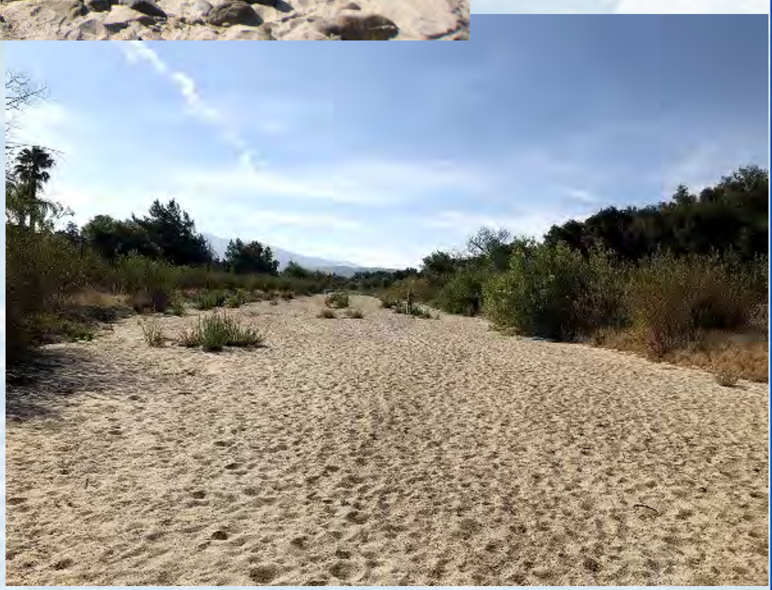
Assessing the biological condition of dry ephemeral and intermittent streams



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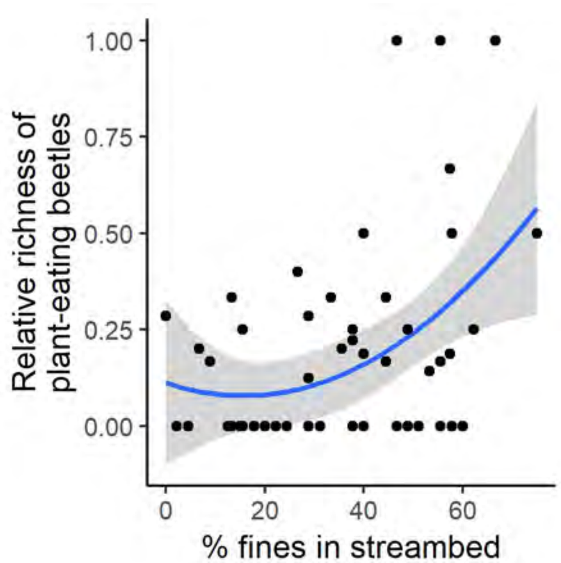
EXECUTIVE SUMMARY

Intermittent and ephemeral streams comprise a large portion of stream-miles in the San Diego region, yet tools to assess stream health have so far only been available for perennial and long-term intermittent streams, meaning that watershed assessments are incomplete — in some watersheds, substantially so. Managers therefore have only a limited ability to assess the effectiveness of their programs. Consequently, nonperennial streams, especially ephemeral streams, are often excluded from regulatory and management programs. To address this gap, researchers at the Southern California Coastal Water Research Project (SCCWRP) and California State University at Monterey Bay (CSUMB) have developed new assessment tools to assess the ecological condition of intermittent and ephemeral streams when they are dry. Although these tools require additional refinement with larger data sets than are currently available, they demonstrate the feasibility of quantitative ecological assessments that transcend hydrologic gradients.

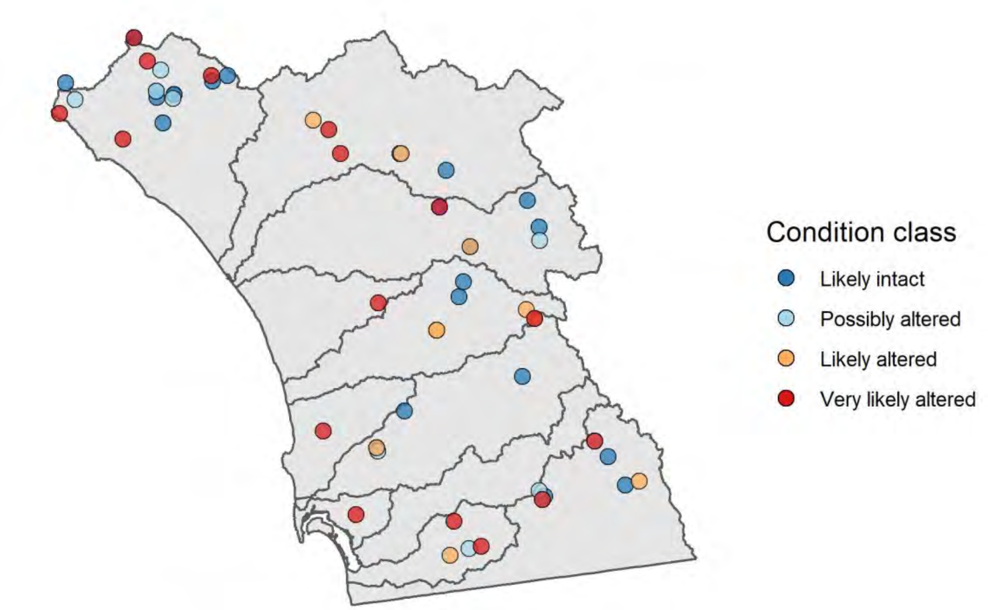
Biological indicators can quantify responses to stress in dry streams



Several biological metrics showed relationships with levels of disturbance, such as altered sediment regimes.

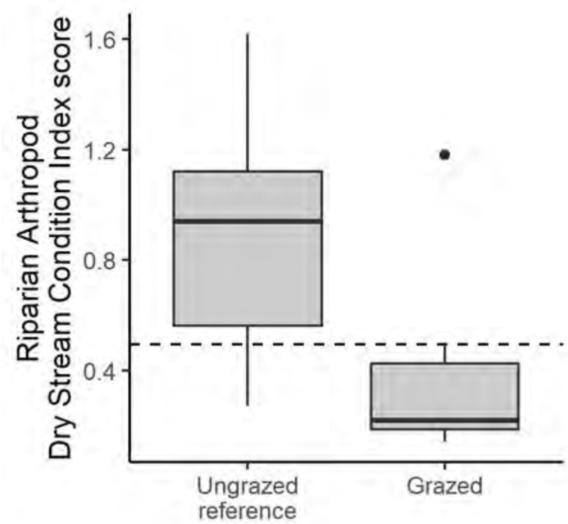
SCCWRP and CSUMB developed new bioassessment indices for dry streams that follow the successful approaches used in perennial and intermittent streams, such as the California Stream Condition Index (CSCI). They developed protocols for sampling biological indicators likely to respond to disturbance in dry streams: terrestrial arthropods (both on the dry streambed and in riparian vegetation) and bryophytes (e.g., mosses and liverworts). Sampling 49 sites over 2 years, they generated data to develop prototype indices modeled after the CSCI that shows promise in its ability to quantify condition in these streams. At the same time, they used these indices to validate the newly developed California Rapid Assessment Method (CRAM) module for episodic streams to see whether CRAM scores are associated with more intensive measures of ecological condition. These data demonstrated how biological communities that use dry streambeds change in response to stress, like increased fines in the streambed substrate.

New indices allow assessment of regional dry stream condition



Several indices were developed to identify which streams were altered from natural conditions.

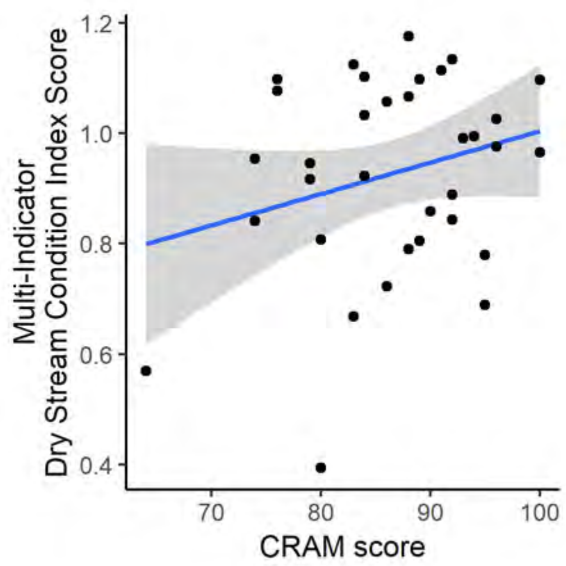
As part of this pilot study, several indices were developed to determine if the biological community of a stream has been altered from natural conditions (one based on riparian arthropods, one based on streambed arthropods, plus one that combines arthropod and bryophyte indicators). These indices found that as many as 49% of sites were in likely altered condition. Sites in poor condition were common in developed areas, as well as open-spaces where grazing occurs. These patterns underscore the need for more monitoring efforts to identify likely impacts to these systems, such as hydrologic alteration, habitat degradation, and sediment contamination.



Several parts of the stream ecosystem were affected by grazing, particularly riparian arthropods.

Rapid and intensive field methods provide a comprehensive view of dry stream condition

Intensive indices based on biological indicators like arthropods and bryophytes validated assessments provided by rapid methods, like the episodic stream module of the California Rapid Assessment Method (CRAM): Indices and CRAM scores were positively correlated, showing that they both reflect condition in a similar way. At the same time, relationships between biological metrics did not consistently show strong relationships with several CRAM attributes, such as biotic structure. This result suggests that CRAM may require additional refinement to be considered a validated rapid assessment method.



An index based on bryophytes, streambed arthropods, and riparian arthropods was positively correlated with CRAM scores.

Recommendations

- **Integrate dry streams into monitoring programs**. This pilot study has generated much of the required infrastructure to begin large-scale monitoring, such as developing protocols and establishing a standard set of metrics and indices for generating and analyzing data. With sufficient training, monitoring practitioners in the San Diego region can begin assessing the condition of dry streams.
- **Refine reference definitions for dry streams.** This study adapted an approach for identifying undisturbed streams that was originally developed for perennial systems, which heavily emphasizes minimizing activity in the upstream watershed. However, in dry streams, upstream disturbance may be a poor indicator of local factors that have a larger influence on in-stream condition. Improved measurements of local disturbance (e.g., measures of habitat alteration, sediment contamination, or hydromodification) may be more useful for identifying reference sites in systems where upstream land-use is a poor proxy.
- **Collect data from additional reference sites, both within and outside the San Diego region.** The limited reference data generated by this pilot study may not capture the full range of natural conditions, nor does it provide information about seasonal or interannual variability. Collecting these data may lead to the development of more precise indices, as well as better guidance on conditions where these indices are best suited.
- **Enhance taxonomic capacity.** Regional taxonomic capacity is likely sufficient, but is untested. Labs that provide taxonomic services for both arthropods and bryophytes expressed willingness and eagerness to generate taxonomic data that might be required by large-scale monitoring programs. Cost estimates average ~$250 per bryophyte sample and ~$300 for arthropod samples for a per-site cost of ~$850. However, these estimates represent best professional judgment, as no respondent had experience processing samples collected by these protocols. Therefore, these estimates could change, and capacity may prove to be insufficient. Molecular methods for bryophytes are a promising way to improve capacity, should it become a problem. Additionally, robust quality assurance protocols are needed so that multiple labs can generate comparable data.

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RESPONSE OF BIOASSESSMENT METRICS TO STRESSOR GRADIENTS IN DRY EPHEMERAL AND INTERMITTENT STREAMS

Introduction

We assessed the relationships among several measures of stress in nonperennial streams and metrics based on three biological indicators we measured at 49 sites across Southern California in 2016 and 2017 (Figure 1). We quantified stress using both watershed measurements of land use and direct habitat measurements related to sediment deposition (i.e., % fine material in the streambed). We then examined the relationships between a subset of our potential biological metrics and our stressor characterizations using both graphical analysis and quantile regression. We observed clear patterns indicating that several metrics were associated with disturbance gradients.

Definition of terms

- *Perennial* streams contain water continuously throughout a year during years with normal rainfall. Streamflow is sustained by groundwater and may be supplemented by snowmelt or surface runoff. These streams are characterized by aquatic-dependent organisms, including benthic macroinvertebrates, algae, and hydrophytic plants.
- *Intermittent* streams contain water for only part of the year during years with normal rainfall. Streamflow is sustained by groundwater and may be supplemented by snowmelt or surface runoff. These streams are characterized by many of the same organisms found in perennial streams.
- *Ephemeral* streams contain water only in direct response to precipitation, and flows for short periods only after large storm events. Stormwater is the primary source of water, and the streambed is always above the local water table. Typically, these streams do not support aquatic-dependent organisms.
- *Nonperennial* streams include both intermittent and ephemeral streams.

Review of stressors affecting nonperennial streams

Nonperennial streams are subject to similar stressors as those affecting perennial streams, but differ in important ways (Chiuh et al. 2017). Because nonperennial streams are typically small waterbodies that represent greater surface area of land-water contact compared to perennial rivers, upland activities may have a greater impact on these systems. Human activities are expected to affect similar factors in nonperennial streams as in perennial systems, namely changes in hydrology, chemistry, or geomorphology (Chiuh et al. 2017). The effects of alteration of these factors to nonperennial streams during flowing periods has been investigated to a degree, but the effects on the assemblages that occupy stream channels during dry periods is largely unknown.

Changes in land use represent one of the key drivers of disturbance affecting streams, although the relationship between land use and dry streambed communities remains largely unstudied. A number of studies have looked at terrestrial arthropod and bryophyte responses to land use in upland habitats, however. Whitford et al. (1999) saw little change in the ant assemblage with increasing amounts of stress in rangelands. Nash et al. (2000) saw decreases in most abundant species with increasing grazing or shrub removal, but low abundance species were unaffected.

Michaels (1999) saw little change in carabid beetle richness with logging, but did observe changes in composition. Willett (2001) also saw decreases in spiders and other arthropods with increasing logging. There is also evidence that logging decreases bryophyte richness due to the loss of decaying wood habitats (Andersson and Hytteborn 1991, Lesica et al. 1991).

Hydrologic alteration represents one of the most important sources of stress to streams in the arid west. Nonperennial streams can be sensitive to hydrologic alterations including both increases and decreases in flow quantity and duration (Chiuh et al. 2017). The effects of flow alteration in nonperennial streams on freshwater invertebrates has been studied (Sabater and Tockner 2009), but the effects of hydrologic changes on terrestrial arthropods in nonperennial streams has not been investigated. A study of riparian arthropods along perennial streams reported decreases in rove beetle abundance and richness related to hydropeaking (Paetzold et al. 2008). Elevated moisture levels from increased runoff has been associated with invasion by exotic ant species (Holway 1998a, Menke and Holway 2006), which in turn may drive numerous other changes in arthropod and plant composition (Hanna et al. 2015)

Bryophytes in nonperennial streams are understudied, but Heino et al. (2015) reported decreases in bryophyte richness in springs with altered hydrology. Given how much the environment changes in nonperennial streams with flow alterations, increases or decreases in flow are expected to affect both terrestrial arthropods and bryophytes in nonperennial streams.

The effects of exposure to toxic chemical pollutants is comparatively better studied, particularly for terrestrial arthropods. Several studies show that terrestrial beetle assemblages decrease in richness when exposed to heavy metals, pesticides, or oil spills (Stone et al. 2001, Butovsky 2011, Bam et al. 2018). Responses of spiders is mixed, with different species showing different responses (Wilczek 2017). Effects of pollution appear to be additive in some cases, with beetles exposed to heavy metals being more susceptible to the effects of pesticides (Stone et al. 2001). Although bryophytes have been shown to accumulate heavy metals (Fernández and Carballeira 2001), changes composition in response to pollution has not been studied.

Geomorphologic alteration may degrade the habitats of nonperennial streams, with increase sedimentation leading to embeddedness that eliminates microhabitats, such as interstitial spaces under cobbles, or fissures within cracked surfaces of dry streambeds (Steward et al. 2018). Increasing embeddedness has been related to decreasing arthropod richness and abundance in beetles (Paetzold et al. 2008, Steward et al. 2018) and spiders (Paetzold et al. 2008). Soil compaction resulting from grazing is also associated with decreased abundance and richness of soil arthropods (Van Klink et al. 2015). Bryophytes are also sensitive to soil stability (Clark 2012) and texture (Eldridge and Tozer 1997).

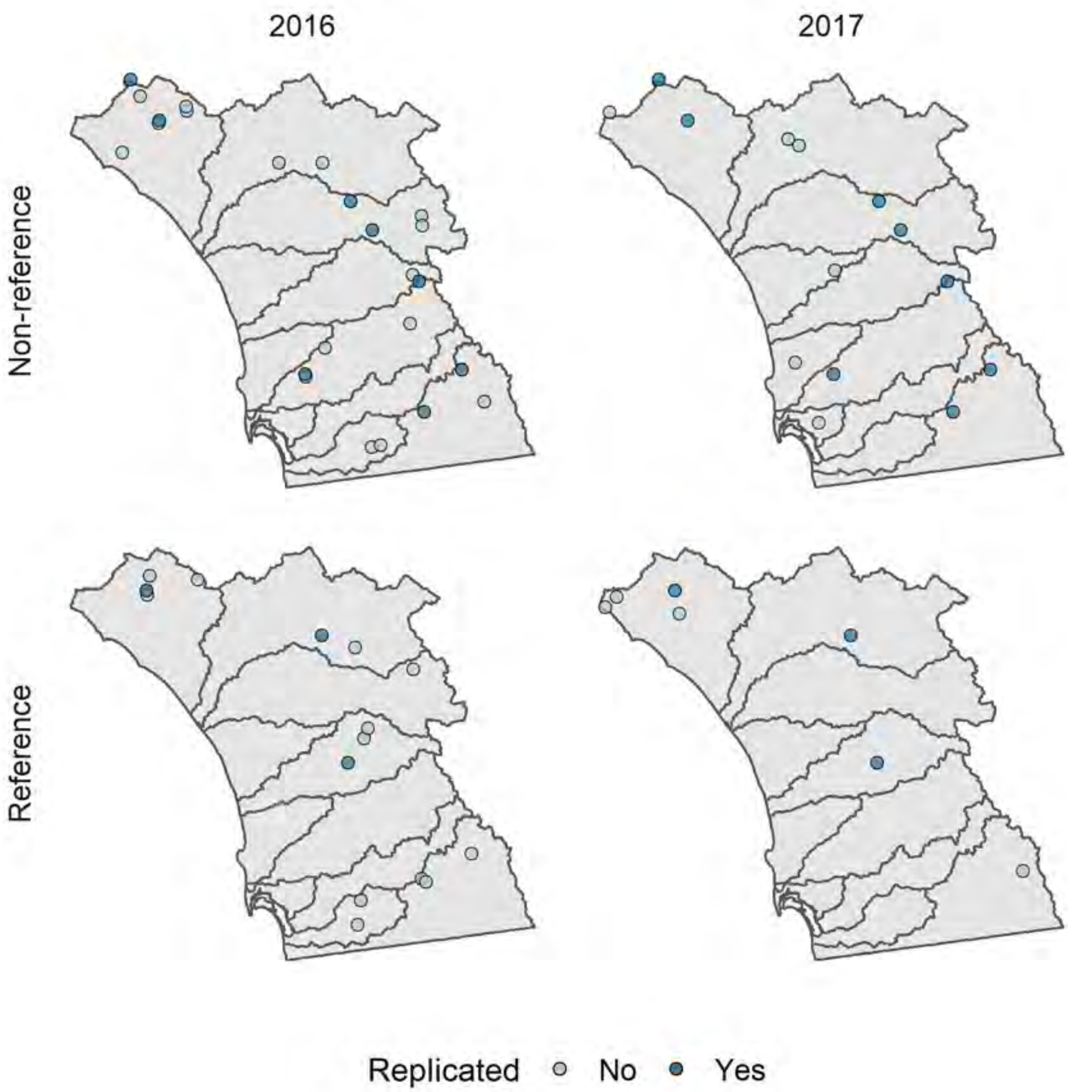

Figure 1. Location of reference and non-reference sites. Outlines indicate hydrologic unites in the San Diego region.

Methods

Sampling

A total of 60 samples were collected from 49 sites representing gradients of both natural and disturbed conditions (Figure 1). 39 sites were sampled in 2016, and 11 of these sites were revisited in 2017, along with 10 new sites that expanded coverage along gradients of interest (e.g., more heavily urbanized sites).

Quantifying Stress

Designated reference sites

A total of 27 candidate reference sites were initially identified based on professional judgment of project leads and Waterboard staff. Subsequently, catchment for each site were delineated, and GIS metrics characterizing stressors at multiple scales (i.e., within the watershed, within a 5-km clip of the watershed, and within a 1-km clip of the watershed) were calculated for screening following Ode et al. (2016), as shown in Table 1. Sites were identified as “high activity” sites if non-natural land use exceeded 50% at any spatial scale, or if road density exceeded 5 km/km^2 at any spatial scale.

Table 1. Stressor and human activity gradients used to identify reference sites and evaluate index performance. Sites that did not exceed the listed thresholds were used as reference sites. WS: Watershed. 5 km: Watershed clipped to a 5-km buffer of the sample point. 1 km: Watershed clipped to a 1-km buffer of the sample point. Variables marked with an asterisk (*) indicate those used in the random forest evaluation of index responsiveness. W1_HALL: proximity-weighted human activity index (Kaufmann et al. 1999). Sources are as follows: A: National Landcover Data Set. B: Custom roads layer. C: National Hydrography Dataset Plus. D: National Inventory of Dams. E: Mineral Resource Data System. F: Predicted specific conductance (Olson and Hawkins 2012). Code 21 is a land use category that corresponds to managed vegetation, such as roadsides, lawns, cemeteries, and golf courses.

Variable	Scale	Threshold	Unit	Data source
% Agriculture	1 km, 5 km, WS	<3	%	A
% Urban	1 km, 5 km, WS	<3	%	A
% Ag + % Urban	1 km and 5 km	<5	%	A
% Code 21	1 km and 5 km	<7	%	A
	WS	<10	%	A
Road density	1 km, 5 km, WS	<2	km/km^2	B
Road crossings	1 km	<5	crossings/ km^2	B, C
	5 km	<10	crossings/ km^2	B, C
	WS	<50	crossings/ km^2	B, C
Dam distance	WS	<10	km	D
% Canals and pipelines	WS	<10	%	C
Producer mines	5 km	0	mines	E

Field observations were also used to screen reference sites. Field observations of human activity such as grazing (e.g., hoof prints, cow patties, terracing of hillslopes) were used to exclude a site from consideration as reference. LocalActivity_prox, A physical habitat metric that describes proximity of diverse human activities, comparable to the “W1_HALL” metric used by Ode et al. (2016) was also used to screen reference sites. For this metric, 75 different types of human activity were noted (Table 2). Activities observed within the active channel were scored as shown in Table 3. Scores were summed across the 75 metrics. Sites scoring below 3 were considered potential reference sites. These metrics were not weighted, meaning that potentially mild disturbance (such as the presence of a single invasive plant within the streambed) would be treated the same as likely more severe disturbances (such as high-density grazing within the streambed).

Table 2. Human activities noted during physical habitat assessment.

Fire Breaks	Dairies	Nutrient Related Water Other
Mowing/Cutting	CAFOs	High Concentration of Salts
Burns	Pasture	Flow Diversions
Cattle Grazing	Rangeland	Groundwater Extraction
Invasive Plants	Agricultural Other	Unnatural Inflows
Animal Burrows	Highway >2 lanes	Water Control Actions Other
Industrial	Paved Roads	Dike/Levee
Landfill	Unpaved Roads	Ditches/Canals
Mining	Parking Lot/Pavement	Dam
Military Land	Railroad	Weirs
Urban Commercial	Air Traffic	Spring Boxes
Urban Residential	Walking Path	Water Control Features Other
Heavy Urban Other	Transportation Other	ATVs
Suburban Residential	Point Source Discharges	Mountain Bikes
Rural Residential	Acid Mine Drainage	Horses
Golf Course/Parks/Sports Fields	Noxious Chemical Odors	Excavation
Excessive Human Visitation	Industrial Water Quality Other	Grading/Compaction
Light Urban Other	NonPoint Source Discharges Stormwater	Feral Pig Disturbance
Crops Irrigated	Trash/Dumping	Sediment Disturbance Other
Crops NonIrrigated	Vector Control	Passive Input (Construction/Erosion)
Vineyards	Urban Water Quality Other	Debris Lines/Silt-Laden Vegetation
Timber Harvest	Agricultural Runoff	Excess Sediment Input Other
Orchards	Algal/Surface Mats/Benthic Algal Growth	RipRap/Armored Channel bed/bank
Hay	Direct Septic/Sewage Discharge	Obstructions (culverts, paved stream crossings)
Fallow Fields	Excess Animal Waste	Hardened Features Other

Table 3. Scoring of stress due to proximity of human activities.

Proximity	Score
Within 1 m of active channel	3
Within 5 m	2
Within 50 m	1.5
Within 100 m	1
Within 250 m	0.5

These screening criteria represent an untested starting point based on experience with flowing intermittent and perennial streams, and may not be appropriate for identifying reference dry streams. Therefore, the final list of reference sites was determined evaluating all three lines of evidence (i.e., best professional judgment, landscape level screens, and field-measured screens), in consultation with Waterboard staff.

Landscape disturbance

Watershed summaries of human land use data was obtained from the StreamCat database (Hill et al. 2016), or from watersheds delineated for each sampling location (as per Ode et al. 2016 and Mazor et al. 2016). These land use metrics were evaluated individually, and in various combinations of stressors to account for the effects of multiple stressors (e.g., combined percent urban and percent agriculture). We also combined multiple factors into a single Anthropogenic Stress Index (ASI) by summing z-scores (i.e., the difference between each observation and the mean of the data divided by the standard deviation) of % agriculture, % urbanization, road and canal densities, road/stream crossings, and number of mines. By combining multiple stressors into a single measure, we intended to characterize a general stressor gradient that could distinguish reference from non-reference sites.

Habitat disturbance

Habitat characteristics were measured at 8 equidistant transects along the 160-m sampling reach and turned into ~200 metrics to characterize conditions of physical habitat. These metrics quantify several aspects of physical habitat, such as channel morphology (e.g., % riffle, as defined by patches of coarse substrate), substrate composition (e.g., % sands and fines), in-stream habitat cover-types (e.g., mean woody debris cover), and levels of human influence (e.g., proximity-weighted human activity metrics). Selected metrics are shown in Table 4. Physical habitat metrics that relate to stress were identified by determining those with a high absolute t-statistic from a test comparing means of reference and non-reference sites.

Table 4. Example physical habitat metrics.

Metric	Description
PCT_BDRK	Percent Substrate as Bedrock
PCT_BIGR	Percent Substrate Larger than Fine Gravel (>16 mm)
PCT_CB	Percent Substrate Cobble
PCT_SAFN	Percent Substrate < 2 mm
PCT_POOL	Percent Pool of Reach
PCT_RIFF	Percent Riffle of Reach
PCT_CASC	Percent Cascade of Reach
SB_PT_D10	Particle Size 10th (d10)
SB_PT_D25	Particle Size 25th (d25)
SB_PT_D50	Particle Size Median (d50)
SB_PT_D75	Particle Size 75th (d75)
SB_PT_D90	Particle Size 90th (d90)
XBKF_H	Mean Bankfull Height
XKBF_W	Mean Bankfull Width
XEMBED	Mean cobble embeddedness
XSLOPE	Mean Slope of Reach, measured along the banks
PCT_WET	Percent wet habitat in overall reach
PCT_CHANGRASS	Percent cover of grass in channel
LocalActivity_prox	Scored proximity of human activity to the channel

Characterizing biological indicators

At each site, three indicators were sampled following the protocols in Mazor et al. (2017). A suite of 230 metrics was calculated to characterize each indicator, as summarized in Table 5. Bryophyte metrics were evaluated as richness, relative richness, or diversity metrics; some bryophyte metrics were calculated at the mesohabitat (i.e., channel or bank) level, as well as at the site level. Arthropod metrics were calculated as log-abundance (base-10 + 0.0001), relative abundance, richness, relative richness, diversity, or evenness metrics.

Table 5. Types of bioassessment metrics evaluated in the study.

Bryophytes	Riparian arthropods	Streambed arthropods
Bryophyte morphospecies	Arthropods	Arthropods
Bryophyte families	Coleoptera	Coleoptera
Bryophyte genera	Hymenoptera	Ground beetles
Acrocarps	Ants	Rove beetles
Pleurocarps	Hemiptera	Ground + Rove beetles
Bryaceae	Thysanoptera	Predator beetles
Pottiaceae	Spiders	Herbivore beetles
	Other arthropods	Fungivore beetles
	Coleoptera + Ants	Fungivore, dead wood, and detritivore beetles
	Coleoptera + Ants + Spiders	Hymenoptera
	Coleoptera + Spiders	Ants
	Ants + Spiders	Thysanoptera (silverfish)
		Diptera
		Hemiptera
		Archaeognatha (bristletails)
		Earwigs
		Spiders
		Wolf spiders
		Ground spiders
		Web spiders
		Ground-hunting spiders
		"Other" hunting spiders
		Mites
		Isopods
		Collembola
		Other arthropods
		Coleoptera + Ants
		Coleoptera + Spiders
		Coleoptera + Ants + Spiders
		Ants + Spiders

Relationship between Biological Metrics and Natural Gradients

In order to evaluate the relationship between selected natural gradients and biological assemblages, a random forest model was calibrated to predict metric values at reference sites from natural watershed characteristics (Table 6). If the percent of variance explained by the model (i.e., the pseudo-R^2) was greater than 0.1, then a model residual (i.e., the deviation from reference expectations) was used in subsequent analyses; otherwise, the raw metric value was used. (This cutoff value, while lower than the 0.2 used to develop the California Stream Condition Index [Mazor et al. 2016], is comparable to cutoff values used in other predictive multimetric indices [e.g., Vander Laan and Hawkins 2014]) Unless otherwise stated, the term "metric value" is henceforth used to refer to both raw values and residuals from modeled values. To determine the most important predictors, we tallied the number of times each predictor was among the top 5 predictors for all random forest models with pseudo-$R^2 > 0.1$, as determined by increased mean-squared error.

Table 6. Natural factors evaluated in modeling biological relationships. Sources: a: National Elevation Dataset (http://www.usgs.gov); b: National Atmospheric Deposition Program, National Trends Network (http://nadp.slh.wisc.edu/NTN/); c: Olsen and Hawkins (2012); and d: PRISM (http://www.prism.oregonstate.edu).

Predictor	Description	Source
Lat	Latitude in decimal degrees	
Long	Longitude in decimal degrees	
SITE_ELEV	Elevation of sampling location in m	a
MAX_ELEV	Maximum elevation in the catchment in m	a
ELEV_RANGE	Range between highest point in the watershed and sampling location in m	a
AREA_SQKM	Watershed area in km2	a
AtmCa	Catchment mean of atmospheric deposition of Calcium	b
AtmMg	Catchment mean of atmospheric deposition of Magnesium	b
AtmSO4	Catchment mean of atmospheric deposition of Sulfate	b
BDH_AVE	Catchment mean bulk soil density	c
UCS_Mean	Catchment mean unconfined compressive strength	c
KFCT_AVE	Catchment mean soil erodibility factor (k) in the watershed	c
LPREM_mean	Catchment mean of log hydraulic conductivity	c
PRMH_AVE	Catchment mean soil permeability	c
CaO_Mean	Catchment mean CaO geology	c
MgO_Mean	Catchment mean MgO geology	c
N_MEAN	Catchment mean N geology	c
P_MEAN	Catchment mean P geology	c
S_Mean	Catchment mean S geology	c
PCT_SEDIM	Percent sedimentary geology in catchment	c
PCT_VOLCNC	Percent igneous geology in catchment	c
PCT_NOSED	Percent metamorphic geology in catchment	c
PCT_CENOZ	Percent Cenozoic sediments in catchment	c
PCT_QUART	Percent Quarternary sediments in catchment	c
CondQR50	Predicted conductivity from natural sources	c
LST32AVE	Catchment mean of 1961 to 1990 first and last day of freeze	d
MAXWD_WS	Catchment mean 1961-1990 annual maximum number of wet days	d
MEANP_WS	Catchment mean of 1971-2000 annual precipitation	d
PPT_00_09	Mean annual precipitation between 2000 and 2009 at the sampling location	d
SumAve_P	Catchment mean summer precipitation between 1971 and 2000.	d
TEMP_00_09	Mean annual temperature between 2000 and 2009 at the sampling location	d
TMAX_WS	Catchment mean of 1971 to 2000 annual maximum temperature	d
XWD_WS	Cathment mean of 1961 to 1990 annual number of wet days	d

Interannual Variability in Biological Metrics

Interannual variability was evaluated at the 11 sites that were sampled in 2016 and 2017. The two years differed greatly in terms of rainfall. For example, in 2016, Lindbergh Field received 8.18 inches of rain (79% of normal), whereas 2017, this region received 22.73 (123% of normal) (data source: https://www.sdcwa.org/annual-rainfall-lindbergh-field, accessed 5/28/2019). Variability of each metric was characterized by calculating Pearson's correlation coefficient between years, using raw (unmodeled) metric values.

Relating Stress to Biological Metrics

Metrics were classified as increasers if the mean at reference sites was lower than the mean at non-reference sites; otherwise, they were classified as decreasers. Unless otherwise stated, only the first sample collected from revisited sites was used in analyses. We looked for significant relationships with stress by computing the t-statistic comparing the means of reference and non-reference sites; t-statistics with a $p < 0.1$ were considered responsive. We then calculated correlations between biological metrics and selected landscape and physical habitat metrics associated with human activity.

We graphically examined the relationships between stressors and biological metrics based on family identifications and morpho-species designations of bryophytes, ground-dwelling arthropods and vegetation-dwelling arthropods. We initially inspected scatter plots of arthropod and bryophyte metrics against each of the stressor gradients for evidence of any strong patterns. We then used quantile regression analysis to determine if any of the metrics that we considered responsive to impairment (i.e., best distinguished reference from impaired sites, determined from t-scores) had statistically significant responses to stressor gradients.

Quantile regression is a particularly useful statistical tool for estimating the effects of limiting factors when multiple unmeasured variables may also be limiting and subsequently increase the heterogeneity of the response. (Cade and Noon 2003; Brooks and Haeusler 2016). The quantile regression algorithm uses a given quantile "T" to fit a linear function where the regression line is fit so the selected proportion of observations (i.e., T) fall at or below the line (Lancaster and Belyea 2006; Brooks and Haeusler 2016). The appropriate maximum T value for a given dataset is calculated as: maximum quantile T < 1-(5/number of sites) (Rogers 1992, Steward et al. 2018). We calculated a T of 0.85 as appropriate for assessing the relationship between metric responses and individual human disturbances. We used p-values derived from the quantile regression models as our basis of inference ($\alpha = 0.05$, $n = 39$) to determine if human disturbances were limiting to metric responses.

All quantile regression analyses were completed using the "rq" function in the quantreg package (Koenker 2016) using R Software.

Building provisional multimetric indices

We evaluated four potential multimetric indices: One comprised of terrestrial arthropod metrics, one comprised of riparian arthropod metrics, one comprised of bryophyte metrics, and one comprised of metrics from all three assemblages. Metrics were screened for inclusion in a multimetric index adapting an approach developed by Stoddard et al. (2008) and Mazor et al. (2016), as described below:

- Unique values: At least 4 unique values
- Range: No more than 2/3 zero values
- Consistency: Year-to-year correlation coefficient > 0.25
- Responsiveness:
    - |t-statistic| > 1.65 (i.e., p<0.1) in comparison of reference and non-reference sites; OR
    - |Spearman's rho| > 0.2 with imperviousness, % fines, or local activity metric

We did not screen bias in individual metrics under the assumption that modeling efforts described above were sufficient to reduce the influence of major natural factors at reference sites.

Metrics that met all criteria were evaluated for inclusion in indicator-specific indices: a Bryophyte Dry Stream Condition Index (BRY-DSCI), a Riparian Arthropod Dry Stream Condition Index (RA-DSCI), and Streambed Arthropod Dry Stream Condition Index (SA-DSCI). Metrics were hand-picked for inclusion in indices to maximize responsiveness (either high absolute t-statistic or high correlation with habitat or landscape stressors) while avoiding thematically related or empirically redundant metrics. Thematically related metrics include different formulations of the same organism group (e.g., richness and relative richness of beetles); empirically redundant metrics had Pearson $r^2 > 0.6$. If fewer than 4 metrics could be identified, an index was not developed for that indicator. Finally, combined index that includes all indicators (Multi-Indicator Dry Stream Condition Index, MI-DSCI) was created by selecting the two most responsive metrics per indicator group, as determined by the absolute t-statistic (excluding high correlated or similar metrics).

Due to the novel nature of this research, we made no assumptions as to how these metrics would respond to stress. Metrics were designated as decreasers if the mean value at reference sites was higher than the mean value at non-reference sites, and as increasers if the opposite was true. Each metric was scored on a scale from 0 (degraded) to 1 (similar to reference) following Cao et al. (2007). Scores were averaged to generate a raw multimetric index (MMI) score. A final MMI was then calculated by dividing by the mean raw score at reference sites. Thresholds were identified at the 30th, 10th, and 1st percentile of reference scores to identify four condition classes: likely intact, possibly altered, likely altered, and very likely altered.

Index performance was assessed adapting the approaches used in Mazor et al. (2016), as described below:

- Precision: Standard deviation among reference sites
- Bias: Pseudo R^2 from a random forest model to predict index scores at reference sites from natural factors (Table 6)
- Consistency: Pearson's correlation coefficient between samples at sites collected in 2016 and 2017
- Responsiveness:
    - T-statistic from a comparison of means at reference and non-reference sites.
    - Pseudo R2 from a random forest model to predict index scores from imperviousness, % fines, and proximity of local activity.
    - Visual examination of index score relationships with selected stressor gradients
- Sensitivity: Number of sites with scores below thresholds.

Except for consistency, all index performance measures were based on the first replicate at re-visited sites.

Results

Identifying reference sites

Based on best professional judgment, GIS analysis of land use in the watershed, and field observations collected during habitat assessment, a total of 25 sites were identified as reference (Table 7). Only 16 sites met criteria for all reference screens. GIS screens were overruled for 6 of the sites; for 2 of these sites, underlying GIS data was determined to be unreliable, and for 5 of these sites, screens only slightly exceeded criteria in Table 1. Field notes were overruled for 2 of the sites because the observed stress (i.e., algae growth at 905SDBDN9 and excess sediment at 911S01142) could not be associated with likely human sources. Details about each overruling are provided in Table 7.

Table 7. Results of reference site screens based on multiple screening approaches. BPJ: Best professional judgment. GIS: Application of screens shown in Table 1 based on landscape metrics calculated in a geographic information system. PHAB: Assessment of physical habitat metrics and field observations collected in one or both years of the study (blank indicates that no data were collected that year). Ref: Site passes reference screens. NonRef: Site does not pass reference screens. BMI: Indicates if BMI samples have been collected at this site under other studies Episodic CRAM data were collected at all sites, except those marked with an asterisk.

			PHAB				
StationCode	BPJ	GIS	2016	2017	Final status	BMI	Notes
801SANT1x	Ref	Ref		Ref	Ref	Yes	
801SHDCYN	NonRef	NonRef		Ref	NonRef		
901AUDCRW	Ref	Ref	Ref		Ref		
901AUDFOX	Ref	Ref	Ref	Ref	Ref		
901BELOLV	Ref	Ref	Ref		Ref	Yes	
901EMRCYN	Ref	NonRef		Ref	NonRef		
901LAUREL	Ref	NonRef		Ref	Ref		Developed land use in watershed ~4%
901NP9CSC	Ref	Ref	Ref	Ref	Ref		
901NP9LCC	NonRef	NonRef	NonRef		NonRef	Yes	
901NP9MRC	Ref	NonRef	Ref		Ref		Road density ~ 4km/km^2 at 5 km
901SJLANV	NonRef	NonRef	NonRef		NonRef	Yes	
901SJMS1x	NonRef	NonRef	NonRef		NonRef	Yes	
901SJOF1x	NonRef	NonRef	NonRef		NonRef	Yes	
901SJVERD	Ref	NonRef		Ref	Ref		Local developed land use ~4%
901TCTCR	NonRef	NonRef	NonRef		NonRef		
902LNGCYN	NonRef	NonRef		NonRef	NonRef		
902NP9CWC	Ref	NonRef	Ref		Ref	Yes	Road density in watershed ~2.2 km/km^2
902PECHNG	NonRef	NonRef	Ref		NonRef		
902SMAS1x	NonRef	Ref	NonRef		NonRef	Yes	

902SMAS2x	Ref	Ref	Ref	Ref	Ref		
902WRMSPC	NonRef	NonRef		NonRef	NonRef		
903ACPCT1	Ref	Ref	Ref		Ref	Yes	
903CVPCT	NonRef	Ref	Ref		NonRef	Yes	
903NP9PRC	Ref	Ref	Ref	Ref	Ref	Yes	
903NP9SLR	Ref	NonRef	Ref		Ref	Yes	Road density ~ 10 km/km^2 at 1 km, likely data source error
903SLFRCx	NonRef	Ref	NonRef	NonRef	NonRef	Yes	
904ESCELN	NonRef	NonRef		NonRef	NonRef		
905DGCC1x	Ref	Ref	Ref		Ref	Yes	
905DGCC2x	Ref	Ref	Ref		Ref		
905DGSY1x	NonRef	Ref	NonRef		NonRef	Yes	
905SDBDN9	Ref	Ref	Ref	NonRef	Ref	Yes	Heavy algal growth noted in 2017
906SLCFGC	NonRef	NonRef		NonRef	NonRef		
907NP9KLC	NonRef	NonRef	NA		NonRef		
907NP9OSD	NonRef	NonRef	NonRef		NonRef	Yes	
907NP9OSU	Ref	Ref	Ref	Ref	Ref		
907SRSD2x	NonRef	Ref	NonRef	Ref	NonRef	Yes	
907SYCAM	NonRef	NonRef	Ref		NonRef		
908CHI805	NonRef	NonRef		NonRef	NonRef		
910NP9ARP	Ref	Ref	Ref		Ref		
910NP9CCN	Ref	Ref	NonRef		Ref		
910NP9RJT*	Ref	NonRef	NonRef		NonRef		Urban land use exceeds 10% at 5 km and watershed scales
910SYCAM*	NonRef	NonRef	Ref		NonRef		
911NP9ATC	Ref	Ref		Ref	Ref	Yes	
911NP9EPC*	Ref	Ref	Ref		Ref	Yes	
911NP9HTC*	Ref	NonRef	Ref		Ref	Yes	Local road density exceeds 10 km/km^2, reflecting likely data source error. Upstream road density ~3 km/km^2.
911NP9UCW	Ref	Ref	Ref		Ref	Yes	
911S01142*	Ref	Ref	NonRef	Ref	Ref	Yes	High sediment levels noted in 2016
911TJKC1x	Ref	Ref	Ref		Ref	Yes	
911TJPC2x	NonRef	NonRef	Ref	NonRef	NonRef	Yes	

Relationship between Biological Metrics and Natural Gradients

Of the 230 metrics we evaluated, natural factors rarely explained a large portion of variation at reference sites: Only 21 metrics (14 for streambed arthropods, 4 for riparian arthropods, and 3 for bryophytes) had a pseudo-$R^2 > 0.1$, and only 4 exceeded 0.2 (Figure 2, example metrics shown in Figure 3). The most important predictors varied widely among these models (Figure 4), although several geological factors (e.g., N_MEAN, KFCT_AVE) were among the top 5 predictors for several models.

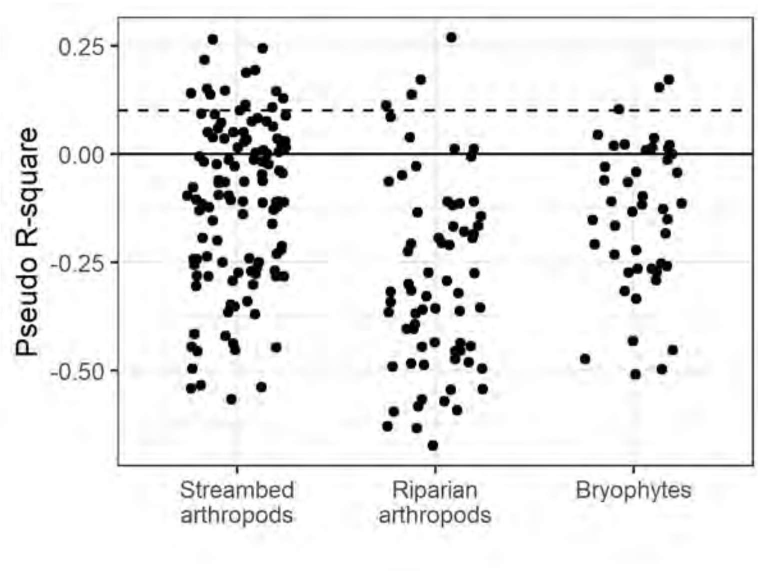

Figure 2. Pseudo-R^2 of random forest models that predict metric values at reference sites based on natural gradients. Negative values indicate that model predictions are not associated with variability in training data, and these values are interpreted as zero. The dashed line represents the critical minimum value (i.e., 0.1) that determines if raw metric values are used vs. deviations from reference expectations in assessments.

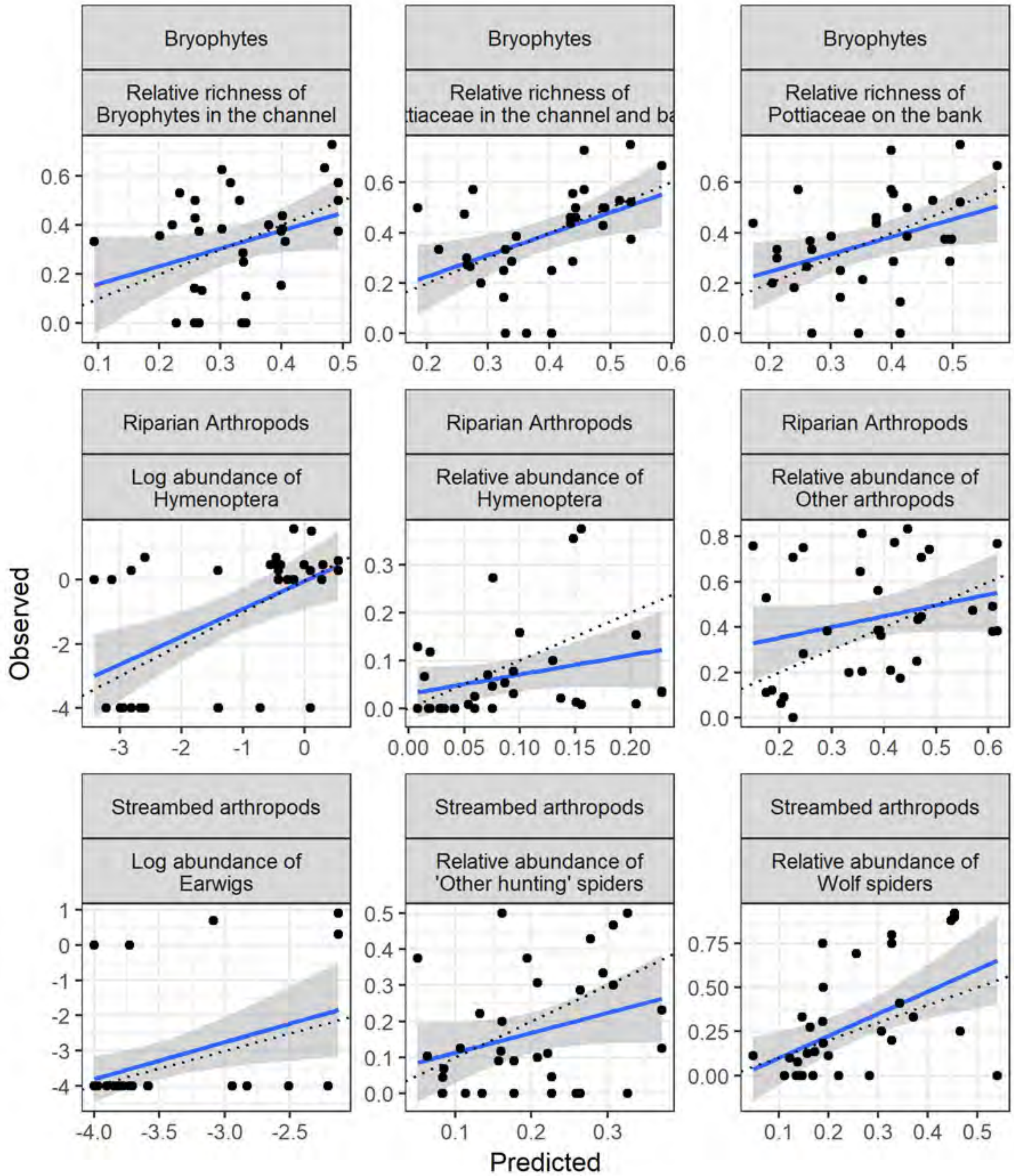

Figure 3. Predicted and observed values of selected metrics at reference sites. The blue line indicates a linear fit, the gray ribbon indicates the fit's 95% confidence interval, and the dotted line represents the line of perfect prediction. Only reference sites used to calibrate the models are shown.

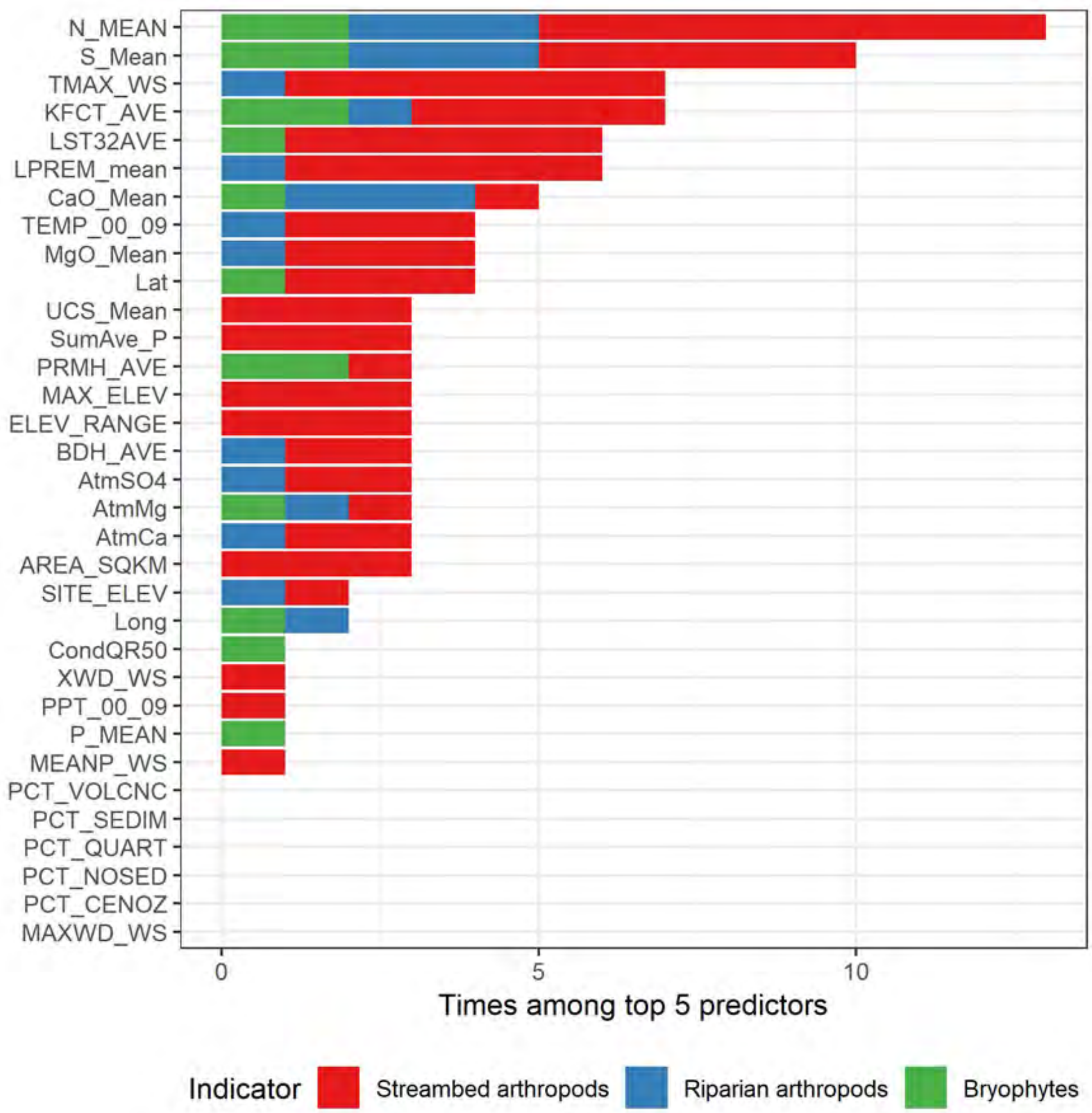

Figure 4. Frequency that each variable was among the top 5 most important predictors in random forest models with pseudo R^2 > 0.1.

Interannual Variability in Biological Metrics

Year-to-year correlations ranged from a high of 0.90 (for pleurocarp richness on the banks) to a low of -0.75 (for evenness of bryophytes on the banks). Selected high-correlation metrics are shown in Figure 5. Overall, 76 metrics had correlations greater than 0.5 between years, and 58 had negative correlations. Although bryophyte evenness was particularly variable, bryophyte metrics tended to be the most consistent between years, followed by streambed arthropod metrics. Riparian arthropod metrics were generally the most variable between years (Figure 6).

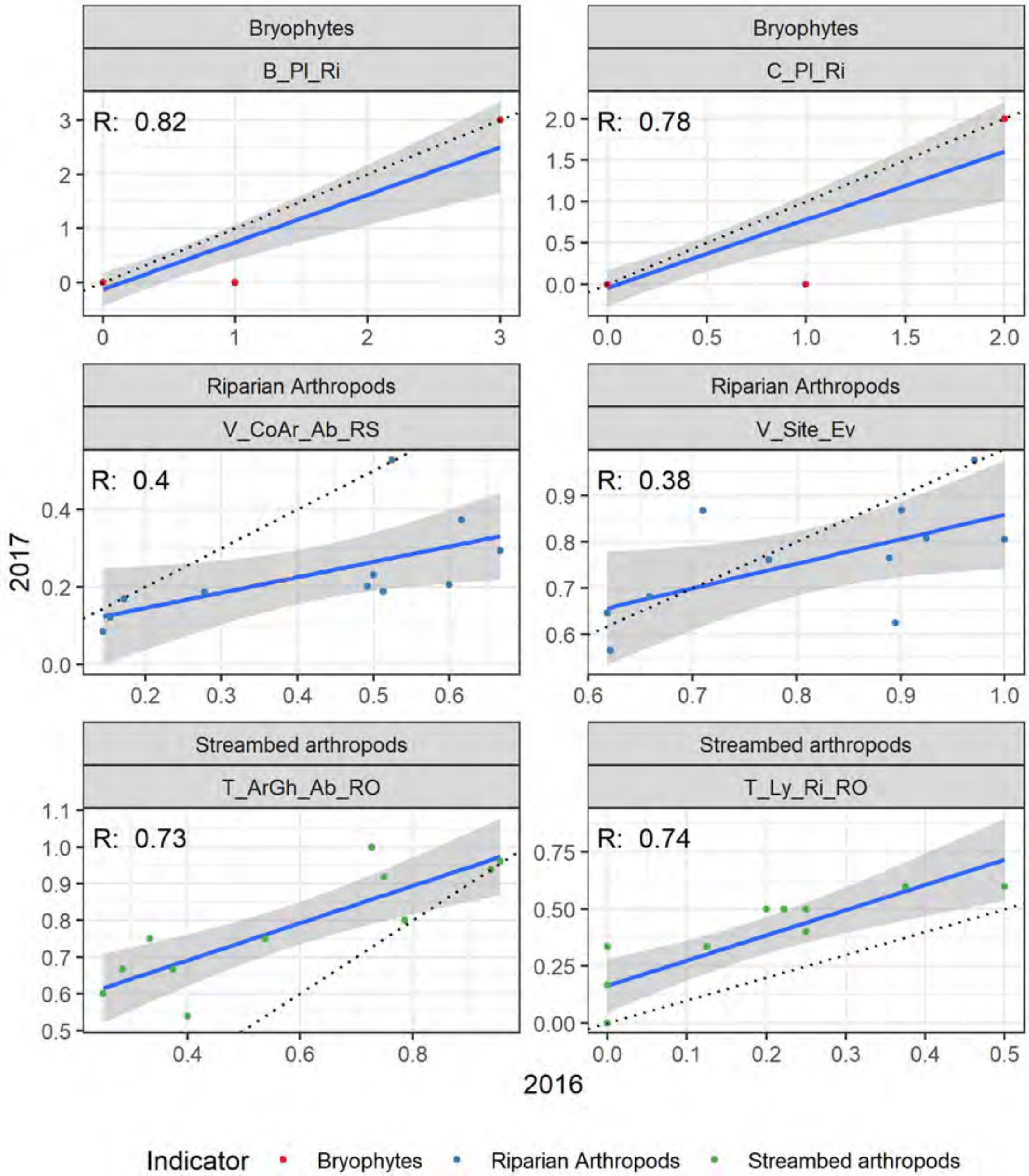

Figure 5. Year-to-year comparisons of metric values with high correlation coefficients. B_Pl_Ri: Richness of pleurocarps on the banks. C_Pl_Ri: Richness of pleurocarps in the channel. V_CoAr_Ab_RS: Relative abundance of beetles and spiders on riparian vegetation. V_Site_Ev. Evenness of arthropods on riparian vegetation. T_ArGh_Ab_RO: Relative abundance of ground-hunting spiders in the streambed. T_Ly_Ri_RO: Relative richness of wolf spiders in the streambed.

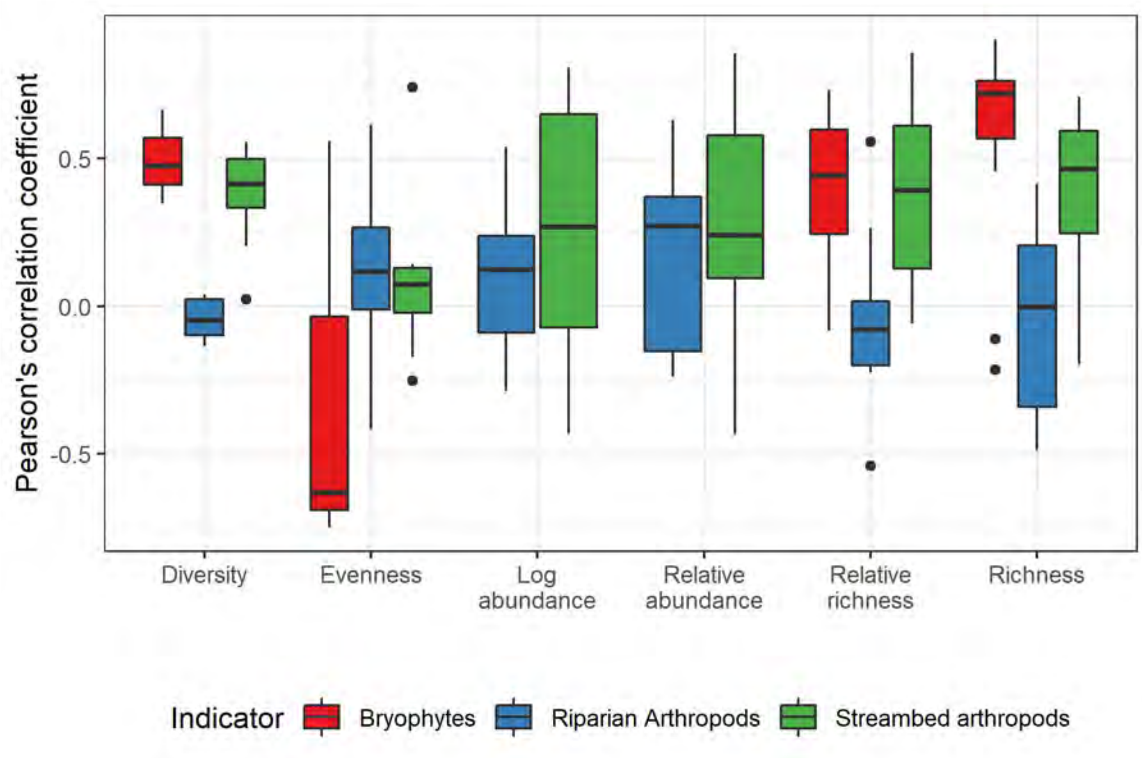

Figure 6. Distribution of correlation coefficients between years by metric form and indicator.

Metric responses to stress

Of the 230 metrics, 123 were classified as increasers, and 107 were classified as decreasers. More than 60% of bryophyte and riparian arthropod metrics increased in response to stress, compared with 45% of streambed arthropod metrics.

Overall, 31 metrics showed a significant ($p < 0.1$) response to reference status. Many riparian arthropod metrics were responsive, but only 6 streambed arthropod metrics, and just 2 bryophyte metrics (Figure 7). Significant responses were more common among increasing metrics, although among streambed arthropod metrics, they were equally numbered by decreasing metrics.

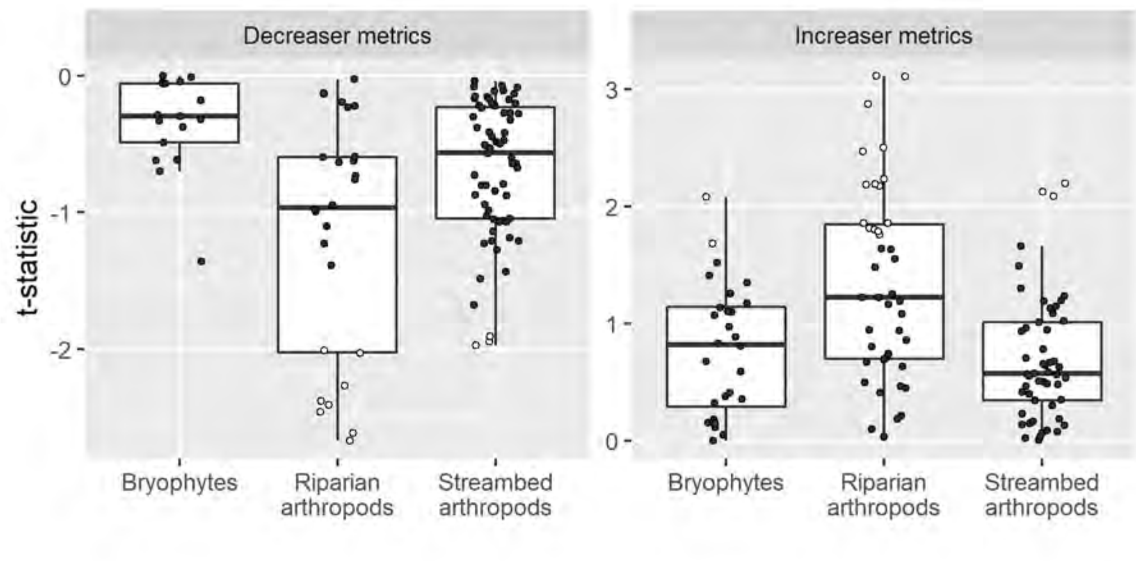

Figure 7. T-statistics for metric responses to reference status. White symbols indicate metrics that were significantly responsive at p < 0.1.

Modeling typically decreased responsiveness of metrics, suggesting that some metrics may reflect differences in natural conditions between reference and non-reference sites, rather than a response to stress (Figure 8). However, only one metric switched to having a significant ($p < 0.1$) t-statistic after modeling (i.e., relative abundance of riparian Hymenoptera), and only one metric become non-significant (i.e., $p > 0.1$) after modeling (i.e., log abundance of riparian Hymenoptera).

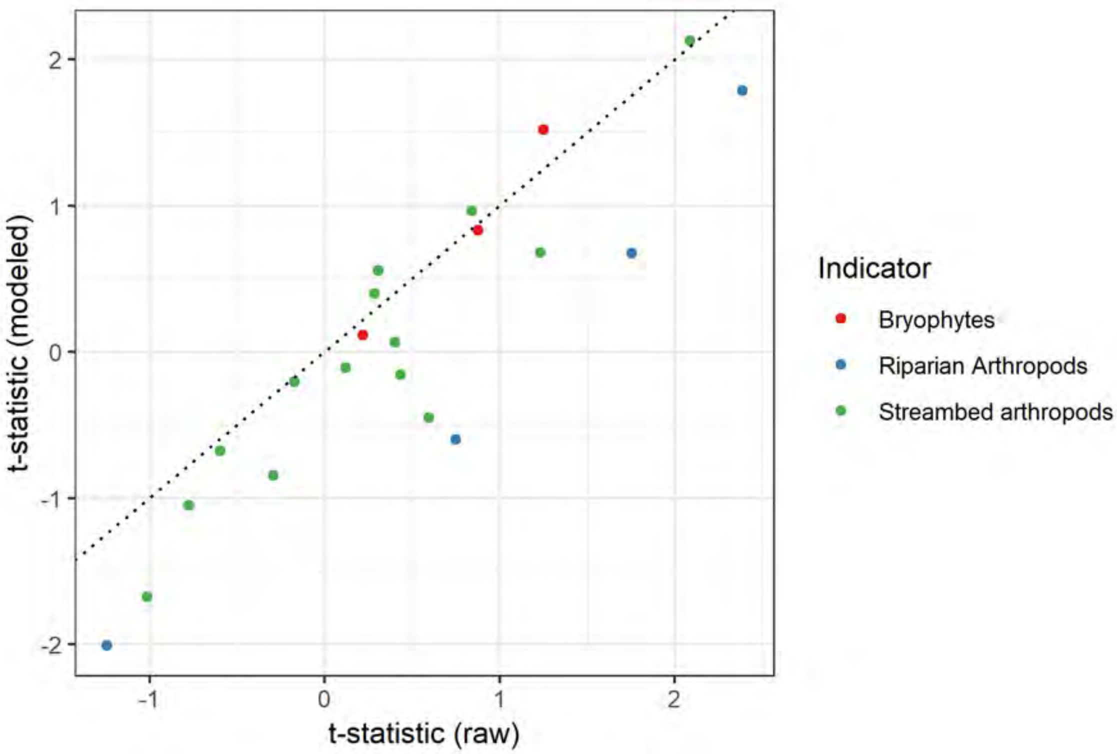

Figure 8. Relationship between t-statistics calculated from raw and modeled metric. The dotted line indicates where both approaches yield similar t-statistics. Only metrics that could be predicted with pseudo R^2 > 0.1 are shown.

Physical habitat stress

Of the 28 physical habitat metrics evaluated, 9 had a significant ($p < 0.1$) response to reference status, excluding the measure of local activity, which was used to determine reference status (Figure 9). Many of these metrics related to slope, indicating the predominance of reference sites among high-gradient regions of steep topography. Bank width was significantly smaller at reference sites, likely due to the same factor. Several substrate metrics, such as % fines and cobble embeddedness, showed that sediment deposition may be elevated at the non-reference sites in the study area. However, the aforementioned differences in slope may provide another reason for differences in streambed substrate composition.

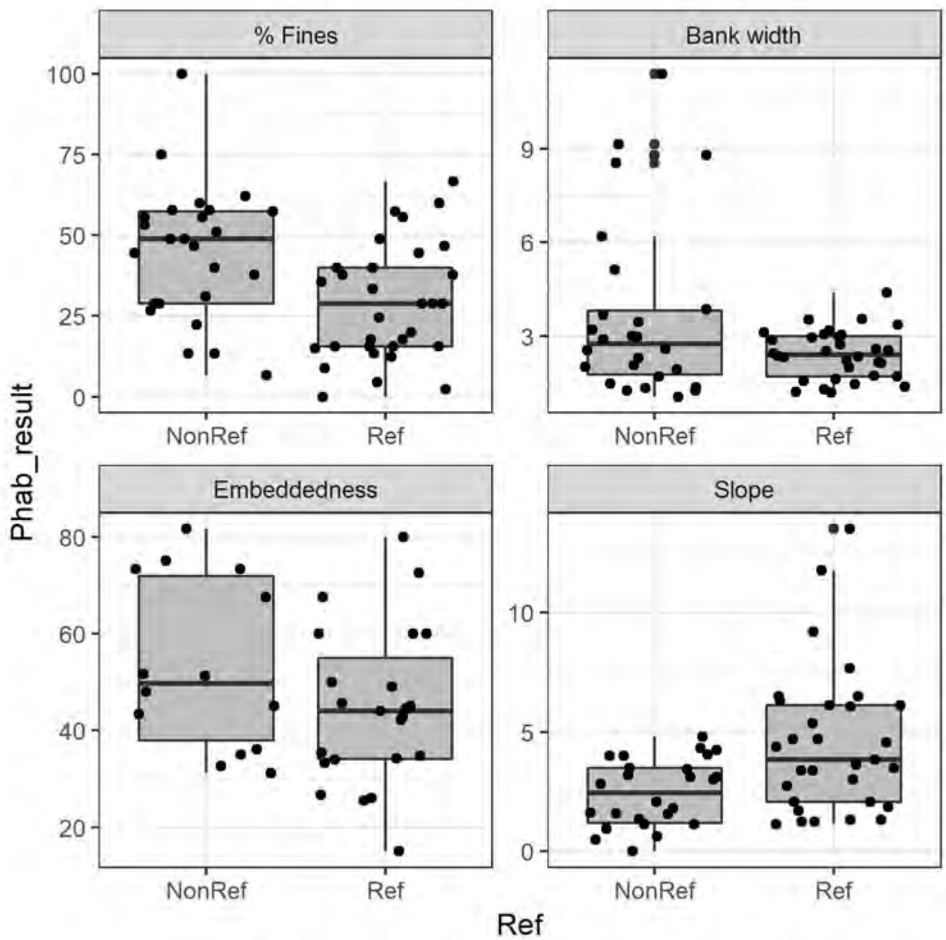

Figure 9. Distributions of selected habitat metrics at reference and non-reference sites.

Several habitat metrics shows strong positive or negative relationships with biological metrics (Figure 10). For example, relative ant richness declined as local activity increased (Spearman's rho: -0.28). In general, bryophytes showed weaker habitat relationships than the arthropod metrics. The strongest relationships were with slope, although substrate composition and human activity metrics were also among the strongest relationships observed. Many biological metrics showed wedge-shaped relationships with habitat metrics, suggesting that multiple factors may account for biological metric values. Both negative (e.g., top-left and bottom-right panels in Figure 11) and positive (e.g., top-right panel in Figure 11) relationships were common, although positive relationships tended to be stronger (Figure 10). However, a few showed a linear relationship, such as % fines in the streambed with the log abundance of riparian arthropods (top right panel in Figure 11).

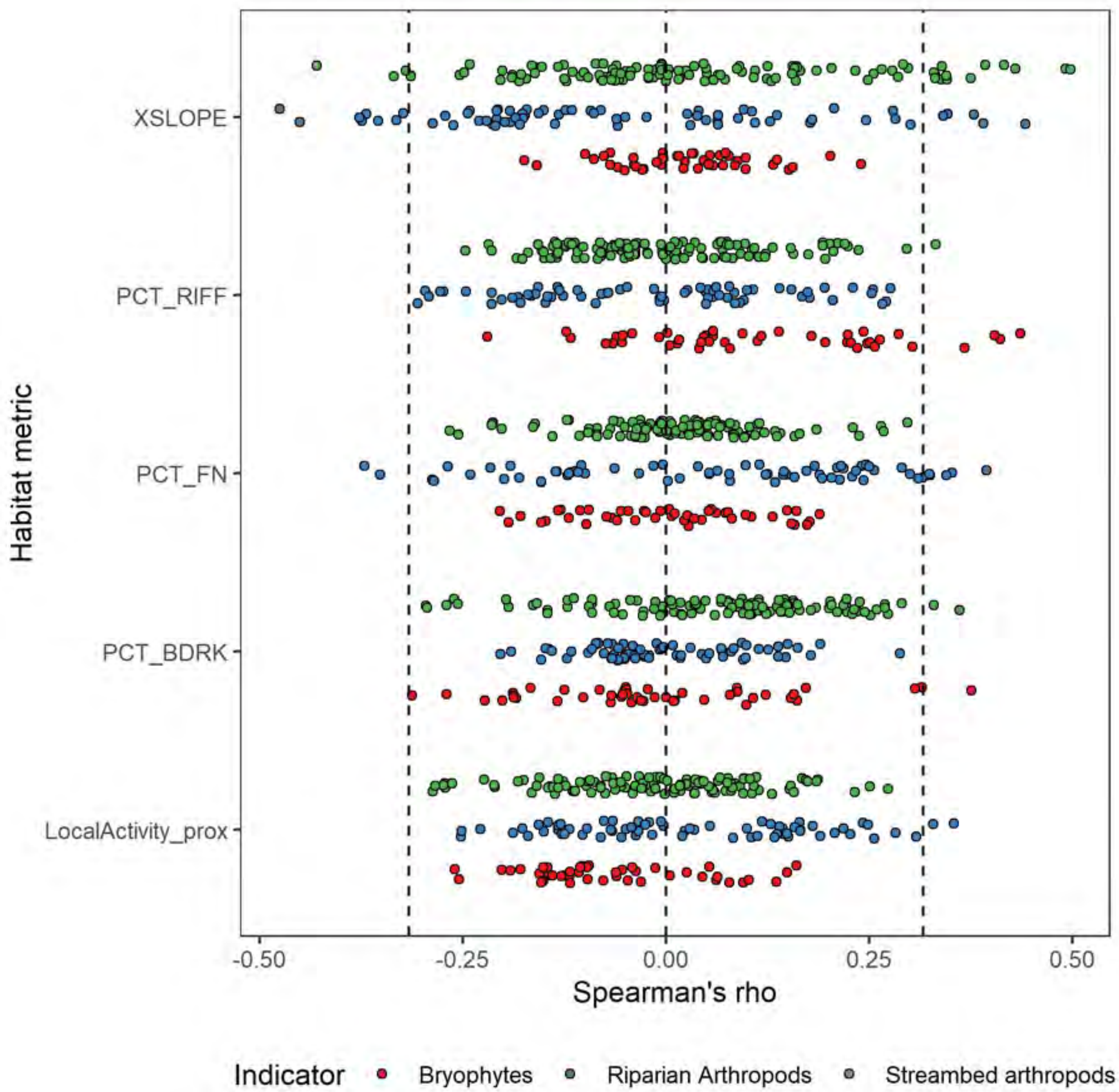

Figure 10. Spearman rho values between biological metrics and selected habitat metrics. Dashed lines indicate boundaries of "strong" correlations (i.e., $rho^2 > 0.1$).

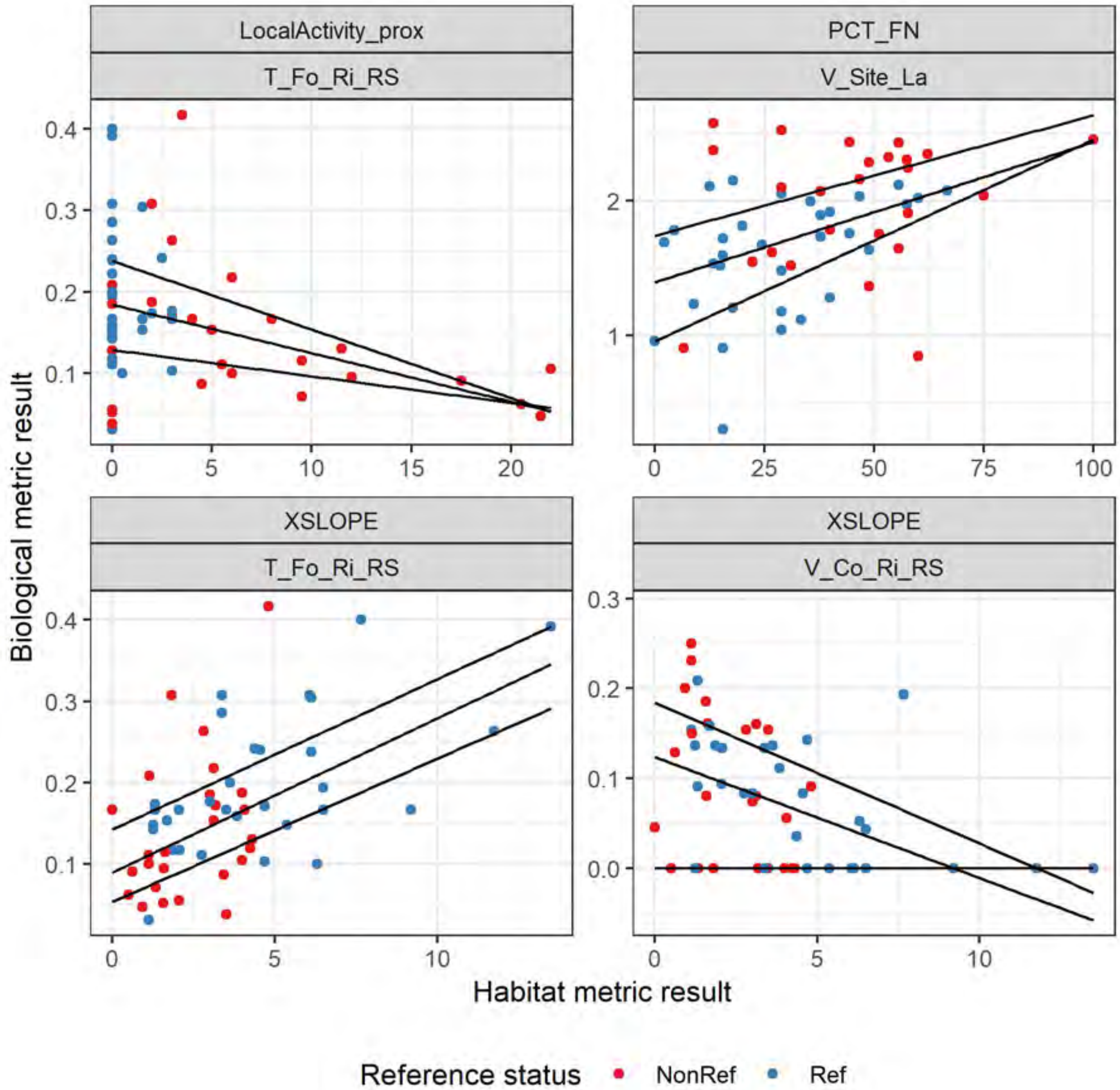

Figure 11. Relationships between selected habitat metrics and biological metrics. The black lines show quantile regressions at the 25th, 50th, and 75th percentiles. T_Fo_Ri_RS: Relative streambed ant richness. V_Site_La: Log abundance of streambed arthropods. V_Co_Ri_RS: Relative richness of riparian beetles.

Landscape stress

Although most landscape measures of stress had relatively weak relationships with biological metrics (comparable to habitat metrics), watershed imperviousness and, to a lesser extent, urbanization, stood out as having strong relationships with several biological metrics (Figure 12). This result suggests that hydrologic alteration may be an important factor in determining the ecological condition of dry streambeds. Most metrics showed a negative response, although some (e.g., log abundance of earwigs in the streambed, Figure 13) increased in response to greater imperviousness.

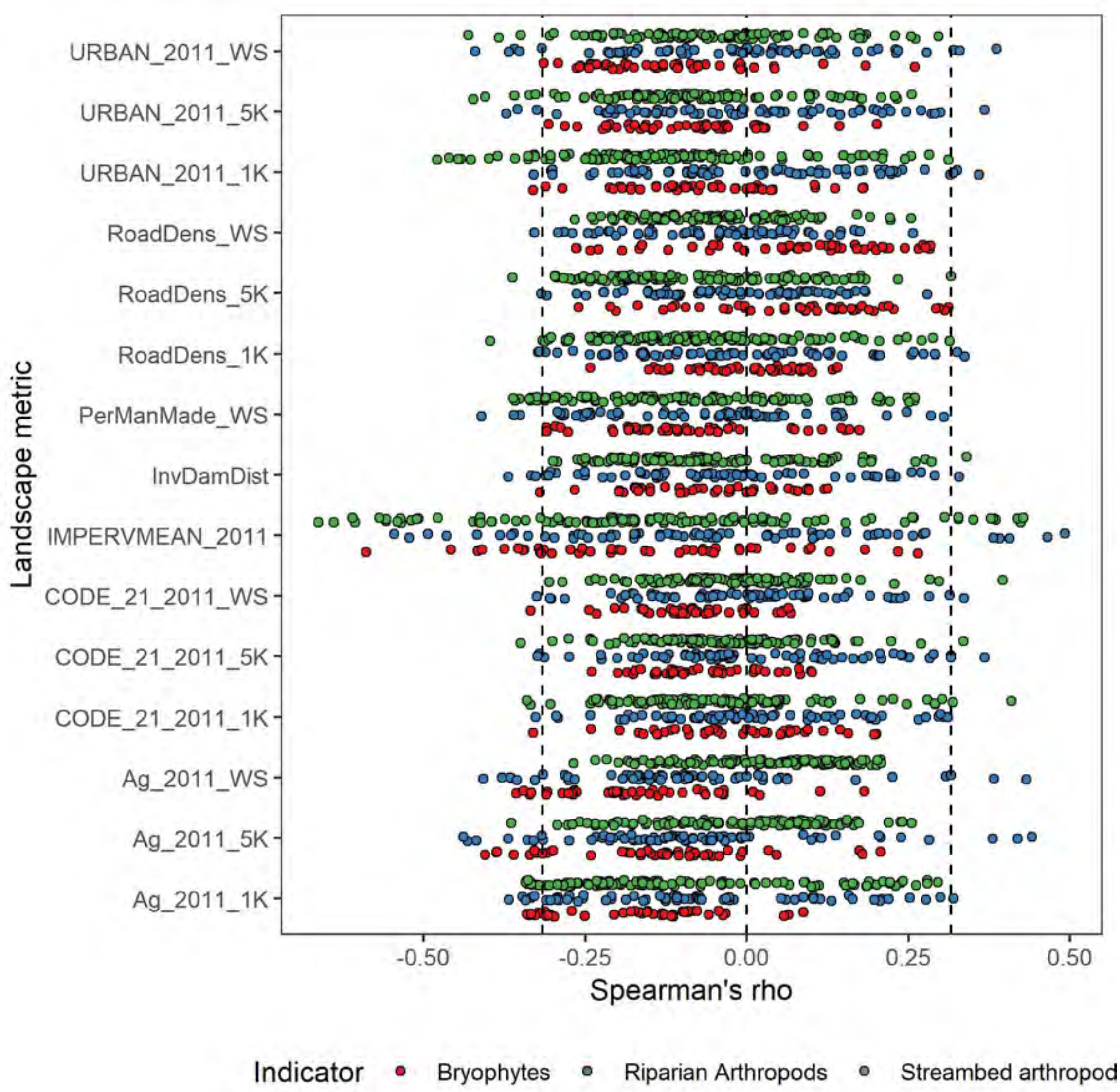

Figure 12. Spearman rho values between biological metrics and selected landscape metrics. Dashed lines indicate boundaries of "strong" correlations (i.e., rho2 > 0.1).

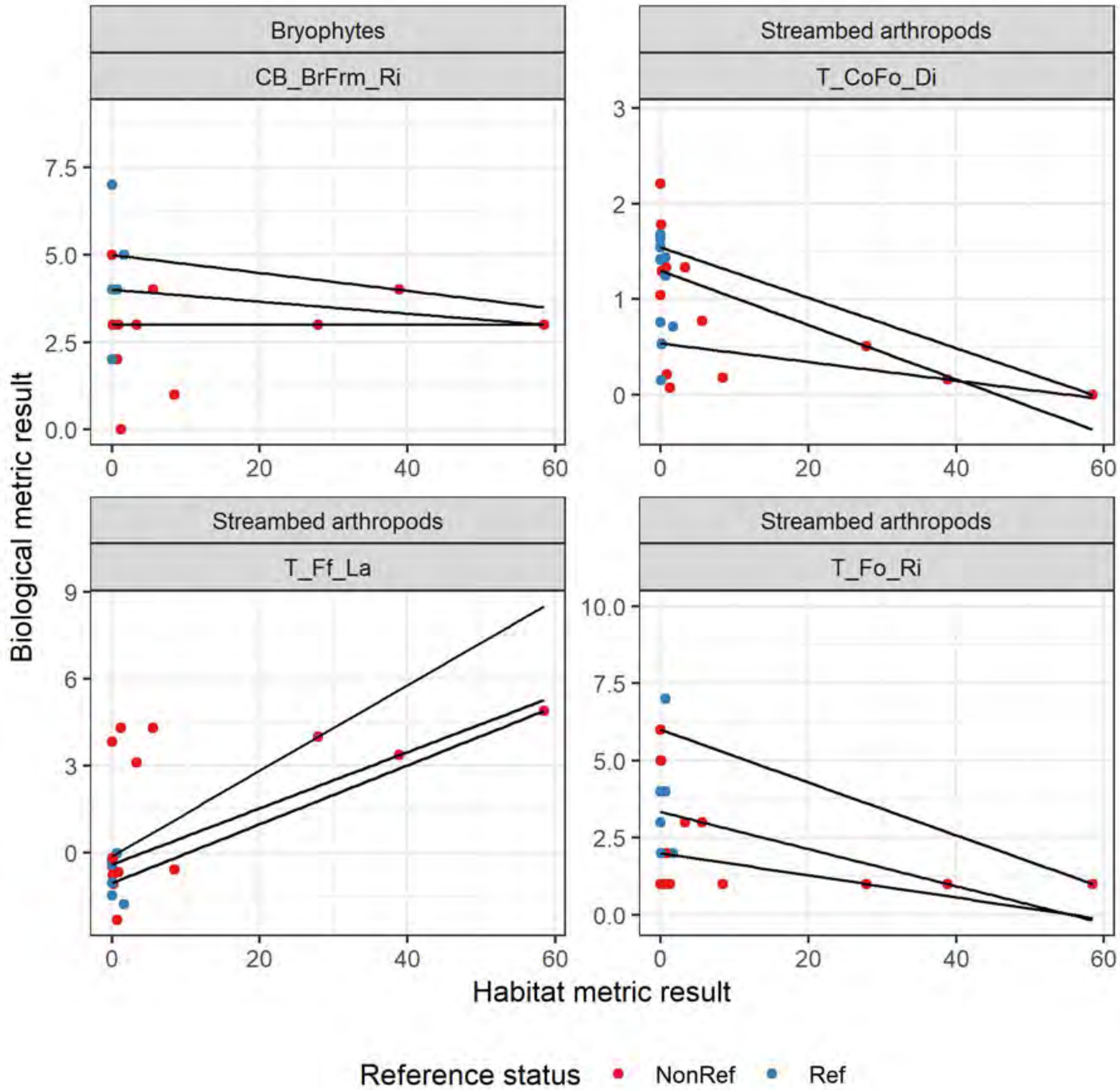

Figure 13. Relationships between selected landscape metrics and biological metrics. The black lines show quantile regressions at the 25th, 50th, and 75th percentiles. CB_BrFrm_Ri: Richness of bryophyte families on the banks and in the channel. T_Ff_La: Log abundance of streambed earwigs. T_CoFo_Di: Diversity of ants and beetles in the streambed. T_Fo_Ri: Streambed ant richness.

Provisional multimetric indices

A total of 4 bryophyte metrics, 12 riparian arthropod metrics, and 8 streambed arthropod metrics met all screening criteria for including metrics in provisional indices (Table 8). Responsiveness was one of the more restrictive criteria, eliminating 91% of bryophyte metrics, 63% of riparian arthropod metrics, and 85% of streambed arthropod metrics; however, 75% of riparian arthropod metrics did not meet consistency criterion. Several of the best-performing metrics were closely related to each other, either in terms of empirical correlation (e.g., high r^2) or close thematic relationships (e.g., beetle and ant diversity vs. beetle, ant and spider diversity; Figure 14). Based on the observed responsiveness and potential redundancy among these best-performing metrics, 4 metrics were selected for a SA-DSCI, and 5 were selected for a RA-DSCI. Too few non-redundant bryophyte metrics met screening criteria to develop a BRY-DSCI, but two metrics were included in a 6-metric MI-DSCI (Table 8). Scoring of these metrics yielded mean reference scores of 0.637 (SA-DSCI), 0.581 (RA-DSCI), and 0.681 (MI-DSCI); these numbers were used to standardize all index scores so that sites in reference condition are expected to have a value of 1. All scores are provided in a table in the Appendix.

Although each index had a distinct set of strengths, the multi-indicator index was overall the best due to its precision, which translated into high responsiveness in terms of discriminating between reference and non-reference sites (Table 9). Examination of boxplots showed very little overlap in scores at reference and non-reference sites for this index, compared to the considerable overlap observed for SA-DSCI (Figure 15).

Application of thresholds (Table 10) showed that the MI-DSCI was the most sensitive, as it identified the greatest number of sites in the lower condition-classes (Table 11, Figure 15). In contrast, RA-DSCI never designated any site as very likely altered — an expected outcome of this index's low precision (and consequent low threshold). For all indices, better-condition sites were clustered to the interior and less-developed coastal portions of the region (Figure 17). Index scores showed relatively strong relationships with measures of habitat and landscape alteration (Figure 18). Scores for all indices declined at grazed sites relative to reference sites—and relative to ungrazed non-reference sites, in the case of RA-DSCI (Figure 19).

Table 8. Summary of metrics selected for dry stream condition indices (DSCI). Dir: Direction of response: D: Decreaser. I: Increaser. |t|: Absolute value of t-statistic comparing means at reference and non-refence sites. Underlined text indicates metrics that were selected for inclusion in an indicator-specific DSCI. Bold text indicates metrics that were selected for a combined, multi-indicator DSCI. Italic text indicates metrics that are modeled to account for natural variability. Gray highlighted cells indicate responsiveness measures that account for the metric's inclusion among the best-performing metrics.

Metric	Description	Dir	Unique values	% zero values	Consistency	Responsiveness |t|	Responsiveness Habitat	Responsiveness Landscape
Streambed arthropods								
T_CoFo_Ri	Beetle and ant richness	D	16		0.51	0.60	0.02	0.37
T_He_Ab_RS	True bug relative abundance	I	56		0.55	2.09	0.00	0.08
T_Ah_Ab_RS	Bristletail relative abundance	D	56		0.51	0.80	0.07	0.29
T_Ff_La	Earwig log abundance	I	8		0.35	2.13	0.07	0.18
T_Site_Di	Arthropod diversity	D	59	3	0.38	0.07	0.01	0.29
T_CoFo_Di	Beetle and ant diversity	D	59	2	0.49	0.48	0.01	0.44
T_FoAr_Di	Ant and spider diversity	D	60		0.44	0.64	0.00	0.29
T_CoFoAr_Di	Beetle, ant, and spider diversity	D	60		0.53	0.27	0.00	0.32
Riparian Arthropods								
V_Site_La	Arthropod log abundance	I	57		0.43	3.11	0.16	0.15
V_Fo_Ab_RS	Ant relative abundance	D	60		0.41	0.02	0.06	0.22
V_Ar_Ab_RS	Spider relative abundance	D	60		0.55	2.67	0.08	0.30
V_FoAr_Ri_RS	Ant and spider relative richness	D	41		0.27	2.41	0.14	0.03
V_CoAr_Ab_RS	Beetle and spider relative abundance	D	60		0.63	2.38	0.07	0.27
V_FoAr_Ab_RS	Beetlae and spider relative abundance	D	60		0.28	2.46	0.02	0.00
V_CoFoAr_Ab_RS	Beetle, ant, and spider relative abundance	D	60		0.36	2.27	0.01	0.00
V_Ot_Ri	Other arthropod richness	I	21	2	0.33	2.19	0.10	0.01
V_ot_Ab_RS	Other arthropod relative abundance	I	60		0.26	1.79	0.00	0.00
V_He_La	True bug log abundance	I	42		0.47	3.11	0.08	0.08
V_He_Ri	True bug richness	I	14	7	0.42	2.19	0.06	0.00
V_Site_Ev	Arthropod evenness	D	59		0.62	2.61	0.08	0.22

Bryophytes								
CB_BrFrm_Ri	Bryophyte family richness	D	10	3	0.73	0.33	0.04	0.35
B_BrFm_Ri	Bryophyte family richness on banks	D	8	5	0.83	0.38	0.02	0.21
C_Po_Ri	Pottiaceae richness in channel	I	8	38	0.72	1.68	0.04	0.06
C_Po_Ri_RS	Pottiaceae relative richness in channel	I	29	38	0.68	2.08	0.02	0.04

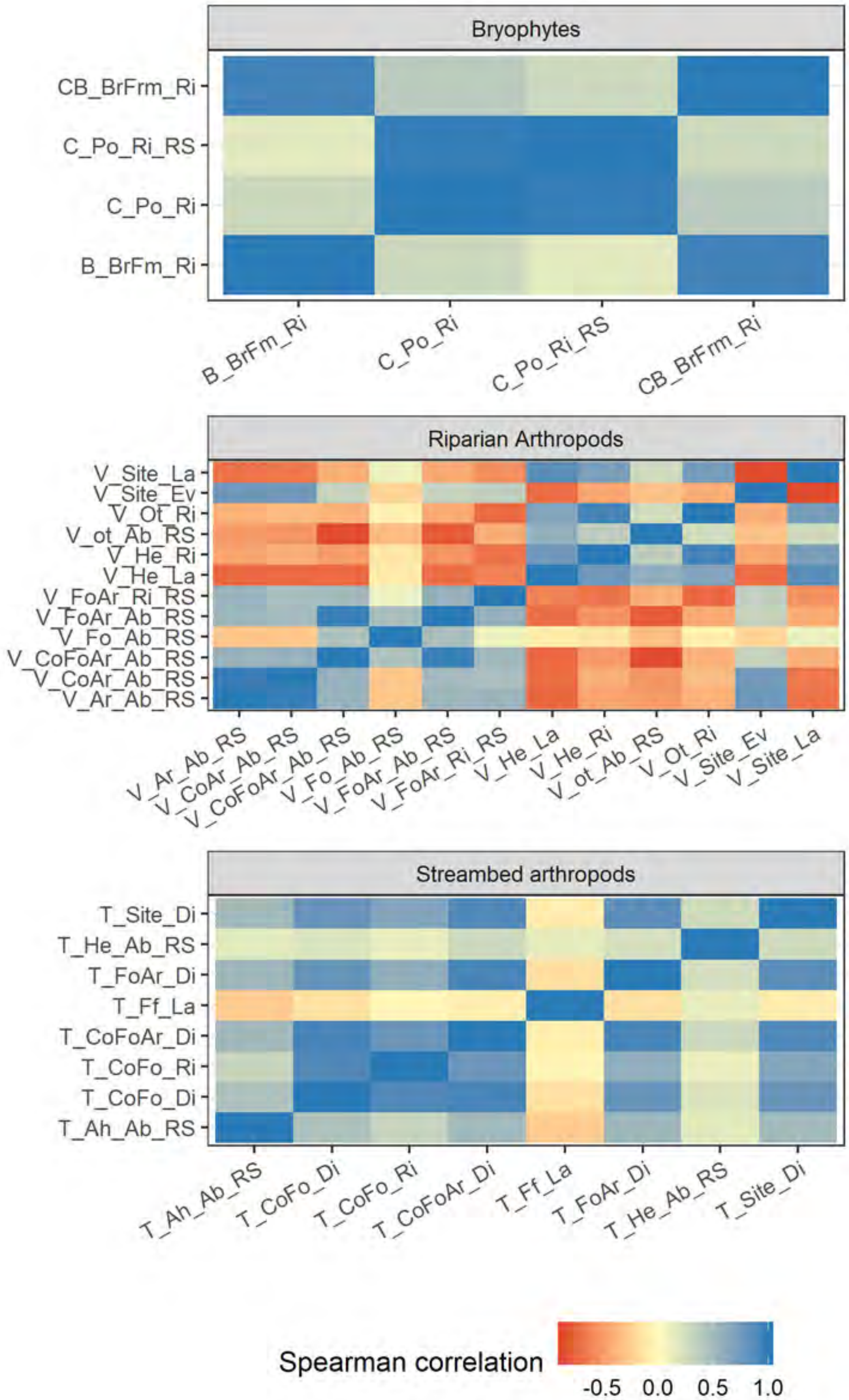

Figure 14. Pearson correlations between best-performing metrics for each indicator group.

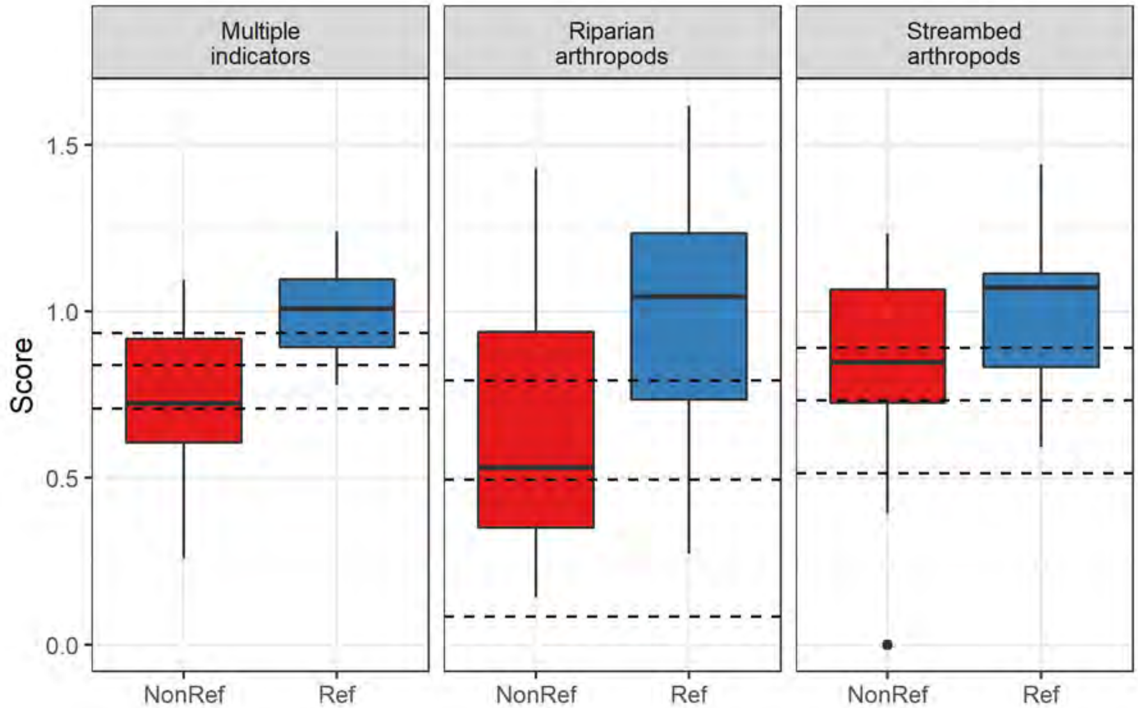

Figure 15. Distribution of index scores at reference and non-reference sites. Dashed lines indicate the three thresholds for designating condition-classes. MI: Multi-indicator DSCI. RA: Riparian arthropod DSCI. SA: Streambed arthropod DSCI.

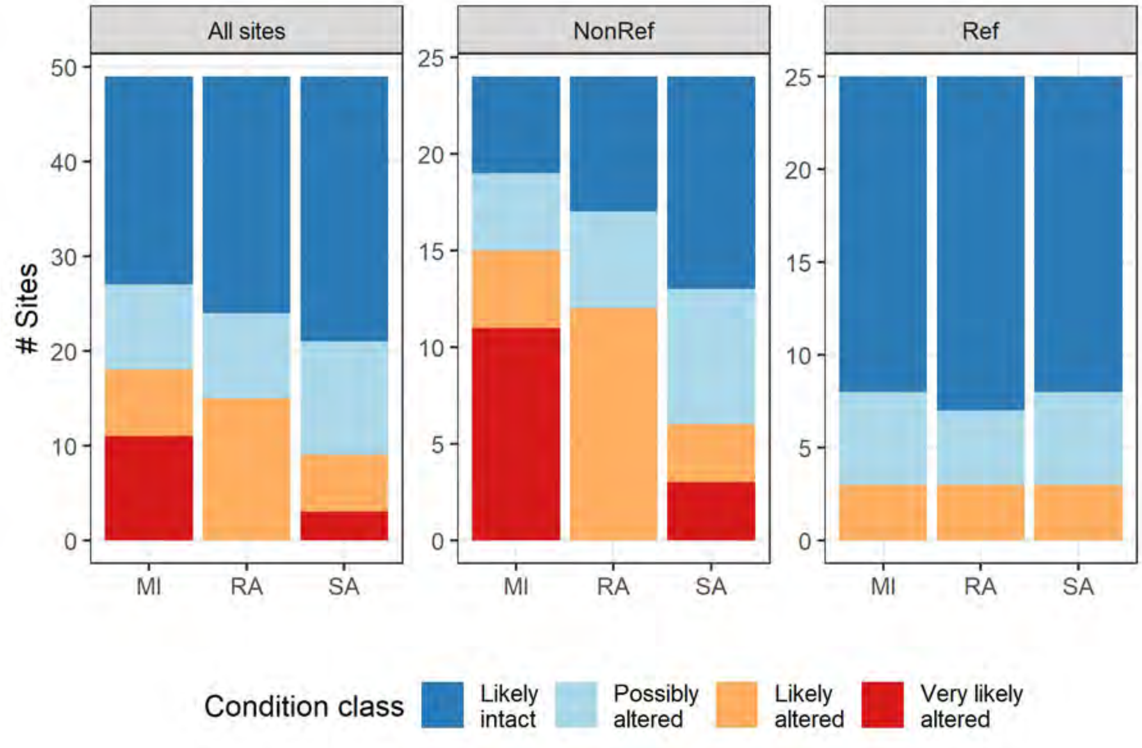

Figure 16. Distribution of sites in each condition class.

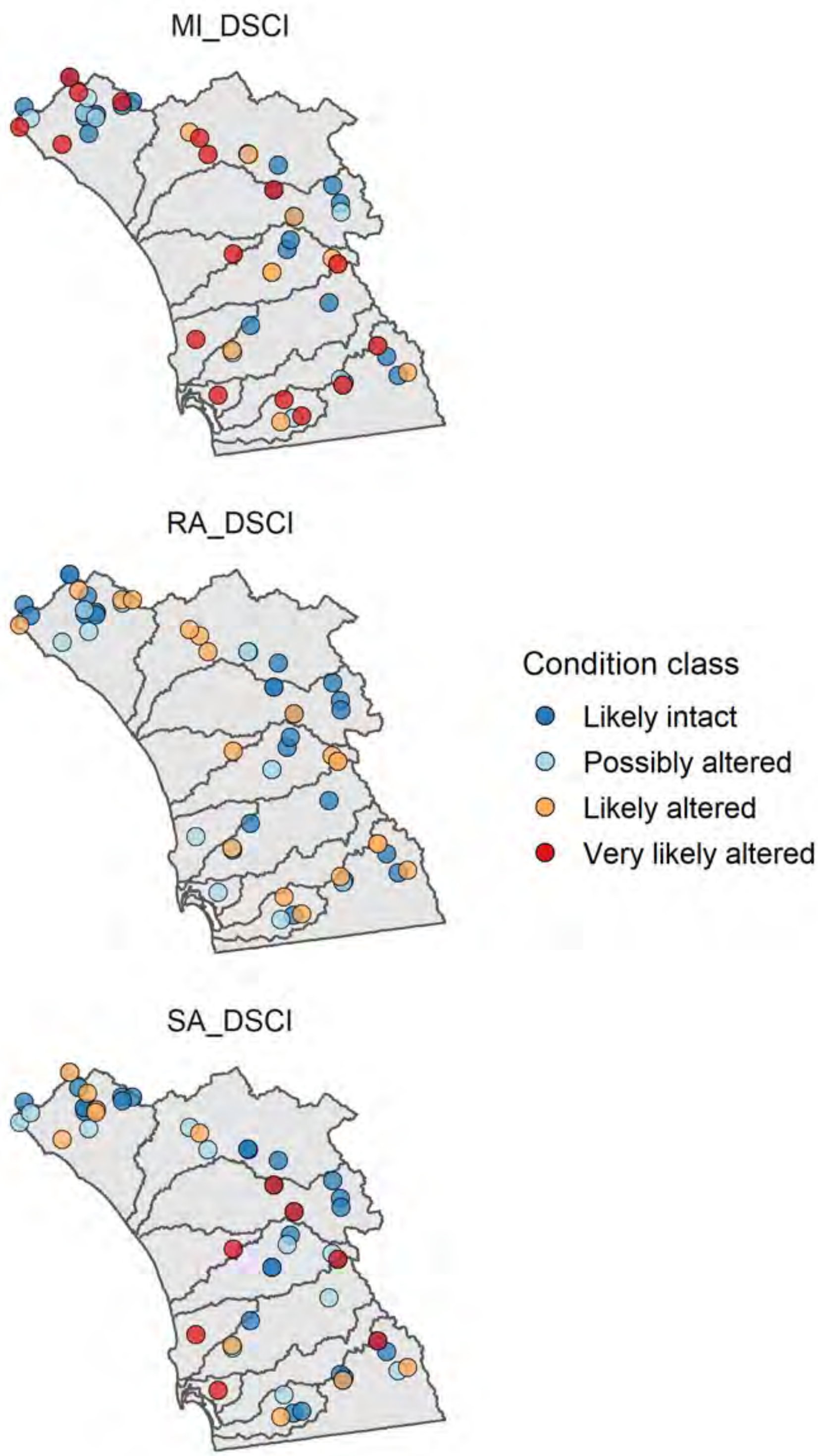

Figure 17. Maps of sites in each condition class for each index.

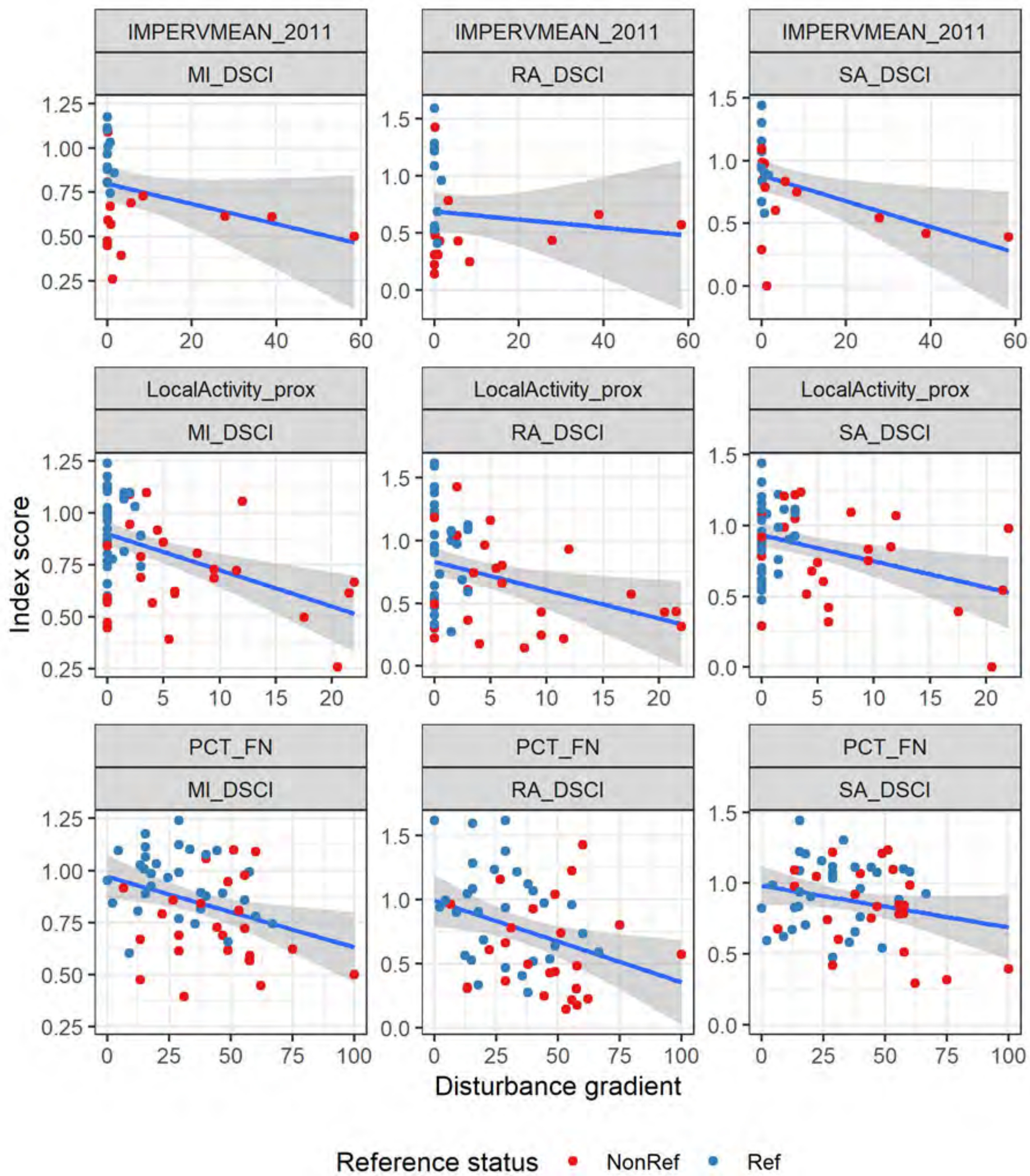

Figure 18. Relationships between landscape disturbance and index scores. Blue lines represent a linear fit.

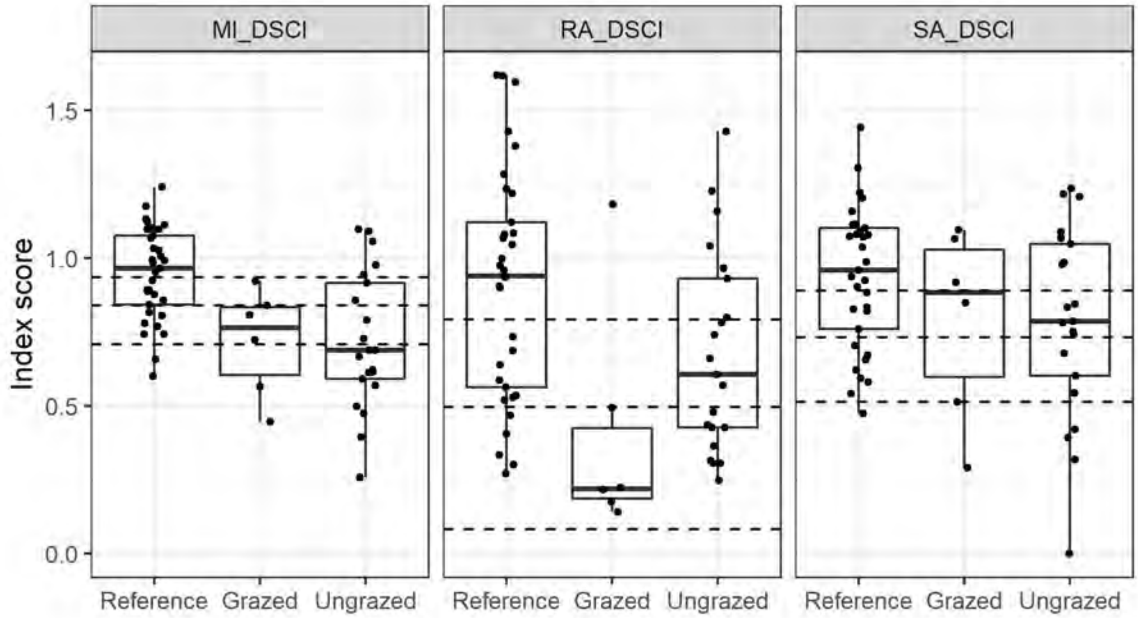

Figure 19. Index scores at reference sites, grazed sites, and ungrazed non-reference sites.

Table 9. Index performance measures. Lower numbers are better for precision and bias; otherwise, higher numbers indicate better performance.

	Precision	Bias	Consistency	Responsiveness	
Index	SD at ref sites	Pseudo R^2	Pearson's r	t-statistic	Pseudo R^2
SA_DSCI	0.21	-0.06	0.57	2.19	0.33
RA_DSCI	0.39	0.00	0.75	3.28	0.27
MI_DSCI	0.13	-0.24	0.69	5.01	0.22

Table 10. Minimum scores to designate sites as likely intact, possibly altered, or likely altered. Sites with scores below the lowest threshold are designated very likely altered.

	Minimum score		
Index	Likely intact	Possibly altered	Likely altered
SA_DSCI	0.89	0.73	0.51
RA_DSCI	0.79	0.50	0.08
MI_DSCI	0.93	0.84	0.71

Table 11. Number of sites in each condition-class.

Index	Likely intact	Possibly altered	Likely altered	Very likely altered
SA_DSCI				
All sites	28	12	6	3
Ref	17	5	3	0
NonRef	11	7	3	3
RA_DSCI				
All sites	25	9	15	0
Ref	18	4	3	0
NonRef	7	5	12	0
MI_DSCI				
All sites	22	9	7	11
Ref	17	5	3	0
NonRef	5	4	4	11

Discussion

We were able to create multiple provisional indices to quantitatively measure condition in dry intermittent and ephemeral streams, proving the feasibility of including these streams in watershed management programs. Once finalized and validated, an assessment index for dry streams will fulfill a major gap in regulatory programs of the San Diego region. A few steps are needed to reach the stage where intermittent and ephemeral streams can be fully integrated in these programs.

The indices require validation with independent data, particularly at reference sites that represent the full range of conditions where the index may be applied. Validation activities should also assess inter- and intra-annual variability to fully assess the precision and repeatability of these assessments. Greater taxonomic resolution may also improve observed strength of metric-stressor relationships, as multiple species within the same families may exhibit different responses to the same stressor.

These analyses were based on the best taxonomic data available at the time, which in general was family or genus level, with morphospecies identified to provide additional resolution. It is likely that additional information may be gained with greater taxonomic effort, which would allow incorporation of available life-history information (Steward et al. 2018, Stubbington et al. 2019). For example, non-native Argentine ants (Formicidae: *Linepithema humile*) may be more common in ephemeral streams that receive urban runoff than in natural ephemeral streams due to the soil moisture preferences of this species (Holway 1998b, Menke et al. 2007). Because our study was limited to morphospecies, we are unable to tell if we are observing this pattern in the San Diego region. Trait-based efforts have been productive for bioassessment applications in perennial streams, and would likely apply here as well. Molecular methods (e.g., DNA barcoding) may also enhance our ability to generate highly resolved taxonomic data for these biological indicators.

To identify reference sites, we followed the approach of Ode et al. (2016), which set criteria for identifying reference-quality perennial and intermittent streams in California (which are generally higher-order than some of the ephemeral headwaters included in this study). It remains unknown if the criteria identified there are meaningful for the indicators we studied. Ode et al. (2016) emphasized screens based on measures of human activity in the upstream watershed (e.g., urban development) under the assumption that these activities can impact in-stream communities. The low frequency of flow in some of our intermittent and ephemeral sites may decouple or weaken the links between upstream disturbance and condition at a site, which may account for the relatively weak relationships we observed between metric scores or the MMI and land use. A reference definition that incorporates locally measured stressors and human activity, covering both habitat and water or sediment quality, should be considered. Our use of a "proximity of local activity" metric represents a first-cut approach to incorporating local information in defining reference sites.

The best index incorporates metrics representing all three biological indicators, and is therefore comparable to hybrid algal indices developed for southern California (Fetscher et al. 2014, Theroux et al. in review). Our motivation to create a multi-indicator index was largely driven by the low number of responsive metrics in any single assemblage. In addition, multi-indicator indices incorporate a greater diversity of lines of evidence when assessing condition, leading to a more complete picture, as well as superior index performance. However, practical concerns may make single-indicator indices (which require less sampling and analysis effort) desirable, and these should be explored in the future, despite their potentially weaker performance.

Our ability to quantify human stressors across the sites we sampled in Southern California is limited by the lack of data on several important stressors like hydrological alterations caused by groundwater extraction or the effects of cattle grazing. This limited our ability to successfully develop a single combined gradient that would allow us to parse reference from non-reference sites, or to evaluate fine-scale gradients of condition within non-reference sites. Because of this, the majority of metrics that correlated well with human activity did not show a consistent response to the stressor gradients we examined.

Our understanding of the mechanisms driving biological responses to disturbance in dry streams is also limited. We can speculate why some metrics increase with stress whereas others decrease, but a better understanding of how upstream stressors affect local channel environments and how this translates into changes in local biota of dry streams is needed. For this reason, our study and its implications for management may be limited by our binary classification of sites (e.g., reference or non-reference) which limits the resolution needed to make direct links between individual stressors and metric responses. Although we were able to show evidence that four of our metrics were likely affected by human land use, we do not know the drivers (e.g., increased runoff, increased sedimentation, water extraction, pollution) associated with developed land use that underlie this relationship. Other factors including the intensity of disturbance, duration of the disturbance, interactions between disturbances and differences among sites (e.g., hydrologic regime, topography, geomorphology) may also play roles in determining how terrestrial biota respond to human disturbance. More quantitative methods of evaluating certain impacts (e.g., using wildlife cameras to measure grazing intensity) may elucidate these relationships.

Although we have demonstrated the feasibility of assessing dry intermittent and ephemeral streams, further work still needs to be done to better understand the community dynamics and complex biotic and abiotic interactions that exist in the dry channels of nonperennial streams, which would give managers better confidence for incorporating these tools in their monitoring programs. Future studies should focus on developing and testing the causal mechanisms driving biological responses to better understand the direct effects of human disturbance on terrestrial dry stream communities.

Riparian conditions in dry ephemeral and intermittent streams in the San Diego region: Results from an "L2" assessment

Introduction

The Episodic Riverine module of the California Rapid Assessment Method (CRAM; CWMW 2013) was developed in recent years as a rapid, "level 2" (L2) tool for assessing wetland structure and function. However, it remains only weakly validated. For example, it's unknown how well CRAM assessments represent measures of condition derived from more intensive "level 3" (L3) measures, such as those based on biodiversity surveys. This study represents a first step in validating CRAM.

Methods

To evaluate the validity of the episodic CRAM module in San Diego ephemeral streams, we conducted CRAM assessments alongside L3 assessments described in the previous sections (n = 44 at time of analysis; 20 of these were reference sites). We evaluated correlations between CRAM scores (both overall and attribute scores) against all biological response metrics (described in Table 5), plus the multimetric index (MMI) mentioned above. Response metrics that had a strong relationship (positive or negative) with CRAM scores suggests good validation; moderate relationships were identified as those with an absolute rho value from a Spearman correlation > 0.1, and strong relationships were those with rho > 0.3. For the MMI, only positive relationships with CRAM scores were considered to validate CRAM.

Results

CRAM scores at reference sites were only somewhat higher than non-reference sites, suggesting that the study did not capture a large gradient of conditions (Table 12, Figure 20). However, the overall score, plus scores for the Buffer and Landscape, plus the Hydrology attributes, were significantly lower at non-reference sites. In contrast, Biotic Attribute scores were essentially identical in the two groups of sites.

Table 12. CRAM index and attribute scores at reference and non-reference sites.

	Mean			
	Reference	Non-reference	t	p
Overall AA Score	89.0	82.9	2.17	0.04
Buffer and Landscape Connectivity	97.7	89.1	2.52	0.02
Hydrology	93.8	86.4	2.43	0.02
Physical Structure	76.3	68.8	1.23	0.23
Biotic Structure	88.1	88.1	-0.01	1.00

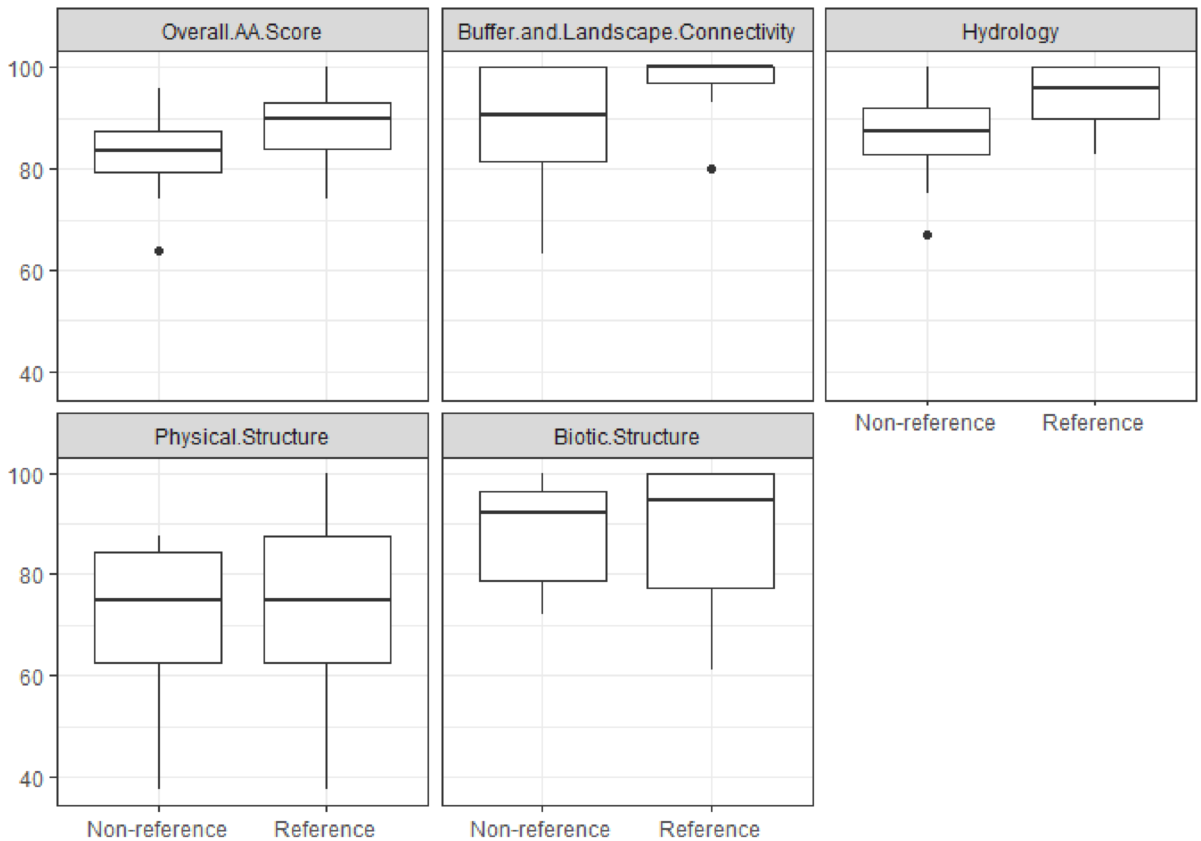

Figure 20. Distribution of CRAM index and attribute scores at reference and non-reference sites.

Correlations with L3 response metrics

Of the 230 evaluated L3 metrics, 70% had a moderate or strong (i.e., absolute rho > 0.1) relationship with the biotic structure attribute — more than for any other attribute. In contrast, only 47% had a moderate or strong relationship with the physical structure attribute (Table 13, Figure 21). In some cases (e.g., biotic structure attribute score versus Shannon diversity of Coleoptera and spiders), diversity increased with higher CRAM scores (Figure 22). However, the opposite trend was common, too (e.g., hydrology attribute score versus Shannon diversity of Coleoptera). Several metrics related to bryophyte richness declined with higher CRAM index or attribute scores.

Each L3 assemblage appeared to capture different aspects of stream condition, reflected in patterns in the frequency of strong relationships between response metrics and each CRAM attribute (Table 13, Figure 23 to Figure 26). For example, strong relationships the buffer and landscape attribute were largely restricted to riparian arthropod metrics, whereas only bryophyte metrics showed a strong response to the physical structure metric. The hydrology and biotic structure attributes had strong relationships with several bryophyte and streambed arthropod metrics, in contrast to no or few riparian arthropod metrics.

Table 13. L3 metrics with strong relationships with CRAM index and attribute scores.

	Percent of metrics			
Overall AA Score	Rho > 0.1	Rho > 0.3	Strongest metric	Rho
Bryophytes (N=45)	56	0	Relative richness of Bryaceae on the banks	-0.26
Riparian arthropods (N=68)	52	7	Ant and spider evenness	-0.38
Streambed arthropods (N=117)	43	1	Log abundance of mites	-0.30
Buffer and Landscape Connectivity				
Bryophytes	49	0	Relative richness of Bryaceae	-0.29
Riparian arthropods	54	4	Relative abundance of spiders	0.36
Streambed arthropods	64	2	Relative abundance of earwigs	-0.32
Hydrology				
Bryophytes	67	13	Relative richness of bryophyte families in the channel	-0.45
Riparian arthropods	49	3	Hymenoptera richness	-0.35
Streambed arthropods	74	25	Richness of fungivore and dead wood detritovore beetles	-0.56
Physical Structure				
Bryophytes	58	4	Relative richness of Pleurocarps on the banks	0.37
Riparian arthropods	52	0	Relative abundance of flies	-0.27
Streambed arthropods	40	1	Log abundance of mites	-0.39
Biotic Structure				
Bryophytes	64	22	Pleurocarp richness in the channel	0.36
Riparian arthropods	62	7	Ant and spider evenness	-0.42
Streambed arthropods	78	23	Spider diversity	0.47

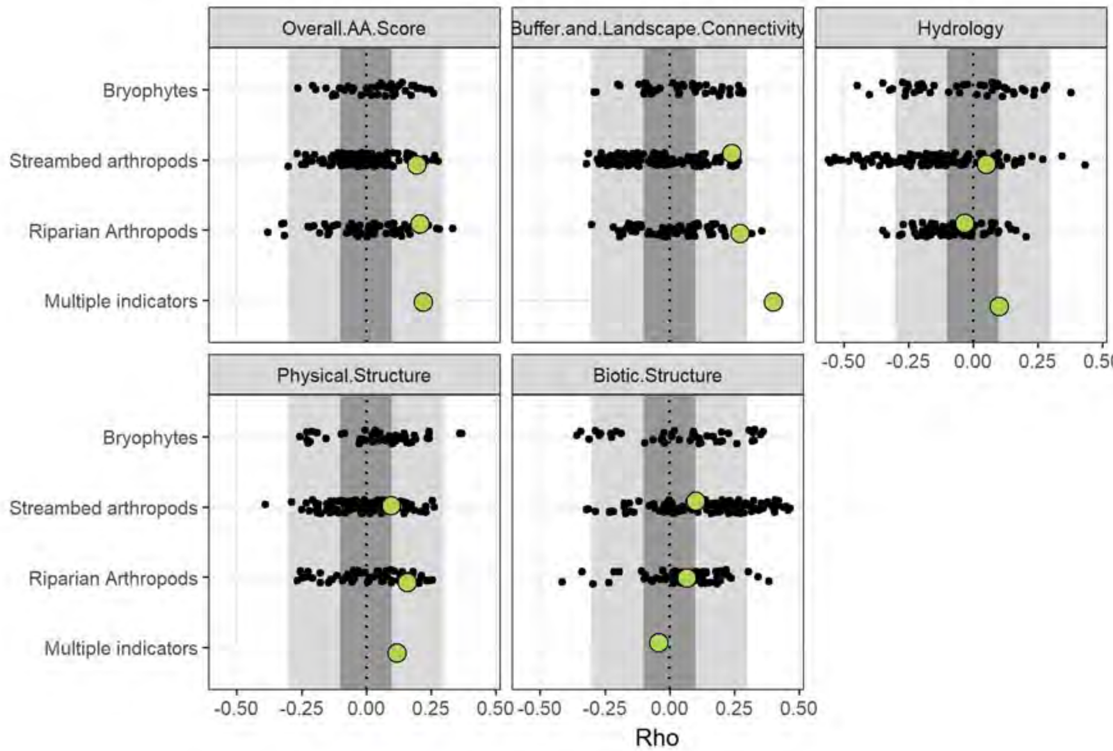

Figure 21. Spearman rho correlations between L3 bioassessment metrics and CRAM index or attribute scores; each point represents a single L3 metric. The green dots indicate the correlation with the DSCIs. The gray band indicates the region of weak and moderate correlations.

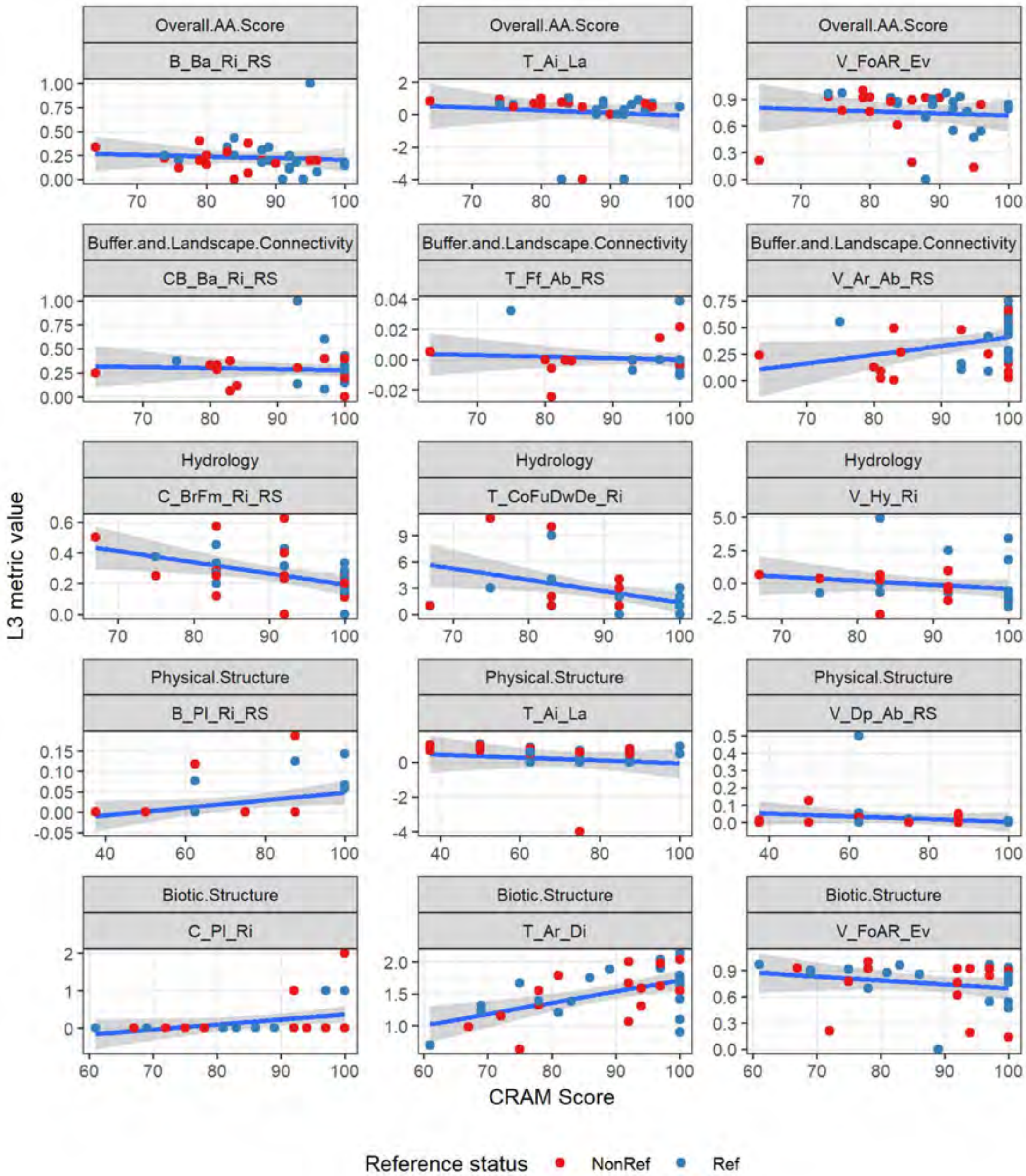

Figure 22. Relationships between selected L3 bioassessment metrics and CRAM index or attribute scores. The blue lines indicate a linear fit. Only the strongest relationships within each assemblage and attribute (indicated in Table 13) are shown. B_BA_Ri_RS: Relative richness of Bryaceae on the banks. T_Ai_La: Log abundance of mites. V_FoAr_Ev: Evenness of ants and spiders. CB_Ba_Ri_RS: Relative richness of Bryaceae. T_Ff_Ab_RS: Relative abundance of earwigs. V_Ar_Ab_RS: Relative abundance of spiders. C_BrFm_Ri_RS: Relative richness of Bryophyte families in the channel. T_CoFuDwDe_Ri: Richness of fungivore and dead wood detritovore beetles. V_Hy_Ri: Richness of hymenoptera. B_Pl_Ri_Rs: Relative richness of Pleurocarps on the bank. V_Dp_Ab_RS: Relative abundance of flies. C_Pl_Ri: Richness of Pleurocarps in the channel. T_Ar_Di: Diversity of spiders.

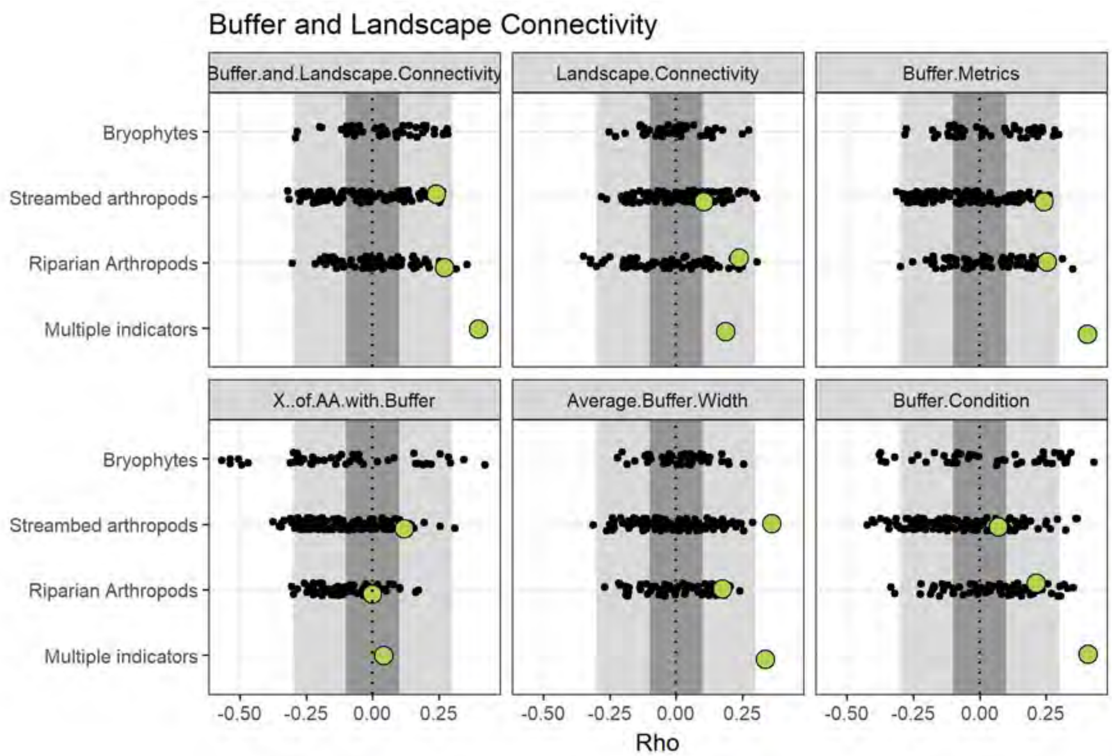

Figure 23. Spearman rho correlations between L3 bioassessment metrics and CRAM buffer and landscape metrics; each point represents a single L3 metric. The green dots indicate the correlation with the DSCIs. The gray band indicates the region of weak and moderate correlations.

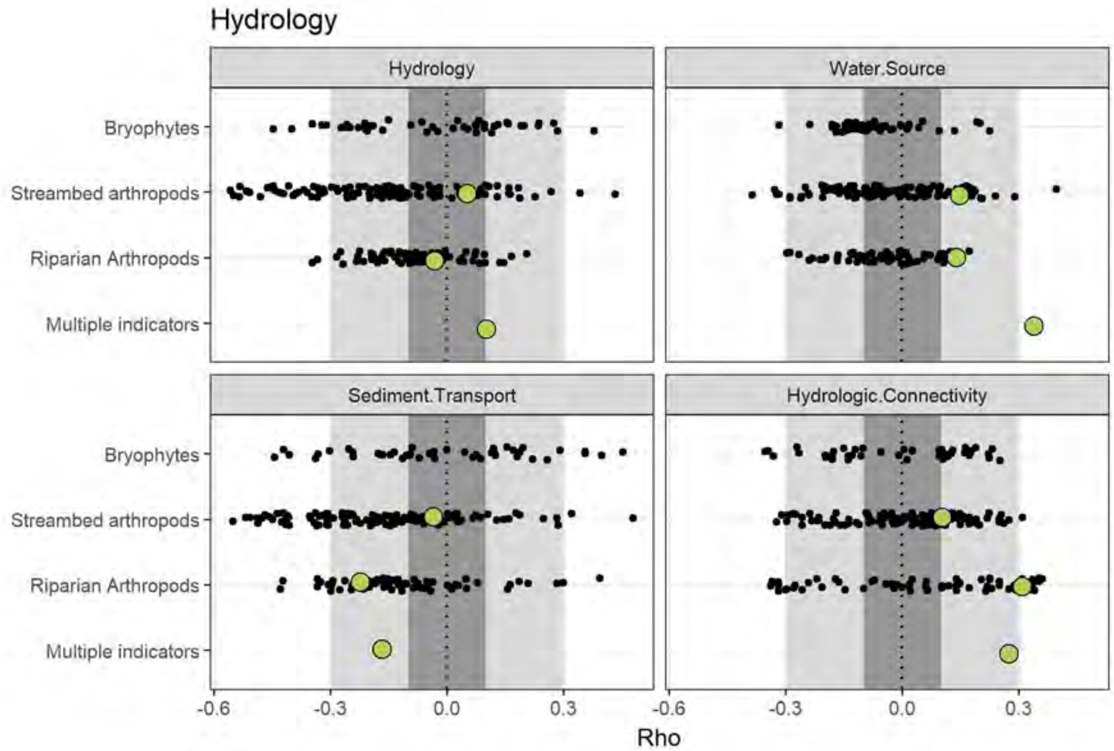

Figure 24. Spearman rho correlations between L3 bioassessment metrics and CRAM hydrology metrics; each point represents a single L3 metric. The green dots indicate the correlation with the DSCIs. The gray band indicates the region of weak and moderate correlations.

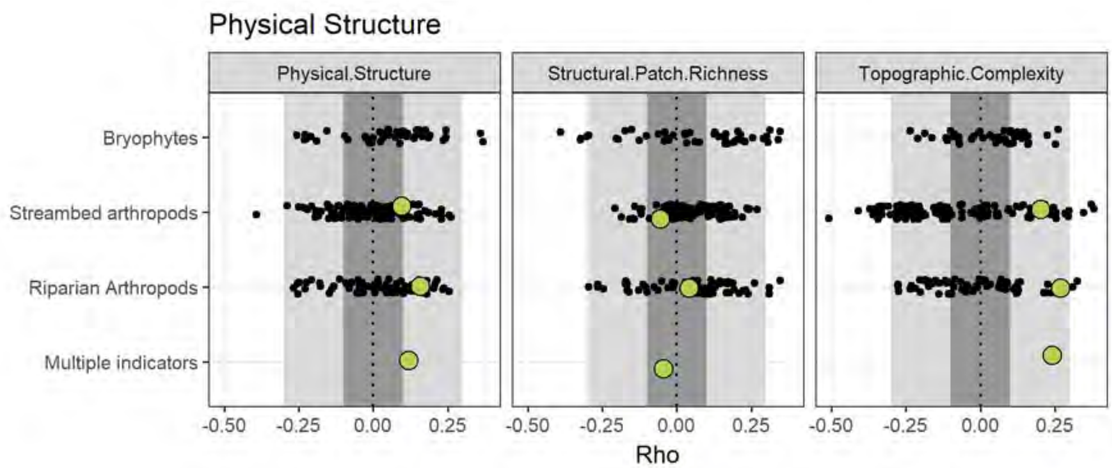

Figure 25. Spearman rho correlations between L3 bioassessment metrics and CRAM physical structure metrics; each point represents a single L3 metric. The green dots indicate the correlation with the DSCIs. The gray band indicates the region of weak and moderate correlations.

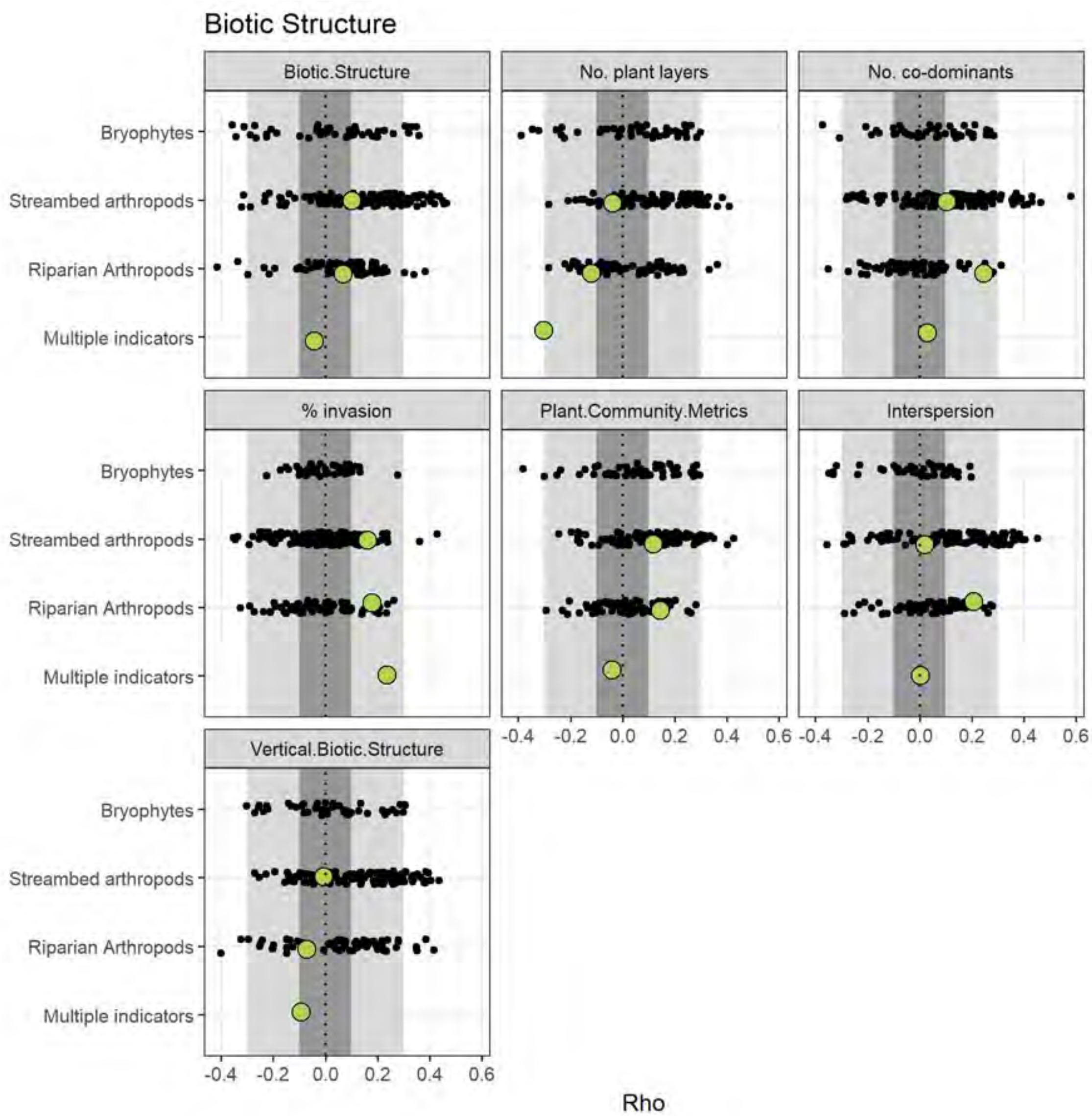

Figure 26. Spearman rho correlations between L3 bioassessment metrics and CRAM biotic structure metrics; each point represents a single L3 metric. The green dots indicate the correlation with the DSCIs. The gray band indicates the region of weak and moderate correlations.

Although the DSCIs had a positive relationship with the overall CRAM score, the relationships were not particularly strong (Rho ranged from 0.20 to 0.22; Figure 27). The indices had stronger relationships with the buffer attribute (range: 0.24 to 0.40), but weaker or negative relationships with other attributes (Figure 27). In general, stronger relationships were observed for the MI-DSCI and the RA-DSCI than the SA-DSCI.

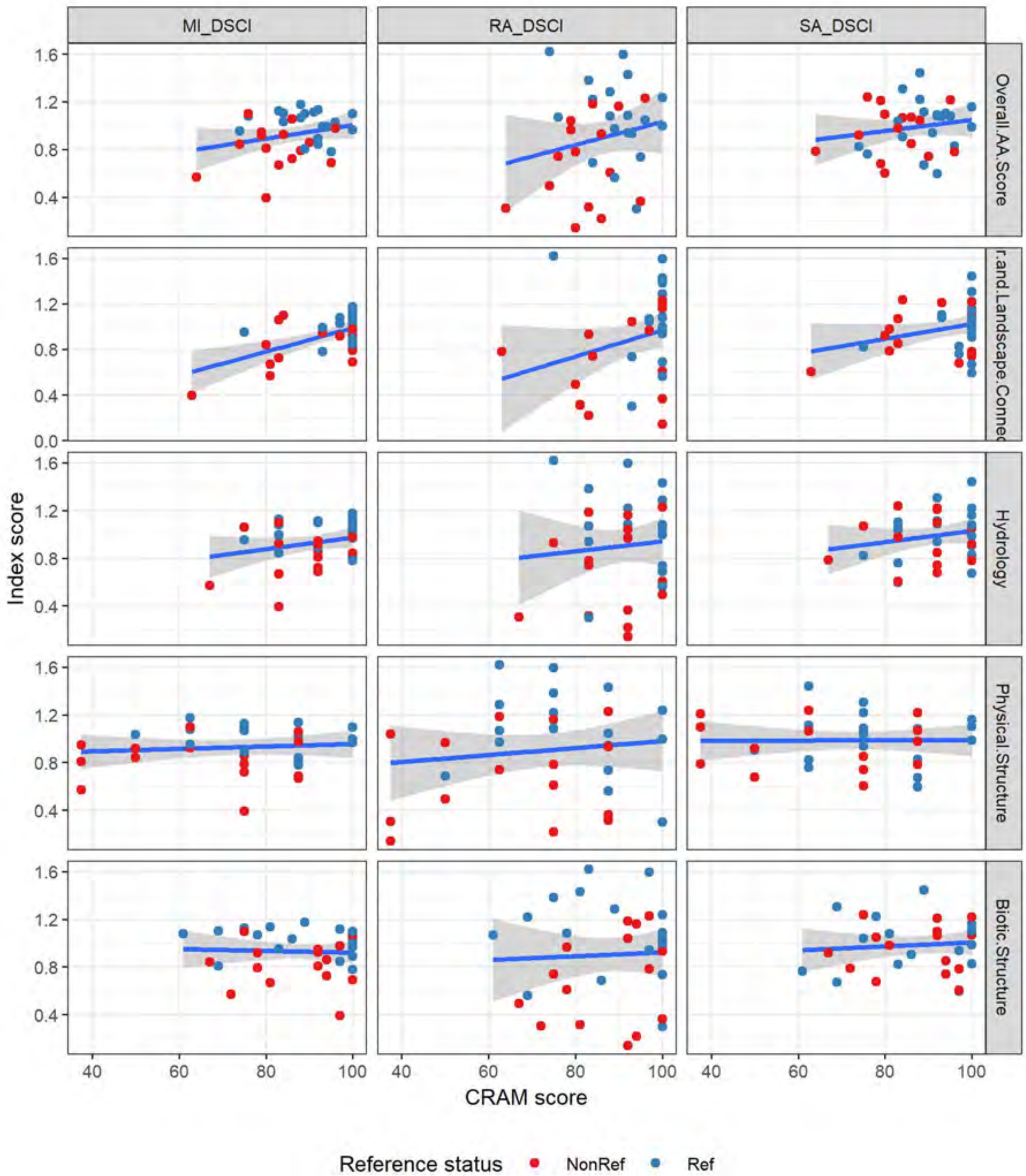

Figure 27. Relationships between DSCI scores and CRAM index or attribute scores. Blue lines indicate a linear fit.

Discussion

This study provides mixed evidence for the validity of the episodic CRAM module in ephemeral streams. Numerous metrics across all assemblages showed strong relationships with each CRAM attribute, but a few observed relationships were counter-intuitive, such as greater richness or diversity measures where physical structure attribute scores were low. This study should be viewed as providing qualified validation of the episodic CRAM module, pending reanalysis with additional data across broader disturbance gradients, as well as improved reference definitions.

This study underscores the challenges in identifying reference ephemeral streams. Our efforts followed the approach of Ode et al. (2016), which emphasizes human activity in the watershed as the primary way to identify disturbed (perennial) streams, supplemented with site-specific measures (e.g., riparian human activity) and field observations (e.g., evidence of grazing) where available. This approach may be inadequate for ephemeral streams due to the apparent decoupling of watershed activity and instream condition, as seen by the poor discrimination ability of the physical and biotic CRAM attributes. The landscape and hydrology attributes, which depend more on watershed-scale measurements, had much better discrimination ability. A reference definition for ephemeral streams should emphasize local factors (e.g., physical habitat disturbance or sediment quality) that may have a greater influence on in-stream conditions.

The value of multi-assemblage validation

No assemblage had metrics with strong relationships with all four attributes; this finding underscores the value of a multi-assemblage approach towards L2 validation. Each assemblage reflects different aspects of wetland condition. For example, buffer and landscape processes had the best relationships with riparian arthropod metrics (e.g., relative abundance of spiders, rho = 0.45). In contrast, few metrics characterizing other assemblages had a strong relationship. Riparian arthropod assemblages may be similar to arthropod assemblages in adjacent uplands, and stressors affecting buffer condition may have an outsize impact on this indicator. In contrast, bryophyte and streambed assemblages may respond to more local stressors strictly occurring within the stream channel.

Hydrologic condition was reflected in several metrics characterizing both bryophyte and stream arthropod assemblages. In the ephemeral CRAM module, this attribute focuses on disruptions to sediment regimes. These disruptions may greatly affect substrate where bryophytes can grow or streambed arthropods can forage and build burrows, while leaving riparian communities unaffected.

The physical structure attribute only had strong relationships with bryophyte metrics, and with none of the metrics for either arthropod assemblage. These results are unexpected. First, the richness or diversity of the streambed arthropod assemblage would be expected to reflect elements of the physical structure attribute, yet we rarely saw this occur. Furthermore, we generally saw negative relationships with bryophyte metrics, suggesting that higher bryophyte diversity may be found where physical structure is simplified. The preponderance of weak or counterintuitive relationships, combined with the poor relationship with reference status suggests that these metrics may need to be re-evaluated to ensure that they properly capture condition gradients in ephemeral streams.

More so than other attributes, the biotic condition attribute was most broadly validated by metrics in all three assemblages. Yet, paradoxically, this attribute had a negative relationship with the MMI. In combination, these findings should be taken as evidence to suggest that this attribute characterizes a condition gradient that is relevant for L3 indicators, yet has little relationship with reference status (as we’ve defined it here) or our measures of deviation from reference condition.

Taxonomic capacity to analyze arthropod and bryophyte samples for assessing the ecological health of dry-phase nonperennial rivers and streams

Introduction

The San Diego Regional Water Quality Control Board in collaboration with the Southern California Coastal Water Research Project (SCCWRP) and California State University Monterey Bay (CSUMB) are developing biological assessment tools for nonperennial rivers and streams (NPRS) during the dry phase. The new assessment protocols include the collection of biological specimens and taxonomic analysis of terrestrial arthropods and bryophytes (specifically mosses) to evaluate their potential use as indicators of anthropogenic disturbance in streams and rivers. To incorporate the new assessment protocols into current monitoring and regulatory programs, the capacity to produce taxonomic data must be known.

To date, all taxonomic data have been produced at CSUMB, but the capacity to produce taxonomic data from biological specimens by other laboratories is not known. To incorporate the new assessment methods into statewide biomonitoring programs in the future, the taxonomic services of additional labs may be needed to efficiently produce the desired data on a large scale. The goal of this section of the report is to determine the regional capacity to analyze dry-phase biological indicators of NPRS ecological health and produce taxonomic data.

We conducted two online surveys to determine if labs specializing in taxonomic services have the current capacity or interest in providing taxonomic data for terrestrial arthropods and bryophytes. Our survey focused primarily on the following questions:

- Do labs currently have the interest or contractual capacity to provide taxonomic services?
- What additional resources (e.g., microscopes, literature, additional taxonomists, etc.) or training would be needed to provide taxonomic services for these taxonomic groups?
- Which taxonomic groups can be identified, and to what resolution?
- What is the estimated cost and time needed to process specimens and produce taxonomic data?
- For bryophytes, are DNA reference libraries adequate to support molecular methods of taxonomic analysis?

Terrestrial Arthropods

Methods

We focused our survey efforts on labs that provide taxonomic services for agencies participating in the Stormwater Monitoring Coalition and individuals who are members of the Southwest Association of Freshwater Invertebrate Taxonomists (SAFIT). We expected that many labs currently providing aquatic benthic macroinvertebrate (BMI) identification services would have the required expertise to provide taxonomic data for terrestrial arthropods. We also surveyed these labs to determine if they have the interest or current capacity to produce bryophyte taxonomic data due to their taxonomic services currently provided to aquatic bioassessment programs.

Results

We received a total of eight responses from taxonomists working in a range of laboratories including those from California State University system labs, California state agency labs and private environmental consulting labs. Three of the eight labs surveyed produce taxonomic data for agencies participating in the Stormwater Monitoring Coalition and five of the eight labs/individuals are SAFIT members (Table 14).

Table 14. Respondents to taxonomic capacity survey. Contact information for labs is available by request.

Arthropod taxonomic lab respondents	Bryophyte taxonomic lab respondents
California State University at Long Beach	Natural History and Science Museum of Porto University
California State University at Stanislaus	Royal Alberta Museum at the University of Alberta
Aquatic Bioassessment Lab, California Department of Fish and Wildlife	MUSCI Natural Resource Assessment
Kansas Biological Survey	Eleanor Edye
Rhithron Associates	David Kofranek Botany,
Aquatic Assessments, Inc.	University of British Columbia
Aquatic Biology Associates, Inc.	Northwest Botanical Institute
	University of Nevada at Las Vegas

Responses indicate that interest and capacity for identifying terrestrial arthropods is high. Lack of literature was the most commonly cited barrier, although at least one lab specified that additional training would be required. Expected costs per sample are less than those required for aquatic insect samples (i.e., under $600 per sample).

Question 1: *Does your lab have interest in providing terrestrial arthropod taxonomic services, including processing and identification?*

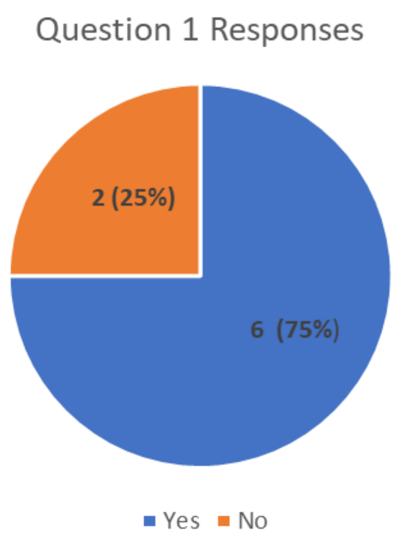

Figure 28. Responses to Question 1: Does your lab have interest in providing terrestrial arthropod taxonomic services, including processing and identification?

Question 2: *Does your lab have the capacity (i.e., resources, experience, and expertise) to provide taxonomic services for terrestrial arthropods?*

Note: Survey participants that responded "No" to Question 1 were not required to respond to Question 2.

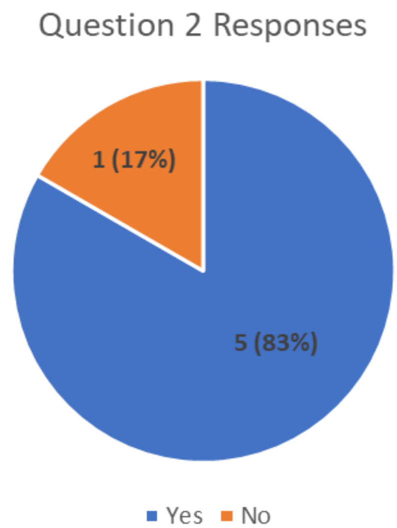

Figure 29. Response to Question 2: Does your lab have the capacity (i.e., resources, experience, and expertise) to provide taxonomic services for terrestrial arthropods?

Question 3: *If your lab does not currently have the capacity to provide taxonomic services for terrestrial arthropods, what additional resources need to be acquired (e.g., microscopes, literature, additional taxonomists, etc.)?*

Note: Survey participants that responded "Yes" to Question 2 were not required to respond to Question 3.

Response: Additional literature and taxonomic specialists will be needed by 3 labs to provide taxonomic services for terrestrial arthropods. Two of these three labs would require additional literature to identify terrestrial arthropods and one lab expressed interest in putting together a team of taxonomists specializing in certain arthropod groups to complete the taxonomic analyses.

Question 4: *What is the approximate cost of acquiring the additional resources necessary to process and identify terrestrial arthropod specimens?*

Note: Survey participants that responded "Yes" to Question 2 were not required to respond to Question 4.

Response: Only 1 of 3 labs provided an estimated cost to acquire additional resources and estimated the total project start-up cost to be $1000. The two labs that did not estimate costs provided feedback stating that acquiring the additional resources would require purchasing the relevant literature as well as incorporating the cost of subcontracting specialists to initially train members of the lab or to hire specialists on a sub-contractual basis to complete identifications. No respondents indicate that availability of taxonomic literature would be an obstacle.

Question 5: *What is the approximate time needed to become proficient in the processing and identifications of terrestrial arthropod specimens once the needed resources are acquired?*

Note: Survey participants that responded “Yes” to Question 2 were not required to respond to Question 5.

Response: The time required to become proficient in the processing and identifications of terrestrial arthropod specimens varied depending on previous experience of individual labs, but all estimates were under 6 months. Two labs responded that a short period of time would be needed to become proficient (e.g., time needed to process ~10 samples and become familiar with the taxa likely to be encountered in the project) and the third responded that 3-6 months would be needed to become proficient.

Question 6: *We focus on morpho species classifications for many of the arthropod specimens using a photo glossary of morpho species types, complete with descriptions of each morpho species. Would your lab be capable of processing samples on a morpho species level given the proper photographic keys and descriptions?*

Note: Survey participants that responded “Yes” to Question 2 were not required to respond to Question 6.

Response: All three labs responding to Question 6 are capable of processing samples on a morpho species level given the proper photographic keys and descriptions.

Question 7: *Beetles are identified to family level for this study. Can your lab achieve family level identifications for beetles?*

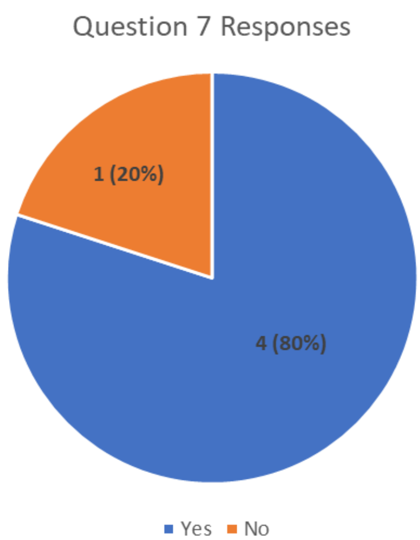

Figure 30. Response to Question 7: Can your lab achieve family level identifications for beetles?

Note: Only five survey participants provided answers for Question 7.

Question 8: *Spiders are identified to family level for this study. Can your lab achieve family level identifications for spiders?*

Note: Only six survey participants provided answers for Question 7.

Response: All six labs that responded to Question 8 can achieve family level identifications for spiders

Question 9: *How much more training would your lab require from terrestrial arthropod taxonomic experts to achieve the desired taxonomic resolution for these taxonomic groups?*

Note: Only five survey participants provided answers for Question 9.

Response: Three labs out of five that need additional training require either the appropriate literature, help from taxonomists specializing in these two groups or access to a reference collection.

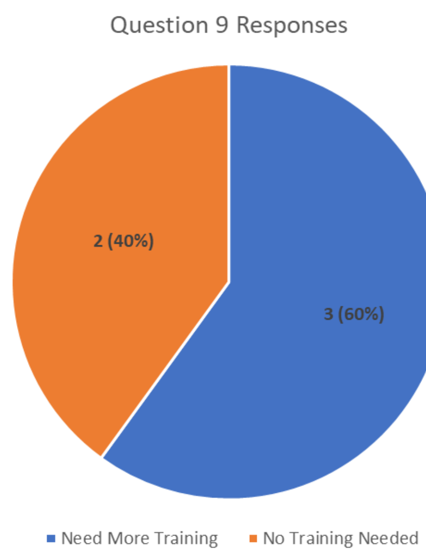

Figure 31. Responses to Question 9: How much more training would your lab require from terrestrial arthropod taxonomic experts to achieve the desired taxonomic resolution for these taxonomic groups?

Question 10: *Would your lab be interested in attending workshops, or training with other taxonomic experts to become proficient in terrestrial arthropod taxonomy?*

Note: Only five survey participants provided answers for Question 10.

Response: Five labs would be interested in attending workshops, or training with other taxonomic experts to become proficient in terrestrial arthropod taxonomy.

Question 11: *Most of the arthropod samples contain an average of 275 specimens per site (8 samples combined). What is the approximate cost anticipated for processing and identifying specimens from one complete site?*

Note: Only five survey participants provided answers f or Question 11.

Table 15. Response to Question 11: What is the approximate cost anticipated for processing and identifying specimens from one complete site?

Participant	Price	Additional Costs
1	$ 200.00	$20/hour sorting
2	$ 400.00	-
3	$ 300.00	-
4	$ 350.00	-
5	$100-$200	-

Question 12: *If your lab can process and identify terrestrial arthropod specimens, what is the expected capacity of the lab (e.g., how many samples can be processed and in what timeframe)?*

Table 16. Responses to Question 12: What is the expected capacity of the lab?

Participant	# Samples	Time Required
2	1	6 hours
3	3 to 5	1 day
4	250	3 months (Aug-Feb)
4	250	2 to 3 months (Mar-Jul)
5	500 to 1,000	3 to 6 months

Note: Only four survey participants provided answers for Question 12.

To standardize these responses we estimated the days required to process 10 samples by assuming 8 hour work-days, and 20 work-days per month, and mid-points of reported ranges:

- Participant 2: 7.5 days
- Participant 3: 2.5 days
- Participant 4:
  - 2.4 days (Aug – Feb, concurrent with ongoing obligations)
  - 2 days (Mar – Jul)
- Participant 5: 1.2 days

Although there is some variability among labs, they suggest a consensus that a handful of samples can be processed in a typical work-week.

Question 13: Does your lab have interest in providing bryophyte taxonomic services, including processing and identification to genus?

Response: Three of the eight labs specializing in aquatic BMI taxonomic services had interest in providing bryophyte taxonomic services. Only one of the three labs have the current capacity to identify bryophytes and produce taxonomic data and two would require additional literature and training from bryologists.

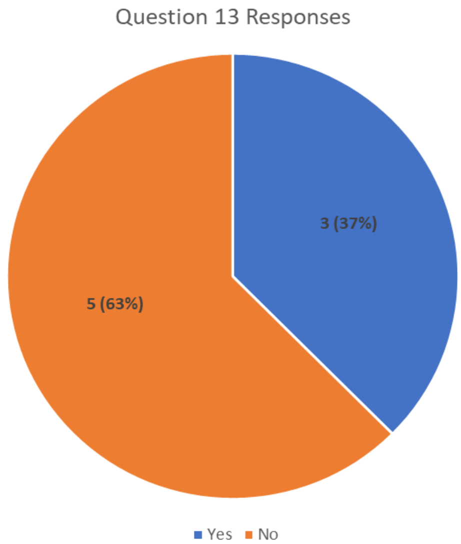

Figure 32. Responses to Question 13: Does your lab have interest in providing bryophyte taxonomic services, including processing and identification to genus?

Bryophytes

Methods

We contacted individual bryologists on the West Coast and sent our survey to members of Bryonet. Bryonet is a closed list email group that is sponsored by the International Association of Bryologists and has 1379 members (March 2017). Bryonet members range from beginner bryophyte hobbyists to bryologists working as professional taxonomists. We expected Bryonet would be an appropriate setting for the survey due to our lack of knowledge of the range of bryophyte taxonomic expertise in the region and the capacity of labs or individuals to produce bryophyte taxonomic data.

Results

We received a total of seven responses from bryologists working at universities, museums, natural resource assessment groups, as well as bryologists working independently as contracted taxonomists.

Question 1: *Does your lab have interest in providing bryophyte taxonomic services, including processing and identification to genus?*

Response: All seven bryologists surveyed have interest in providing bryophyte taxonomic services, including processing and identification to genus.

Question 2: *Does your lab have the capacity (i.e., resources, experience, and expertise) to provide taxonomic services for bryophytes?*

Response: All seven bryologists have the capacity (i.e., resources, experience, and expertise) to provide taxonomic services for bryophytes.

Question 3: *If your lab can process and identify bryophyte specimens, what is the expected capacity of the lab (e.g., how many samples can be processed and in what timeframe)*

Note: One of the seven participant responses indicated that their lab capacity is highly time/specimen-dependent and the response was not included in the table below.

Table 17. Responses to Question 1: What is the expected capacity of the lab?

Participant	# Samples	Time Required	Taxonomic Resolution
1	20	1 day	not specified
2	200	~ 3 to 4 months	species
3	20	1 week	not specified
4	50 to 250	1 day	species
5	30 to 50	1 day	genus
5	15 to 20	1 day	species
6	12	4 weeks	not specified

To standardize these responses, we estimated the days required to process 10 samples by 5 work-days per week, 20 work-days per month, and mid-points of reported ranges:

- Participant 1: 0.5 days for 10 samples
- Participant 2: 3.5 days
- Participant 3: 2.5 days
- Participant 4: 0.1 days
- Participant 5: 0.3 days for genus, 0.5 days for species
- Participant 6: 16.7 days

These estimates range widely, suggesting that these labs either conduct substantially different practices during identifications, they did not understand the survey question, or that they do not have sufficient experience to provide reliable estimates.

Question 4: *What is the approximate cost anticipated for processing and identifying specimens?*

Table 18. Responses to Question 4: What is the approximate cost anticipated for processing and identifying specimens?

	Cost per specimen		Cost of a typical (median) sample		Cost of richest sample from pilot study	
Participant	Species	Genus	Species (10 taxa)	Genus (8 taxa)	Species (23 taxa)	Genus (14 taxa)
1	$ 11.00		$ 110		$ 253	
2	$ 60.00		$ 600		$ 1,380	
3	$ 20.00		$ 200		$ 460	
4	$ 10.00	$ 4.00	$ 100	$ 32	$ 230	$ 56
5	$ 15.00		$ 150		$ 345	
6	$ 10.00		$ 100		$ 230	
7	$ 30.00	$ 15.00	$ 300	$ 120	$ 690	$ 210

Capacity to conduct molecular identifications on bryophytes of California

Methods

After reviewing EFlora (a database of California mosses maintained by UC Berkeley; http://ucjeps.berkeley.edu/CA_moss_eflora/) and Malcom et al. (2009), we assembled a list of 219 genera of mosses occurring in California. Liverworts and hornworts were excluded. On 11/16/18, we searched three DNA libraries for matches against these names:

- GenBank (https://www.ncbi.nlm.nih.gov/genbank/). We searched for any reference sequences with at least 200 base-pairs that matched the genus names for four barcode regions (specifically, 18S, 16S, rbcL, and ITS). We then repeated the search to look for other barcodes for these genera.
- Silva (https://www.arb-silva.de/). We searched for any matches to genus name. All sequences in this library are a minimum of 1200 basepairs, and are restricted to the 16S and 18S rRNA barcode regions.
- Barcode Of Life Database (BOLD, http://v3.boldsystems.org/). All sequences in this library are a minimum of 1200 basepairs, and are restricted to the 16S and 18S rRNA barcode regions.

We tabulated the number of sequences for each genus within each database (by barcode region for Genbank). A genus was rated as "good" (i.e., full-length sequences likely available) if it had a 500 basepair or longer sequence; "fair" (i.e., partial sequences likely available) if only shorter fragments were in databases; or "poor" if no sequences of any length were found in any database.

Results

Among the 219 genera found in California, 61 had "good" sequences available in reference libraries, and another 156 had "fair" sequences Table 19. Only 2 genera (i.e., *Hylocomiadelphus* and *Tetradontium*) were "poor" (i.e., missing from all reference libraries). For the bryophytes, the most popular reference barcode regions were 18S/rbcL/ITS. The best coverage was found either with the 18S/rbcL/ITS barcodes in GenBank, or in ITS/rbcL in BOLD. For California mosses specifically, more than 95% of genera had at least one reference barcode in Genbank, and 88% in BOLD. The assessment of each genus is presented in Table 20.

Table 19. Percent of bryophyte species with barcodes in DNA databases.

Database	Barcode	Percent
GenBank	Any barcode	0.98
	18S	0.82
	16S	0.22
	rbcL	0.84
	ITS	0.87
Silva	16S/18S	0.29
BOLD	(18S/ITS/rbcL)	0.88
	18S/ITS/rbcL > 500 basepairs	0.71

Discussion

We surveyed a total of 15 labs and determined that most labs have the capacity to produce taxonomic data for biological specimens collected as indicators of dry stream health in NPRS. Multiple aquatic BMI labs currently have the capacity to begin processing and identifying terrestrial arthropod specimens, and multiple bryologists currently have the capacity to begin processing and identifying bryophyte specimens. Many of the labs without the current capacity are interested in acquiring the skills and resources needed to produce the taxonomic data. Most labs surveyed have calculated the costs required to process and identify specimens.

The capacity to produce taxonomic data from samples collected following the dry stream protocol is currently limited to a single lab at CSUMB. The ability of multiple labs to produce the needed taxonomic data presents an opportunity to improve processing times and allow for the collection of more biological samples than a single lab can currently process. Additionally, the knowledge gained from this survey may be used to inform the future costs of contracting taxonomic specialists and may aid in estimating the costs of expanding the project in the future.

Table 20. Assessment of genetic reference libraries for representation of California moss species.

Genus	Genbank					Silva	BOLD (18S/ITS/rbcL)		Summary
	ALL	18S	16S	rbcL	ITS	16S/18S	Any length	>500bp	
Acaulon	Y	Y	N	Y	Y	N	1	1	Good
Aloina	Y	N	N	N	Y	N	0	0	Fair
Alsia	Y	Y	N	Y	Y	N	7	3	Good
Amblystegium	Y	Y	N	Y	Y	N	5	1	Good
Amphidium	Y	N	N	Y	Y	N	7	4	Good
Anacolia	Y	Y	N	Y	Y	N	2	1	Good
Andreaea	Y	Y	Y	Y	Y	Y	1	1	Good
Anoectangium	Y	Y	N	N	Y	N	10	3	Good
Anomobryum	Y	Y	Y	Y	Y	Y	3	0	Fair
Antitrichia	Y	Y	N	Y	Y	N	12	3	Good
Aphanorrhegma	Y	Y	N	Y	Y	Y	2	0	Fair
Archidium	Y	Y	N	Y	N	Y	2	0	Fair
Arctoa	Y	Y	N	Y	Y	N	3	1	Good
Atractylocarpus	Y	Y	N	Y	Y	N	0	0	Fair
Atrichum	Y	Y	Y	Y	Y	Y	7	4	Good
Aulacomnium	Y	Y	N	Y	Y	Y	16	6	Good
Barbula	Y	Y	Y	Y	Y	N	8	2	Good
Bartramia	Y	Y	Y	Y	Y	Y	2	0	Fair
Bartramiopsis	Y	Y	N	Y	N	N	3	1	Good
Bestia	Y	N	N	N	Y	N	4	2	Good
Blindia	Y	Y	N	Y	Y	Y	22	11	Good
Brachydontium	Y	Y	N	Y	Y	N	0	0	Fair
Brachymenium	Y	Y	N	Y	Y	Y	2	0	Fair
Brachytheciastrum	Y	Y	N	Y	Y	N	14	3	Good
Brachythecium	Y	Y	N	Y	Y	Y	4	2	Good
Braunia	Y	Y	N	N	N	N	0	0	Fair
Breidleria	N	N	N	N	N	N	4	3	Good
Bruchia	Y	N	N	N	N	N	0	0	Fair
Bryoerythrophyllum	Y	Y	N	N	Y	N	9	2	Good
Bryolawtonia	Y	Y	N	N	Y	N	1	0	Fair
Bryoxiphium	Y	Y	N	Y	Y	Y	4	4	Good
Bryum	Y	Y	Y	Y	Y	Y	4	2	Good
Buckiella	Y	Y	N	Y	Y	N	0	0	Fair
Bucklandiella	Y	Y	N	Y	Y	N	1	1	Good

Buxbaumia	Y	Y	Y	Y	Y	Y	12	7	Good
Calliergon	Y	Y	N	Y	Y	N	14	7	Good
Calliergonella	Y	Y	N	Y	Y	N	15	8	Good
Campylium	Y	Y	N	Y	Y	N	7	2	Good
Campylopodiella	Y	Y	N	Y	Y	N	0	0	Fair
Campylopus	Y	Y	N	Y	Y	N	1	0	Fair
Campylostelium	Y	N	N	Y	N	N	1	1	Good
Ceratodon	Y	Y	Y	Y	Y	Y	2	1	Good
Cirriphyllum	Y	Y	Y	Y	Y	N	6	3	Good
Claopodium	Y	Y	N	Y	Y	N	1	0	Fair
Climacium	Y	Y	Y	Y	Y	Y	18	2	Good
Codonoblepharon	Y	N	N	Y	N	N	1	1	Good
Codriophorus	Y	Y	N	Y	Y	N	2	0	Fair
Conardia	Y	Y	N	Y	Y	N	5	3	Good
Conostomum	Y	Y	N	Y	Y	N	14	7	Good
Coscinodon	Y	Y	N	Y	Y	N	3	2	Good
Cratoneuron	Y	Y	Y	Y	Y	N	10	4	Good
Crossidium	Y	Y	N	N	Y	N	4	1	Good
Crumia	Y	N	N	N	N	N	9	2	Good
Cynodontium	Y	Y	N	Y	N	N	6	3	Good
Dacryophyllum	Y	Y	N	Y	Y	N	2	1	Good
Daltonia	Y	Y	Y	N	Y	N	2	0	Fair
Dendroalsia	Y	Y	N	N	Y	N	5	2	Good
Drepanocladus	Y	Y	N	Y	Y	N	292	48	Good
Dichelyma	Y	N	N	Y	Y	N	2	2	Good
Dichodontium	Y	N	N	N	N	N	3	2	Good
Dicranella	Y	Y	Y	Y	Y	N	2	0	Fair
Dicranodontium	Y	Y	N	Y	Y	Y	6	3	Good
Dicranoweisia	Y	Y	N	Y	Y	N	37	3	Good
Dicranum	Y	Y	Y	Y	Y	N	6	3	Good
Didymodon	Y	Y	Y	Y	Y	N	1	0	Fair
Discelium	Y	N	N	Y	Y	N	11	4	Good
Distichium	Y	N	N	Y	Y	N	46	15	Good
Ditrichum	Y	Y	N	Y	Y	N	9	3	Good
Drepanocladus	Y	Y	N	Y	Y	N	130	12	Good
Encalypta	Y	Y	N	Y	Y	Y	12	6	Good
Entosthodon	Y	Y	N	Y	Y	Y	1	0	Fair
Ephemerum	Y	Y	N	Y	Y	Y	0	0	Fair
Epipterygium	Y	N	N	Y	N	N	0	0	Fair

Eucladium	Y	Y	N	Y	Y	N	3	1	Good
Eurhynchiastrum	Y	Y	N	Y	Y	N	16	2	Good
Eurhynchium	Y	Y	Y	Y	Y	N	4	2	Good
Fabronia	Y	Y	N	Y	Y	N	3	3	Good
Fissidens	Y	Y	N	Y	Y	Y	22	9	Good
Fontinalis	Y	Y	Y	Y	Y	Y	38	11	Good
Funaria	Y	Y	Y	Y	Y	N	1	1	Good
Gemmabryum	Y	Y	N	Y	Y	Y	0	0	Fair
Grimmia	Y	Y	Y	Y	Y	Y	4	2	Good
Gymnostomum	Y	Y	N	Y	Y	N	16	7	Good
Hamatocaulis	Y	Y	N	Y	Y	N	4	2	Good
Haplodontium	Y	Y	N	Y	N	Y	0	0	Fair
Hedwigia	Y	Y	N	Y	Y	Y	13	8	Good
Helodium	Y	Y	N	Y	Y	N	14	8	Good
Hennediella	Y	Y	N	N	Y	N	1	0	Fair
Herzogiella	Y	Y	N	Y	Y	Y	1	0	Fair
Heterocladium	Y	Y	N	Y	Y	N	1	1	Good
Homalia	Y	Y	N	Y	Y	N	1	0	Fair
Homalothecium	Y	Y	N	Y	Y	N	8	2	Good
Homomallium	Y	N	N	Y	Y	N	4	2	Good
Hookeria	Y	Y	N	Y	Y	Y	8	3	Good
Hydrogrimmia	Y	N	N	N	N	N	3	1	Good
Hygroamblystegium	Y	Y	N	Y	Y	N	6	3	Good
Hygrohypnum	Y	Y	N	Y	Y	N	8	5	Good
Hylocomiadelphus	N	N	N	N	N	N	0	0	Poor
Hylocomium	Y	Y	N	Y	Y	N	4	2	Good
Hymenostylium	Y	Y	N	Y	Y	Y	4	0	Fair
Hypnum	Y	Y	Y	Y	Y	N	6	2	Good
Isopterygiopsis	Y	Y	N	Y	Y	N	6	2	Good
Isopterygium	Y	N	N	Y	Y	N	1	1	Good
Isothecium	Y	Y	N	Y	Y	N	31	3	Good
Iwatsukiella	Y	N	N	Y	Y	N	2	2	Good
Jaffueliobryum	Y	N	N	Y	N	N	1	1	Good
Kiaeria	Y	N	N	Y	N	N	6	3	Good
Kindbergia	Y	Y	N	Y	Y	N	6	2	Good
Leptobryum	Y	Y	N	Y	Y	Y	24	7	Good
Leptodictyum	Y	N	N	Y	Y	N	4	3	Good
Leptophascum	Y	Y	N	Y	Y	N	0	0	Fair
Lescuraea	Y	Y	N	Y	Y	N	6	4	Good

Leskea	Y	Y	N	Y	Y	N	11	6	Good
Leucolepis	Y	Y	N	Y	Y	Y	1	1	Good
Limbella	Y	Y	N	N	Y	N	1	0	Fair
Limprichtia	N	N	N	N	N	N	2	1	Good
Lorentziella	Y	Y	N	Y	Y	Y	2	0	Fair
Meesia	Y	Y	N	Y	Y	Y	12	3	Good
Meiotrichum	Y	Y	Y	Y	Y	N	1	1	Good
Meiotrichum	Y	Y	Y	Y	Y	Y	0	0	Fair
Metaneckera	Y	Y	N	N	Y	N	9	3	Good
Meteorium	Y	Y	N	N	Y	N	1	1	Good
Microbryum	Y	N	N	N	Y	N	4	2	Good
Micromitrium	Y	Y	N	Y	N	N	0	0	Fair
Mielichhoferia	Y	Y	N	Y	Y	Y	1	1	Good
Mnium	Y	Y	N	Y	Y	Y	2	1	Good
Myurella	Y	N	Y	Y	Y	N	5	0	Fair
Neckera	Y	Y	N	Y	Y	N	2	2	Good
Niphotrichum	Y	Y	N	Y	Y	N	2	2	Good
Nyholmiella	Y	Y	N	Y	Y	N	1	1	Good
Oedipodium	Y	Y	Y	Y	Y	N	6	5	Good
Oligotrichum	Y	Y	Y	Y	Y	Y	1	1	Good
Oncophorus	Y	Y	N	Y	Y	N	1	0	Fair
Orthodicranum	Y	N	N	Y	Y	N	1	1	Good
Orthodontium	Y	Y	N	Y	N	Y	1	1	Good
Orthothecium	Y	Y	N	Y	Y	N	10	5	Good
Orthotrichum	Y	Y	Y	Y	Y	Y	11	5	Good
Oxyrhynchus	Y	Y	Y	Y	Y	N	0	0	Fair
Oxystegus	Y	Y	N	Y	Y	N	9	0	Fair
Palustriella	Y	Y	N	Y	Y	N	7	5	Good
Phascum	Y	N	N	N	N	N	0	0	Fair
Philonotis	Y	Y	N	Y	Y	N	14	3	Good
Physcomitrella	Y	Y	Y	Y	Y	Y	1	0	Fair
Physcomitrium	Y	Y	N	Y	Y	Y	2	1	Good
Plagiobryoides	Y	Y	N	Y	N	N	0	0	Fair
Plagiobryum	Y	Y	N	Y	Y	Y	1	0	Fair
Plagiomnium	Y	Y	N	Y	Y	Y	5	1	Good
Plagiopus	Y	Y	N	Y	N	N	3	2	Good
Plagiothecium	Y	Y	N	Y	Y	N	5	0	Fair
Platydictya	Y	Y	N	Y	Y	N	1	0	Fair
Platyhypnidium	Y	Y	N	Y	Y	N	5	0	Fair

Plaubelia	Y	Y	N	N	Y	N	0	0	Fair
Pleuridium	Y	N	N	Y	Y	N	2	1	Good
Pleurozium	Y	Y	N	Y	Y	N	26	19	Good
Pogonatum	Y	Y	Y	Y	Y	Y	2	2	Good
Pohlia	Y	Y	Y	Y	Y	Y	2	1	Good
Polytrichastrum	Y	Y	Y	Y	Y	Y	22	12	Good
Polytrichum	Y	Y	Y	Y	Y	Y	1	1	Good
Porotrichum	Y	Y	N	N	Y	N	1	0	Fair
Pseudocalliergon	Y	Y	N	Y	Y	N	17	11	Good
Pseudobraunia	Y	Y	N	N	N	N	4	2	Good
Pseudocrossidium	Y	Y	N	N	Y	N	6	2	Good
Pseudoleskea	Y	Y	N	N	Y	N	12	6	Good
Pseudoleskeella	Y	N	N	N	Y	N	8	2	Good
Pseudoscleropodium	Y	Y	N	Y	Y	N	7	4	Good
Pseudotaxiphyllum	Y	Y	N	Y	Y	N	9	3	Good
Pterigynandrum	Y	N	N	N	Y	N	8	5	Good
Pterogonium	Y	N	N	Y	Y	N	7	2	Good
Pterygoneurum	Y	Y	N	N	Y	N	2	1	Good
Ptilium	Y	Y	N	Y	Y	N	1	0	Fair
Ptychomitrium	Y	Y	N	Y	N	Y	1	0	Fair
Ptychostomum	Y	Y	N	Y	Y	N	2	0	Fair
Pyramidula	Y	Y	Y	Y	Y	N	1	0	Fair
Racomitrium	Y	Y	Y	Y	Y	N	8	4	Good
Rhizomnium	Y	Y	N	Y	Y	Y	8	3	Good
Rhynchostegium	Y	Y	N	Y	Y	N	13	1	Good
Rhytidiadelphus	Y	Y	N	Y	Y	N	2	1	Good
Rhytidiopsis	Y	N	N	Y	Y	N	3	1	Good
Rhytidium	Y	Y	N	Y	Y	N	138	12	Good
Roellia	Y	N	N	N	N	N	0	0	Fair
Rosulabryum	Y	Y	N	Y	Y	Y	2	1	Good
Sanionia	Y	Y	Y	Y	Y	Y	10	3	Good
Sarmentypnum	Y	Y	N	Y	Y	N	185	1	Good
Schistidium	Y	Y	N	Y	Y	N	9	4	Good
Schistostega	Y	N	N	Y	Y	N	6	4	Good
Scleropodium	Y	Y	Y	Y	Y	N	3	0	Fair
Scopelophila	Y	N	N	Y	Y	N	5	1	Good
Scouleria	Y	Y	N	Y	Y	Y	20	5	Good
Seligeria	Y	N	N	Y	Y	N	1	1	Good
Sematophyllum	Y	Y	N	Y	Y	N	0	0	Fair

Sphagnum	Y	Y	Y	Y	Y	Y	3	1	Good
Sphagnum	Y	Y	Y	Y	Y	N	0	0	Fair
Splachnum	Y	Y	N	Y	Y	Y	7	4	Good
Steerecleus	Y	N	N	N	Y	N	0	0	Fair
Stegonia	Y	Y	N	Y	Y	N	13	5	Good
Straminergon	Y	Y	N	Y	Y	N	10	4	Good
Syntrichia	Y	Y	Y	Y	Y	Y	1	0	Fair
Tayloria	Y	Y	Y	Y	Y	Y	0	0	Fair
Tetradontium	N	N	N	N	N	N	0	0	Poor
Tetraphis	Y	Y	Y	Y	Y	Y	6	5	Good
Tetraplodon	Y	Y	Y	Y	Y	Y	2	1	Good
Thamnobryum	Y	Y	N	Y	Y	Y	7	3	Good
Thuidium	Y	Y	Y	Y	Y	Y	16	9	Good
Timmia	Y	Y	N	Y	Y	Y	15	8	Good
Timmiella	Y	N	N	Y	N	N	3	2	Good
Tomentypnum	Y	Y	N	Y	Y	N	7	3	Good
Tortella	Y	Y	Y	Y	Y	Y	12	4	Good
Tortula	Y	Y	Y	Y	Y	N	4	0	Fair
Trachybryum	Y	N	N	N	Y	N	0	0	Fair
Trematodon	Y	N	N	N	N	N	8	4	Good
Trichodon	Y	Y	Y	Y	Y	N	5	2	Good
Trichostomum	Y	Y	N	Y	Y	N	6	3	Good
Tripterocladium	Y	Y	N	N	Y	N	6	2	Good
Triquetrella	Y	Y	N	Y	Y	Y	1	0	Fair
Ulota	Y	Y	Y	Y	Y	Y	3	2	Good
Vesicularia	Y	Y	Y	Y	Y	N	1	1	Good
Warnstorfia	Y	Y	N	Y	Y	N	1	1	Good
Weissia	Y	Y	N	Y	Y	N	1	0	Fair
Zygodon	Y	Y	N	Y	Y	N	3	1	Good

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APPENDIX

Index scores for all sites sampled in 2016 and 2017.

					MI-DSCI		SA_DSCI		RA_DSCI	
StationCode	Lat	Long	Ref	Year	Score	Class	Score	Class	Score	Class
901NP9LCC	33.6275	-117.42862	NonRef	2016	0.69	Very likely altered	1.22	Likely intact	0.36	Likely altered
901SJLANV	33.50156	-117.64946	NonRef	2016	0.39	Very likely altered	0.60	Likely altered	0.78	Possibly altered
901SJMS1x	33.58246	-117.52364	NonRef	2016	0.92	Possibly altered	0.68	Likely altered	0.96	Likely intact
901SJOF1x	33.61645	-117.42656	NonRef	2016	1.10	Likely intact	1.24	Likely intact	0.74	Possibly altered
901TCTCR	33.66066	-117.58454	NonRef	2016	0.67	Very likely altered	0.98	Likely intact	0.31	Likely altered
902PECHNG	33.45977	-117.118	NonRef	2016	0.57	Very likely altered	0.79	Possibly altered	0.31	Likely altered
902SMAS1x	33.45574	-116.96974	NonRef	2016	0.79	Likely altered	1.05	Likely intact	0.61	Possibly altered
903CVPCT	33.26799	-116.6388	NonRef	2016	0.92	Possibly altered	1.06	Likely intact	1.18	Likely intact
903SLFRCx	33.344	-116.88	NonRef	2016	1.06	Likely intact	1.07	Likely intact	0.93	Likely intact
905DGSY1x	33.12778	-116.67761	NonRef	2016	0.72	Likely altered	0.85	Possibly altered	0.22	Likely altered
907NP9KLC	32.99088	-116.69268	NonRef	2016	0.98	Likely intact	0.78	Possibly altered	1.23	Likely intact
907NP9OSD	32.84798	-117.05018	NonRef	2016	0.86	Possibly altered	0.74	Possibly altered	1.16	Likely intact
907SRSD2x	33.10938	-116.65748	NonRef	2016	0.81	Likely altered	1.10	Likely intact	0.14	Likely altered
907SYCAM	32.92859	-116.98161	NonRef	2016	0.95	Likely intact	1.21	Likely intact	1.04	Likely intact
910NP9RJT	32.6987	-116.86973	NonRef	2016	0.69	Very likely altered	0.83	Possibly altered	0.43	Likely altered
910SYCAM	32.64566	-116.80611	NonRef	2016	0.47	Very likely altered	1.09	Likely intact	0.31	Likely altered
911TJPC2x	32.85372	-116.52251	NonRef	2016	0.84	Possibly altered	0.92	Likely intact	0.49	Likely altered
801SANT1x	33.70866	-117.61543	Ref	2016	0.95	Likely intact	0.82	Possibly altered	1.62	Likely intact
901AUDCRW	33.58576	-117.56319	Ref	2016	0.97	Likely intact	1.16	Likely intact	1.23	Likely intact

901AUDFOX	33.59874	-117.56467	Ref	2016	1.18	Likely intact	1.44	Likely intact	1.28	Likely intact
901BELOLV	33.64158	-117.55241	Ref	2016	0.84	Possibly altered	0.59	Likely altered	0.94	Likely intact
901NP9CSC	33.59088	-117.52132	Ref	2016	1.07	Likely intact	1.22	Likely intact	1.08	Likely intact
901NP9MRC	33.62658	-117.38848	Ref	2016	0.99	Likely intact	1.10	Likely intact	0.30	Likely altered
902NP9CWC	33.419	-116.861	Ref	2016	1.13	Likely intact	1.08	Likely intact	1.43	Likely intact
902SMAS2x	33.45641	-116.97191	Ref	2016	1.10	Likely intact	1.31	Likely intact	1.22	Likely intact
903ACPCT1	33.296	-116.639	Ref	2016	1.10	Likely intact	1.11	Likely intact	0.97	Likely intact
903NP9PRC	33.26036	-116.80925	Ref	2016	1.10	Likely intact	0.99	Likely intact	1.00	Likely intact
903NP9SLR	33.35192	-116.66522	Ref	2016	0.99	Likely intact	1.07	Likely intact	0.94	Likely intact
905DGCC1x	33.15908	-116.84042	Ref	2016	1.03	Likely intact	0.83	Possibly altered	1.04	Likely intact
905DGCC2x	33.1889	-116.82746	Ref	2016	1.11	Likely intact	0.94	Likely intact	1.60	Likely intact
905SDBDN9	33.09154	-116.89716	Ref	2016	0.78	Likely altered	1.08	Likely intact	0.73	Possibly altered
907NP9OSU	32.8551	-117.0519	Ref	2016	1.03	Likely intact	0.90	Likely intact	0.69	Possibly altered
910NP9ARP	32.63001	-116.88292	Ref	2016	0.80	Likely altered	0.67	Likely altered	0.56	Possibly altered
910NP9CCN	32.64149	-116.83598	Ref	2016	0.89	Possibly altered	1.09	Likely intact	1.09	Likely intact
911NP9EPC	32.74431	-116.64791	Ref	2016	1.24	Likely intact	1.11	Likely intact	1.62	Likely intact
911NP9HTC	32.7552	-116.66199	Ref	2016	0.92	Possibly altered	1.20	Likely intact	0.33	Likely altered
911NP9UCW	32.81992	-116.49137	Ref	2016	1.12	Likely intact	1.04	Likely intact	1.38	Likely intact
911S01142	32.73729	-116.65398	Ref	2016	0.89	Possibly altered	1.11	Likely intact	1.12	Likely intact
911TJKC1x	32.76072	-116.45148	Ref	2016	1.08	Likely intact	0.76	Possibly altered	1.07	Likely intact
801SHDCYN	33.61987	-117.78564	NonRef	2017	1.09	Likely intact	0.99	Likely intact	1.43	Likely intact
901EMRCYN	33.55738	-117.80311	NonRef	2017	0.59	Very likely altered	0.84	Possibly altered	0.48	Likely altered
902LNGCYN	33.5099	-117.1447	NonRef	2017	0.62	Very likely altered	0.54	Likely altered	0.44	Likely altered

902WRMSPC	33.52961	-117.182	NonRef	2017	0.73	Likely altered	0.75	Possibly altered	0.25	Likely altered
903SLFRCx	33.344	-116.88	NonRef	2017	0.62	Very likely altered	0.32	Very likely altered	0.80	Likely intact
904ESCELN	33.15125	-117.03646	NonRef	2017	0.26	Very likely altered	0.00	Very likely altered	0.43	Likely altered
906SLCFGC	32.89201	-117.18096	NonRef	2017	0.61	Very likely altered	0.42	Very likely altered	0.66	Possibly altered
907SRSD2x	33.10938	-116.65748	NonRef	2017	0.45	Very likely altered	0.29	Very likely altered	0.22	Likely altered
908CHI805	32.71904	-117.10724	NonRef	2017	0.50	Very likely altered	0.39	Very likely altered	0.57	Possibly altered
911TJPC2x	32.85372	-116.52251	NonRef	2017	0.57	Very likely altered	0.51	Very likely altered	0.18	Likely altered
801SANT1x	33.70866	-117.61543	Ref	2017	0.60	Very likely altered	0.62	Likely altered	0.90	Likely intact
901AUDFOX	33.59874	-117.56467	Ref	2017	0.88	Possibly altered	0.96	Likely intact	0.52	Possibly altered
901LAUREL	33.58551	-117.76368	Ref	2017	0.86	Possibly altered	0.88	Possibly altered	0.96	Likely intact
901NP9CSC	33.59088	-117.52132	Ref	2017	0.99	Likely intact	0.70	Likely altered	0.91	Likely intact
901SJVERD	33.5328	-117.5506	Ref	2017	1.01	Likely intact	0.83	Possibly altered	0.53	Possibly altered
902SMAS2x	33.45641	-116.97191	Ref	2017	0.89	Possibly altered	1.07	Likely intact	0.54	Possibly altered
903NP9PRC	33.26036	-116.80925	Ref	2017	0.77	Likely altered	0.47	Very likely altered	0.47	Likely altered
905SDBDN9	33.09154	-116.89716	Ref	2017	0.74	Likely altered	0.92	Likely intact	0.59	Possibly altered
907NP9OSU	32.8551	-117.0519	Ref	2017	0.74	Likely altered	0.58	Likely altered	0.41	Likely altered
911NP9ATC	32.76814	-116.41737	Ref	2017	0.82	Likely altered	0.66	Likely altered	0.27	Likely altered
911S01142	32.73729	-116.65398	Ref	2017	0.66	Very likely altered	0.54	Likely altered	0.64	Possibly altered