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AN EVALUATION OF FOOD WEBS
IN SIERRA NEVADA STREAMS

By

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A capstone project submitted for Graduation with University Honors

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University Honors

University of California, Riverside

APPROVED

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Abstract

Global change has been altering environmental conditions at unprecedented rates in mountain ecosystems causing shifts in species distributions. Additionally, predators maintaining top-down control on macroinvertebrate communities also have large influences on food web structure. However, the relative importance of these two mechanisms in determining macroinvertebrate food web structure remains unresolved. In order to understand the individual and interactive effects of environmental change and predators on stream food webs, we studied macroinvertebrate food webs from high elevation stream ecosystems in the presence of predatory fish and from different locations that characterize an environmental gradient. Using generalized linear models (GLMs) to characterize shifts in macroinvertebrate biomass, community weighted means (CWMs), and food web structure, we compared the individual and combined effects of predators and environmental gradients to examine variation in macroinvertebrate food web structure. Community mean body size demonstrated an increase in downstream communities relative to those in the headwaters, while the biomasses of the functional feeding groups exhibited greater variability in response to predatory fish populations. Food web structure was influenced by both fish presence and the environment. Overall, environmental variability and predators influenced macroinvertebrate food web structure, although their effects varied depending on the food web metrics considered. This study provides insight for land managers working to maintain alpine ecosystems responding to environmental change.

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Introduction

Streams worldwide are subjected to multiple anthropogenic stressors that threaten biodiversity and ecosystem function (Dudgeon et al. 2006). For organisms that inhabit stream ecosystems, changes to their habitats pose a threat to their survival. One such affected community of organisms are macroinvertebrates: organisms that lack a spine and are large enough to be seen with the naked eye. Macroinvertebrates play an important role in the ecology of stream ecosystems through the transfer of organic matter throughout the stream food web (Hanau et al., 2007). Climate driven range shifts have been well documented for individual species (Wilson et al. 2005), which creates novel species assemblages. However, it is largely unknown how global warming is altering feeding interactions among macroinvertebrate species and how these translate into altered patterns of feeding relationships, referred to as food web structure. In addition, humans have both introduced and extirpated top-predators globally (Estes et al. 2011). Predators can have large impacts on food web structure and ecosystem processes, although the magnitude of predator effects (i.e. trophic cascade strength) varies among and within ecosystems (Shurin et al. 2002, Symons and Shurin 2016). Understanding how food web structure is influenced by both environmental gradients and predator presence is important to understand the capacity of macroinvertebrate communities and stream ecosystems to respond to global change.

Food webs are a basic organizational unit for ecologists, yet until recently consideration of how food webs interact across spatial scales and along environmental gradients has been largely absent (Schoener 1989, Holt 1993, Polis et al. 1997, Holt and Hoopes 2005). Food webs are constructed based on networks of interactions, or linkages, between species as well as the energy fluxes that pass between them. By understanding trends in food web structure along

environmental gradients, ecologists can understand how species turnover can impact in the function of ecosystems.

Among the many morphological and behavioral traits that macroinvertebrates encompass, body size has been linked to trends seen in stream ecosystems. Body size has been identified as a key contributor to community structure and population dynamics with studies linking size-related patterns emanating from constraints posed by the basal metabolic rate of organisms (Woodward, 2007; Brown, 2004). Communities can be impacted directly by ecological factors such as size-selective predation and indirectly through habitat size constraints from the environment (Townsend, 2007). Body size variation among taxa in a constructed food web has been attributed to fluctuations in energy fluxes due as a result of size-dependent consumption (Thompson, 2012). The advantage of using body size as a descriptor for changes in aquatic ecosystems is that this variable is generally easy to measure and is expected to vary along environmental gradients (Basset, 2004). Using the trends observed in body size differences may give rise to a more detailed understanding of effects of environmental gradients and predators on food webs.

In the Sierra Nevada of California, many historically fishless alpine lakes have been stocked with non-native trout to create recreational fisheries and have subsequently colonized connecting streams (Bahls 1992). Currently, Sierra Nevada lakes are fishless, either having fish removed or never stocked, or with fish present that have self-sustaining populations (Knapp et al. 2001). These fish are mostly non-native trout in the Sierra Nevada that negatively impact amphibian and native trout species, as well as large bodied zooplankton and macroinvertebrate species (Knapp et al. 2005, Herbst et al. 2009). This top-down effect results in increased algal and periphyton biomass, and changes in microbial communities although the later are less well

understood (Herbst et al. 2009). The effects of fish predation on food web structure in Sierra Nevada aquatic systems has been limited to analyses of individual lakes or streams (Knapp et al. 2001, 2005, Herbst et al. 2009, Symons and Shurin 2016), despite evidence that the presence of predators can alter ecological processes and food web dynamics across spatial scales (Leibold et al. 2018).

We explored the joint effects of environmental factors and fish presence on stream macroinvertebrate food webs in the Sierra Nevada, CA. We used predictions from the river continuum hypothesis, that along a latitudinal stream gradient, communities change to functionally adapt to the shifting environment (Looy 2006). Therefore, we propose that food web structure increases in complexity with increasing distance from stream headwaters. This is dependent on the observation that the distribution of species and resources change longitudinally from the river's source to the mouth, which should result in more feeding interactions downstream. We also predict that top predator identity influences body size, mainly as a result of trout predatory interactions serving as a larger impact on the average body size more so than the longitudinal gradient. Top-down trophic cascades have often been attributed to significant changes in macroinvertebrate densities in aquatic systems with predation driving patterns in macroinvertebrate assemblages (Williams, 2003). We tested this prediction by exploring functional feeding groups, functional diversity, community weighted mean of body size, as well as network structure metrics.

The results of this study will be of great interest to those studying the effects of environmental changes on stream macroinvertebrate communities. Additionally, this research can provide insight of the consequences associated with alterations in the environment, such as global warming, or fluctuations in predator dynamics.

Methods

Study Area and Field Methods

The study area is located in the Sierra Nevada of eastern California, and encompasses portions of Inyo National Forest, Sequoia-Kings Canyon National Park, and Yosemite National Park (Figure 1). Field data was collected in Sierra Nevada streams spanning an elevational gradient throughout the Sierra Nevada to understand spatial variability in aquatic communities. Five replicate stream networks were sampled at high spatial resolutions from their headwaters downstream and along a gradient downstream from lakes. At each site, environmental measurements including water chemistry, benthic productivity, substrate size, stream velocity and size, and temperature were taken. Eight to twelve macroinvertebrate samples at each sampling site were collected using a D-frame kick net (250 μm mesh, 30cm opening, 0.09m² sample area). Samples were taken from 30cm \times 30cm plots in the streambed where the net was used to gather the invertebrates carried in by the current. Invertebrate samples were stored in 75% Ethanol for laboratory identification and measurements.

In the laboratory, species identification and body size measurements were taken to characterize the diversity and size structure of food webs. Macroinvertebrate taxa were identified to the finest taxonomic level possible using a stereomicroscope, (Merritt and Cummins 2008). Once taxa were identified, individual body size measurements were taken using a light microscope with a built-in ruler to measure the species in millimeters. Species were then be placed in glass jars for long term storage. Macroinvertebrate samples sorted in the laboratory were taken to characterize the diversity and size structure of food webs.

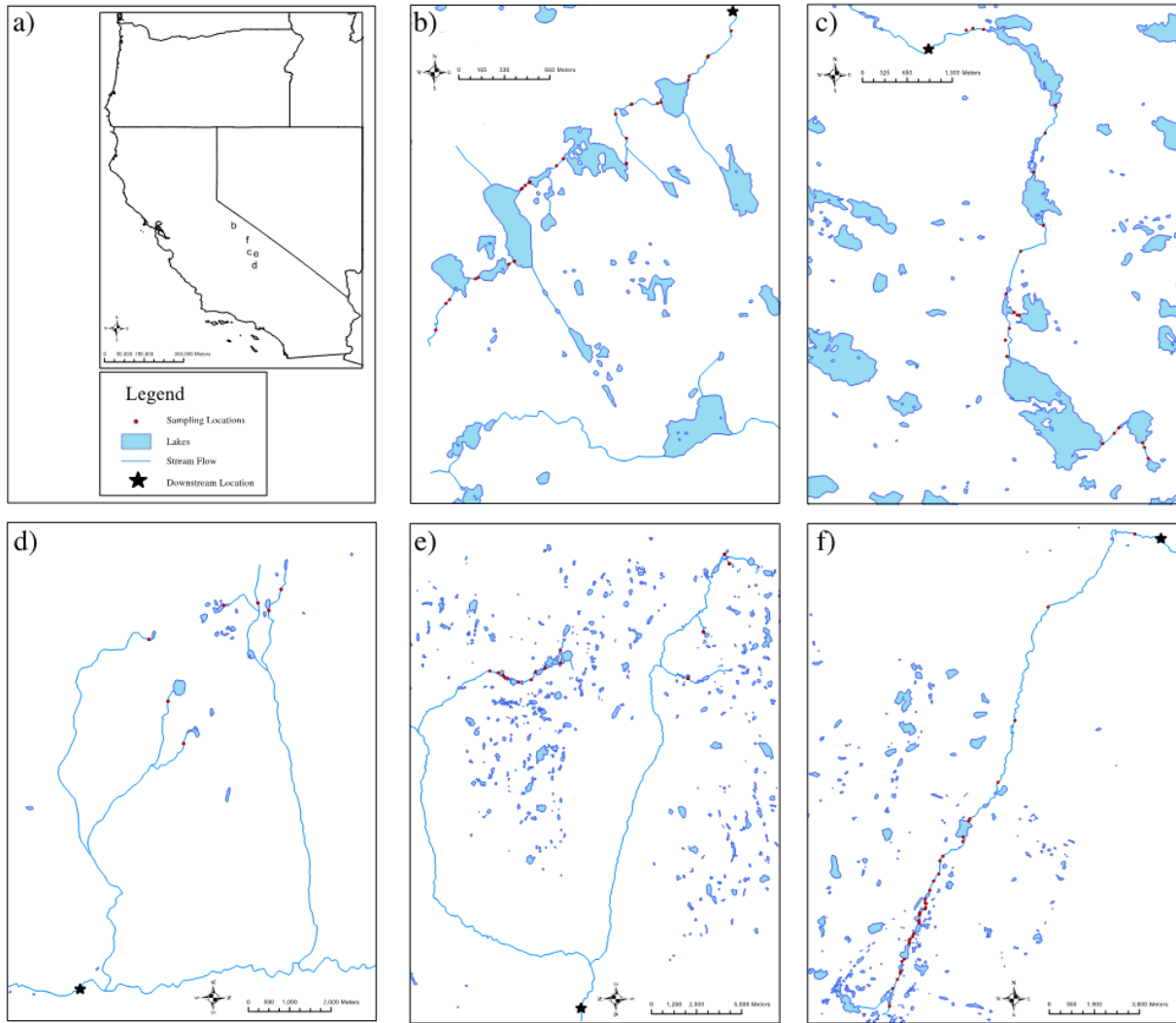


Figure 1: Distribution of field sampling sites in the Sierra Nevada, CA. (a). Five lake-stream networks (b) Cascade Lake Network, (c) Evolution Lake Network, (d) Kern Lake Network, (e) Bubbs Lake Network, and (f) Rock Creek Network were sampled across a spatial gradient from the headwaters moving downstream and a spatial gradient from lake outlets moving downstream.

Spatial Data

Stream distances between sample sites were calculated using the R package “Riverdist”, which utilizes data from the USGS National Hydrological Dataset Flowline in order to determine pairwise distances from sampling sites along the river network. We also determined community distance from headwaters with the starting position of the stream indicated by the endpoint (beginning) of the flowline. Upstream lake area and perimeter measurements were determined

using the USGS Watershed Boundary Dataset. Land-cover proportions were computed using the 2016 USGS National Land Cover Database (Jin et al. 2019).

Functional Traits

The functional feeding groups of the sampled taxa used in the study were identified based on characteristics outlined by Poff (2006). Data on functional feeding groups was used from the EPA Freshwater Biological Traits database. Groups included the following categories: collector-gatherers (CG), feeders (F), shredders (SH), predators (PR), herbivores (HB), collector-filterers (CF), and gatherers (G). The biomasses of these groups was then used to assess whether a correlation exists between the sampled sites containing absent or present predators and environmental gradients.

In order to quantify species body size, we used the EPA Freshwater Biological Traits Database on species body size and used mass length regression curves to estimate biomass using published equations for the finest taxonomic resolution from Benke et al. (1999).

Statistical Analysis

We ran a principal components analysis (PCA) on measured environmental variables which included dissolved oxygen, chlorophyll-A concentration, pH, temperature, discharge, stream size, and land cover metrics. Dissolved oxygen, temperature, discharge, chlorophyll-A concentration, elevation, and pH all loaded on the first PC axis which explained 23% of the environmental variation and defined a gradient from environmentally harsh sites with low temperatures and low productivity to environmentally favorable sites with higher temperatures and productivity.

The following response variables were evaluated to explore the influence of the environment and fish presence on food web structure: (1) functional feeding group biomass, (2) community weighted means, and (3) food web structure.

Biomasses of the functional feeding groups (FFG) were estimated using body-length dry-mass relationships (Benke, et al. 1999). In order to test how FFG densities are influenced by the environment and predators, we ran Generalized Linear Models (GLM's) for each functional group. We used a model selection approach by assessing delta AIC of all models to determine best fit models via the "AICtab" function in the "bbmle" package (Bolker et al. 2020). Pseudo R-squared values were determined by first subtracting the null deviance from the model deviance and then dividing that value by the model null deviance. Linear models used include the comparison of a null model to three scenarios: the effect of the environment, the effect of predatory fish, and the effect of both the environment and predatory fish. We used the canonical logit link function for the binomial error distributions to then test which models had the best explanatory power. It was also noted that there was left-censoring of the data at zero that arose from calculations of the FFG density ratios where numerous sites censored at zero since negative values are unattainable. Sites then that did not contribute to the functional feeding group density were then removed from the dataset. Average FFG density ratios were also calculated across sites that contained fish and sites that did not contain fish (Table 2).

We tested the effect of fish and environmental gradients on macroinvertebrate body size using the community weighted mean (CWM). CWM evaluates the relationship between species abundance and the variability in body sizes among taxa. We used the site level variability of CWM to evaluate how average community body sizes are influenced along environmental gradients and by predators. CWM was calculated using the 'dbfd' function in the FD package

(Laliberté, 2010). Based on the body masses collected, the community weighted means were calculated and plotted against the site's distance from the headwaters as a quantitative representation of the environmental gradient. The influence of predators in certain networks were then used to compare between values to observe changes based on the differences in the values. The GLMs for all the CWMs tested against the four models as described previously for the FFG biomasses using the delta AIC values (Table 3).

Trophic interactions were determined using known feeding relationships identified in the literature that included observational studies, diet analyses, and stable isotope analyses. We combined our data sets of trophic interactions with those found in the function WebBuilder to determine feeding relationships for co-occurring organisms found in each site (Gray et al. 2015). We used the genus resolution to determine feeding relationships because many of the taxa in our study system have limited data on feeding interactions. The ecological networks can then be connected by a set of L links, which are possible interactions among each ordered pair of species. In addition, we introduce another measurement for the level of food web complexity by using a variable that ecologists have coined as connectance (C). Connectance is a measure of the proportion of interactions among all the possible ones in a network. Linkage density (L.S.) is another measurement used to understand the average level of specialization of the network calculated as the average number of links per species (Landi, 2018). From this, we quantified the topological structure of food webs for the number of trophic links (L), the trophic link density (L.S.) and connectance ($C = L/S^2$) using the cheddar package (Hudson et al. 2012).

In order to understand in the influence of environmental gradients and fish presence on food web structure we analyzed Generalized Linear Models (GLM's) for each food web metric separately. We used gaussian error distributions for the biomasses of each FFG, gaussian error

distributions for CWM, gaussian error distributions for Connectance and Linkage Density, and lastly, we used Poisson error distributions for the number of trophic links. All data analysis were conducted using R (R Development Core Team 2018).

Results

Functional Feeding Group Analysis

Functional feeding-group densities of the sites studied appeared to be modelled best by presence of predatory fish. The strongest support for this model comes from two groups-the collector-filterers and collector-gatherers- with significant differences in AIC values for the null and environmental models (Table 1). Although the trends for the predatory fish model and the environment combined with predators were very similar, we chose to use the Environment \times Fish model as this provided better visualization of the trends occurring across the sites. A comparison of the trends in the functional feeding groups showed no significant difference between sites that had predators and sites that did not have predators. Notably, for both collector-filterers and collector-gatherers groups there was no significant difference in the trends between predator present and absent sites. Although it is noted that for the collector-filterer group, the density ratios were generally higher in the fish present sites while the opposite was true for the collector-gatherers (Table 2). The remaining groups were the herbivores, predators, micro-predators and shredders which did not have any strong trends (positive or negative) in both sites (Fig. 2).

Table 1: Results for each functional feeding group. Four models compared by looking at the effect of the environment combined with predators, the environment and predators separately, and a null model in which none of the variables tested play any role. Also included are the effective degrees of freedom (df) and the fraction of null deviance (R^2) explained by the model.

Model	Collector-filterers			
	Delta AIC	Df	Weight	R^2
Fish	0	2	0.77	0.01
Environment \times Fish	2.4	4	0.23	0.01
Null	14.6	1	0	0
Environment	16.5	2	0	0

Model	Collector-gatherers			
	Delta AIC	Df	Weight	R^2
Fish	0	2	0.82	0.13
Environment \times Fish	3.0	4	0.18	0.18
Null	16.8	1	0	0
Environment	19.2	2	0	0.02

Model	Herbivores			
	Delta AIC	Df	Weight	R^2
Null	0	1	0.56	0
Environment	2.0	2	0.2	0.2
Fish	2.0	2	0.2	0.01
Environment \times Fish	6.0	4	0.03	0.22

Model	Micro-Predators			
	Delta AIC	Df	Weight	R^2
Null	0	1	0.56	0
Environment	2.0	2	0.2	0.014
Fish	2.0	2	0.21	0.0003
Environment \times Fish	6.2	4	0.026	0.027

Model	Predators			
	Delta AIC	Df	Weight	R ²
Null	0	1	0.56	0
Environment	2.0	2	0.21	0.01
Fish	2.0	2	0.21	0
Environment × Fish	6.0	4	0.03	0.013

Model	Shredders			
	Delta AIC	Df	Weight	R ²
Null	0	1	0.56	0
Environment	2.0	2	0.21	0
Fish	2.0	2	0.20	0.12
Environment × Fish	6.0	4	0.027	0.14

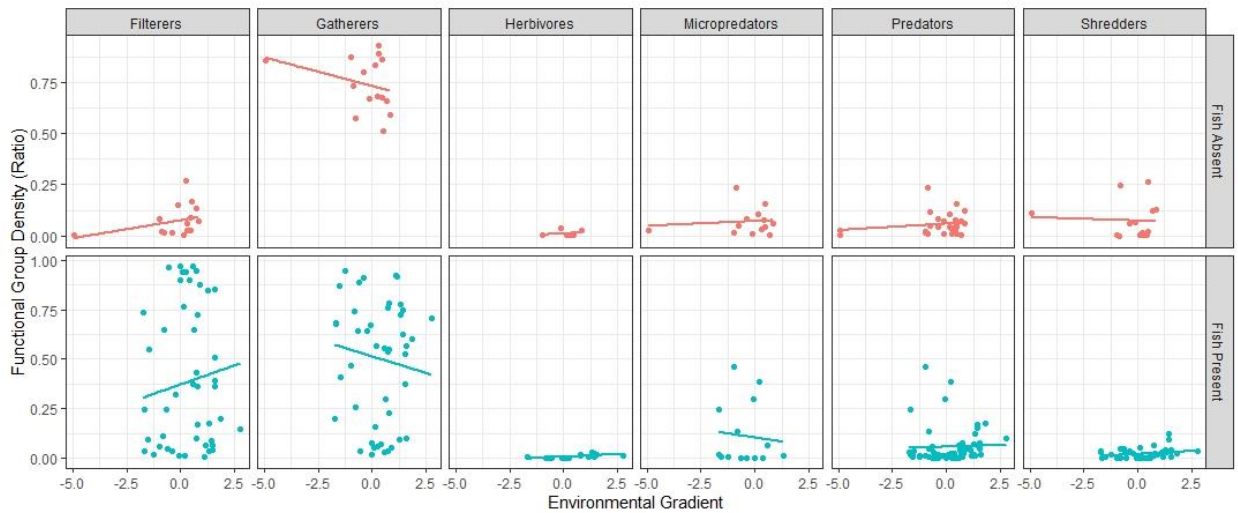


Figure 2: The comparison of functional feeding-group densities using the environmental Principal Components Analysis, or PCA (x-axis) and separated by sites with fish (blue) and without fish (red); Densities are represented as a ratio of the total density of functional groups in the sampled site (y-axis). The separate graphs each represent each functional feeding group (from left to right): collector-filterers, collector-gatherers, herbivores, micro-predators, predators, and shredders

Table 2: Averages for density ratios plotted in Fig. 1 compared between fish and fishless sites across the different functional groups

	Filterers	Gatherers	Herbivores	Micro-predators	Predators	Shredders
Fish Present	0.39	0.50	0.01	0.12	0.07	0.02
Fish Absent	0.12	0.74	0.01	0.06	0.06	0.07

Community Weighted Mean (CWM)

The comparison of alternative statistical models for community weighted means showed that the model using the environment as a predictor explains best the observed pattern of taxa richness (Table 3). This model showed that the community weighted mean across sites had significant differences along the environmental gradient over the presence of fish. Using the model based only in the influences of the environment, the community weighted mean shifts positively with less extreme environments (Fig. 3).

Table 3: Statistics for the community weighted mean (CWM). Four models compared by looking at the effect of the environment combined with predators, the environment and predators separately, and a null model in which none of the variables tested play any role. Also included are the effective degrees of freedom (df) and the fraction of null deviance (R^2) explained by the model.

Model	Community Weighted Mean (CWM)			
	Delta AIC	Df	Weight	R^2
Environment	0	3	0.8	0.200
Environment \times Fish	2.8	5	0.2	0.210
Null	18.9	2	<0.001	0
Fish	19.8	3	<0.001	0.012

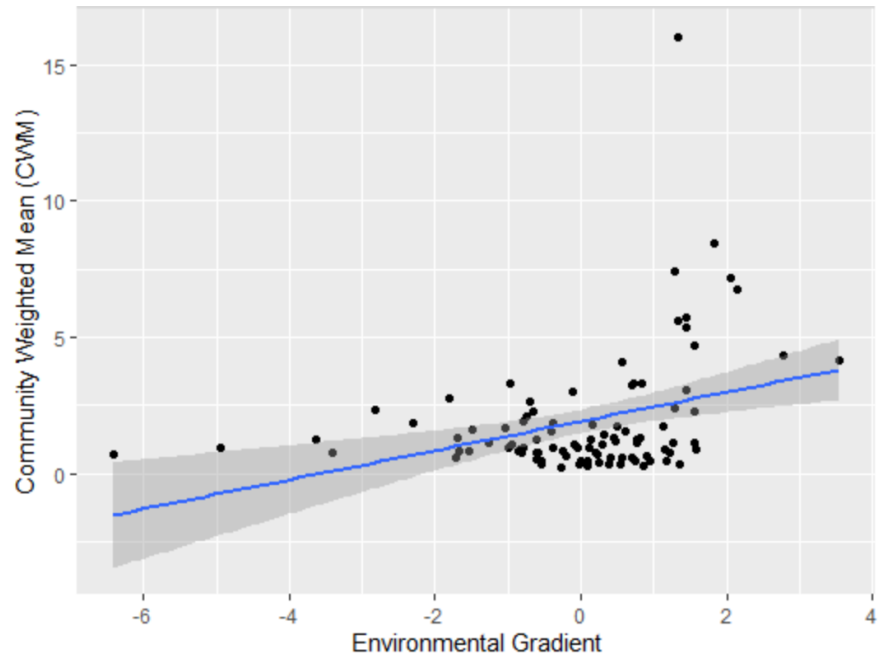


Figure 3: Graph of the community weighted means of sites using the environmental gradient established using Principal Components Analysis, or PCA (x-axis). The best fit trend line is denoted in blue.

Food Web Structure

The number of trophic links (L) was structured by interaction of the environmental gradient and fish presence (Table 4; Fig.4), where in fishless sites the L increased moving from environmentally harsh to favorable sites. However, this pattern was reversed in sites with fish presence, where the number of trophic links decreased as the environment became more favorable. Linkage Density (L.S.) was also structured by the interaction of the environmental gradient and fish presence (Table 4; Fig.4), where in fishless sites the L.S increased moving from environmentally harsh to favorable sites. However, this pattern was reversed in sites with fish presence, where the number of trophic links decreased as the environment became more favorable. Food web connectance (C) was determined by the environmental gradient, where connectance decreased moving from environmentally harsh to favorable sites (Table 4, Fig. 4). Fish did influence connectance, but only when it was interacting with the environmental gradient (Table 4, Fig. 4) Despite the GLMs for connectance favoring the environmental model, the AIC values for the Environment \times Fish model did not have a significant difference from the ideal environment model. Thus, for visualization purposes, the Environment \times Fish model was used to help compare the differences in the trends across all three variables.

Table 4: Results for three food web characteristics-trophic links (L), Linkage Density (L.S), and Connectance (C). Four models compared by looking at the effect of the environment combined with predators, the environment and predators separately, and a null model in which none of the variables tested play any role. Also included are the effective degrees of freedom (df) and the fraction of null deviance (R^2) explained by the model.

Model	Trophic Links (L)			
	Delta AIC	Df	Weight	R^2
Environment \times Fish	0	4	1	0.179
Environment	331.5	2	<0.001	0.009
Fish	346.8	2	<0.001	0.001
Null	347.1	1	<0.001	0

Model	Linkage Density (L.S)			
	Delta AIC	Df	Weight	R ²
Environment × Fish	0	5	0.889	0.116
Null	5.4	3	0.059	0
Fish	6.9	3	0.029	0.006
Environment	7.3	2	0.023	0.001

Model	Connectance (C)			
	Delta AIC	Df	Weight	R ²
Environment	0	3	0.757	0.067
Environment × Fish	3.6	5	0.125	0.071
Null	4.5	2	0.081	0
Fish	6.0	3	0.037	0.005

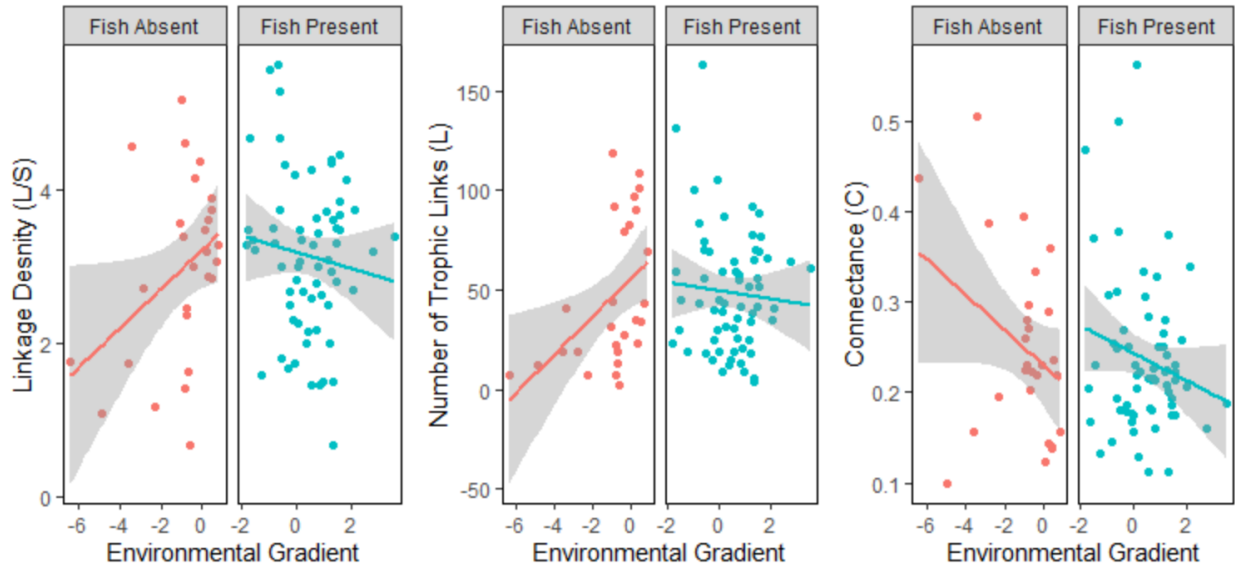


Figure 4: Generalized linear models for trophic linkages (L), linkage density (L.S), and connectance measured using the environmental Principal Components Analysis, or PCA (x-axis) and separated by the presence of predators (absent/present)

Discussion

Our study of the Sierra Mountain streams provides strong evidence that fluctuations in macroinvertebrate food webs were driven by influences from both the environment and predators. There were varying degrees in which both of these factors affected the macroinvertebrates in this study that likely extends similar populations and landscapes. The linear models showed that both the environment and predatory population affected macroinvertebrate functional feeding groups, community weighted means, and food web structure in various degrees. The biomasses of the functional feeding groups in this study were shown to be driven mainly by predators. The community weighted means were impacted more by the environment than the presence of predators. The combination of both the environment and predators contributed the most to food web structure.

First, we found that functional feeding groups had weak responses to environmental gradients and the presence of predators. The collector-filterers and collector-gatherers groups had shown resistance to changes to the environment or fish predator populations, or a combination thereof, while the herbivores, shredders, micro predators and predators showed no responses to these measures. There was a significant difference in average densities for the collector-gatherer and collector-filterers groups in the presence of predators, which suggests that predation negatively affected densities for the collector-filterers while stimulating the growth of collector-gatherers. A possible explanation for these observations may be due to these FFG groups dependence on scavenging for reliable food sources from decaying vegetation and biofilm that decrease in distances away from the headwaters. In addition, cooler temperatures associated with downstream environments make conditions harsher for collector-filterers, collector-gatherers, and shredders to persist compared to the stable conditions in the headwaters (Richardson, 2019). Fish also tended to drive the negative trends seen in the collector-filterers and collector-gatherers

where sites populated with fish experienced a decline in biomass of the collector-filterers and collector-gatherers compared to the sites where fish were absent (Figure 2). This signifies that these declining trends of functional groups like collector-filterers and collector-gatherers may be a result of consumption by predatory fish and that these macroinvertebrates constitute an important source of food for numerous fish. As a result, sites where fish are absent would expect to see greater numbers of those functional groups that do not have predators to consume them. This supports the hypothesis that the top-down influence of predatory fish overwhelms the influence of the environment in which we would expect to see a cascade of other trophic levels affected by changes in macroinvertebrates due to predation. In a study done on artificially isolated stream systems in Arkansas, the top-down influence of predatory fish demonstrated significant negative effects on densities and assembly of macroinvertebrates (Williams, 2003). Despite their results suggesting strong short-term effects, the similar declining biomass trends our study suggests that the influence of fish predation may persist in the long-term. While there possibly may be other underlying mechanisms driving FFG biomass patterns, there are also some considerations to be made because fish presence and distance from headwaters may be confounded as fish tend to be more present in downstream sites. Fish dispersal is limited in waterways with an accumulation of fish species in the downstream direction in favor of this lateral migration and reduced competitive pressures in these sites (Stegmann, 2019). Future studies in functional feeding group biomass may be able to explore other variables beyond environmental gradients and predators to find a causal link in possible trends in these river systems.

Similarly, there were associated patterns seen in community weighted means of macroinvertebrates with a positive increase in average community body size along the

environmental gradient. The increase in community weighted means in response to the environmental gradient implies that greater variance in spatial metrics results in stronger effects on the macroinvertebrates over predators. This suggests that smaller bodied macroinvertebrates were able to persist in more extreme environmental conditions. In support of this finding, a similar study on the observation of the taxonomic structure of macroinvertebrates that exhibited greater variability due to environmental factors such as pH, nutrients, and stream size (Heino, 2017). Studies done by Neves, et al (2016) have proposed that small-sized organisms tend to dominated more distressed systems with more variation in size in less stressed systems; they suggest these patterns emerge as a result of growth being constrained in stressful environments resulting in smaller-bodied organisms being more abundant in such conditions. In contrast, more species are able to achieve greater growth in non-disturbed systems that would correlate with trends observed in our study. Furthermore, our study is in support of the river continuum hypothesis that suggests shifts in physical gradients along the river results in shifts in communities. Thus, we conclude that the environmental gradient served as a more accurate model to better explain trends in the body masses for the sampled species. Despite other studies suggesting trout selectively predate on large sized macroinvertebrate species (Knapp, 2010 and Herbst, 2009), our study found that the environmental gradient is more dominant than the predatory fish influence on the community weighted mean of body size.

We found that the environment and predator population jointly influenced the food web structure of macroinvertebrates. The number of trophic links increased in fishless sites further downstream from the headwaters. In fish present sites, the opposite was observed where there was a decrease in the number and density of trophic links the farther away from the headwaters. On the other hand, predatory interactions combined with environmental shifts were shown to

influence trophic linkages and densities. This is expected as studies have shown macroinvertebrates to be a key component in fish-invertebrate linkages and macroinvertebrate linkages with resources and habitats (Wallace, 1996). However, somewhat unexpectedly, connectance was shown to have not been affected by predator populations with greater connectance in more extreme environments. A possible explanation for macroinvertebrate connectivity to be driven by environmental factors comes from a study on the ability of species dispersal (Sarremejane et al., 2017). The flying ability of each species restricted dispersal of weak flyers in isolated river sites as opposed to stronger flyers that are able to overcome this spatial barrier. Our findings suggest that there is a delicate balance in maintaining the integrity of the food web structure with consequences resulting in shifts in both the environment and predator populations. Macroinvertebrates influence nutrient cycles, primary productivity, decomposition, and translocation of materials in streams as well as being consumers at intermediate trophic levels, so fluctuations in the environment and predator populations would result in cascading effects in the stream ecosystems.

While studies have already implicated impacts of global warming on ecosystems and communities, they have largely focused on predicted consequences on a broad scale of decreasing biodiversity that does not fully encompass the fragility macroinvertebrate food webs that comes with environmental shifts (Jacobsen *et.al*, 2014). Despite being a key component in many ecosystems, the strength of food web networks has not been explored for its ability to adapt to environmental changes when predators also vary. The findings from this study offers a unique point of view of the underlying effects of environmental changes as well as predator-prey relationships on macroinvertebrate network interactions.

With heightening changes to the global climate, there are expected community responses within ecosystems to alterations in the environment. Climate change threatens high latitude and mountainous areas, and warming is occurring more rapidly in many of these regions than anywhere else (Muhlfeld et al., 2011). These alpine regions are more sensitive to changes which would greatly impact richness and abundances of macroinvertebrates specific to these areas. By studying the complex of living organisms in mountainous regions, alpine ecology offers guidance in maintaining many other species around the world that are also faced with impacts of climate and anthropogenic change. Planning for macroinvertebrate conservation efforts can be modelled from the results of this study and extracting regions that consider both environmental factors and food web interactions. Thus, the evaluation of the nature of mountainous river ecosystems will offer extensive applications for maintaining species diversity, while encouraging conservation efforts for land management in these regions.

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