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Thermal Networks – Do You Really Mean It?

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While the mean and maximum water temperatures drive many ecological processes and are important indicators of stream health and function, these may not be the aspects of the thermal regime most relevant to fish or for particular management needs. The distribution and drivers of mean stream temperature are well known; however, aquatic organisms do not experience mean temperature. They live in thermal microclimates (Figure 1) composed of facets of the thermal regime (e.g. daily range, annual variability) during relevant time windows (e.g. winter, juvenile outmigration). Salmon eggs, for example, incubate in river gravels in the winter; timing of fry emergence is largely determined by winter temperature and even its variability. Knowing the monthly or annual mean temperatures fish experience cannot fully explain observed timing and condition of emerging fry.

Recent advances in temperature monitoring technology, such as inexpensive sensors and remote-

Figure 1: Sunday Creek on the North Fork of the Snoqualmie River.

StreamNotes is an aquatic and riparian systems publication with the objective of facilitating knowledge transfer from research & development and field-based success stories to on-the-ground application, through technical articles, case studies, and news articles. Stream related topics include hydrology, fluvial geomorphology, aquatic biology, riparian plant ecology, and climate change.

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sensing techniques combined with development of new models (e.g. NorWeST Stream Temp), have improved our understanding of the complexities of thermal regimes in stream systems (Figure 2). These tools offer insight about natural thermal landscapes, how humans have altered these temperature patterns, and the possibility to fine-tune management of stream systems for particular species and given forecasts of future conditions.

What is a Facet?

A facet of the thermal landscape is a particular spatial or temporal element of interest. For example, the thermal facet driving mayfly emergence timing is temperature experienced after eggs are deposited (Li et al. 2011). To capture this facet, we might define a mathematical metric such as "number days after July 20th until 1075 degree days are accumulated." Predictions of salmonid emergence timing requires an understanding of total accumulated temperature units (e.g. degree days) and how those units are delivered (e.g. variability). Such facets could be captured as "Julian day at which 1600 degree days have accumulated since spawning began" and "daily variability over the first 80 days after approximately half of fish have spawned." Therefore, since exact thresholds linking temperature and biological response are often unknown, multiple metrics may be needed to capture a particular facet.

Natural Riverine Thermal Regimes are Complex

While the complexity of natural thermal regimes is commonly understood by most ecologists, the details and their implications are only now being articulated. To investigate this, we used spatial stream network models to build continuous predictions of stream temperature facets on one river network in western Washington (Steel et al. 2016). We found that there is not a uniform shift in stream temperature with elevation or season, spatial pattern for one facet of the thermal regime may differ substantially from others, some thermal facets have more spatial structure than others, and the amount of spatial structure in any facet may shift over time (Figure 3).

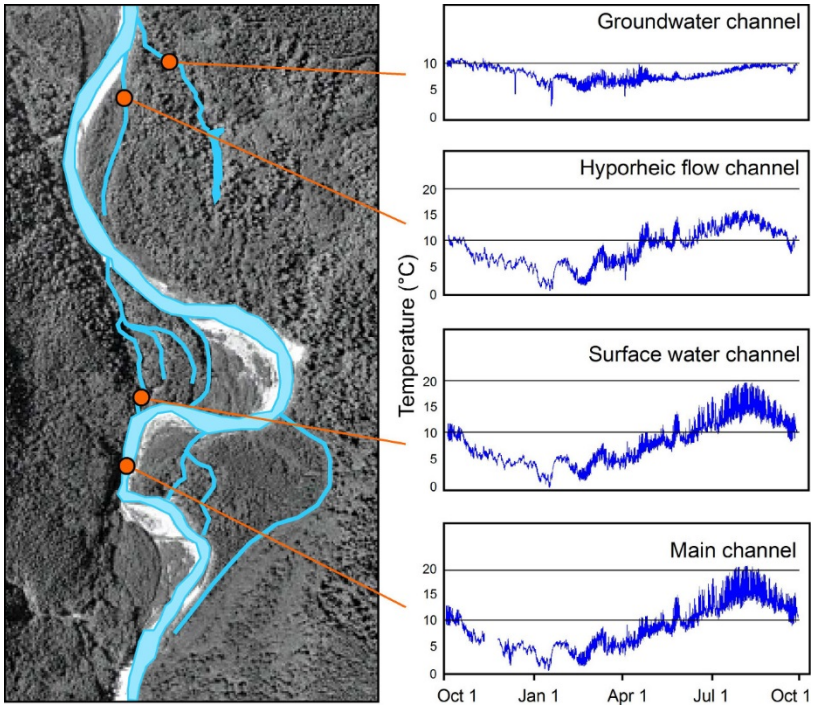

Figure 2: Water temperature fluctuations over time in the main channel and three side channels of a relatively undisturbed floodplain on the Sauk River near Darrington, WA. Water temperatures measured from October 2004 through September 2005 illustrate that a surface water side channel has the same seasonal and diel temperature pattern as the main channel, a hyporheic flow channel has the same seasonal pattern but reduced diel variation in summer, and a groundwater channel has reduced seasonal and diel variation. Figure by Tim Beechie, NOAA Fisheries. Reproduced from Steel et al. 2017.

Meta-analyses of airborne remotely sensed river temperatures for hundreds of Pacific Northwest rivers illustrate that thermal patterns are also diverse at both broad spatial scales, i.e., across rivers (Fullerton et al. 2015), and at finer spatial scales, i.e., within rivers (Fullerton et al. In Press, Figure 5). To explore how thermal landscapes vary over time and at fine spatial scales simultaneously, we used empirical data from our monitoring array on the Snoqualmie River, Washington and spatial stream network models to create videos of how water temperature changes over time and on a river network (Steel et al. 2017).

Humans are Altering Stream Systems

Humans impact natural thermal regimes not just by increasing the mean temperature but also by shifting the variability. Dams, for example, reduce thermal variability over daily and weekly timescales (Steel and Lange 2007). More changes to variance in water temperature are likely, given climate change and increasing human development.

In one example we used wavelet decomposition - a method for

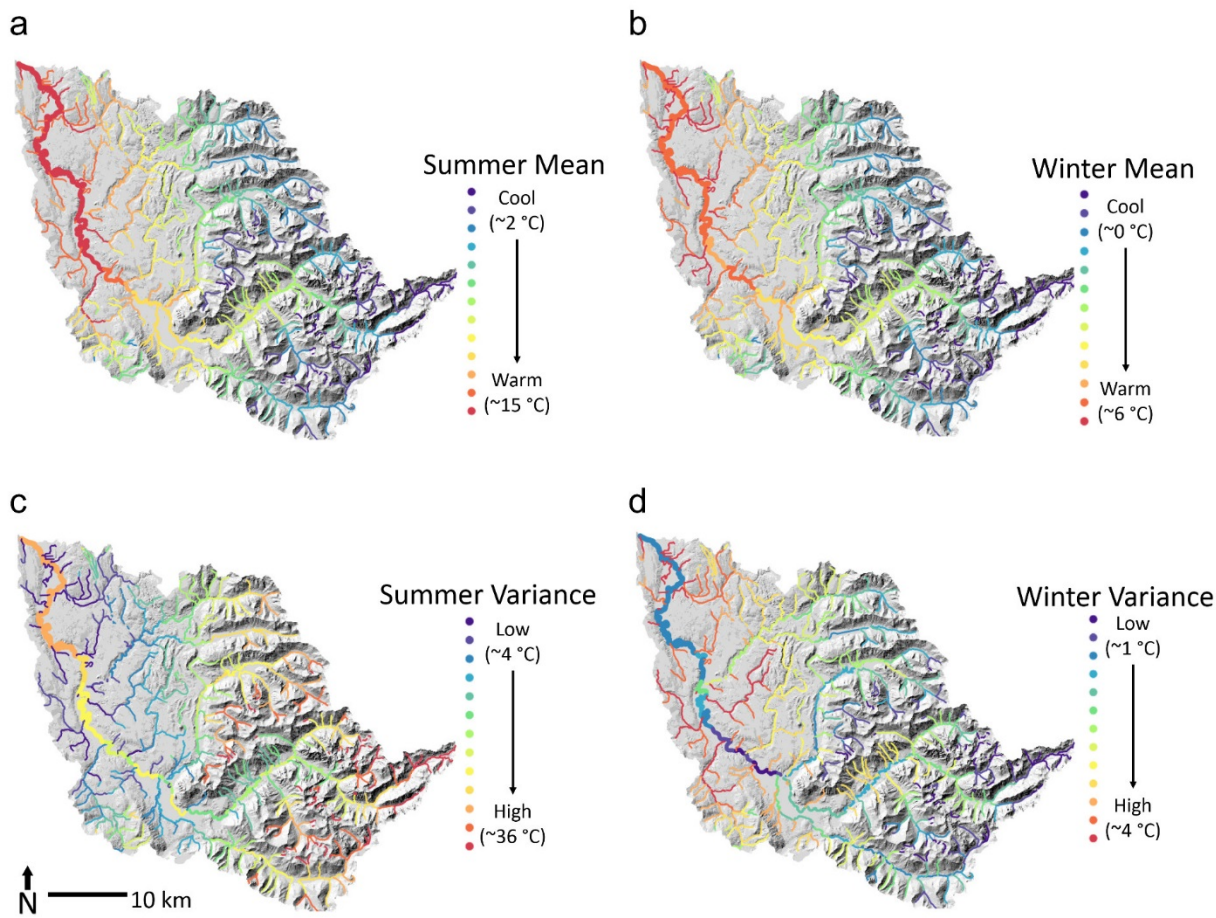

Figure 3: Modeled mean temperature and thermal variance over summer and winter on the Snoqualmie River in western Washington, USA, based on a spatial stream-network model. Images describe stability in the distribution of relative mean temperatures and instability in the relative distribution of variability in temperatures across seasons. Modified from Steel et al. 2017.

estimating variability at each of several time scales within a time series of data - to assess relationships between landscape features and variability in water temperature across the Willamette River basin, Oregon. Some fairly strong relationships between water temperature variability and landscape features emerged (Figure 4); more interestingly, the strength of these relationships depended on whether we considered temperature fluctuations at daily versus weekly or monthly time scales. The percent of the watershed that was forested, percent with rain-on-snow hydrology, and maximum air temperature, for example, were strongly correlated with monthly variance in water temperature and

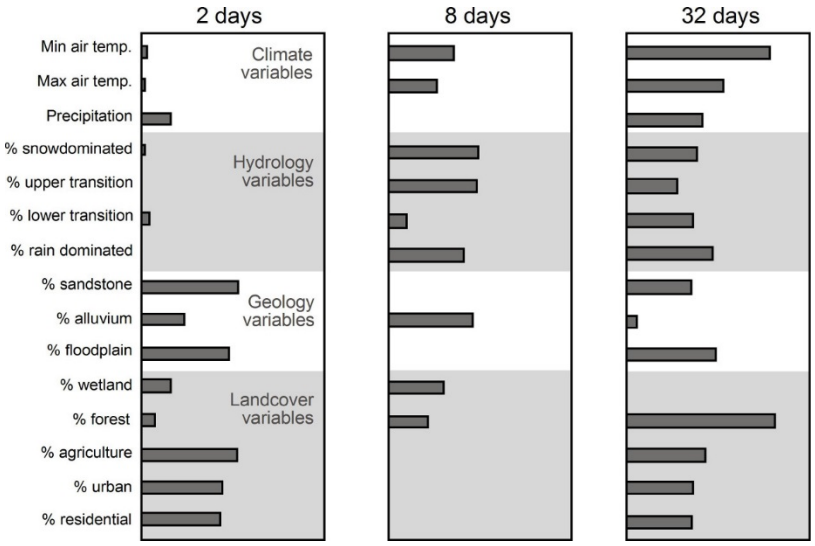

Figure 4: R-squared values for each independent simple linear regression of landscape-scale predictors on log-transformed wavelet coefficient variances of water temperature within the Willamette River basin, OR, USA. Reproduced from Steel et al. 2017.

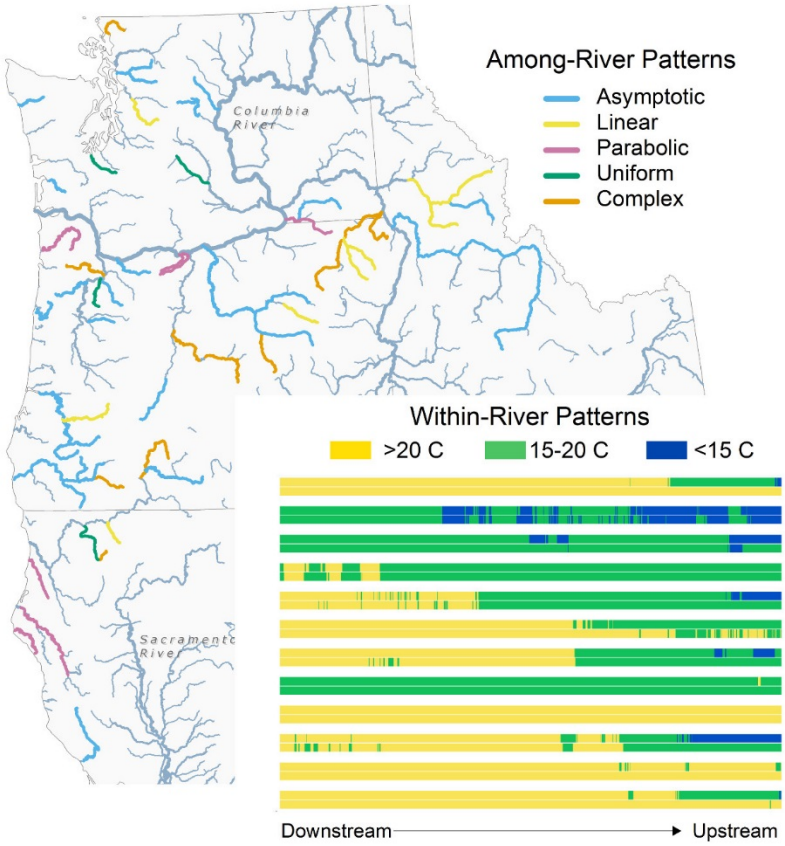

Figure 5: Main panel: Broad scale patterns of water temperature across rivers. Geographic locations of rivers in each of 5 longitudinal thermal profile shape classes from airborne remotely-sensed thermal infrared (TIR) water temperature. Modified from Fullerton et al. (2015). Inset: Spatial variability in water temperature within rivers. Longitudinal profiles from TIR, depicted as proportional linear distance from the bottom of each survey (left) to the top of each survey (right) for the parts of the river accessible to anadromous fish. For each river, plots depict patterns of thermal patches based on observed data (top portion of each bar) and projected thermal heterogeneity for the 2080s (bottom portion of each bar). Adapted from Fullerton et al. (in press).

only weakly correlated with water temperature at shorter temporal scales. These results suggest that human actions such as urbanization, which are understood to affect mean and maximum temperatures, and climate (e.g. air temperature and precipitation patterns) also influence other facets of the thermal regime and some facets more than others.

Biological Consequences of Temporal Variability

Every component of the thermal regime (e.g., magnitude, duration, frequency) has potential ecological consequences (Table 1). Of particular interest are variability and winter temperatures, aspects of the thermal landscape that receive less attention than summertime means.

We conducted an experiment that demonstrated the potential for changes in thermal variability, aside from changes in mean temperature, to alter emergence timing (Steel et al. 2012). Traditional degree day models explaining the effects of mean temperature on life-history timing in Chinook salmon are insufficient to explain our results. We estimate that altered variance alone (with relatively little change to the daily mean temperature) could lead to a difference in emergence timing of nearly a week in streams with winter temperatures averaging 3º C. When we tried to reproduce these experimental results with an established model of egg development as a function of temperature, earlier emergence with natural variability was reproduced but later emergence with extreme and unnatural patterns of variability was not, suggesting that there is both a physiological and a behavioral component in fish response to thermal variability (Beer and Steel, In Press).

Results of a second experiment on the effect of thermal regime on early life history of Chinook salmon clearly demonstrated differences in behavior (emergence timing) and morphology (length and weight at emergence) between populations and even between families within populations (Fuhrman et al. 2015). For example, fry from some populations accumulated more temperature units before emergence than fry from other populations. Interestingly, the amount of difference in emergence characteristics between populations was greater when eggs were incubated at warmer temperatures.

Modeled estimates of emergence timing based on empirical data from a natural river suggest that inter-annual thermal variability is predominantly responsible for variability in emergence timing but that small-scale fluctuations in water temperature also matter, as do family lineage, egg size, fertilization timing within the population, and temperature-based spawning cues (Beer and Steel, In Press).

Biological Consequences of Spatial Variability

The distribution of relatively cooler and warmer patches on the stream network also has implications for

Table 1: Five main attributes of thermal regimes, presumed or documented facets of biological or ecological importance, and example metrics of those facets (modified from Steel et al. 2017).

Components of thermal regime	Facet of biological or ecological importance	Example Metric
Magnitude	Differences in mean temperature across rivers circumscribe species ranges.	Daily mean temperature in summer
	Sub-lethal effects may result from prolonged exposure to temperatures below lethal thresholds.	Mean of the 7-day maximum in Aug
	Reduced metabolic rate reduces growth.	Mean daily minimum Apr - Oct
	Thermal exposure drives egg development and emergence timing.	Accumulation of degree days after Sep 15th
Frequency	Species-specific tolerances to high temperatures provides advantages to particular species.	Days >20°C during the hydrologic year
	Reductions in growth caused by low temperatures may reduce individual fitness.	Number of days <0°C after Mar 1
Duration	Accumulated stress may trigger migration and other major life-history transitions.	Longest period with mean daily temperatures >15°C
	Proximity of predators and prey is partially regulated by movements to maximize growth.	Total days in a year with mean daily temperature <5°C
	Pathogens may require long periods of warm, stable temperatures.	Maximum consecutive days with daily mean >5°C and range <2°C
Rate of change	Fast temperature shifts may cause stress, increasing susceptibility to disease.	Mean diurnal range in summer
	Rate of warming may alter timing or developmental stage of emergence.	Variability at scales between 1d and 1y, using wavelet coefficients
	Competitive advantages may be determined by conditions in both summer and winter.	Difference between mean temperature in Aug and in Feb
Timing	Seasonal thermal patterns determine timing of emergence relative to high flow events.	Julian date of maximum daily temperature
	Reduced metabolic demand when fewer food resources are available.	Julian date when the lowest 30-day minimum temperature begins

the viability of imperiled Pacific salmon and steelhead. Salmon evolved in a thermally diverse landscape; the breadth of life history strategies employed is partially governed by habitat diversity, and their long-term persistence may be enhanced by conservation of thermally diverse habitats (Schindler et al. 2010). We used a meta-analysis of airborne remotely sensed thermal infrared data to discover that patterns of water temperature are diverse even at large spatial scales. Across rivers throughout the Pacific Northwest and northern California there are five dominant shapes describing downstream warming patterns, and these shapes are not geographically clustered but instead are distributed throughout the region (Fullerton et al. 2015, Figure 5). Zooming in, we found that spatial diversity across river networks was mirrored within individual rivers, where the frequency, size, and spacing of cool-water (<15˚ C) patches was unique to particular rivers (Figure 5). By exploring fine-scale spatial data, we identified biologically-relevant fine-scale thermal heterogeneity that could not have been envisioned if only aggregated data were available (Fullerton et al., In Press).

To explore how spatiotemporally dynamic thermal landscapes influence population performance, we developed an individual-based model that predicts the behavior of individual salmon in response to water temperature on the river network. In the model, fish experience daily fluctuations in water temperature and also respond to thermally-dependent conspecific densities. We applied this model in the Snoqualmie River watershed using spatiotemporally explicit water temperatures predicted by a spatial stream network model. We predicted, for juvenile Chinook salmon, that growth was lower but survival was higher in a "typical" year (2014) compared to an abnormally warm, dry year (2015). To determine what aspect of a warmer thermal regime had the most effect, we compared responses across scenarios in which we increased, one at a time, the magnitude of temperatures during winter, spring, or summer, or increased variability (Fullerton et al., in review). Each scenario impacted life stages in a unique way. Emergence timing was most influenced by a warmer winter, whereas growth and survival were most influenced by a warmer spring.

Stream Temperature Monitoring

Given that mean summer temperature provides only part of the story and that spatial patterns in water temperature are unique to particular rivers, there is a growing interest in setting up water temperature monitoring arrays that can facilitate measuring and modeling other facets of interest (e.g. mean winter temperature or daily range in summer) across entire stream networks. We used data collected every 30 minutes over 40 monitoring stations on the Snoqualmie River to simulate various strategies for designing such a monitoring array and to provide guidance with respect to necessary sample size, location of new sites, and fine-tuning the use of spatial stream network models (Marsha et al. 2018).

Based on the results of these and other simulation experiments (Som et al. 2014), we make six **suggestions for designing water temperature monitoring arrays on river networks:** (1) use pilot data and existing research, when possible, to identify areas that might be unusual and/or landscape features that influence water temperature patterns; (2) maintain a distribution of monitors across the stream network (i.e., over space and across the full range of landscape features that likely influence water temperature); (3) maintain multiple closely spaced sites for more accurately estimating similarity in water temperature regimes between nearby sites; (4) if sites are to be added, prioritize capturing a range of landscape features over adding new tributaries; (5) maintain a sensor array in winter; and (6) expect reduced accuracy and precision when predicting metrics other than means.

Management Implications

- Management of aquatic and riparian systems can be enhanced by considering the thermal landscape in its full complexity rather than focusing on mean temperatures and lethal biological thresholds.
- For management of a particular aquatic species, explicitly identifying the facets of the thermal landscape that are of greatest importance at each life stage, and modeling metrics that describe these facets, enables identification of suitable thermal habitats and how their distribution may shift in the future.
- Models of thermal landscapes that include temporal and spatial variability provide refined estimates of how species-specific microclimates may respond to mitigation efforts, restoration actions, and future climates.
- Monitoring and modeling variability in stream temperatures over time and on the river network can help land managers design suites of protection and restoration actions that rebuild thermally dynamic river systems.
- Even relatively small water temperature monitoring arrays can provide useful data; archive the raw data and maintain the monitoring array all year where possible.

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Notices and Technical Tips

- **Direct technical assistance from applied scientists at the National Stream and Aquatic Ecology Center** is available to help Forest Service field practitioners with managing and restoring streams and riparian corridors. The technical expertise of the Center includes hydrology, fluvial geomorphology, riparian plant ecology, aquatic ecology, climatology, and engineering. If you would like to discuss a specific stream-related resource problem and arrange a field visit, please contact a scientist at the Center or David Levinson, the NSAEC program manager.

- **Guidelines for Dam Decommissioning Projects** has been published by the U.S. Society of Dams to provide a comprehensive reference for managers and practitioners who are considering a dam removal. Subjects included in this reference include factors to consider for dam decommissioning projects, project planning and decision making, the engineering design process, sediment management, construction activities, and monitoring and mitigation. Case studies of dam removals are also provided.

The primary objective of these Guidelines for Dam Decommissioning Projects is to provide dam owners, dam engineers, and other professionals with the information necessary to help guide decision-making when considering dam removal as a project alternative.

Tools for Understanding Riparian Vegetation Distribution using a Plant Guilds Approach

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Riparian vegetation is a critical resource, providing greater ecosystem services relative to other vegetation types in most landscapes and climates (Naiman et al., 2005, Sabo et al., 2005). Understanding how riparian plant composition may change under future climate and hydrologic conditions is a challenge (and an opportunity) for river scientists and land managers around the world (Capon et al., 2013). In order to develop predictive models that can forecast riparian plant composition, it is necessary to understand the physical processes that shape riparian plant communities. This is a central focus for riparian ecologists at the National Stream and Aquatic Ecology Center: to model and understand riparian plant communities under shifting streamflow regimes in order to enhance resource management capabilities of the U.S. Forest Service. One current area of emphasis is the analysis of streamflow and associated riparian vegetation on streams that flow through both National Forest System lands and Department of Defense managed lands in the southwestern US. This partnership is one of several efforts to address the question of appropriate environmental flows for riparian vegetation on National Forests. A cutting-edge approach for evaluating and modeling riparian plant communities is the riparian response guilds framework (Merritt et al., 2009, Merritt et al., 2010). In the guilds approach, species are grouped into guilds according to their functional traits and how these groups (guilds) relate to streamflow and groundwater availability. Here, we build on an earlier StreamNotes article on riparian guilds, provide an overview of the guilds approach to riparian plant-streamflow modeling, and discuss its application in the context of a Forest Service – Department of Defense partnership (Merritt et al., 2009).

Streamflows Are Changing, Riparian Vegetation Will Respond

Streamflow in many river systems worldwide has been altered or is currently in the process of shifting from historic norms (Koirala et al., 2014). Changes in streamflow can be caused by flow regulation, water diversions and extractions, groundwater use, and climate shifts in temperature and precipitation. Direct human impacts like dams and diversions can affect many aspects of the flow regime (Graf, 1999). For instance, flow regulation can lower peak flows, lower or artificially elevate base flows, and in extreme cases cause sections of rivers to stop flowing. Climate change is also expected to result in changes in timing, quantity, and variability of peak and low flows (Palmer et al., 2008). Regardless of the cause, riparian vegetation will adjust to new hydrologic regimes and associated processes (e.g., sediment regimes) in predictable ways. The challenge is to understand the specifics of how riparian vegetation will change in composition and abundance, and to quantify the ecological consequences in the context of sustaining this critical resource.

Riparian plants are closely linked to and dependent on the surface and groundwater hydrology of the streams where they reside (Naiman et al., 2005). Current vegetation is a reflection of existing hydrology as well as the legacy of earlier flows and geomorphic processes. Many riparian plant species depend on flood disturbance to create new habitat for seedlings; floods rework floodplain sediments, deliver nutrients and water, clear areas for new plant establishment, and moisten seedbeds. Riparian plants also depend on the availability of shallow riparian groundwater, whether living near gaining or losing streams. Plant species that persist in riparian habitats shift in form and composition along a gradient from abundant water and frequent disturbance near the channel to scarce water and less frequent disturbance further from the channel (Figure 6). This gradient is often captured in a restoration framework by the idea of "riparian planting zones" (see Chris Hoag's 2016 StreamNotes article for an overview). To understand how riparian plant communities are distributed along this floodplain gradient from near channel to the uplands, and to develop predictive ability, we use streamflow-plant guild models to quantify plant distributions in riverscapes (Merritt et al., 2009, Merritt et al., 2010).

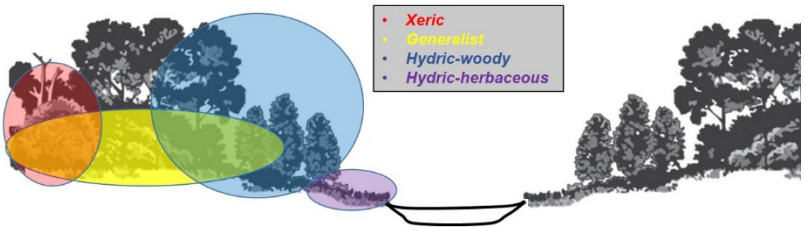

Figure 6: Cross section of a stream channel and floodplain with the positions of common riparian plant guilds on the floodplain highlighted: xeric plant guild (red shading), generalist plant guild (yellow shading), hydric-woody plant guild (blue shading), and hydric-herbaceous plant guild (purple shading).

Riparian Vegetation Flow-Response Guilds

There are many ways to model plant distributions along environmental gradients, including mechanistic and statistical models. Such models facilitate an understanding of how plants are linked to their environment and are essential for predicting plant distributions under various climate, water, and land management scenarios. Our goal is to produce models that can inform resource management and be effective tools for understanding riparian plant communities and how they respond to changing streamflow. Individual plant species distributions are often the focus of modeling, but an alternative approach that is gaining traction is to model functional guilds instead of species (Bejarano et al., 2012, Lawson et al., 2015b). Species with similar functional traits (eg: rooting depth, height, leaf thickness, stem density, etc.; Table 2) can be sorted into groups called guilds, based on their traits.

Guilds are useful because they transcend species and taxonomy, which vary from region to region, and elevate plants to groups with similar functional relationships to physical gradients (Hough-Snee et al., 2015, McCoy-Sulentic et al., 2017). Therefore, the same guild can appear on streams across broad regions and may include different combinations of species depending on the geographic location. For example, a "hydric riparian tree" guild in coastal California may include sycamore, alder, and tree willows and the same hydric riparian tree guild on the Colorado Plateau may include cottonwood, tamarisk, Russian olive, and other willow species, yet both guilds are characterized by similar functional traits: tall, long-lived, deep-rooted, and early-successional. Here, we apply the riparian vegetation streamflow-response guild modeling approach in which guilds of species with similar functional traits are identified on streams and then modeled with respect to their distribution along moisture and disturbance gradients.

Table 2: Functional trait descriptions for riparian plant-streamflow guilds (adapted from Diehl et al. 2017).

Trait	Description	Function
Specific leaf area	Dry leaf mass per area of leaf surface (g/cm^2)	Investment in photosynthetic capacity, leaf nitrogen content, adaption to submergence, leaf life-span
Carbon isotope ratio	$Carbon^{12}$:$Carbon^{13}$ isotopic ratio	Water-use efficiency, drought tolerance
Wood density	Stem dry mass per volume (mg/mm^3)	Xylem cavitation resistance, mechanical stability, growth rate, stress tolerance
Maximum height	Height at plant maturity (m)	Competitive ability
Root depth	Depth of roots at plant maturity (m)	Water and nutrient extraction, mechanical stability
Seed mass	Mass per 1000 seeds (g)	Reproductive strategy, establishment characteristics

Steps for building riparian vegetation flow-response guilds:

1. Construct a hydraulic model for the study reach (ideally a 2-D model, 1-D can suffice) to obtain water surface elevations over a range of discharges for mapping flood exceedance probabilities and other hydraulic attributes across the riverscape.
2. Take direct trait measurements for as many plant species as possible across the floodplain and uplands, ideally 3-5 individuals per species (See Table 2 for traits to measure).
3. Build a database of traits measurements for all plant species at the study site. Take average trait values across sampled individuals within species. For species where there is no measured trait data, draw information from online trait databases such as USDA PLANTS Characteristics Database, Kew Royal Botanical Gardens Database, or the TRY Plant Trait Database.
4. Using a combination of cluster analysis and ordination to group species in your database, develop functional guilds based on species trait values.
5. Sample vegetation abundance and frequency in plots and/or along transects across the floodplain, balancing the sample evenly across the moisture/disturbance gradient from the channel to the uplands (Figure 6).
6. Use the hydraulic model to plot topographic positions on the floodplain and assign flood exceedance probabilities and hydraulic variables (e.g., velocity, shear stress at a given discharge) to each plot. Build statistical models of guild probability of occurrence (guild distribution) across the floodplain.
7. For future predictions, adjust flow through the hydraulic model using management or climate scenarios. Management or climate scenarios can be simple (drawn from literature) or complicated (hydrologic models forced with climate projections) depending on the goals of the project. Based on the resulting changes in flood probabilities across the floodplain, translate flood probabilities to predicted guild probabilities using the guild distribution models.

Case Study of Modeling Guilds on Arid Land Streams

Here, we present work being done on three study rivers: the San Antonio River in central coastal California, the Santa Margarita River in southern coastal California and the Purgatoire River in southeastern Colorado (Figure 7).

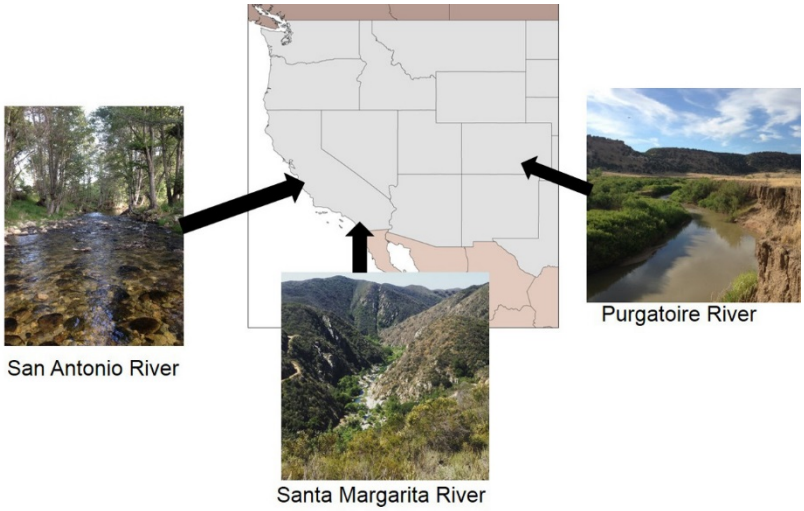

Figure 7: Map of study sites in coastal California, the San Antonio and Santa Margarita Rivers (left and bottom) and in southeastern Colorado, The Purgatoire River (right).

The San Antonio River's headwaters are on the Los Padres National Forest and drain 217 square miles of the Santa Lucia Mountains, in the Coast Range of central California. Our study reach on the San Antonio is on the Fort Hunter Liggett U.S. Army Training installation, immediately downstream from the Los Padres National Forest. The Santa Margarita River drains 600 square miles of the Santa Lucia Range in southern California, including headwater portions in the Cleveland National Forest. Our study reach on the Santa Margarita is on U.S. Marine Corps Base Camp Pendleton, downstream of the Cleveland National Forest. The Purgatoire River is the largest of our study watersheds and drains 2,758 square miles off of the Spanish Peaks and Sangre de Cristo Mountains in the Pike San Isabel National Forest and Comanche National Grassland of southern Colorado. The Purgatoire River flows through the U.S. Army Fort Carson's Pinyon Canyon Maneuver Site and our study reach is on a downstream section that flows through the Comanche National Grassland.

At each study site we collected data on floodplain topography, trait measurements for a range of plant species, and species distribution data in vegetation plots. We are using floodplain topography data to build detailed surface elevation maps of the floodplains that will, in turn, be used to model hydraulics on the floodplain including flood exceedance probabilities and flow velocities for a range of discharges (Figure 8).

We collected vegetation distribution data across the floodplain on transects to link species to their position on the floodplain, specifically their location with respect to flood frequency (flood exceedance probability), as well as flood flow velocities and shear stress. These variables quantify disturbance and water availability. We also collected data on traits that are relevant to plant growth and energy allocation strategies on floodplains (McCoy-Sulentic et al., 2017) for nearly 100 species in California and almost 60 species in Colorado. These are traits that have been established in the peer-reviewed literature that relate to things such as competitive ability, water use, resource allocation, growth rate, and reproduction (Westoby, 1998).

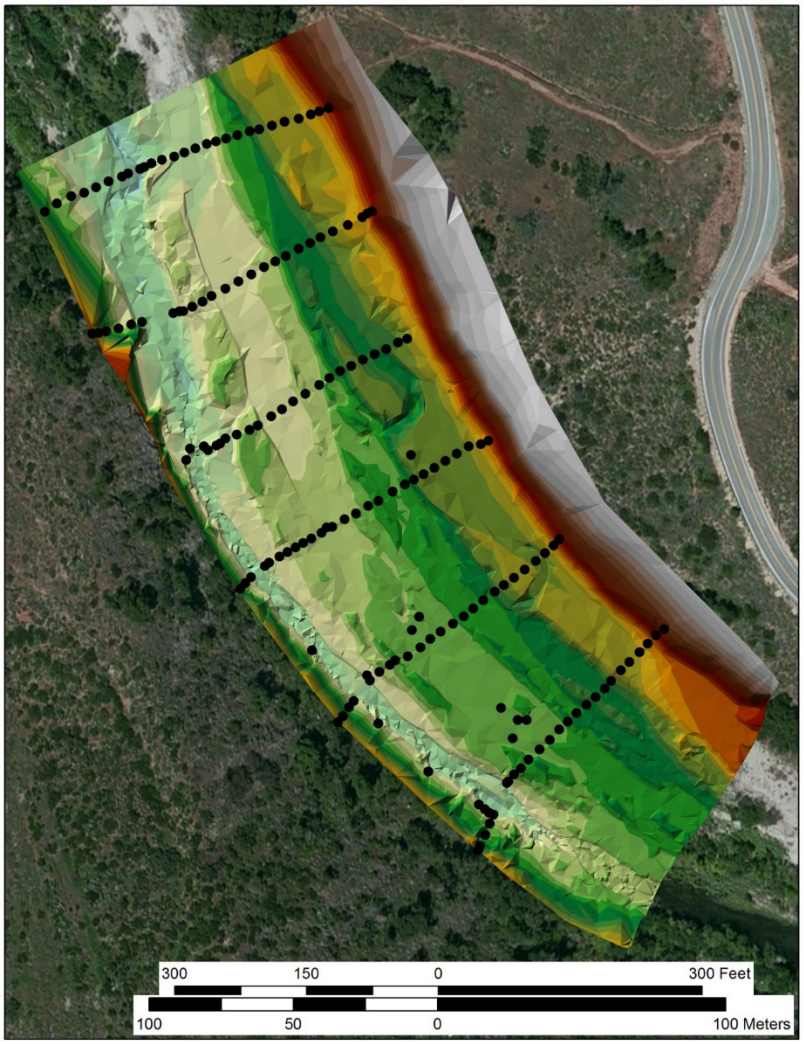

Figure 8: Surveyed floodplain topography overlain on satellite imagery of the Santa Margarita River near Fallbrook Bridge, California with color depicting elevation of the survey: blue are low elevations (river channel), greens are moderate elevations on the floodplain, and yellow to orange and red-brown are increasingly high elevations into the uplands. Black dots indicate locations of vegetation survey plots. Flow is from lower right to upper left.

For example, the trait "specific leaf area" is a measure of leaf mass per area and indicates plant investment in photosynthetic tissue, and indirectly, whether a plant is fast- or slow-growing. Wood density indicates growth speed and stress tolerance; woody plants with high wood density are slow growing with the potential to be more water-stress (drought) tolerant, while plants with low wood density are fast-growing with higher water demands and lower stress tolerance (Lawson et al., 2015a). For the 154 species, we obtained average trait values for:

specific leaf area (leaf toughness), maximum height (a measure of competitive ability), leaf Carbon13:Carbon12 ratios (a measure of drought tolerance), and wood density (an index of growth rate and stress tolerance; Table 2). We also obtained seed mass estimates from the Kew Royal Botanical Gardens Database (seed mass indicates resource investment in reproduction; Table 2).

With trait data for our study species, we used ordination (Figure 9) to develop guilds for our California sites which resulted in seven guilds on the two California rivers: vine/shrubs, xeric shrubs, hydric floodplain trees, hydric floodplain shrubs, upland drought-tolerant trees, mesoriparian annual herbs/grasses, and generalist perennial herbs/grasses (Figure 10). The next step is to link these guilds to their position on the floodplain and to the hydraulic models. Once the guilds are statistically modeled with floodplain position, we will project distributions using expected future flows, driven by changes in river management or changes in climate. We plan to analyze the floodplain distributions of these guilds in comparison to other guild studies on rivers across the western U.S. including the San Joaquin River, the Colorado River, and the Yampa River in northwestern Colorado.

This approach is an exciting and innovative way to analyze riparian vegetation by considering guilds: groups of species that have similar functional traits, rather than modeling every species in an ecosystem, and enables interpretation across different rivers. With a basic understanding of plant composition on floodplains, the models that result from these efforts can be used and applied by resource managers across regions with different species compositions.

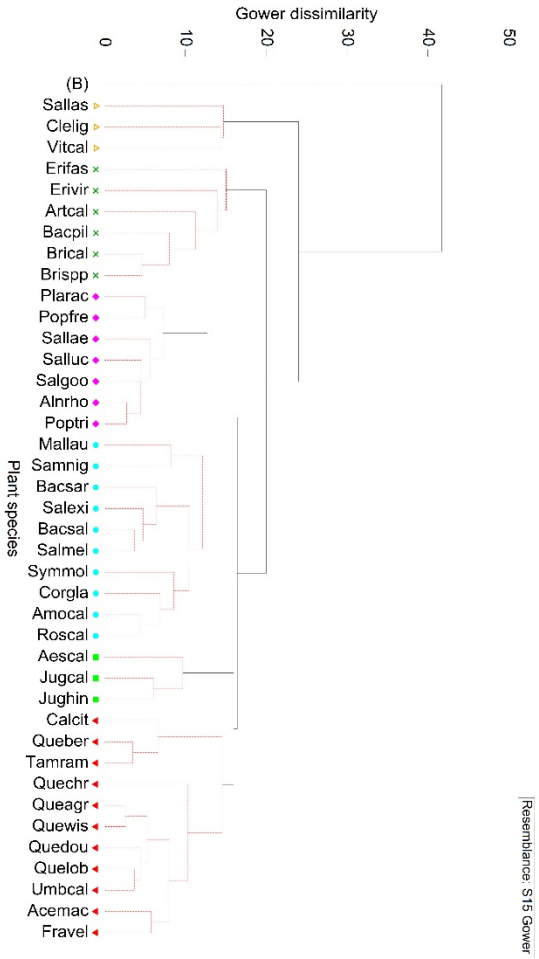

Figure 9: Example of a portion of an ordination plot, grouping species into functional guilds depicted by symbols. Yellow triangle: vine/shrubs, green x: xeric shrubs, pink diamond: hydric trees, blue circle: hydric shrubs, and green squares and red triangles: drought-tolerant trees.

Figure 10: Photos of trait sampling and vegetation plot sampling of species on the Santa Margarita River, California.

Management Implications

- Understanding how riparian vegetation and its functional characteristics will shift under future streamflow regimes is essential for land management, planning, and restoration.
- Riparian guild models that link plant guilds to streamflow can help inform management in a way that functionally links plants to stream processes.
- Guilds are a useful way to analyze riparian plant communities because they move beyond species and result in fewer groupings of plants, based on functional similarities and response to physical gradients.
- Guilds provide the potential for transferring modeled relationships from well-studied species to species of concern that are rare or difficult to investigate.
- Models of guild distributions on floodplains can be applied across regions with different species compositions.

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