Favorable Environmental Conditions of Invasive Vegetation Found in Post-Dam Removal Dynamic Floodplains

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Abstract:

As dams begin to exceed their 50 year life spans across the USA, removal is becoming necessary. Post-dam removal riparian floodplains are seasonally harsh environments and prone to invasive vegetation. Invasive vegetation distributions along the post-dam Elwha river did not match predictions. Thus gathering data on post-dam removal sites can help us understand what environmental factors are most favorable to invasive vegetation, which can aid in successful mitigation strategies. Our project aimed to determine what combination of variables creates the most favorable environment for the invasive vegetation found in post-dam removal dynamic floodplains of Geyser Valley. We used systematic sampling to collect data on the density of invasive vegetation, sediment type, percent ground coverage, and canopy cover in 47, $1m^2$ plots within Geyser Valley. We used an Information Theoretic Approach to identify a single multivariate model consisting of sediment types; fine sediment, sand, and cobble, had the greatest empirical support for invasive plant density with an $\log(\ell)r^2$of 75%, an AIC score of 1010.409, a Delta score of 0, and a Weight of 0.9836. Our results can help management agencies develop efficient invasive plant mitigation/removal strategies by identifying areas at most risk.

Introduction

The removal of a dam causes a massive flush of the accumulated sediments that leaves behind a barren riparian zone that will undergo succession. Invasive plant species can easily displace the native plants by altering ecosystem processes, such as the hydrological cycle, nutrients cycle, and fire regimes, if not actively managed (Walker et al. 1997). The expected life cycle of a dam is approximately 50 years before there are diminishing returns on functions the dam provides, and 85% of the dams built by the Army Corps of Engineers National Inventory of dams are over 50 years old (Maclin et al. 1999). According to the National Inventory of Dams (NID), the nation has 92,065 dams, with an age averaging around 61 years. A total of 76% of these dams are labeled as “High Hazard Potential Dams” and have an an Emergency Action Plan in place (NID 2020).While there are safety risks surrounding these dams, as well as concerns over their economic viability, there are other environmental factors to consider when determining if dam removal is prudent (Brown et al. 1988). The initial daming of a river fundamentally changes the chemical, physical and biological conditions of the river and the surrounding ecosystems (Maavara et al. 2020). The blockage changes the dynamics of sediment transport, nutrient flow, temperature/oxygen level of the water and wildlife dependent on the unimpeded flow for migration (Maavara et al. 2020). A water reservoir is created by the damming of a river, and sediment accumulates over time in these reservoirs creating more lentic conditions in contrast to the natural lentic conditions of a river (Maciej 2019). As seen in the Elwha dam removal project, the sediment flushing of the reservoir creates temporary hazardous conditions downstream as well as stripping the reservoir basin bare (Randle et al. 2015). The newly created riparian zone is often void of any fine sediments necessary for primary succession and instead the sediment is coarse, low nutrient, low moisture availability and has high sun/wind exposure (Randle et al. 2015). Additionally, the native forests will be far from the new river flow edges and this limits the detritus, seed and spore availability to the farthest reach of the dewatered reservoir (Maclin et al. 1999).

Invasive vegetation poses a threat to the survival of native species, as they alter the ecosystem's hydrological cycle, nutrient cycle, and decrease overall biodiversity (Harrod 2001). Phenotypic plasticity of invasive vegetation allows for them to more easily colonize the harsh conditions of the new riparian zone and outcompete native vegetation (Molina-Montenegro et al. 2018). Once invasive populations have become established, successional transition of native species diminishes as the non-native populations can persist for decades (Cai et al. 2020). Eradication efforts prior to the establishment of invasive species are costly and often unsuccessful due to narrow approaches that fail to recognize the non-static nature of invasion. Therefore, well-informed strategies focused on preventive or proactive measures are critical in successfully mitigating the establishment or spread of invasive populations and subsequently conserve the equilibrium of the system (Davies et al. 2017).

The Elwha River Dam removal and ecosystem restoration projects focused on restoring exposed riparian floodplains to pre-dam historical conditions while emphasizing native plant species successional strategies (Chenoweth et al. 2011). The Glines and Elwha Dams had trapped approximately 1.84×10^7 yards^3 of sediment which was released downstream during and after removal (Sharpe et al. 2013). Post-dam removal, the density of newly exposed land ranging from coarse floodplain sediment to finer sediments along the valley walls was seeded and/or planted with drought-tolerant native species to mitigate invasive species from dominating the exposed riparian zone (Foley et al. 2017; Shafroth et al. 2002; Parks et al. 2005).

The native riparian plants of the Elwha have adapted to flood disturbances but are prone to fluvial deposition and sediment stripping impacting long-term survival and growth (Del Moral et al. 200**5).** However, invasive and pioneer vegetation often has a greater density in these zones, (Jauni et al. 2014; Bolpagni et al. 2021), particularly in younger riparian communities (Planty-Tabacchi et al. 1996). Newly established riparian plants begin to alter their local habitat by trapping and stabilizing sediments in between their roots and other similar structures. This process can become self-reinforcing by the establishment of other plants, leading to the development of riverbanks or vegetated islands (Gurnell et al. 2012). This process helps to control the rate of sediment erosion and deposition, which is a foundational function for riparian ecological succession (Corenblit et al. 2009). Coarse floodplain sediments tend to retain nutrients due to up-river bank erosion and increase moisture retention during wet seasons, but during hot/dry seasons cobble has low nutrient availability and reduced moisture retention from high wind and sun exposure(Danalatos et al. 1995; Hopkins et al. 2018). These conditions decrease the survivability of native riparian species (Cavaliere et al. 2012). Invasive plant species can rapidly and fully occupy the available niche space as well as complete their life cycles earlier, avoiding the harsher conditions of summer (Molina et al. 2018). Over time, the compounding vegetative mass acts as an abiotic determinant, increasing moisture retention and increasing nutrient availability via detritus (Parks et al. 2005). These conditions are naturally more favorable to native species, enabling the primary succession of native species. The larger woody species shade out the invasive vegetation, forcing non-woody species to colonize the edges of the habitat and continue the process of facilitation (Parks et al. 2005). This process is better seen with the seeding of *Lupinus rivularis* **(**Riverbank lupine**)**, which was done to increase sediment nutrients and organic matter (Kardouni 2020). However it is unknown if the detritus of *Lupinus rivularis* is also positively benefiting invasive species by acting as habitat in areas far from the forest edge where spontaneous seeding would otherwise occur.

Several knowledge gaps surrounding the mechanisms that spread and facilitate the invasive vegetation within the dewatered reservoirs of the Elwha River persist, and early estimates on the extent of vegetative colonization on the newly exposed substrates could not be accurately predicted (Prach et al. 2019). Prior to dam removal, studies predicted how reservoir sediments may affect the germination success and growth of native and invasive vegetation, and the results suggested that native vegetative species would be slow to recolonize the reservoir's basin in the initial post-dam removal years (Michael et al. 2011). The invasive species, *Cirsium arvense* (Creeping Thistle), was also predicted to thrive on the newly exposed substrate, however, post-dam removal studies did not observe this in the dewatered reservoir. The absence of *Cirsium arvense* in the region is suspected to be due to the success of early mitigation efforts to eradicate and control their spread from the high-priority areas surrounding the dam's reservoir (Woodward et al. 2011). Spontaneous succession of native vegetation has largely been successful in areas with fine sediment composition. However, the trajectory of spontaneous succession in areas with coarse sediment composition remains poorly understood (Prach et al. 2019).

Identifying environments that are vulnerable to invasion while also identifying the favorable environmental conditions for invasive species that are well-adapted to those environments is key to preventing, detecting and/or eliminating invaders while they are still in the initial early stages of colonization (Peterson et al. 2001; Zalba et al. 2000). Environmental factors that influence vegetation composition are necessary to predict the distribution of both native and invasive vegetation **(**Ehrenfeld, J. 2003; Funk et al. 2016**)**. The use of an Information Theoretical Approach to determine which environmental variables best explain the response variable should be used to build robust predictive models (Rushton et al. 2004). By Identifying the combination of variables that creates the most favorable environment for the invasive vegetation found in post-dam removal dynamic floodplains, stakeholders can develop efficient and effective mitigation and/or elimination management strategies.

Environmental factors such as shading, ground coverage and sediment types are all determinants for species composition, but the degree to which they positively affect invasive species is unknown. Our project aims to determine what environmental factors are influencing plots with dominant invasive vegetation density in the post-dam removal dynamic floodplains of the Elwha River. We expect a combination of one or more of the environmental variables; sediment type(s), percent canopy cover as a surrogate for light availability, and open ground availability, will have a significant influence on the density of invasive vegetation. Our results can help inform management agencies as to how best to control/limit invasive spread in the Elwha system or future dam removal sites by quantifying the expected density of invasive vegetation based on environmental synergies.

Methods

Field Data Collection

Our study was conducted within the dynamic floodplains of Geyser Valley, located along the Elwha River in the Olympic Peninsula of Washington State. In 2015, after the removal of the Elwha and Glines Canyon Dams, the road that once led to the Whiskey Bend trailhead was washed out, making accessing Geyser Valley impossible by vehicle. Geyser Valley is located approximately 4 miles past the Whiskey Bend trailhead, but 7.8 miles from the parking area. We surveyed 47 plots using a systematic sampling grid that extended from the river's edge to the forest's edge. Each cell was $25m^2$ in area. We collected our data at the cell center in plots that were $1m^2$. At each plot, total invasive vegetation was counted, and environmental variables, including percent ground cover, sediment type, and canopy coverage, were measured and recorded.

- Invasive vegetation within the plot was individually counted and recorded.
    - Total number of individual invasives per meter squared.
- Ground coverage was categorized as anything unsuitable or available for vascular plant establishment and/or seed germination.
    - Ground coverage was estimated on a scale of 0 - 100%, by dividing our 1 m^2 plot into 10, 10 cm x 10 cm squares.
    - Ground coverage consisted of bryophytes, detritus, large boulders, and/or woody debris.
- Shade was measured as canopy cover (0 - 100%) using a convex spherical densiometer.
- Sediment type was distinguished into four main categories; fine, sand, gravel, and/or cobble.
    - Sediment within plots was determined by the dominant type being greater than 80%, however, some plots contained a combination of two different dominant sediment types and were designated as such.

Data Entry

Data collected in the field were entered into a generated Google Sheet that had the appropriate formatting for exporting to RStudio. Data entered fell into two categories: Field Data and Site Data. Field Data included all measured independent variables; percent canopy coverage, percent ground coverage, and sediment type; fine, sand, gravel, cobble. Additionally, the sheet contained a column of the total invasive vegetation found in each plot. Site Data included columns for Site and plot numbers.

Information Theoretic Approach

We generated a table from our Information method that contains the scores for each parameter (See Table 1). The Variables column is the number of predictor variable(s) in each model. The K column is the number of parameters required to fit each model; a measure of model complexity. The Log(ℓ) column is a measure of the probability of the data in the model being "true"; or the probability you would obtain these plant counts if the model was "true". The Deviance or "residual deviance" column is a measure of the amount of variability in response variables not explained by the model. The residual deviance of the model is compared against the residual deviance of the null model, which is equal to the total deviance. The AIC column is the AIC score, a measure of balance between fit and simplicity, for that model. The Delta column is the transformed AIC score, obtained by subtracting the lowest AIC score from all other AIC scores. By definition, the model with greatest empirical support has Delta = 0. The Weight column is the probability that the model would score best (Delta = 0) if you conducted analysis with a replicate data set. Weight can also be interpreted as confidence in that model relative to other models in your candidate set.

We used information theoretic methods to evaluate relative empirical support for each model in our candidate set of 42 models for each plant response variable. Candidate models included a null model, univariate models for each predictor variable, 15 bivariate models, and 20 models containing three predictor variables. We calculated Akaike information criterion scores (AIC) and weights for each model (Anderson et al. 2000, Burnham and Anderson 2002). We fit the global model, and performed a Chi-square GOF test to evaluate the variable set. We fit candidate models using Poisson regression. We generated a table for the invasive vegetation that showed the scores for all variable models. Model selection was determined by AIC score. Plots of each statistically significant variable were generated against the response variable.

Results

Plot Summary

The Geyser valley riparian zone had an average invasive plant density of 11 invasive plants per plot with a median of 2 and a range of 97. Plots with sand in the substrate had the highest density at 482 invasive plants total across all of our plots. Fine sediments had the second highest total density at 482 and cobble had the third highest at 160. We found the highest density of invasive plants in plots that were roughly halfway between the river edge and forest edge. All invasive plants we measured were herbaceous as we encountered no invasive woody plants. Graminoids were not measured. We observed that plots with extensive bryophyte ground coverage seemed to be suppressing invasive plants as there were non-invasive typically in abundance but often no invasive plants present.

Information Theoretic Approach

A single multivariate model with four parameters had the greatest empirical support for invasive plant density, This model used the variables: fine sediment, sand, and cobble. The model has a log(ℓ) score of -501.205, a Deviance score of 886.484 compared to the null Deviance score of 1173.793, an AIC score of 1010.409, a Delta score of 0, and a Weight of 0.9836 (See Table 1). The measure of the absolute fit of our best model is 75%.

$$log(\ell)r^2 = 1 - (\frac{886.484}{1173.93_{null}}) = 0.75$$

The multivariate general linear model for all invasives has an intercept estimate of 0.5314, an intercept standard error of 0.2489, an intercept z-value of 2.13, and a statistically significant intercept p-value of < 0.05 (See Table 2). Fine sediments have an estimate of 0.8539, a standard error of 0.0939, a z-value of 9.09, and a statistically significant p-value of < 0.05 (See Table 2). Sand has an estimate of 2.0619, a standard error of 0.2416, a z-value of 8.54, and a statistically significant p-value of < 0.05. Cobble has an estimate of -0.6525, a standard error of 0.0987, a z-value of -6.61, and a statistically significant p-value of < 0.05 (See Table 2).

The general linear model for all invasives and fine sediments has an intercept estimate of 2.1203, an intercept standard error of 0.0577, an intercept z-value of 36.72, and a statistically significant intercept p-value of < 0.05 (See Table 3). Fine sediments have an estimate of 0.7802, a standard error of 0.0913, a z-value of 8.55, and a statistically significant p-value of < 0.05 (See Table 3). The general linear model for all invasives and sand has an intercept estimate of 0.588, an intercept standard error of 0.236, an intercept z-value of 2.49, and an intercept p-value of 0.013 (See Table 3). Sand has an estimate of 1.979, a standard error of 0.240, a z-value of 8.24, and a statistically significant p-value of < 0.05 (See Table3). The general linear model for all invasives and cobble has an intercept estimate of 2.7379, an intercept standard error of 0.0542, an intercept z-value of 50.5, and a statistically significant intercept p-value of < 0.05 Cobble has an estimate of -0.8816, a standard error of 0.0959, a z-value of -9.2, and a statistically significant p-value of < 0.05 (See Table 3).

Figures and Tables

Table 1. Results from the output table using an Information Theoretic Approach. A single multivariate model consisting of sediments; fine + sand + cobble, had the greatest empirical support.

Table for Information Theoretic Approach Models						
Independent Variables	**K**	**log(ℓ)**	**Deviance**	AIC_i	Δ_i	ω_i
GLMNULL	1	-644.859	1173.793	1291.719	281.31	8.08E-62
Cover	2	-622.731	1129.536	1249.461	239.052	1.21E-52
Shade	2	-644.343	1172.761	1292.687	282.278	4.98E-62
Fine	2	-610.926	1105.927	1225.852	215.443	1.62E-47
Sand	2	-579.203	1042.48	1162.405	151.996	9.71E-34
Gravel	2	-641.158	1166.391	1286.317	275.908	1.20E-60
Cobble	2	-599.195	1082.464	1202.39	191.981	2.02E-42
Cover + Shade	3	-620.587	1125.249	1247.174	236.765	3.80E-52
Cover + Fine	3	-592.192	1068.458	1190.384	179.975	8.16E-40
Cover + Sand	3	-556.616	997.306	1119.232	108.823	2.30E-24
Cover + Gravel	3	-617.364	1118.804	1240.729	230.32	9.54E-51
Cover + Cobble	3	-580.378	1044.83	1166.755	156.346	1.10E-34
Shade + Fine	3	-605.112	1094.299	1216.225	205.816	2.00E-45
Shade + Sand	3	-577.555	1039.185	1161.111	150.702	1.86E-33
Shade + Gravel	3	-640.994	1166.062	1287.987	277.578	5.22E-61
Shade + Cobble	3	-599.194	1082.462	1204.388	193.979	7.43E-43
Fine + Sand	3	-524.282	932.638	1054.563	44.154	2.54E-10
Fine + Gravel	3	-610.925	1105.924	1227.85	217.441	5.97E-48
Fine + Cobble	3	-571.728	1027.531	1149.456	139.047	6.30E-31
Sand + Gravel	3	-573.574	1031.222	1153.147	142.738	9.95E-32
Sand + Cobble	3	-539.757	963.589	1085.515	75.106	4.83E-17
Gravel + Cobble	3	-595.397	1074.868	1196.794	186.385	3.31E-41
Cover + Shade + Fine	4	-581.29	1046.655	1170.58	160.171	1.63E-35
Cover + Shade + Sand	4	-552.166	988.407	1112.332	101.923	7.25E-23
Cover + Shade + Gravel	4	-616.134	1116.344	1240.269	229.86	1.20E-50
Cover + Shade + Cobble	4	-579.969	1044.013	1167.938	157.529	6.11E-35
Cover + Fine + Sand	4	-505.356	894.787	1018.712	8.303	0.01548
Cover + Fine + Gravel	4	-591.913	1067.901	1191.827	181.418	3.97E-40
Cover + Fine + Cobble	4	-553.808	991.69	1115.616	105.207	1.40E-23
Cover + Sand + Gravel	4	-544.21	972.494	1096.419	86.01	2.07E-19
Cover + Sand + Cobble	4	-515.493	915.061	1038.986	28.577	6.13E-07
Cover + Gravel + Cobble	4	-572.644	1029.363	1153.288	142.879	9.27E-32
Shade + Fine + Sand	4	-508.234	900.544	1024.469	14.06	0.0008705
Shade + Fine + Gravel	4	-604.116	1092.306	1216.232	205.823	1.99E-45
Shade + Fine + Cobble	4	-569.603	1023.281	1147.206	136.797	1.94E-30
Shade + Sand + Gravel	4	-539.471	963.016	1086.941	76.532	2.37E-17
Shade + Sand + Cobble	4	-595.335	1074.745	1198.67	188.261	1.30E-41
Shade + Gravel + Cobble	4	-595.335	1074.745	1198.67	188.261	1.30E-41
Fine + Sand + Gravel	4	-524.134	932.343	1056.269	45.86	1.08E-10
Fine + Sand + Cobble	**4**	**-501.205**	**886.484**	**1010.409**	**0**	**0.9836**
Fine + Gravel + Cobble	4	-571.706	1027.488	1151.413	141.004	2.37E-31
Sand + Gravel + Cobble	4	-533.614	951.303	1075.228	64.819	8.27E-15

Table 2. General Linear Model for our model of best fit showing all of our variables were statistically significant.

General Linear Model for Invasives and Fine + Sand + Cobble				
Statistic	**Intercept**	**Fine Sediment**	**Sand**	**Cobble**
Estimate	0.5314	0.8539	2.0619	-0.6525
Standard Error	0.2489	0.0939	0.2416	0.0987
Z-value	2.13	9.09	8.54	-6.61
P-value	<0.05	<0.05	<0.005	<0.05

Table 3. General Linear Model for each of our selected variables showing all of our variables were statistically significant. Cobble shows a negative influence.

General Linear Model for Invasives and Each Variable				
Variable	**Estimate**	**Standard Error**	**Z value**	**P value**
Fine Sediments	0.7802	0.0913	8.55	<0.05
Intercept	2.1203	0.0577	36.72	<0.05
Sand	1.979	0.240	8.24	<0.05
Intercept	0.588	0.236	2.49	<0.05
Cobble	-0.8816	0.0959	-9.2	<0.05
Intercept	2.7379	0.0542	50.5	<0.05

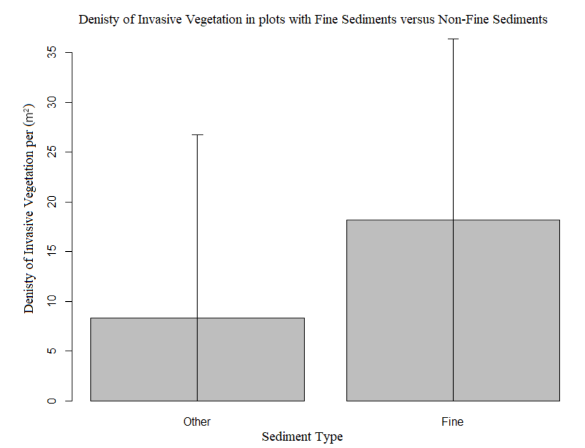

Figure 1. Fine sediment had the strongest positive influence on invasive plant density in our multivariate model but there is a relatively high uncertainty within the model.

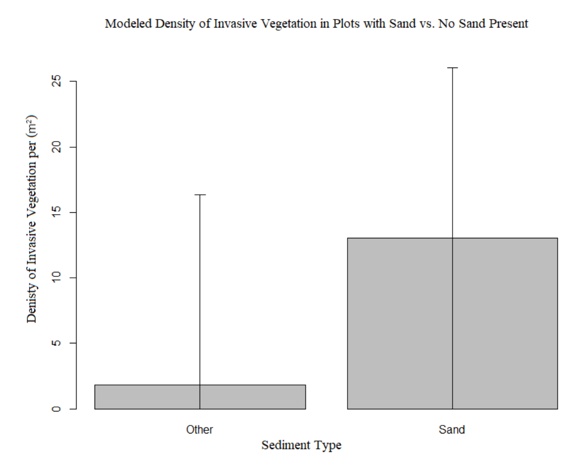

Figure 2. Sand had the second strongest positive influence on invasive plant density in our multivariate model but there is a relatively high uncertainty within the model.

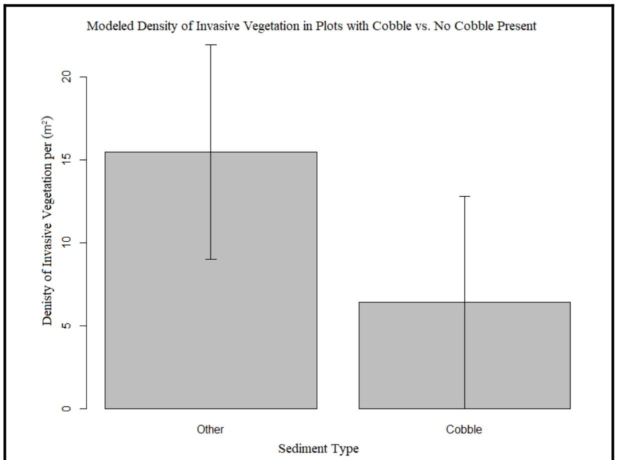

Figure 3. Cobble has a relatively small positive influence compared to the other sediments on invasive plant density in our model. Cobble, when combined with other sediments, was empirically stronger than other environmental variables.

Figure 4. A plot containing cobbles, gravel and sand. Bryophytes often seemed to out-compete any types of vegetation in the floodplain where no fine sediment was present.

Figure 5. A plot with fine soils, sand and cobble present that closely represents our strongest ITA model. Note that the cobbles are acting as physical barriers to plant establishment, but are also helping to trap the other sediments and retain soil moisture.

Figure 6. An example of the lack of canopy coverage. Due to the study area being a dynamic flood plain, there was little canopy coverage in our plots but where there was canopy coverage, it was still virtually non-existent due to the time of year.

Discussion

A single multivariate model, consisting of a combination of sediments; fine, sand and cobble, has the single greatest empirical support. Fine sediments in conjunction with sand and cobble were the best descriptors of invasive plant density of the variables we measured (Table 1) even though cobble itself appeared to have a negative influence on invasive plant density(Figure 3). The positive effects of these sediments outweigh the individual negative effects of cobble. Other environmental variables measured; gravel, ground coverage and canopy cover in any combination, had very little influence over vegetative composition (Figures 5, 6). The measure of the absolute performance or fit of our model was 75%. This does not mean we captured the exact mechanisms that are most favorable to invasive plant density, but rather we have illuminated what environmental factors matter the most to invasive plant density to the other variables we measured. Our results demonstrate the importance of substrate composition with overwhelming support for models with these substrate variables.

Fine sediment is the preferred substrate for all types of vegetation, as it retains moisture and is highly concentrated with nutrients relative to larger sediments (Figure 1). Fine sediments facilitate rapid growth of native woody vegetation, which can decrease the abundance of invasive herbaceous plants through physically occupying space and/or shading out smaller herbaceous plants. However, the availability of fine sediment within the dynamic floodplains is scarce relative to other types of sediment, as the ebb inflow of winter runoff can easily flush fine sediments away. Our ITA showed that sand has the greatest relationship to our response variable; invasive vegetation density (Figure 2). Sand retains less moisture and has less nutrient availability relative to finer sediments. Many invasive plants are unaffected by this, as they have adapted to germinate early on in the season, enabling them to complete their life cycles during early-to-late spring. This adaptation means they are unaffected by the lower moisture retention of sand, as they complete their life cycles while water is still in abundance (Gioria et al. 2016). Native riparian species require time to develop the belowground structures that keep them secure during floods. However, sand is loose and prone to flushing, making it difficult for natives to become established. Thus, within the dynamic floodplains, the overall competition between invasive species and native species is relatively low, allowing for invasives to easily establish. Additionally, sand is abundant in the dynamic floodplains of Geyser Valley, and the frequent disturbances that the region is subject to opens up large expanses of land prime for succession by invasive vegetation. Our ITA model showed that of the three sediments, cobble had a negative relationship with invasive plant density (Figure 3). Cobble exerts multiple forces on vegetation, both negative and indirectly positive. Cobble exerts a negative influence on vegetation in the form of ground coverage, as the physical body obstructs the establishment of any vascular plant. However, the positive effects of cobble outweigh the negative effects, as cobble can alter the flow of water and create spaces for sediments to accumulate, which can aid in vegetative growth through moisture retention and nutrients (Figure 5). These microhabitats may also be providing substrate and vegetation and protection from harsh environmental conditions, such as flooding, heat, wind, and/or herbivory**.** Areas that lack cobble, but consist of fine sediments and/or sand might be too exposed, and therefore may inhibit the establishment of young vegetation. The combinations of sand, fine sediment, and some cobble appears to offset the negative effect of cobble as a space occupier. (Figure 3).

Shade appeared to have no effect, however, this could be because the season was early and the riparian shrubs were bare with no foliage (Figure 6). The effect of shade on plants is well understood but the degree to which shade affects a particular species is important. Future studies should conduct research on an individual species level as well as collect data in the early and late season so that shade by canopy coverage can be properly measured. Ground cover, which consisted of bryophytes, detritus, and/or woody debris, also did not appear to have a significant positive effect on invasive vegetation density (Figure 4). We hypothesized that percent ground coverage would aid in nutrient and moisture retention, supporting vegetative growth, but were unable to detect any relationship between the two variables during the time of our study.

Future studies should perform a similar study later on in the season to gain a better understanding of the relationship between invasive vegetation and shade, as the leaves on the riparian vegetation had not yet developed during the time of our study. We suspect that shade will influence invasive vegetation densities within Geyser Valley, as shade has been known to limit the success of invasive vegetation (Evangelista et al. 2016).

A closer look at species composition in conjunction with the Information Theoretic Approach might also be very informative as to which variables influence species of interest. This could yield useful information on targeted elimination strategies. Future studies also should examine the relationship between vegetation and bryophytes specifically, as the dynamic floodplains had immense patches of bryophytes. These bryophyte patches may provide an ideal substrate for vegetation that retains moisture and fixes nitrogen through cyanobacteria-bryophyte symbiosis (Adams et al. 2008). The positive influence bryophytes may exert on vegetation may favor native over invasives as we often encountered few invasive plants relative to non-invasive in our plots. Finally, abiotic and biotic soil composition should be measured, as soil composition is critical in understanding the preferred environmental conditions of both native and invasive plant species. An indepth look at what the fine sediment consisted of might be more conclusive than examining different combinations of sediment sizes. Similar studies performed in the Mills and Aldwell reservoirs would also be beneficial in understanding the dynamic nature of dam removal, as these environmental conditions surrounding them differ significantly from Geyser Valley. As dams approach or exceed their lifespans, removal is imminent. Through understanding the biotic and abiotic factors that surround invasive vegetation, we can target our efforts to efficiently mitigate, eradicate, and prevent the spread of invasive vegetation in these highly disturbed zones.

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