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Bioassessment of Non-Perennial Streams Affected by Oil and Gas Extraction

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Executive Summary

Dry-stream ecosystems are an important component of freshwater systems. We have a limited understanding of how biota respond to severe alterations like those associated with resource extraction, limiting our ability to quantify damages when spills or other impacts occur. In order to develop a quantitative method of assessing impacts in dry-stream ecosystems, we examined how bryophyte and arthropod assemblages responded across a gradient of increasing amounts of upstream oil and gas extraction and associated physical and chemical stress in ephemeral streams near Bakersfield, CA. We quantified the amount of stress using oil-field cover area, oil well counts, sediment size, and hydrocarbon soil concentrations, and related these measures of stress to potential biological end points possibly sensitive to alteration. We found that the abundance of bryophytes increased with increasing extraction stress, while richness of some arthropods (especially beetles) decreased at stressed sites. This information gives us a deeper understanding for the role of dry streams within the freshwater network and how these ecosystems respond to stress. These results also indicate the feasibility of developing tools like these that resource agencies can use for monitoring and assessing the ecological condition of freshwater streams when they are dry.

Contents

1 Introduction

1.1 Overview

With an increasing population and global change leading to extreme floods and droughts, land managers need to understand how freshwater systems respond to human impacts and relate to our clean water supply. Humans in industrialized countries have had a significant impact on freshwater ecosystems (Sondergaard & Jeppesen 2007). To understand these systems, we can monitor and assess the relationship between the biota and the rivers, lakes, wetlands, and streams that create the above-ground freshwater network. Traditionally, bioassessments of freshwater systems have included an evaluation of the flora and macrofauna within and near the flowing streambeds, but with low precipitation rates in large areas of western United States, much of these typical fauna (like fish and aquatic macroinvertebrates) are absent, and the health of the non-perennial streams and rivers (i.e., ephemeral or intermittent streams) are impossible to assess during times of low or no-flow using standard techniques (Steward et al. 2018).

Most of the recent studies on anthropogenic effects on non-perennial streams have been in Europe and Australia (Stubbington et al. 2017, Steward et al. 2018, Mazor et al. 2018), but the Watershed Environments and Ecology lab at California State University Monterey Bay (https://csumb.edu/wee) has been developing sampling protocols to assess these effects in the western United States (Robinson et al. 2018). These protocols are adapted from standard flowing-stream bioassessment protocols (i.e., the California Surface Water Ambient Monitoring Protocol, Ode 2016) and enable characterization of compositional and functional characteristics of the terrestrial arthropods and bryophyte (moss) assemblages collected in and around dry stream beds. These protocols proved able to detect the effects of human stress across southern California (Mazor et al. 2019). With non-perennial streams making up 73% of California's streams (Ode et al. 2011), it is important to understand the current health and future impacts that climate change and further development will have on these systems.

Bioassessment indices offer a way to quantify changes in stream biological composition (Bonada et al. 2006). The composition of biological assemblages can provide great insight into ecosystem health because of the diversity of life histories and stressor tolerances exhibited by different species. In aggregate, arthropod or bryophyte assemblages can provide a broad-spectrum picture of the impacts of disturbance on dry-stream systems. These assemblages are typically characterized with multi-metric indices (MMI), in which different metrics are calculated to describe different aspects of community structure and function. MMIs are widely used in the United States to characterize stream condition, and have been used to assess damages to natural resources (Norris and Hawkins 2000, Mebane 2001) or to track progress of stream restorations (e.g., Loflen et al. 2016). A preliminary MMI for dry stream indicators has been developed for San Diego County (Mazor et al. 2019), and it could prove useful for dry streams in the San Joaquin valley.

1.2 Objectives

Our study objectives were to:

- Characterize arthropod and bryophyte assemblages in dry streams along a gradient of increasing disturbance from oil extraction activities
- Examine how stresses related to oil production affect the health of the dry stream ecosystems using these assemblages
- Evaluate the ability of the dry stream assessment protocols to detect ecosystem alteration

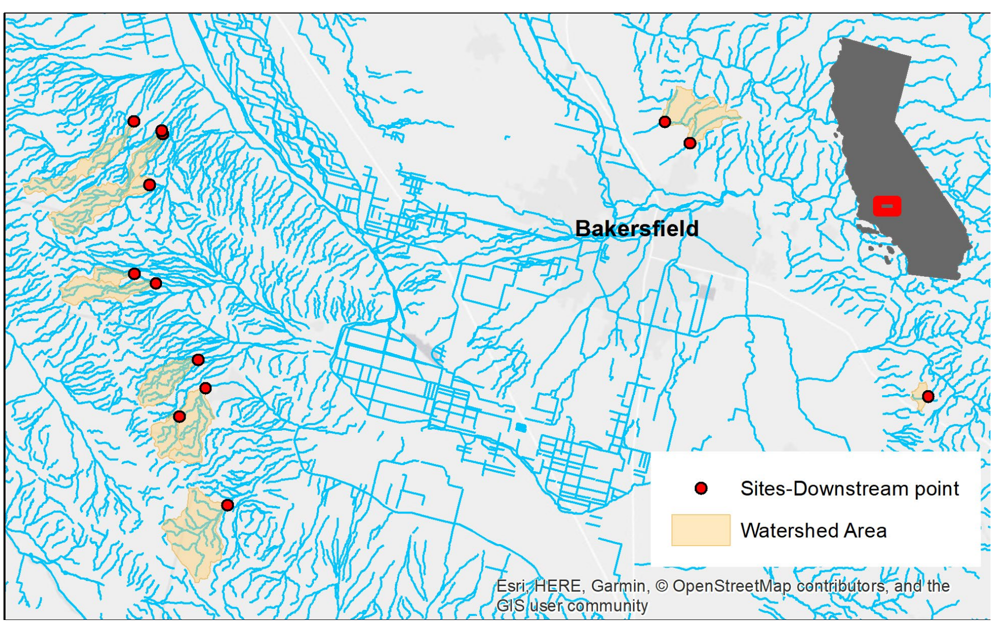
In addition we also evaluated the usefulness of an existing MMI to quantify damages associated with impacts from oil extraction (e.g., spills).

2 Methods

2.1 Study Area, Site Selection, Site Evaluation

Our study area was located at the southern tip of the San Joaquin Basin Province Boundary near Bakersfield, CA (Figure 1). We selected 13 sites that represented a gradient of gas and oil extraction stress based primarily on evaluations using aerial photos in Google Earth and StreamCat data (https://www.epa.gov/national-aquatic-resource-surveys/streamcat).

Figure 1. Study area and corresponding watersheds.



At each site we evaluated physical habitat, stream morphological characteristics, and human activity levels following Robinson et al. (2018). To evaluate physical habitat, we measured the channel width, channel depth, pebble count, and channel slope, at 9 transects placed 20 m apart over a 160-m stream reach. We characterized stream morphology by estimating the percent cover of each channel microhabitat (i.e., riffle, run, pool, and steps/cascade), the percent of channel currently wetted, and cover of vegetation types (grasses, non-woody, woody) in the channel and adjacent riparian areas. We assessed human activity based on the proximity, extent, and intensity of land-use, chemical stressors, hydrologic stressors, physical stressors, and biological stressors observed at a site (Table 1).

Table 1. Human activities assessed at each site. For each activity observed to be present at a site, the proximity, extent, and intensity was recorded.

Metrics	Examples
	Land Use Effects
Heavy Urban	Industrial, Urban commercial, Urban Residential
Light Urban	Suburban Residential, Rural residential, Excessive Human Visitation
Agricultural	Crops (Irrigated), Crops (non-irrigated), Rangeland
Transportation	Highway (more than 2 lanes), Parking lot/Pavement, Walking path
	Chemical Stressors
Industrial Water Quality	Point source Discharges, Acid Mine Drainage, Noxious Chemical odors
Urban Water Quality	Non-point Source Discharges, Trash or Dumping, Vector Control
Agricultural Water Quality	Agricultural Runoff
Nutrient Related Water	Algal/surface Mats, Direct Septic or Sewage Discharge, Excess Animal Waste
Other	High Concentration of Salts
	Hydrologic Stressors
Water Control Actions	Flow Diversions, Groundwater Extraction, Unnatural Inflows
Water Control Features	Dike/Levee, Ditches/Canals, Dam
	Physical Stressors
Sediment Disturbance	ATVs, Excavation, Grading/Compaction
Excess Sediment Input	Construction/Erosion, Debris Lines or Silt-laden Vegetation
Hardened Features	Riprap, Armored Channel, Culverts, Paved Stream crossings
	Biological Stressors
Vegetation Management	Fire Breaks, Mowing or Cutting, Burns
Grazing	Cattle Grazing
Invasive Plants	Invasives Present
Other	Animal Burrows

2.2 Sampling Biological Indicators

We evaluated three potential biological indicators at each site: terrestrial arthropods in the dry stream-bed, arthropods on riparian vegetation, and bryophytes (i.e., mosses) growing in the channel or on the banks. Typically, all three indicators are sampled over the course of a 2-day sampling event.

We sampled terrestrial arthropods in dry channels using ramp traps, a type of modified pitfall trap that is more efficient and has less bycatch than traditional pitfall traps (Patrick and Hansen 2013). A trap was set-up at eight random locations between each transect. Traps were filled with approximately 250 mL of propylene glycol (which acts as both a kill agent and preservative) for approximately a 24-hour period, and then contents were gathered into a sample jar, labeled, and sealed for transport.

We sampled the riparian vegetation arthropod assemblage at the beginning of the second day of sampling, before other activities in and along the sampling reach. Between each transect we identified the most robust plant closest to the channel that provided good habitat for arthropods to sample. An approximately 1-m^2 cloth bag was placed over the plant (or a portion of the plant), closed and beat 30 times to dislodge arthropods. Then, all the contents of the bag except for large debris were collected in a jar, labeled, preserved with ethanol, and sealed for transport.

Bryophytes were collected in three mesohabitats of a reach: channel, left and right riparian zones. We surveyed each mesohabitat for 20 minutes in order to identify and flag all microhabitats that contained bryophytes; microhabitats include boulders, soil, tree roots, and other stable substrate where bryophytes typically grow). We then collected bryophytes for 12 minutes across a representative sample of the identified microhabitats using spray bottle (to help identify bryophytes which re-green upon wetting), spoon, and collection envelopes. Samples were then labeled and allowed to dry.

2.3 Soil Sampling and Hydrocarbon Detection

We collected soil samples using a 5-cm diameter metal sampling ring, mallet, and spade. We collected soil by placing the sampling ring over a part of the channel with deposited sediment, hammering the ring until the soil reached the 5cm depth in the ring and then using a spade to dig around and under the sample. We stored samples in a glass jar covered with foil and kept on ice and sent to SCCWRP (Costa Mesa, CA) for total petroleum hydrocarbons (TPH) analysis.

TPH was measured for each sample by extracting a freeze-dried soil sample (5g) with methylene chloride using a Dionex Accelerated Solvent Extraction (ASE) 300 system. The extract was cleaned up on a silica/alumina column. The sample extract was analyzed by full scan under electron ionization (EI) mode on an Agilent 7890 gas chromatography coupled to a 5975C mass selective detector. The total peak area of *m/z* 57 was integrated for external standard quantitation using a motor oil (5W-30) as the standard. The detection limit of TPH was 7.33 μg/g dry weight.

2.4 Arthropod and Bryophyte Identification

We separated both trap-caught and vegetation-caught arthropods into groups of non-arthropods, families, and identified them to morphospecies (which generally corresponded to genera). We sorted dry bryophyte samples into different morphospecies using a dissecting scope, then identified to family or genus based on leaf morphology using a compound microscope.

2.5 Metric Analysis and MMI Scores

We performed metric calculation according to the techniques in Robinson 2019. Many metrics were adapted from those commonly used in traditional bioassessment for perennial streams (e.g., richness, taxonomic composition, diversity, and feeding groups). We evaluated arthropod and bryophyte richness on multiple levels: order, family, and morpho-species level. All abundance metrics were log-transformed (+0.0001) to increase the normality of their distributions. Random forest models were used to account for metric bias caused by natural environmental variation (Robinson 2019).

We calculated MMI scores from the provisional multi-assemblage index described in Mazor et al. (2019). Each metric was scored on a scale from 0 (degraded) to 1 (similar to reference). Metric scores were averaged to generate a raw MMI score. A final MMI was then calculated by dividing by the mean raw score at reference sites (i.e., 0.77). We divided all scores by this value so that reference scores would have an expected value of 1.0, and lower scores would indicate deviation from reference conditions (Mazor et al. 2019). Although there are no established thresholds to identify MMI scores that indicate poor conditions, we followed Mazor et al. (2019) and classified sites as likely intact, possibly altered, likely altered, and very likely altered by comparing MMI scores to the 30th, 10th, and 1st percentile of scores at reference sites (Table 2); thus, sites with scores at or below the 10^{th} percentile have no more than a 10% probability of representing reference conditions.

Table 2 Multi-metric index score thresholds relative to reference condition.

Class	Percentile range	Threshold
Likely intact	>30th	0.935
Possibly altered	10th to 30th	0.83
Likely altered	1st to 10th	0.692
Very likely altered	0th to 1st	0

2.6 Biology-Stressor Relationships

We quantified five stressors, two based on watershed analysis of oil/gas extraction activities, one based on in-situ sediment chemistry, and two indicators of increased sediment deposition. To assess oil/gas extraction activities, we obtained oil field boundary and oil well location shapefiles from the California Department of Conservation website (https://www.conservation.ca.gov/dog/maps/Pages /GISMapping2.aspx). We calculated well counts using a spatial join between oil well points and watershed polygons and well density by dividing the count of these oil wells in the watershed and dividing by the watershed area (m^2).

We calculated percent oil field cover through a spatial join between the oil field polygon and watershed polygon. The proportion of overlap was calculated by taking the area of overlap and dividing by the total area of the watershed (m^2).

We obtained oil concentration in the soil from SCCWRP's hydrocarbon analysis. Oil concentration was originally calculated based on the dry weight (µg/g) of TPH, then log converted to adjust for the wide spread of values (between 3.665 and 442.8). All values that were below the detectable limit of 7.33 µg/g, were given the value 3.665 for all stress comparisons.

We calculated median sediment size (D_{50}) from the all of the pebble size counts made at transects at each site. We calculated percent fine sediment by finding the proportion of sediment below 2mm compared to the rest of the sediment from each site. We considered percent pebble embeddedness as a stressor, but too few pebbles were large enough for use as a stressor for this data set.

A simple linear regression for all stressors was produced that compared each stressor to each metric of each site. The top five metrics with the highest R^2 values were chosen to represent the strongest metrics related to the stressors (Appendix B).

3 Results

3.1 Oilfield Stressors

Study sites represented a range of stress levels, from nearly natural to highly disturbed. Oil sediment concentrations ranged from <7.33 to 442.8 μg/g; median sediment size ranged from <2 to 16 mm; percent fine sediment ranged from 0 to 71%; percent oilfield cover area within watershed ranged from 0 to 100% (m^2); and oil well density ranged from 0 to 0.0003 (number of wells/m^2). Most stressors were positively correlated with one another (Pearson's r >0.49) except median sediment size (Table 3), as fine-grained sediments were more common at disturbed sites.

Several arthropod and bryophyte metrics had a relatively strong relationships with oil field stress (i.e., R^2 values >0.33). These responsive metrics included: 12 metrics with strong relationships with log oil concentration, 16 metrics with percent oilfield cover, 5 metrics with median sediment size, 6 metrics with oil well density, and 15 metrics with percent fine sediment (Appendix A, Table A1). Of these relationships, 33 were negative (i.e., metrics decreased with increasing stress) and 21 were positive.

Table 3. Pearson's correlation test between stressors.

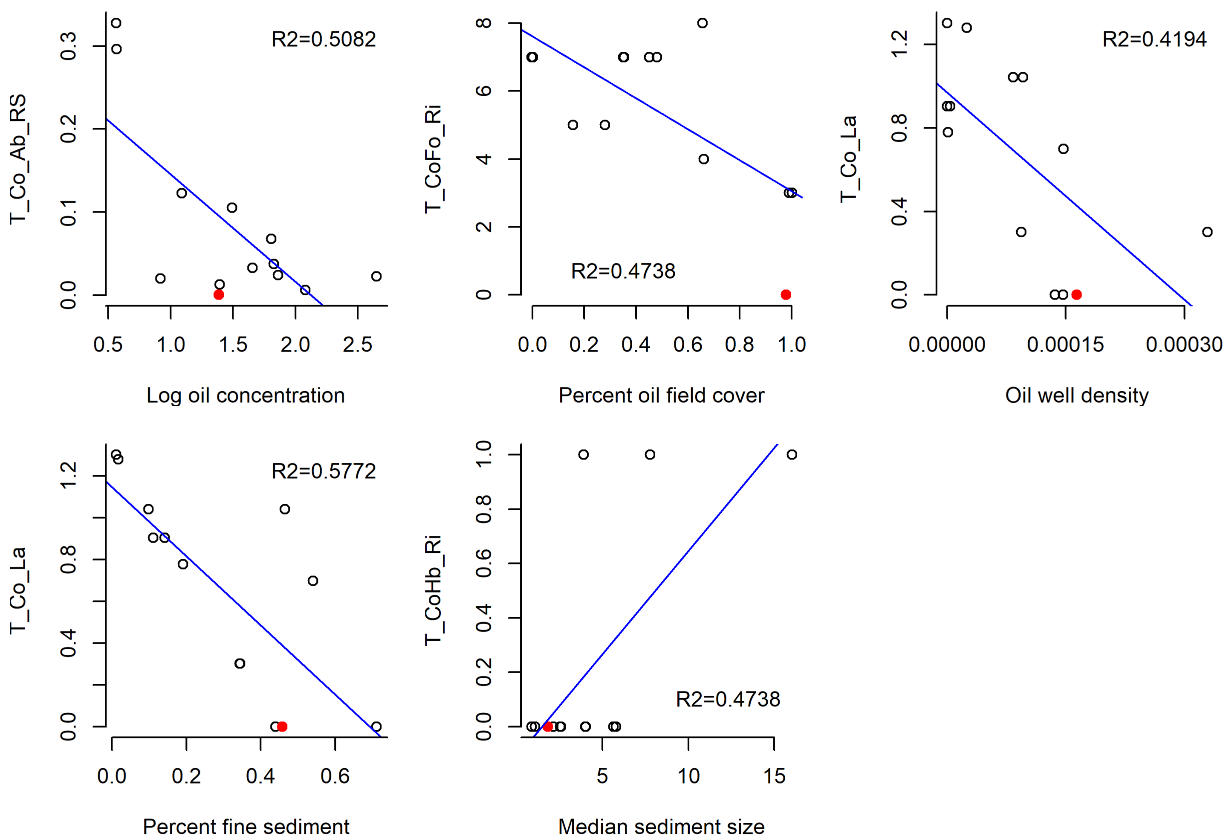
	Percent Oil Field Area	Well Density	Log Oil Concentration	Median Sediment Size	Percent Fine Sediment
Percent Oil Field Area	1.00	0.63	0.52	-0.64	0.77
Well Density		1.00	0.60	-0.49	0.60
Log Oil Concentration			1.00	-0.55	0.86
Median Sediment Size				1.00	-0.75
Percent Fine Sediment					1.00

3.2 Arthropods

A total of 4094 individual arthropods were collected from ramp traps, and 7833 were collected from riparian vegetation. Richness in traps ranged from 14 to 24 taxa, with a mean richness of 18.5. Acari, Collembola, and Pheidole (an ant genus) were the most commonly occurring taxa, present at 9 or more sites. Richness in vegetation ranged from 2 to 42 taxa, with a mean richness of 22. Hemipterans and Araneidae (orb-weaver spiders) were the most commonly occurring taxa in vegetation samples.

Many arthropod metrics responded to measures of stress, and beetle metrics were among the most responsive (Figure 2). In general, vegetation and trap beetle richness, diversity,

Figure 2. Top arthropod metrics for each stressor, where trap Coleoptera abundance relative to site (T_Co_Ab_RS), trap Coleoptera-Formicidae richness (T_CoFo_Ri), trap Coleoptera log abundance (T_Co_La), and trap Coleoptera-Herbivore richness (T_CoHb_Ri) are represented with R^2 values on each graph. The red point indicates the sample from the Berry Petro spill site.



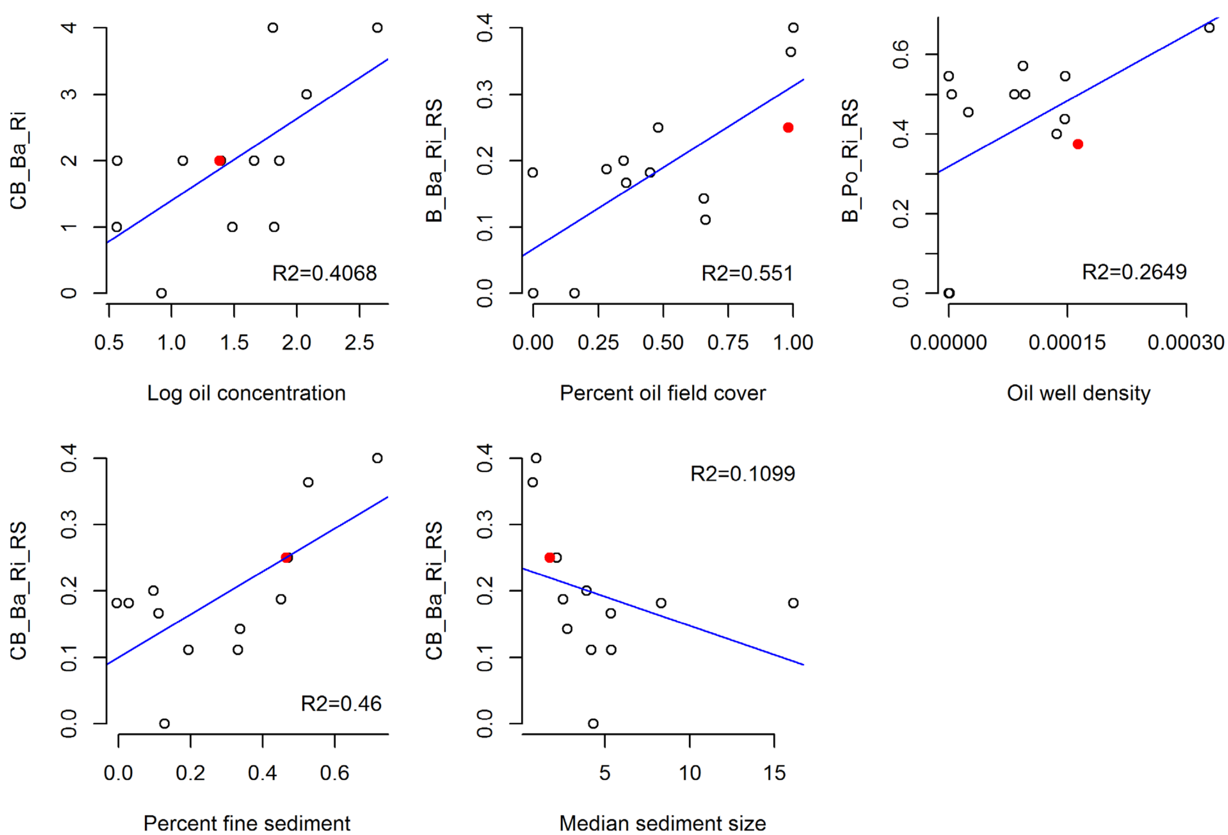
evenness, and abundance had a negative relationship with increasing stress. Other metrics showed a range of responses, including some that increased with stress (e.g., richness of herbivorous beetles in ramp traps) (Appendix A, Table A1).

3.3 Bryophytes

Bryophytes were collected at 12 of the 13 sites. A total of 122 samples were collected at individual microhabitats. There were 20 different morphospecies amongst these samples. Common taxa included the genera Didymodon, Funaria, and Gemmabryum.

Bryaceae (a family of bryophytes) were among the top indicators to the oil and sediment stressors (Figure 3, Appendix A, Table A1). The most closely related metrics and stressor relationships were a positive relationship between bank Bryaceae richness relative to site and percent oilfield cover, bank Pottiaceae richness relative to site and oil well density, site Bryaceae richness relative to site and median fine sediment, and site Bryaceae richness and both log oil concentration and percent fine sediment (Figure 3). In general, Bryaceae richness had a positive relationship with increasing stress.

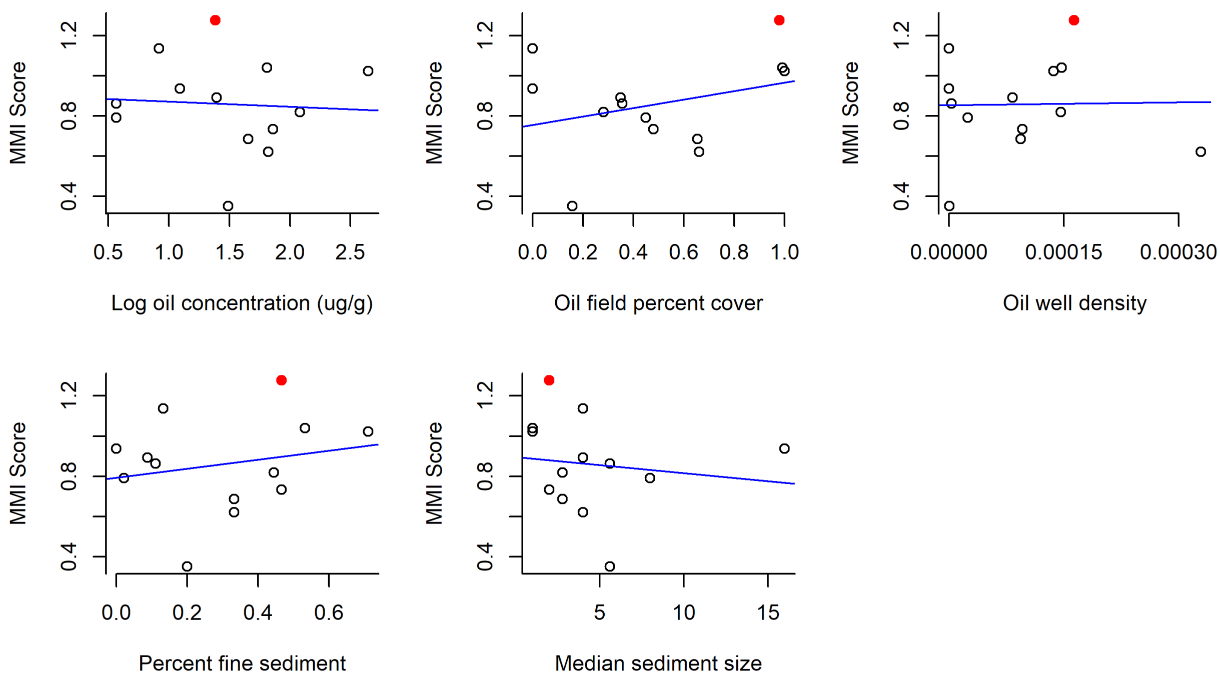
Figure 3. Top bryophyte metrics for each stressor, where site Bryaceae richness (CB_Ba_Ri), bank Bryaceae richness relative to site (B_Ba_Ri_RS), bank Pottiaceae richness relative to site (B_Po_Ri_RS), and site Bryaceae Richness relative to site (CB_Ba_Ri_RS) showed the strongest relationships for each stressor. The red point indicates the sample from the Berry Petro spill site.



3.4 MMI

The MMI calibrated for San Diego did not distinguish between the most and least stressed sites (Figure 4). Only one of the MMI component metrics, trap Coleoptera relative abundance, had an R2 value > 0.3 for any of the five stress gradients examined (see T_Co_La in Appendix A table A1). However trap Coleoptera relative abundance was an increasing metric in the MMI but negatively correlated with increasing stress in our data. Berry Petro Spill Site was the only known spill site of the 13 sites but had the greatest MMI score. Oil concentration in the sediment at this site was below average compared to the other sites (24.20 µg/g; mean of all sites=70.65 µg/g), while oil well density, oil field cover area, percent fine sediment, and median sediment size were all relatively high stress at this site.

Figure 4. Preliminary MMI of sites and stressors. Red is indicative of Berry Petro Spill Site.



4 Discussion

This study demonstrates the feasibility of using biological indicators to assess the condition of dry streams, and the potential for using them in quantitative evaluations of damages to these ecosystems. Although the index developed for San Diego did not show a meaningful relationship with stress levels at sites in this study, the strong responses we observed in numerous biological metrics (particularly for metrics related to beetles) underscores the promise these indicators have for assessing dry stream condition.

4.1 Arthropod Response to Oilfield and other Stress

Beetles showed a negative response to increasing stress. Previous studies have shown that various beetles can be useful as bioindicators to detect changes in the environment and can respond negatively to increased habitat alteration such as grazing and urbanization (Boscaini et al. 2000, Michaels 2007, Rainio & Niemela 2003). Often, beetles and other sediment sensitive invertebrates will respond negatively to increased disturbance and can be used to access the level of stress (Steward et al. 2018). Fine sediment deposition can fill in interstitial spaces in a dry streambed and reduce available refuge for some of the larger ground beetles (Steward et al. 2018) and may contribute to the trend we observed. However, strong relationships between arthropods and sediment were not seen in the San Diego area (Robinson 2019). This may have been due to the stronger effects of hydrologic and chemical alteration coming from urbanization and agriculture. It is important to note that the land-use cover for these watersheds only ranged between 0-6%, compared to the oil field cover in the watersheds which ranged between 0 and 100%. The difference between land-use cover of these sites and the sample size (N_B=13 vs N_{SD}=39) may explain the difference in sediment-arthropod trends in San Diego versus Bakersfield.

4.2 Bryophyte Response to Oilfield and other Stress

Bryaceae showed a positive response to increasing stress. High moss richness has been associated with intermediate levels of substrate disturbance (Suren & Duncan 1999) and increasing richness associated with disturbances like floods may be caused by gaps in riparian vegetation which allow for the colonization of previously excluded species of bryophytes (Kimmerer & Allen 1982). If the level of waste-water disturbance is at a desirable level for the Bryaceae and other mosses, then this could explain why we see an increase in Bryaceae richness at more stressed sites. Additionally, the input of nutrients from this waste-water could be potentially benefiting the mosses, but further analysis would be needed to determine this.

An additional mechanism to consider is the stability of the soil. Microhabitat stability is often associated with higher diversity of soil crusts (Thompson et.al. 2006). Oil can be used in conjunction with other materials as a stabilizing agent in soils (Tuncan et.al. 2000). The trend we see in our data may suggest that the additional oil in these systems may provide a more stable habitat for the moss.

4.3 Condition of Ephemeral Streams

Oil field impacted streams have less beetles and more bryophytes, yet the MMI score did not correlate with the gradient of stress at the sites. This may suggest that the provisional MMI is not applicable to sites with stress associated with extraction, and that further development of this index is needed. Only one of the eight component metrics included in the MMI responded to stress from oil/gas extraction. This is exemplified by the Berry Petro oil spill site, which had a lower than average hydrocarbon concentration in the soil (24.2 µg/g), high stress otherwise, but the best score with the provisional MMI. This could be due to the fact that the MMI was developed using data from the San Diego region, but the lack of correlation is more likely caused by selection of metrics using a very narrow range of stress. Because the more heavily stressed sites tested in this study were not available in San Diego, metric sensitive to large amounts of stress may not have been included in the MMI.

The Berry Petro spill site had lower values for the best performing arthropod metrics and intermediate values for the best performing bryophyte metrics (Figure 2 & 3). It is possible that the effectiveness of spill clean-up did accomplish the goal for reducing oil washed down channel, but the clean-up techniques may have led to higher sedimentation at the Berry Petro spill site (percent fine sediment = 47%, mean for all sites = 30%). This observation is consistent with the trends found in sediment-sensitive invertebrates that respond negatively to a reduction in interstitial streambed spaces (Steward 2018).

4.4 Recommendations for impact assessment

Our results suggest that quantitative impact assessment in these areas is feasible, due in part to the strong response of biota in dry streams to fine sediments and oil deposition. Oil and gas extraction may have a stronger effect on invertebrate and bryophyte assemblages than urbanization or agriculture-related stress as observed in San Diego. Moss may absorb air-born heavy metals or other toxins associated with oil and gas extraction, similar to the absorption capacity of moss near mines (Ward et al. 1977). In order to create more robust and widely applicable results, we recommend recalibrating the San Diego index with reference and stressed sites that represent a wider range of stream types, such as those in Bakersfield.

4.5 Limitations and short comings

Our sample size of 13, non-random sites cannot be generalized to determine the condition of dry stream beds across the valley. Future studies should include random streams across a gradient of oilfield stress to inform generalizations about these ecosystems. It is difficult to pin-point any single extraction related stressor as the cause for the decline in beetle diversity, abundance, and richness. However, future studies should consider measuring other stressors related to oil fields such as various toxins, heavy metals, and waste water to provide a more detailed look at how these stressors affect the biota. We did not have any other current or prior active spill data to compare our results to and would need a way to monitor or gather this data for future studies.

5 References

Bonada, N., Prat, N., Resh, V.H., and Statzner, B. 2006. Developments in aquatic insect biomonitoring: A comparative analysis of recent approaches. Annual Review of Entomology 51: 495–523.

Boscaini, A., Franceschini, A., and Maiolini, B. 2000. River ecotones: carabid beetles as a tool for quality assessment. Hydrobiologia 422, 173–181.

Kimmerer, R.W., and Allen, T.F.H. 1982. The role of disturbance in the pattern of a riparian bryophyte community. The American Midland Naturalist 107(2): 370–383.

Loflen, C., Hettescheimer, H., Busse, L.B., Watanabe, K., Gersberg, R.M, and Lüderitz, V. 2016. Inadequate monitoring and inappropriate project goals: A case study on the determination of success for the Forester Creek Improvement Project. Ecological Restoration 34(2): 124–134.

Mazor, R., and Olson, J.R. 2019. Assessing the biological condition of dry ephemeral and intermittent streams. Draft report to the San Diego Regional Water Quality Control Board.

Mebane, C.A. 2001. Testing bioassessment metrics: macroinvertebrate, sculpin, and salmonid responses to stream habitat, sediment, and metals. Environmental Monitoring and Assessment 67(3): 293–322.

Michaels, K.F. 2007. Using staphylinid and tenebrionid beetles as indicators of sustainable landscape management in Australia: a review. Anim. Prod. Sci. 47, 435–449.

Newmaster, S.G., Belland, R.J., Arsenault, A., Vitt, D.H., and Stephens, T.R. 2005. The ones we left behind: comparing plot sampling and floristic habitat sampling for estimating bryophyte diversity. Diversity and Distributions 11(1): 57–72.

Norris, R.H., and Hawkins, C.P. 2000. Monitoring river health. Hydrobiologia 435(1–3): 5–17.

Ode, P.R., Kincaid, T.M., Fleming, T., and Rehn, A.C. 2011. Ecological Condition Assessments of California's Perennial Wadeable Streams: Highlights from the Surface Water Ambient Monitoring. Program's Perennial Streams Assessment (PSA) (2000–2007). Web. Accessed April 26, 2019 from: https://www.waterboards.ca.gov/water_issues/programs/swamp/docs/reports/mgmt_memo2extent.pdf

Patrick, L.B., and Hansen, A. 2013. Comparing ramp and pitfall traps for capturing wandering spiders. The Journal of Arachnology 41(3): 404-406.

Rainio, J., and Niemelä, J., 2003. Ground beetles (Coleoptera: carabidae) as bioindicators. Biodiv. Conserv. 12, 487-506.

Robinson, M. 2019. Development of biological indicators for the dry phase of non-perennial rivers and streams. Thesis for the School of Natural Sciences California State University Monterey Bay.

Robinson, M., Clark, T., Mazor, R., and Olson, JR. 2018. Field protocol for assessing ecological health of dry phase non-perennial rivers and streams. Central Coast Watershed Studies. The Watershed Institute. Report No. WI-2018-XX. July 10, 2018.

Sondergaard, M., and Jeppesen, E. 2007. Anthropogenic impacts on lake and stream ecosystems, and approaches to restoration. Journal of Applied Ecology. 44: 1089-1094.

Steward, A., Negu,s P., Marshall, J., Clifford, S., and Dent, C. 2018. Assessing the ecological health of rivers when they are dry. Ecological Indicators. 85: 537-547.

Thompson, W.A., Eldridge, D.J., and Bonser, S.P. 2006. Structure of biological soil crust communities in callitris glaucophylla woodlands of New South Wales, Australia. Journal of Vegetation Science 17:271-280.

Tuncan, A., Tuncan, M., and Koyuncu, H. 2000. Use of petroleum-contaminated drilling wastes as sub-base material for road construction. Waste Management and Research 18:489-505.

Ward, N.I., Brooks, R.R., and Roberts, E., 1977. Heavy metals in some New Zealand bryophytes. The Bryologist 80(2): 304-312.

Data Sources & Software

“Field Boundaries” 2019. California Department of Conservation Division of Oil, Gas, and Geothermal Resources. Web. Downloaded April 1, 2019 from: https://www.conservation.ca.gov/dog/maps/Pages/GISMapping2.aspx

“Inland district wells” 2019. California Department of Conservation Division of Oil, Gas, and Geothermal Resources. Web. Downloaded April 1, 2019 from: https://www.conservation.ca.gov/dog/maps/Pages/GISMapping2.aspx

NHDPlusV21 – California hydrodem18b

NAIP – Kern County, USDA data gateway

ArcMap GIS

R

Appendix A. Stressor-Metric relationships

Table A1. R^2 (>0.3) of biotic metrics compared to stressors. Metric codes are defined in Appendix B.

Stressor	Direction of Effect	R^2	Metric	Stressor	Direction of Effect	R^2	Metric
				median			
log oil				*sediment*			
concentration	Decreaser	0.51	T_Co_Ab_RS	*size*	Increaser	0.47	T_CoHe_La
	Increaser	0.47	T_CoFu_Ri_RO		Increaser	0.47	T_CoHb_Ri
	Decreaser	0.46	T_Co_La		Increaser	0.39	T_Co_La
	Decreaser	0.43	T_CoFuDwGe_La		Increaser	0.39	T_CoFuDwGe_La
	Decreaser	0.43	T_Co_Ri		Increaser	0.32	T_Co_Ri
	Decreaser	0.43	T_Co_Di				
				oil well			
	Increaser	0.41	CB_Ba_Ri	*density*	Decreaser	0.42	T_Co_La
	Increaser	0.39	T_CoFu_Ab_RO		Decreaser	0.40	T_CoFuDwGe_La
	Decreaser	0.38	T_Co_Ri_RS		Increaser	0.40	T_ArOH_La
	Increaser	0.34	B_Ba_Ri		Decreaser	0.38	T_CoFo_Di
	Decreaser	0.34	V_Site_Ev		Decreaser	0.32	T_CoFo_Ri
	Increaser	0.31	CB_Ba_Ri_RS		Decreaser	0.31	T_Co_Ri
percent				*percent fine*			
oilfield cover	Increaser	0.55	B_Ba_Ri_RS	*sediment*	Decreaser	0.58	T_Co_La
	Increaser	0.55	CB_Ba_Ri_RS		Decreaser	0.56	T_CoFuDwGe_La
	Decreaser	0.47	T_CoFo_Ri		Increaser	0.46	CB_Ba_Ri_RS
	Increaser	0.43	T_ArOH_Ab_RO		Decreaser	0.44	T_Co_Di
	Increaser	0.42	B_Ba_Ri		Increaser	0.44	CB_Ba_Ri
	Decreaser	0.41	T_Cl_La		Increaser	0.42	B_Ba_Ri_RS
	Increaser	0.41	CB_Ba_Ri		Decreaser	0.42	T_CoFo_Ri
	Decreaser	0.37	T_CoFo_Di		Decreaser	0.41	T_Co_Ri
	Decreaser	0.36	T_Co_La		Increaser	0.40	B_Ba_Ri
	Decreaser	0.35	T_CoFo_Ri_RS		Decreaser	0.38	T_CoFo_Di
	Decreaser	0.35	T_CoFuDwGe_La		Decreaser	0.33	V_Site_Ev
	Decreaser	0.34	V_CoAr_Ev		Decreaser	0.33	T_Co_Ri_RS
	Decreaser	0.34	V_FoAR_Ev		Decreaser	0.32	T_Co_Ev
	Increaser	0.32	B_BrFm_ri_RS		Decreaser	0.32	T_Co_Ab_RS
	Decreaser	0.31	T_Cl_Ab_RS		Decreaser	0.31	T_CoFo_Ri_RS
	Decreaser	0.31	V_Site_Di				

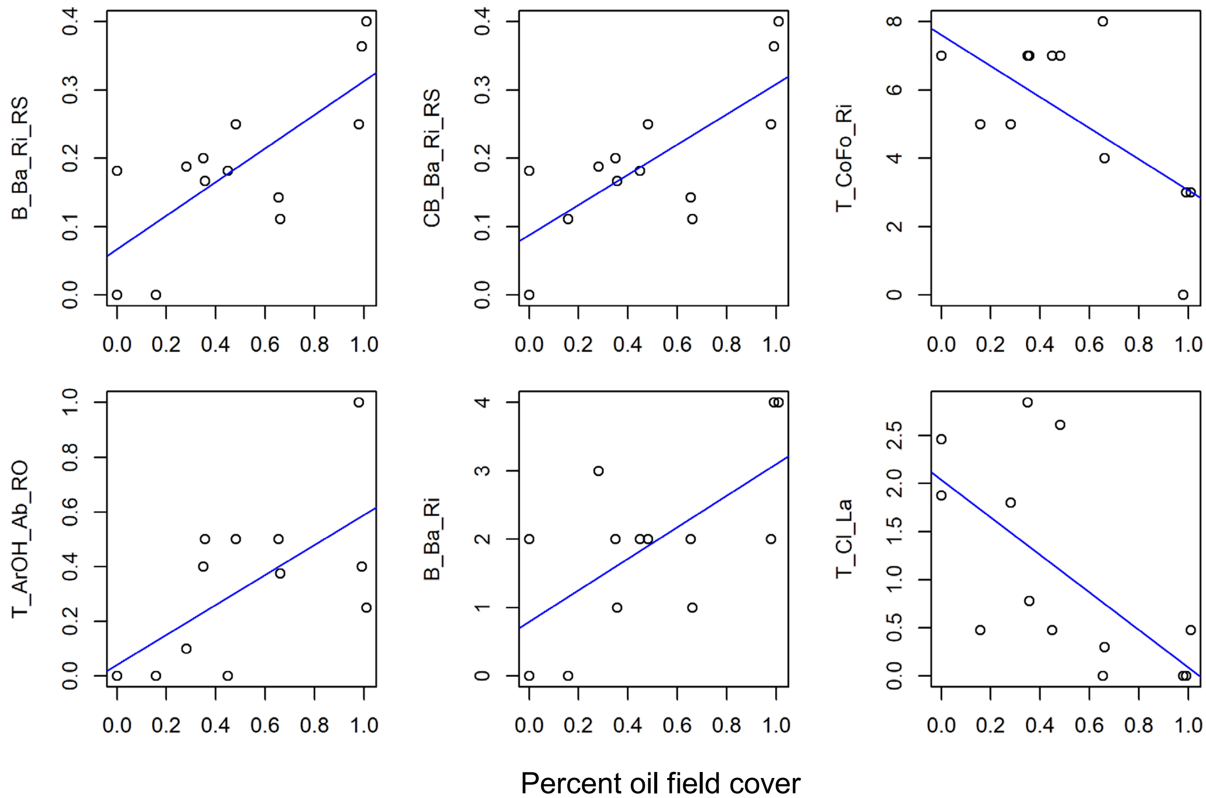


Figure A2. Oil well density and top metrics with best R^2 values. Refer to Table A1 for R^2 values.

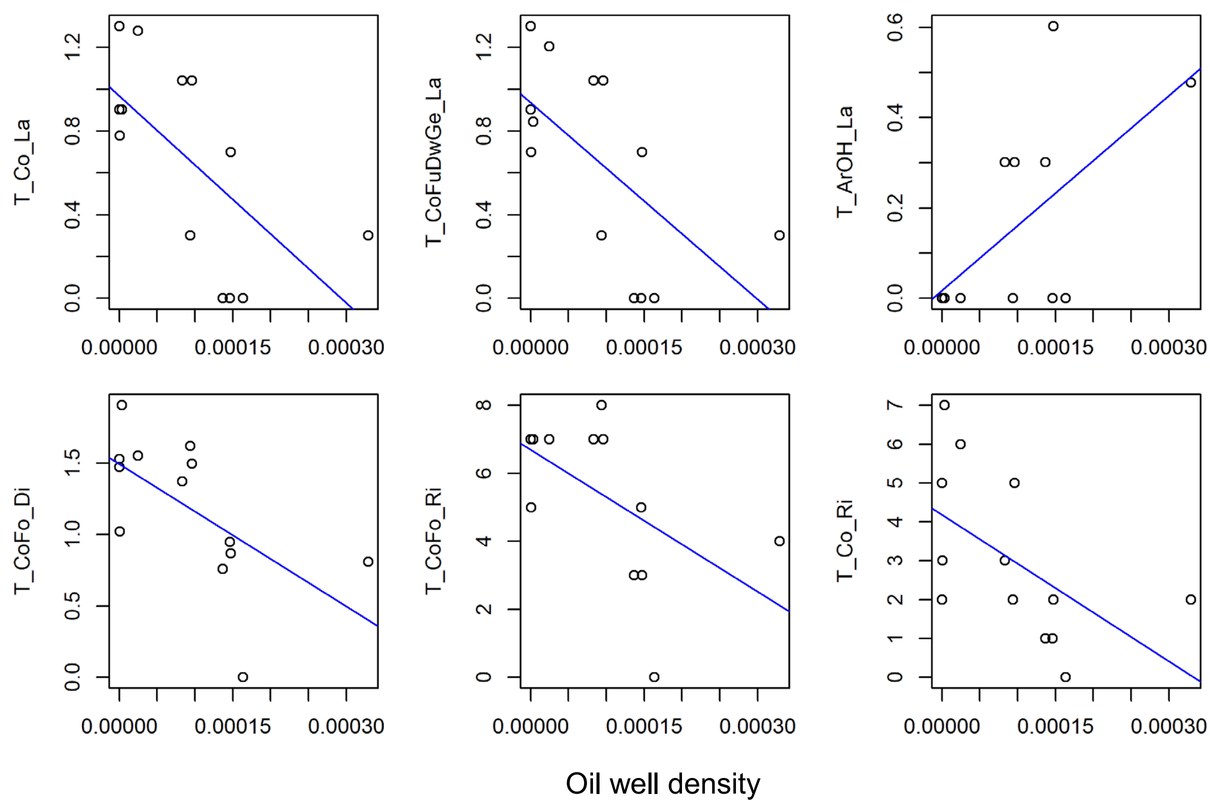


Figure A3. Percent fine sediment and top metrics with best R^2 values. Refer to Table A1 for R^2 values.

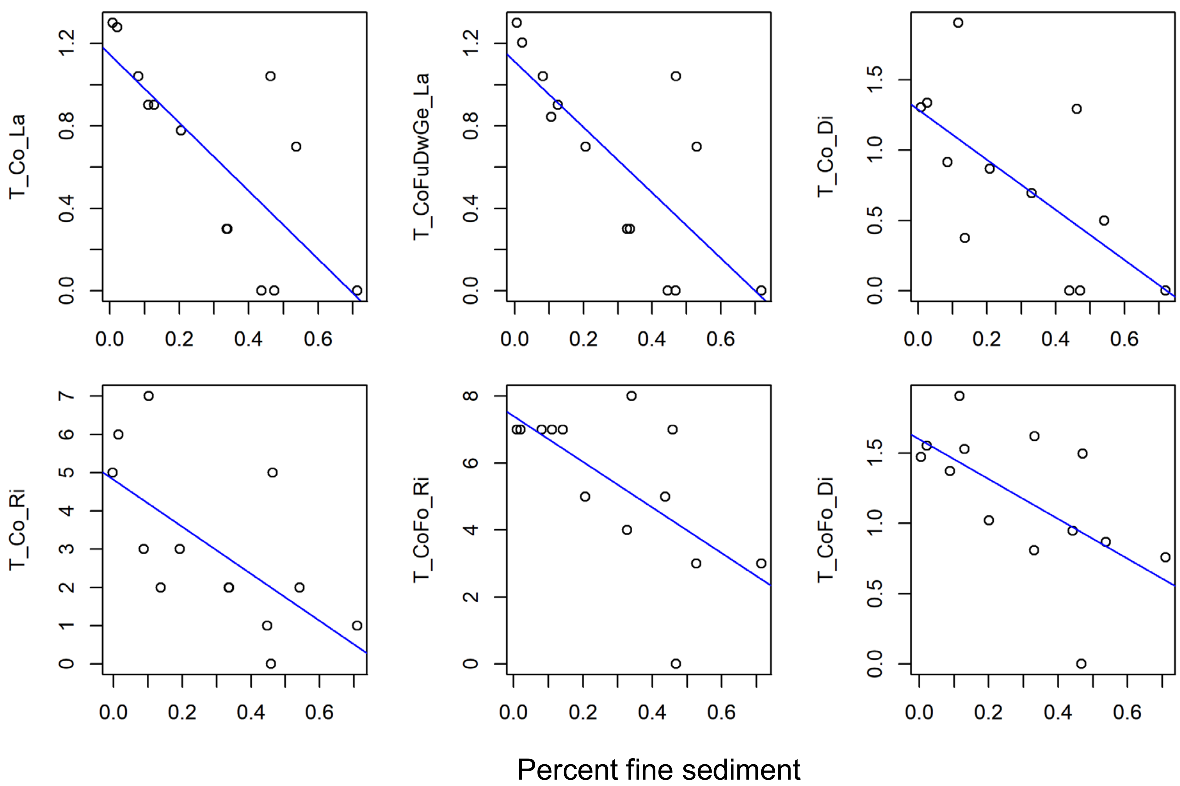
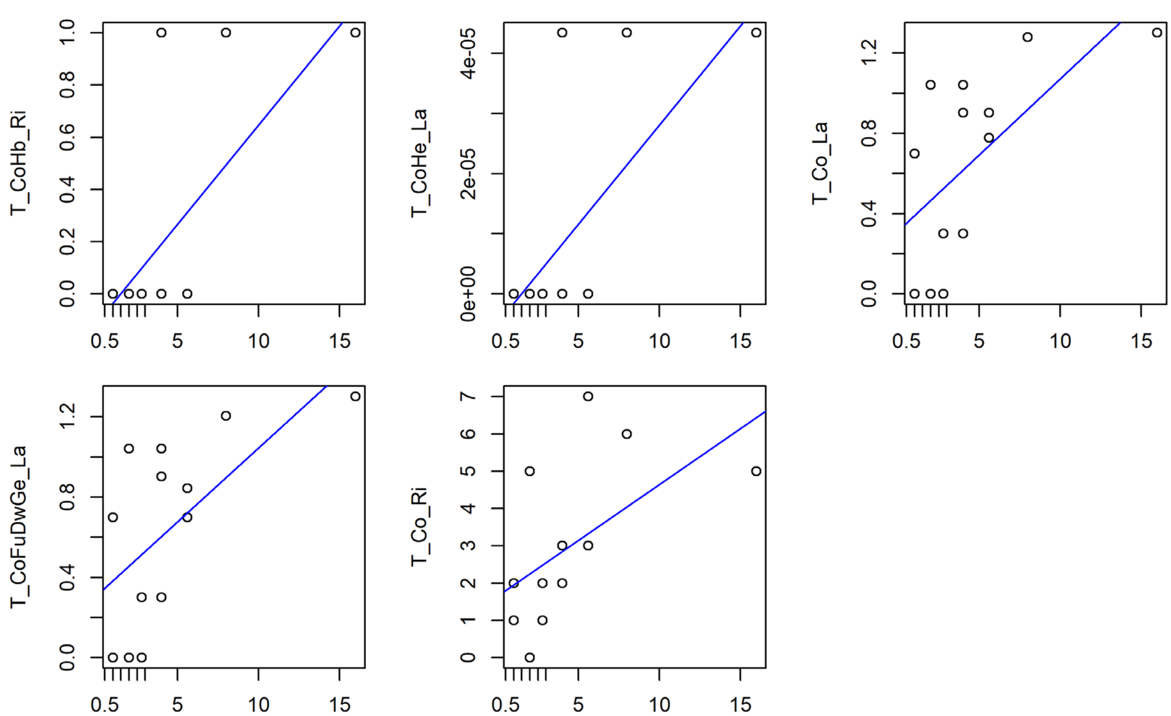


Figure A4. Median sediment size and top metrics with best R^2 values. Refer to Table A1 for R^2 values.



Appendix B. Naming conventions for metrics

1. Assemblage – Method of collection or Location	Abbreviation	Type
	B	bank
	CB	channel
	CB	entire site
	T	pitfall trap
	V	vegetation
2a. Subgroup – Taxon		
	Ac	Acrocarp
	Ai	Acari
	Ar	Aranae
	Ba	Bryaceae
	Br	Bryophyte
	Ca	Carabids
	Cl	Collembola
	Co	Coletoptera
	Ff	Forfic
	Fo	Formicidae
	He	Hemiptera
	Hy	Hymenoptera
	Is	Isopods
	Ot	Other
	Pl	Pluerocarp
	Po	Pottiaceae
	St	Staphylinidae
	Th	Thysanura

2b. Functional Feeding Group or Taxon level (see taxons from 2a)	Abbreviation	Type
	DW	Dead Wood eater
	Fm	Family
	Fu	Fungivore
	Ge	Genus
	Ge	Detritivore/ Generalist
	Gh	Ground hunter
	Gr	Ground
	Hb	Herbivore
	Oh	Other hunter
	Pr	Predator
	We	Web
3. Calculation		
	Ab	Abundance
	Di	Diversity
	Ev	Evenness
	La	Log Abundance
	Ri	Richness
4. Relative to site or order (RS, or RO)		