Candidate metrics for an index to assess the ecological condition of intermittent and ephemeral streams in Southern California when they are dry

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Technical Report 1398

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December 2024

Technical Report 1398

ACKNOWLEDGEMENTS

This research was funded by the Surface Water Ambient Monitoring Program of the California Water Resources Control Board (Agreement #19-078-270). We thank Moss Landing Marine Labs for assistance in sample collection. We thank Theresa Clark for reviewing bryophyte identifications. Brady Richards and Dan Pickard of the California Department of Fish and Wildlife's Aquatic Bioassessment Lab provided taxonomic analysis of terrestrial arthropods. Abel Santana and Adriana Le Compte Santiago assisted with data management.

Prepared for:

As a Deliverable for the California Surface Water Ambient Monitoring Program (Agreement No. 19-078-270)

This report should be cited as:

Mazor, R.D., R. Darling, J. Brown, C. Loflen, J. Olson, G.M. Keating, and M. Robinson. 2024. Candidate metrics for an index to assess the ecological condition of intermittent and ephemeral streams in Southern California when they are dry. Technical Report 1398. Southern California Coastal Water Research Project. Costa Mesa, CA.

ABSTRACT

The widespread prevalence of non-perennial streams necessitates the development of tools to assess their ecological conditions. Traditional approaches using aquatic biological indicators, such as fish, benthic macroinvertebrates, and/or algae, are not suitable for intermittent or ephemeral stream-reaches during low or no flow conditions, or may be difficult to implement at streams with very short flow duration during all years with typical climate conditions. Thus, we explored the value of biological indicators based on terrestrial organisms—specifically, arthropods and bryophytes. We collected samples of three assemblages (i.e., bryophytes, arthropods from streamside vegetation, and arthropods from the streambed) from 99 sites representing a range of natural and disturbed conditions within southern California; bryophytes were identified at least to the genus level, while arthropods were identified to the Family level (ants to species). All three assemblages showed responsiveness to measures of human activity, although the arthropods on the streambed likely have the greatest potential for use in ecological assessments. Among the most responsive arthropod metrics were those related to invasiveness and synanthropy (i.e., affinity for human-dominated environments), as well as those related to ant richness. Several bryophyte trait-based metrics (e.g., tolerance to heavy metals in soil) also showed strong responsiveness. We conclude this study by making a series of recommendations for the development of bioassessment indices for dry intermittent and ephemeral streams, such as continued sampling campaigns focused on minimally disturbed reference sites to better understand natural factors that could affect the use of dry stream indicators in assessment applications, as well as the expansion of traits data for these taxa.

KEY MESSAGES

- Effective assessment of nonperennial streams requires bioindicators that can be measured when reaches are dry.
- Terrestrial arthropods show promise for potential use as a such an indicator. Bryophytes show potential as well, although less destructive sampling methods should be developed.
- Further sampling of reference sites, improved taxonomic resolution, and development of bioindicator life history trait databases are needed to develop bioassessment indices for dry nonperennial streams.

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INTRODUCTION

Intermittent and ephemeral stream-reaches comprise a large portion of stream-miles in the arid southwest of the USA, yet at this time, we have few tools that can be used to assess their condition when they are dry. Consequently, monitoring programs may exclude these streams, despite their importance in providing benefits or protecting adjacent perennial waters. Bioassessment tools can provide managers with information they need to evaluate impacts to nonperennial streams (Karr 1991, Rosenberg and Resh 1993). For California, the only tools available either focus on wet-phase indicators, such as benthic macroinvertebrates (Mazor et al. 2016) or algae (Theroux et al. 2020), or are semi-quantitative rapid tools focused on structural components of the ecosystem, rather than biological assemblage composition (e.g., the California Rapid Assessment Method [CRAM]; CWMW 2013a, 2013b, 2020). We evaluated the potential for three biological indicators to be used as assessment tools in intermittent or ephemeral rivers (collectively referred to as “nonperennial” rivers or streams) when they are dry: terrestrial arthropods on the streambed, terrestrial arthropods on riparian vegetation, and bryophytes.

Although still uncommon, there are a few examples of using streambed arthropods as biological indicators in nonperennial streams when they are dry (e.g., Steward et al. 2018, Stubbington et al. 2019, Mazor et al. 2023a). Arthropods may be particularly effective indicators due in part to their ease of sampling, ubiquity, and diverse life histories (Gerlach et al. 2013, Steward et al. 2017, 2022). Bryophytes are not established as indicators in dry rivers, but they have a long history as water pollution indicators (Gecheva and Yurukova 2014) due to their sessile nature and close relationship with sediment quality (Longton 1988, Muotka and Virtanen 1995, Mazor et al. 2023a).

Nonperennial stretches of rivers are common features in headwater systems, but can be found throughout river networks (Steward et al. 2012, Messager et al. 2021) and play key ecological roles in a watershed context during dry and wetted phases (Datry et al. 2023, Brinkerhoff et al. 2024). Datry et al. (2014) described nonperennial streams as continuously shifting habitat mosaics driven by alternating phase-changes (i.e., flowing, drying, and dry) which maintain habitat heterogeneity. These alternating phases can lead to temporal shifts in nutrient processing and availability which may affect nutrient balances and export downstream (von Schiller et al. 2017). Even when surface water is completely absent, dry river channels often have sub-surface flows that sustain river flows downstream (Goodrich et al. 2018), making them important for maintaining watershed connectivity. Additionally, dry river channels function as storage areas for nutrients and organic material (Wyatt et al. 2014, von Schiller et al. 2017). Alternating phase changes can act as disturbances for both aquatic and terrestrial biota, but nonperennial streams provide habitat for organisms with various strategies and adaptations (physiological or behavioral) to cope with these changes (Datry et al. 2016, Sánchez-Montoya et al. 2020). For example, some taxa (e.g., aquatic invertebrates), are present as juveniles during the flowing phase and are dormant as eggs during dry phases and require both phases to persist within a system (Stubbington and Datry 2013, Stubbington et al. 2018). Given their widespread distribution, abundance, and important ecosystem functions including hydrologic connectivity with adjacent perennial waters, the condition of nonperennial stream systems and their ability to provide ecological functions can greatly influence the health of entire watersheds.

Nonperennial streams are particularly abundant and widespread in drier regions of southern California. Most stream systems in California exhibit some degree of nonperennial flow (Levick et al. 2008, McKay et al. 2014, Goodrich et al. 2018). Despite their intrinsic values and importance to hydrologically connected waterbodies, nonperennial streams, especially ephemeral streams, are typically excluded from ambient surveys and overlooked in management programs because most wetland and stream assessment tools have been focused on perennial streams (Boulton 2014, Datry et al. 2017). Assessments of the ecological condition of dry streambeds provide a direct measure of some beneficial uses, such as wildlife (WILD), as well as indirect measures of others, such as aquatic life (e.g., WARM) during the wet phase or in adjacent waterbodies. Potential sources of stress to nonperennial streams are increasing, including new urban/suburban and infrastructure projects, and, most recently, alternative energy production facilities (e.g., wind and solar) (Chiu et al. 2017). Landscape alteration has the potential to disrupt the natural hydrology and introduce contaminants that could affect both the wet and dry phases of nonperennial streams. In addition to development-related projects, nonperennial streams are often exposed to other anthropogenic activities, such as fire, grazing, or off-road vehicle use, which can impact the immediate reach as well as downstream water quality (Homan 2024, Brinkerhoff et al. 2024). Assessment tools for ephemeral and intermittent streams are necessary to allow resource and land managers to prioritize streams for protection or restoration, assess impacts associated with projects or anthropogenic activities, and develop and evaluate performance standards for mitigation or remediation (e.g., California State Water Resources Control Board 2004, Bureau of Land Management 2021).

In this report, we describe the results of an effort to apply bioassessment indicators to the dry phase of nonperennial streams in Southern California to attain a preliminary understanding of the ecological conditions of these ecosystems. We identify candidate bioassessment index metrics based on terrestrial arthropod and bryophyte communities that have potential for use as assessment tools and explore stressor metrics for anthropogenic disturbance. This study paves the way for assessing the conditions of streams in southern California, regardless of the presence of surface water.

METHODS

For the purposes of this study, we define streamflow duration classes as follows:

- **Perennial stream reaches** flow year-round in years of typical rainfall. They may cease to flow during extreme droughts or due to diversions or groundwater extraction.
- **Intermittent stream reaches** flow for extended periods of years with typical rainfall (often longer than a month). Surface flows are typically sustained by groundwater, although other sources (e.g., snowmelt) may also sustain flows. Intermittent reaches may or may not retain permanent pools during periods of low flows. In years with high precipitation, intermittent stream reaches may flow year-round, and in years with low precipitation, they may not flow at all. Intermittent streams in mediterranean California may be classified as *regularly flowing intermittent* (RFI), which flow for several months in years with typical rainfall, and *seldomly flowing intermittent* (SFI), which only exhibit flow for more than a few weeks in years with high precipitation.
- **Ephemeral stream reaches** only flow for short periods (typically less than a month), and only in direct response to precipitation events. In contrast to intermittent stream reaches, ephemeral stream reaches do not have flows sustained by groundwater.
- **Nonperennial stream reaches** include both intermittent and ephemeral stream reaches.

These definitions are not intended to be used for regulatory purposes or jurisdictional determinations. These definitions apply to stream channels that exhibit or historically exhibited natural bed and bank forms, as opposed to swales or erosional gullies that may at times sustain flows, nor to entirely artificial channels constructed from historically terrestrial environments.

Study area

Coastal southern California is a semi-arid region with a Mediterranean climate, which experiences nearly all of its precipitation as rainfall during winter months. Lower elevations are characterized by chaparral, oak woodlands, grasslands, and coastal sage scrub. The region is bordered by the Transverse Ranges to the North, and the Peninsular Ranges to the East, and continues to the Mexican border to the South. Both Transverse and Peninsular ranges contain peaks that exceed 10,000 feet and regularly experience winter snow, although contributions to stream flow are typically limited. Much of the higher elevations are undeveloped and remain protected in a network of national, state, and county parks and forests. The lower elevations have been largely urbanized or converted to agriculture. Wildfires and drought are frequent in the region, with extensive fires occurring in 2009, 2013, 2017, and 2018 throughout much of the area (major wildfires also occurred in 2024, after sample collection). By area, the overall region is 59% undeveloped open space, 28% urban, and 13% agricultural (Jon Dewitz 2024). Overall, 59% of the stream-miles in the region are estimated to be nonperennial, although this number is substantially (>90%) higher in certain areas, such as inland portions of San Diego, the Santa Clara watershed, and the San Jacinto watershed (Mazor 2015).

Sample collection

Between 2017 and 2021, a total of 99 dry intermittent or ephemeral streams in southern California were sampled following the method described by Robinson et al. (2018) (Figure 1). These sites were selected to represent a range of natural conditions (e.g., different ecoregions, climatic conditions, and watershed sizes) as well as disturbance gradients. Of these 99 sites, bryophytes were collected at 92 sites, and no bryophytes were observed at 7 of these sites. Streambed arthropods were collected at 56 sites, and arthropods on riparian vegetation were collected at 63 sites. (Although additional arthropod samples were collected, only this subset was used in analysis because it was subjected to a focused taxonomic review, which was not possible for all samples collected.)

A single year’s worth of data was available for most sites, and two years of bryophyte samples were available at 11 sites. At one of these 11 sites, a second year of sampling of streambed and riparian arthropod samples was also conducted. Across the entire data set, there were 111 unique sampling events, 50 of which included data from all 3 indicators and 46 had bryophytes alone; other combinations accounted for 7 or fewer samples (15 samples total).

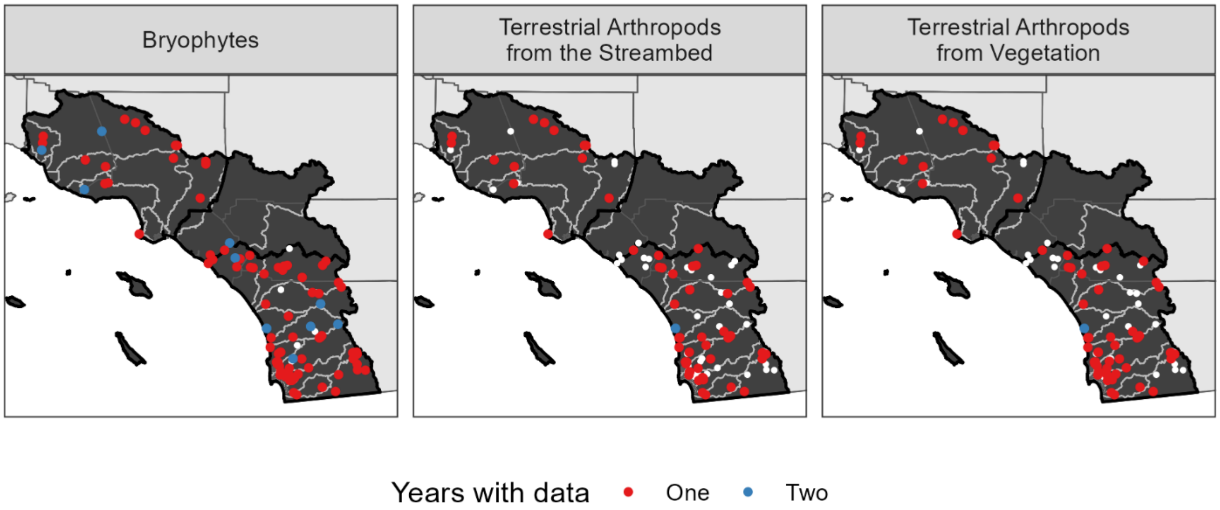

Figure 1. Sampled locations in southern California. Light gray lines indicate major watershed boundaries. Thick black lines indicate boundaries between the Los Angeles, Santa Ana, and San Diego Regional Waterboards' jurisdictions. Large red dots indicate sites with one year of data. Large blue dots indicate sites with two years of data. Small white dots indicate sites with no data for the indicator.

Environmental data collection

Physical habitat data

Physical habitat (PHAB) measurements were taken at each site following Robinson et al. (2018). Upon arriving at the site, field crews laid out 9 transects 20 m apart to establish a 160-m long assessment reach. At each transect, crews measured bankfull width, hydraulic height at 25%, 50%, and 75% of the channel width. Crews measured median axis size of all particles at 0%, 25%, 50%, 75%, and 100% of channel width at each transect (45 counts per sampling event) using either a gravelometer or taking direct measurements. If cobbles were encountered, percent embeddedness was visually estimated. For the entire reach, field crews estimated percent cover of geomorphic microhabitat types (e.g., riffles, pools, runs), cover of vegetation types in the channel or riparian zone (i.e., grasses, non-woody vegetation, or woody vegetation), and extent wetted habitat. Crews recorded up to 71 human activities in terms of proximity, extent, and intensity, as well as 4 disturbance types with potentially natural origin (i.e., animal burrows, burns, debris and silt, or salt deposits). Slope of the reach was measured using a clinometer. A suite of 38 physical habitat metrics was calculated for each sampling event (Table 1).

Table 1. Physical habitat metrics

Type	Metric	Description
Channel morphology	XBKF_W	Mean bankfull width
Channel morphology	Mn_HydHght	Mean hydraulic height
Channel morphology	Mn_CrossSect	Mean hydraulic cross sectional area
Channel morphology	Mn_MaxHydHght	Maximum hydraulic height
Channel morphology	XSLOPE	Channel slope
Flow microhabitat	Pct_WetHab	Percent of reach with wetted habitat
Flow microhabitat	Pct_FastGHab	Percent of reach with fast-water geomorphic habitats (i.e., riffles, runs, and cascades) in the channel
Flow microhabitat	Pct_PoolGHab	Percent of reach with pool geomorphic habitat in the channel
Vegetation	Pct_VgInstream	Percent of reach with woody or nonwoody vegetation cover on the streambed
Vegetation	Pct_VgWdChan	Percent of reach with woody vegetation cover in the channel
Vegetation	Pct_VgNwdChan	Percent of reach with nonwoody vegetation cover in the channel
Vegetation	Pct_VgGrsChan	Percent of reach with grass vegetation cover in the channel
Vegetation	Pct_VgWdRip	Percent of reach with woody vegetation cover in the riparian zone
Vegetation	Pct_VgNwdRip	Percent of reach with nonwoody vegetation cover in the riparian zone
Vegetation	Pct_VgGrsRip	Percent of reach with grass vegetation cover in the riparian zone
Vegetation	Pct_VgChan	Sum of woody, nonwoody, and grass vegetation in the channel
Vegetation	Pct_VgRip	Sum of woody, nonwoody, and grass vegetation in the riparian zone
Vegetation	Pct_VgWdTotal	Sum of woody vegetation cover in the channel and the riparian zone
Vegetation	Pct_VgNonWdTotal	Sum of nonwoody vegetation cover in the channel and the riparian zone
Vegetation	Pct_VgGrsTotal	Sum of grass vegetation cover in the channel and the riparian zone
Substrate	PCT_SAFN	Percent sands and fines on the streambed
Substrate	SB_PT_D50	Median particle size on the streambed
Substrate	Pct_CbBlBr	Percent cobbles, boulders, or bedrock on the streambed
Disturbance	HumanActivity_Ext	Extent of human activities in the reach*
Disturbance	HumanActivity_Int	Intensity of human activities in the reach
Disturbance	HumanActivity_Prox_SWAMP	Proximity of human activities in the reach using SWAMP weighting
Disturbance	AlgalMats_Ext	Extent of algal mats in the reach
Disturbance	AlgalMats_Int	Intensity of algal mats in the reach
Disturbance	AlgalMats_Prox	Proximity of algal mats in the reach
Disturbance	Burns_Ext	Extent of burns in the reach

Type	Metric	Description
Disturbance	Burns_Int	Intensity of burns in the reach
Disturbance	Burns_Prox	Proximity of burns in the reach
Disturbance	Salts_Ext	Extent of salt deposits in the reach
Disturbance	Salts_Int	Intensity of salt deposits in the reach
Disturbance	Salts_Prox	Proximity of salt deposits in the reach
Other	AnimalBurrow_Ext	Extent of animal burrows in the reach
Other	AnimalBurrow_Int	Intensity of animal burrows in the reach
Other	AnimalBurrow_Prox	Proximity of animal burrows in the reach

Next, metrics that describe levels of human activity were calculated from field-measured physical habitat data. These metrics consisted of 4 total values that summed the extent, intensity, and proximity of 69 analytes that we designated as human activity metrics, per site (listed Appendix B). Extent and intensity are measured with values 1-3 (low to high intensity/extent). These values were left as-is and were summed across each site. Proximity is measured in five ranges of distance (meters) and thus each range was converted to a midpoint or an ordinal score for ease of summation. The fourth metric was a Stormwater Ambient Monitoring Program (SWAMP) summed proximity score with different ordinal and midpoint values based on SWAMP protocols. In summary, the human activity metrics yielded 4 total metrics: sum of human activity extent scores (HumanActivity_Ext), sum of human activity intensity scores (HumanActivity_Int), sum of human activity proximity scores (HumanActivity_Prox), and sum of human activity proximity SWAMP scores (HumanActivityProx_SWAMP), per site. The seven non-human activity stressors were calculated using the same method, but instead of being combined into one total score per site, they were calculated individually per site. For the stream characterization metrics most (width, height, slope) were averaged over each site while cross sectional area was calculated as the mean of the hydraulic height including two values of zero (due to lack of bank measurements) multiplied by stream width, then averaged over all transects per site. For all metrics, any analyte listed as "Not Recorded" or "Not Present" was assigned a value of zero.

Geospatial data

In order to characterize anthropogenic and natural environments in upstream catchments, we delineated watersheds and calculated GIS metrics following Boyle et al. (2020). Briefly, we created polygons representing upstream catchments as well as 5-km and 1-km clips of upstream catchments. Within each polygon, we calculated a suite of metrics characterizing natural environmental gradients, such as geology and long-term climatic conditions. Metrics were also calculated based on points representing the sampling location. In addition, we calculated metrics representing human activity gradients, such as land use, road density, and dam density. Geospatial metrics are shown in Table 2.

Table 2. Geospatial metrics used in analysis. Metrics were calculated at multiple spatial scales; ws: watershed scale. 1k: 1-km clip of the watershed scale. 5k: 5-km clip of the watershed scale. point: sampling location. For all metrics ending in "_*", the * is replaced with the appropriate abbreviation shown in the Scales column. All sources of geospatial data are described in Ode et al. (2016) and Boyle et al. (2020).

Type	Subtype	Metric	Description	Scales
Disturbance	Disturbance	ag_*	Sum of % row crops and % pasture (NLCD codes 81 and 82). NLCD year 2016	1k, 5k, ws
Disturbance	Disturbance	ur_*	Sum of % low, % medium and % high intensity urban land use (NLCD codes 22-24) . NLCD year 2016	1k, 5k, ws
Disturbance	Disturbance	agur_*	Sum of % agriculture and % urban. NLCD year 2016	1k, 5k, ws
Disturbance	Disturbance	code_21_*	Percent developed open space (NLCD code 21). NLCD year 2016	1k, 5k, ws
Disturbance	Disturbance	roaddens_*	Density of road classes 1, 2 and 3 (i.e., sum of highway, paved and improved surface road length) plus rail (all classes)	1k, 5k, ws
Disturbance	Disturbance	paved_int_*	Number of intersections between paved roads and NHD flow line network (paved bridges)	1k, 5k, ws
Disturbance	Disturbance	mines	Total count of producer mines in 5-km catchment clip	5k
Disturbance	Disturbance	cnl_pi_pct	Percent of total NHD flow line length in the upstream watershed as canal or pipeline	ws
Disturbance	Disturbance	nrst_dam	Distance to nearest upstream dam (value of -9999 indicates no dam in catchment)	ws
Natural	Atmospheric deposition	AtmCa	Atmospheric deposition of Calcium*	ws
Natural	Atmospheric deposition	AtmMg	Atmospheric deposition of Magnesium*	ws
Natural	Atmospheric deposition	AtmSO4	Atmospheric deposition of Sulfate*	ws
Natural	Climate	LST32AVE	Catchment mean of mean 1961-1990 first and last day of freeze	ws
Natural	Climate	MAXWD_WS	Catchment mean of 1961-1990 annual max number of wet-days	ws
Natural	Climate	MEANP_WS	Catchment mean of mean 1971-2000 annual ppt	ws
Natural	Climate	MINP_WS	Catchment mean of mean 1971-2000 min monthly ppt	ws
Natural	Climate	PPT_00_09	Long-term mean precipitation	point

Type	Subtype	Metric	Description	Scales
Natural	Climate	SumAve_P	Mean June to September 1971 to 2000 monthly precipitation averaged across the entire catchment	ws
Natural	Climate	TEMP_00_09	Average temperature (2000 to 2009) at the sample point	point
Natural	Climate	TMAX_WS	Catchment mean of mean 1971-2000 max temperature	ws
Natural	Climate	XWD_WS	Catchment mean of mean 1961-1990 annual number of wet days	ws
Natural	Geology	BDH_AVE	Average soil bulk density	ws
Natural	Geology	CaO_Mean	Average calcium oxide (quicklime) in the catchment geology	ws
Natural	Geology	KFCT_AVE	Average soil erodibility (K) factor	ws
Natural	Geology	LPREM_mean	Catchment mean log geometric mean hydraulic conductivity	ws
Natural	Geology	MgO_Mean	Average magnesium oxide (magnesia) in the catchment geology	ws
Natural	Geology	N_MEAN	Nitrogen content of the catchment geology	ws
Natural	Geology	P_MEAN	Phosphorous content of the catchment geology	ws
Natural	Geology	PRMH_AVE	Catchment mean soil permeability	ws
Natural	Geology	S_Mean	Sulfur content of the catchment geology	ws
Natural	Geology	UCS_Mean	Catchment mean unconfined Compressive Strength	ws
Natural	Location	New_Lat	Latitude (WGS84) snapped to nearest NHD+ flowline	point
Natural	Location	New_Lat	Longitude (WGS84) snapped to nearest NHD+ flowline	point
Natural	Location	SITE_ELEV	Elevation at snapped point	point
Natural	Other	CondQR01	Predicted 1st percentile of natural levels of specific conductivity from Olson and Cormier (2019)	ws
Natural	Other	CondQR10	Predicted 10th percentile of natural levels of specific conductivity from Olson and Cormier (2019)	ws
Natural	Other	CondQR50	Predicted 50th percentile of natural levels of specific conductivity from Olson and Cormier (2019)	ws
Natural	Other	CondQR90	Predicted 90th percentile of natural levels of specific conductivity from Olson and Cormier (2019)	ws

Type	Subtype	Metric	Description	Scales
Natural	Other	CondQR99	Predicted 99th percentile of natural levels of specific conductivity from Olson and Cormier (2019)	ws
Natural	Other	EVI_MaxAve	Enhanced vegetation index	ws
Natural	Watershed	AREA_SQKM	Watershed area	ws
Natural	Watershed	ELEV_RANGE	Elevation range within watershed	ws
Natural	Watershed	MAX_ELEV	Maximum elevation	ws

Biological data collection

Arthropods on the streambed

Following the protocol described in Robinson et al. (2018), field crews collected biological and physical habitat data at a selection of nonperennial stream sites throughout California. All samples were collected in the summer when sites were dry. At each site, crews designated a representative 160-m reach, which were separated into eight sections. In each section, crews collected channel using ramped pitfall traps (Robinson et al. 2018). Ramped pitfall traps offer advantages over traditional pitfall traps because they reduce disturbance to the habitat, and they are more suitable for sampling in stream beds with hard substrates (i.e., cobbles, bedrock, or concrete) that make digging pitfall traps impractical (Pearce et al. 2005; Patrick and Hansen 2013). The traps were left out for approximately 24 hours to collect both diurnal and nocturnal arthropods, which were stored in jars along with the contents of the traps for later identification. Arthropods were identified to the levels specified in Mazor (2023); briefly, most ants were identified to genus, while most other insects were identified to family, and most non-insects to order.

Arthropods on riparian vegetation

Vegetation-dwelling arthropods were collected on plants in or near the channel, following Robinson et al.'s methodology of visually picking the healthiest plant in each section. Field crews wrapped the plant in a 1-m^2 canvas bag and hit it a total of 30 times (Robinson et al. 2018), using a plastic pipe to dislocate any vegetation-dwelling arthropods. The contents of the bag were placed in a jar and preserved with 70% ethanol for subsequent identification. Arthropods were identified to the levels specified in Mazor (2023); briefly, most ants were identified to genus, while most other insects were identified to family, and most non-insects to order.

Bryophytes

Along with arthropods, bryophytes were collected at each site using a floristic approach (Newmaster et al. 2005; Robinson et al. 2018). First, the assessment reach was divided into three mesohabitats: the right bank, left bank, and the channel bottom. Each mesohabitat was searched for 20 minutes (60 minutes total) to identify locations where bryophytes could be found. Then, 12 minutes were spent in each mesohabitat (36 minutes total) collecting mosses by hand, targeting all microhabitats (e.g., soil, rock, or wood) within a location present. Bryophytes were identified to genus following Mazor et al. (2023).

Biological metric calculation

We calculated a suite of 414 metrics (107 for each Arthropod assemblage and 200 for bryophytes) to characterize major biological gradients in our data set. Some metrics were based on taxonomic composition (e.g., relative abundance of spider taxa, richness of bryophytes in the Pottiaceae family), whereas others were based on species traits (e.g., average body size, percent of bryophyte taxa with fugitive life strategies).

Species traits were acquired from published literature (General insects: Gossner et al. 2015, 2016, Franken et al. 2018, Will et al. 2020; Ants: Snelling 1995, Jumbam et al. 2008, Del Toro et al. 2009, Chown et al. 2009, Parr et al. 2017, Roeder et al. 2021, Lubertazzi et al. 2023; Beetles: Evans and Hogue 2006, Barton et al. 2011, Gossner et al. 2015, Will et al. 2020; Spiders: Gossner et al. 2015, 2016, Ubick et al. 2017, Pekár et al. 2021b ; Isopods: Karagkouni et al. 2016. Bryophytes: Longton 1988, Malcolm et al. 2009, Bernhardt-Römermann et al. 2018, Van Zuijlen et al. 2023). Arthropod traits described native status, aquatic habitat affinity, stratum (e.g., ground-dwelling vs. arboreal), functional feeding group, body size, dispersal ability, and temperature tolerance (Table 3). Bryophyte metrics focused on growth form (e.g., pleurocarp vs. acrocarp), life strategy, generation time, hemeroby (i.e., affinity for manmade environments) and indicator status for a range of environmental gradients (specifically, light, salinity, temperature, heavy metals, acidity, substrate; Table 4).

Table 3. Arthropod traits that were used to derive biological metrics.

Trait	Description/Values	Source(s)
Nonnative/Synanthropy	Native or synanthropic status	Langston and Powell (1975), Snelling (1995), Arnett and Thomas (2001, 2002), Brusca et al. (2001), Ward (2005), Evans and Hogue (2006), Bowser (2012), Ubick et al. (2017), Parr et al. (2017), Shultz (2018), Will et al. (2020), Lubertazzi et al. (2023)
Aquatic	Aquatic status: • Not aquatic • Some aquatic taxa • Aquatic	Merritt et al. (2019)
Stratum	Stratum where the taxon occurs • Ground or soil layer • Herbaceous layer • Tree layer • Water • Unspecific	Gossner et al. (2015), Ubick et al. (2017), Lubertazzi et al. (2023)
Functional feeding group	Feeding mode of the taxon • Predator • Detritivore • Fungivore • Algivore • Herbivore • Omnivore • Nonfeeding adult	Evans and Hogue (2006), Barton et al. (2011), Gossner et al. (2015), Ubick et al. (2017), Parr et al. (2017), Merritt et al. (2019), Will et al. (2020)

Trait	Description/Values	Source(s)
Body size	Mean maximum body size (mm)	Evans and Hogue (2006), Del Toro et al. (2009), Gossner et al. (2015), Karagkouni et al. (2016), Ubick et al. (2017), Parr et al. (2017), Will et al. (2020), Pekár et al. (2021a)
Dispersal ability	Ranked dispersal ability ranging from 0 (poor dispersers) to 1 (strong dispersers) in increments of 0.25	Gossner et al. (2015)
Maximum thermal tolerance	Maximum thermal tolerance in °C.	Jumbam et al. (2008), Karagkouni et al. (2016), Franken et al. (2018), Roeder et al. (2021)

Table 4. Bryophyte traits that were used to derive biological metrics

Trait	Description/Values	Source(s)
Life strategy	Life strategy, as defined by Dierßen (2001) • Colonist • Fugitive • Annual shuttle • Short-lived shuttle • Long-lived shuttle • Perennial	Dierßen (2001), Bernhardt-Römermann et al. (2018), Van Zuijlen et al. (2023)
Life form	Life form • Turf • Cushion • Mat • Weft	Bernhardt-Römermann et al. (2018), Van Zuijlen et al. (2023)
Growth form	Growth form • Acrocarpous • Pleurocarpous	Bernhardt-Römermann et al. (2018), Van Zuijlen et al. (2023)
Generation time	Generation time • Short (1 to 5 years) • Medium (6 to 10 years) • Long (11 to 25 years)	Dierßen (2001), Van Zuijlen et al. (2023)
Light indicator value	Light affinity, ranging from 1 (deep shade) to 9 (full light)	Van Zuijlen et al. (2023)
Temperature indicator value	Temperature affinity, ranging from 1 (alpine-nival) to 9 (extreme warmth indicator)	Van Zuijlen et al. (2023)
Moisture indicator value	Moisture affinity, ranging from 1 (extreme dryness) to 9 (wet-site indicator	Van Zuijlen et al. (2023)
Acidity indicator value	Acidity affinity, ranging from 1 (extreme acidity) to 9 (high pH soils)	Van Zuijlen et al. (2023)
Nutrient indicator value	Nutrient affinity, ranging from 1 (nutrient poorest) to 9 (nutrient richest)	Simmel et al. (2021), Van Zuijlen et al. (2023)
Salinity indicator value	Salinity tolerance, ranging from 0 (absent from saline sites) to 5 (highest salt tolerance)	Van Zuijlen et al. (2023)

Trait	Description/Values	Source(s)
Heavy metal indicator value	Heavy metal tolerance, ranging from 0 (absent from sites with moderate to high heavy metal concentrations) to 5 (confined to sites with moderate to high heavy metal concentrations)	Van Zuijlen et al. (2023)
Substrate affinity	Substrate affinity (not mutually exclusive): • Carcass or dung • Bark • Epiphytic on non-woody living substrate • Rock • Soil • Dead wood	Van Zuijlen et al. (2023)
Aquatic	Aquatic status • Aquatic • Not aquatic	Van Zuijlen et al. (2023)
Habitat affinity	Habitat affinity (not mutually exclusive) • Artificial/terrestrial • Forest • Grassland • Rocky areas • Shrublands • Wetlands (inland)	Van Zuijlen et al. (2023)
Forest	Affinity for forest habitat, ranked from 1 (restricted to closed forests) to 4 (may occur in forests but prefers open land)	Van Zuijlen et al. (2023)
Hemeroby	Affinity for disturbed habitats, ranked in two ways: • Influence of man on habitats in which the species is found, ranked from 1 (mainly in natural habitats) to 5 (mainly in hemerobic environments. • Occurrence in the gradient of background human impact on the ecosystem, ranked from 1 (absent) to 9 (very strong)	Bernhardt-Römermann et al. (2018), Van Zuijlen et al. (2023)
Temperature affinity	Temperature affinities in terms of: • Diurnal range • Isothermality • Seasonality • Maximum temperature in coldest and warmest months • Annual range • Mean temperature during the warmest and coldest quarters	Van Zuijlen et al. (2023)
Precipitation	Precipitation affinities in terms of: • Mean annual precipitation • Total precipitation in the wettest and driest months and quarters • Seasonality • Total precipitation in the warmest and coldest quarters	Van Zuijlen et al. (2023)
Growing degree days	Sum heat and number of growing degree days: • Above 0°C • Above 5°C • Above 10°C	Van Zuijlen et al. (2023)

A total of 124 metrics were calculated to characterize arthropod assemblages (Table 5). Most metrics were calculated using four standard formulations: richness, abundance, relative richness, and relative abundance. Metrics based on the non-native Argentine ant (*Linepithema humile*) did not include a richness formulation. Metrics based on the average and maximum body size were also calculated. Metrics were calculated separately for streambed samples and vegetation samples.

200 metrics were calculated to characterize bryophyte assemblages (Table 6). Bryophyte metrics were based on life history, indicator values, and habitat affinity traits, in addition to metrics based on taxonomic composition. Bryophyte traits were derived from the Bryophytes of Europe Traits database (BET; Van Zuijlen et al. 2023a, 2023b), a database of ecological, biological, and bioclimatic traits for bryophyte species occurring in Europe. There is a strong overlap between species found in California and the BET database as a majority of North American species are also found in Europe (Frahm and Vitt 1993). Traits based on indicator values should be interpreted as reflecting the ecological conditions under which a species is typically found (i.e., affinities), which may be different from their preferred or optimal growing conditions (Simmel et al. 2021). Biological traits include: life strategy (i.e., fugitive, annual shuttle, short-lived shuttle, long-lived shuttle, colonist, or perennial; During 1979, 1992); growth form (i.e., acrocarpous or pleurocarpous); and generation time (i.e., ~3.3, 6.7, or 16.7 years; Dierßen 2001). Ecological traits include: affinity for moisture, substrate, acidity, salinity, light, nutrients, and heavy metals; habitat affinities (e.g., forest, grasslands, wetlands, etc.); and hemeroby (i.e., affinity for pristine habitats versus those dominated by human activity). Bioclimatic variables include: affinity for precipitation and air temperature; growing degree days heat sums (heat sum of days above 0°C; 5°C; 10°C over one year), and number of growing degree days over a set of temperatures (0°C; 5°C; 10°C). Where necessary, trait information in the BET database was supplemented with information from other sources (i.e., Longton 1988, Malcolm et al. 2009, Sagar and Wilson 2009, Bernhardt-Römermann et al. 2018). Because bryophyte taxonomy data were based on presence-absence, most ecological and biological metrics were formulated as richness or relative richness, while bioclimatic metrics were mostly formulated using maxima, minima, or means.

Table 5. Arthropod metrics calculated in this study. R: Richness. A: Abundance. RR: Relative richness. RA: Relative abundance.

Metric type	Group	Abbreviation	Formulations
Taxonomic	Arthropods	Arth	R, A
Taxonomic	Insects	Insect	R, A, RR, RA
Taxonomic	Non-insects	Noninsect	R, A, RR, RA
Taxonomic	Coleoptera	Coleo	R, A, RR, RA
Taxonomic	Hemiptera	Hemip	R, A, RR, RA
Taxonomic	Araeneae	Araeneae	R, A, RR, RA
Taxonomic	Araeneae (native, non-synanthropic)	Araeneae_Nat	R, A, RR, RA
Taxonomic	Formicidae	Formicidae	R, A, RR, RA
Taxonomic	Formicidae (native, non-synanthropic)	Formicidae_Nat	R, A, RR, RA
Taxonomic	Coleoptera, Araneae, and Formicidae	CAF	R, A, RR, RA
Taxonomic	Coleoptera, Araneae, and Formicidae (native, non-synanthropic)	CAF_Nat	R, A, RR, RA
Taxonomic	Non-native taxa	Nonnat	R, A, RR, RA
Taxonomic	Non-native and synanthropic taxa	NonnatSynanth	R, A, RR, RA
Taxonomic	*Linepithema Humile*	LinEpi	A, RR, RA
Habitat	Aquatic taxa	Aquatic	R, A, RR, RA
Habitat	Ground layer taxa	Ground	R, A, RR, RA
Habitat	Herbaceous layer taxa	Herbaceous	R, A, RR, RA
Habitat	Arboreal layer taxa	Arboreal	R, A, RR, RA
Feeding style	Detritivores	Detritivore	R, A, RR, RA
Feeding style	Fungivores	Fungivore	R, A, RR, RA
Feeding style	Detritivores and Fungivores	DetrFung	R, A, RR, RA
Feeding style	Predators	Predator	R, A, RR, RA
Feeding style	Ground predators	PredatorGround	R, A, RR, RA
Body size	Small-bodied taxa (<9 mm)	BodySizeSmall	R, A, RR, RA
Body size	Medium-bodied taxa (9 to 16 mm)	BodySizeMedium	R, A, RR, RA
Body size	Large-bodied taxa (>16 mm)	BodySizeLarge	R, A, RR, RA
Body size	Largest body size	BodySizeLargest	Maximum
Body size	Average body size	BodySizeAverage	Average
Dispersal ability	Poor dispersers	DisperserPoor	R, A, RR, RA
Dispersal ability	Good dispersers	DisperserGood	R, A, RR, RA

Table 6. Bryophyte metrics calculated in this study. R: Richness. RR: Relative richness. Min: Minimum value. Mean: Mean value. Max: Maximum value.

Metric Type	Group	Abbreviation	Formulations
Acidity affinity	All	indR	Max, Min, Mean
Acidity affinity	Acidity affinity rating 8 or higher	indR_High	R, RR
Generation time	Long generation (>16.7 years)	Long_Generation	R, RR
Generation time	Medium generation (6	Medium_Generation	R, RR
Generation time		Short_Generation	R, RR
Growth form	Acrocarpous	Acrocarp	R, RR
Growth form	Pleurocarpous	Pleurocarp	R, RR
Habitat		Aquatic	R, RR
Habitat		Forest_And_Open_Land	R, RR
Habitat		Forest_Edge	R, RR
Habitat		Forest_Only	R, RR
Habitat		Forest_Only_and_Edge	R, RR
Habitat		Forest_Open_land_Preference	R, RR
Habitat		hab_ar	R, RR
Habitat		hab_fo	R, RR
Habitat		hab_gr	R, RR
Habitat		hab_ro	R, RR
Habitat		hab_sh	R, RR
Habitat		hab_sum_High	R, RR
Habitat		hab_sum_Low	R, RR
Habitat		hab_we	R, RR
Heavy metal tolerance		indHM	Max, Mean
Heavy metal tolerance		indHM_Low	R
Hemeroby		Hem_e_Distubred	R, RR
Hemeroby		Hem_e_Indifferent	R, RR
Hemeroby		Hem_e_Indifferent_Disturbed	R, RR
Hemeroby		Hem_e_Undisturbed	R, RR
Hemeroby		Hemeroby	Max, Min, Mean
Hemeroby		Hemeroby_High	R, RR
Life strategy		Annual_Shuttle	R, RR
Life strategy		Colonist	R, RR
Life strategy		FC	R, RR
Life strategy		FCA	R, RR
Life strategy		FCAS	R, RR
Life strategy		Fugitive	R, RR

Metric Type	Group	Abbreviation	Formulations
Life strategy		Long_Lived_Shuttle	R, RR
Life strategy		PL	R, RR
Life strategy		Perennial	R, RR
Life strategy		Short_Lived_Shuttle	R, RR
Light affinity		indL	Max, Min, Mean
Light affinity		indL_High	R, RR
Moisture affinity		indF	Max, Min, Mean
Moisture affinity		indF_High	R, RR
Moisture affinity		indF_Low	R, RR
Nutrient affinity		indN	Max, Min, Mean
Nutrient affinity		indN_High	R, RR
Nutrient affinity		indN_Low	R, RR
Precipitation affinity		MAP	Max, Min, Mean
Precipitation affinity		P_coldQ	Max, Min, Mean
Precipitation affinity		P_dryM	Max, Min, Mean
Precipitation affinity		P_dryQ	Max, Min, Mean
Precipitation affinity		P_warmQ	Max, Min, Mean
Precipitation affinity		P_wetM	Max, Min, Mean
Precipitation affinity		P_wetQ	Max, Min, Mean
Precipitation affinity		Ppt_seas	Max, Min, Mean
Salt affinity		indS	Max, Min, Mean
Salt affinity		indS_Low	R
Substrate affinity		sub_ba	R, RR
Substrate affinity		sub_ro	R, RR
Substrate affinity		sub_so	R, RR
Substrate affinity		sub_sum_High	R, RR
Substrate affinity		sub_sum_Low	R, RR
Substrate affinity		sub_wo	R, RR
Taxonomic		Bryaceae	R, RR
Taxonomic		Bryo	R
Taxonomic		Grimmiaceae	R, RR
Taxonomic		Pottiaceae	R, RR
Temperature affinity		T_DiurR	Max, Min, Mean
Temperature affinity		T_annualR	Max, Min, Mean

Metric Type	Group	Abbreviation	Formulations
Temperature affinity		T_coldQ	Max, Min, Mean
Temperature affinity		T_dryQ	Max, Min, Mean
Temperature affinity		T_warmQ	Max, Min, Mean
Temperature affinity		T_wetQ	Max, Min, Mean
Temperature affinity		Temp_seas	Max, Min, Mean
Temperature affinity		Therm_iso	Max, Min, Mean
Temperature affinity		Tmax_warmM	Max, Min, Mean
Temperature affinity		Tmin_coldM	Max, Min, Mean
Temperature affinity		gdd0	Max, Min, Mean
Temperature affinity		gdd10	Max, Min, Mean
Temperature affinity		gdd5	Max, Min, Mean
Temperature affinity		indT	Max, Min, Mean
Temperature affinity		indT_High	R, RR
Temperature affinity		indT_Low	R, RR
Temperature affinity		ngd0	Max, Min, Mean
Temperature affinity		ngd10	Max, Min, Mean
Temperature affinity		ngd5	Max, Min, Mean

Data analysis

Identification of less-disturbed "reference" and "stressed" sites

California has established criteria for identifying minimally disturbed reference sites for perennial and intermittent wadeable streams (Ode et al. 2016); in addition, Mazor et al. (2016) presented criteria for identifying "stressed" sites with high levels of human activity. Whereas having many broad-based reference criteria are helpful to identify minimally disturbed sites, only a small number of stressed criteria are needed to identify sites where human activity is likely to have degraded biological condition. We evaluated sites in this data set against criteria adapted from those studies (Table 7).

Table 7. Criteria used to screen reference and stressed sites from disturbance metrics. Reference criteria are adapted from Ode et al. (2016), whereas stress criteria are adapted from Mazor et al. (2016). Agricultural land use was calculated as the combined percent cover of categories 81 and 82 in the 2016 version of the National Land Cover Dataset (NLCD; Jon Dewitz 2024). Urban land use was calculated as the combined percent land cover of categories 22 through 24. 1k: Metric calculated at the 1 km-clip of the watershed. 5k: Metric calculated at the 5 km-clip of the watershed. ws: Metric calculated at the entire watershed scale.

Disturbance metric	Spatial scale	Reference criterion	Stress criterion
Agricultural land use	1k, 5k, ws	<3%	None
Urban land use	1k, 5k, ws	<3%	None
Agricultural + urban land use	1k, 5k, ws	<5%	None
"code 21" land use	1k, 5k	<7%	None
"code 21" land use	ws	<10%	None
Agricultural + urban + "code 21" land use	1k, 5k, ws	None	≥50%
Road density	1k, 5k, ws	<2 km/km2	≥5
Paved road intersections	1k	<5	None
Paved road intersections	5k	<10	None
Paved road intersections	ws	<50	None
Distance to nearest dam	ws	>10 km	None
Canals and pipes	ws	<10%	None
Maximum human activity proximity metric	Reach	<1.5	≥5

Biological data

We summarized biological data by evaluating the frequency of major taxonomic groups (e.g., certain insect orders) across samples, and identifying the most speciose groups for each sampling method.

Identification of biological gradients through multivariate ordination

In order to identify and characterize major biological gradients that differentiate sites, we conducted nonmetric multidimensional scaling (NMS) on each of the three assemblages (i.e., arthropods collected from traps, arthropods collected from vegetation, and bryophytes) independently.

Evaluation of biological metrics

We evaluated the suitability of biological metrics for bioassessment applications:

Percent dominance: We calculated the frequency of the most common metric values in samples. Metrics with dominance ≥95% are less suitable for bioassessment purposes because they lack sufficient variation in metric values.

Responsiveness: We evaluated responsiveness using an analysis of variance (ANOVA) of metric values against stress levels. Metrics with a p-value <0.01 were considered responsive. ANOVAs were conducted only on those metrics with <95% dominance.

RESULTS

Identification of reference sites

Sixteen of the 99 sites met the criteria for reference sites presented in Table 7. The most sensitive criterion was the field-based proximity-weighted measure of human activity, for which only 34 sites met the reference criterion. In contrast, nearly half of the sites (n=44) met the next most sensitive criterion (i.e., road density within a 5 km-clip of the watershed). However, none of the sites that met all geospatial reference criteria failed the field-based human activity criterion, suggesting that the field-based criterion did not add new information not provided by the geospatial criteria. The least sensitive criteria included agricultural land use (all scales), the distance to the nearest upstream dam, and the number of paved road intersections (all scales) were the least sensitive criteria; between 80 to 95 of the sites met criteria for these disturbance metrics (Table 8, Figure 2). 51 of the 99 sites met the criteria for high levels of stress. The percentage of sites exceeding criteria in Table 7 ranged from a low of 33% (for % development in the watershed) to a high of 42% (for % development within a 1-km clip of the watershed). Local-scale screens identified more stressed sites than did 5-km or watershed-scale screens.

Table 8. Sensitivity of disturbance metrics for rejecting sites from reference site status.

Disturbance metric	% sites passing reference criterion
Max_HumanActivity_prox	34%
roaddens_5k	44%
roaddens_ws	45%
agur_1k	46%
agur_5k	47%
agur_ws	47%
roaddens_1k	48%
urban_1k	48%
urban_5k	48%
urban_ws	48%
code_21_1k	52%
code_21_5k	58%
code_21_ws	75%
paved_int_5k	81%
cnl_pi_pct	87%
paved_int_1k	89%
ag_ws	92%
paved_int_ws	92%
mines	93%
ag_5k	94%
nrst_dam	95%

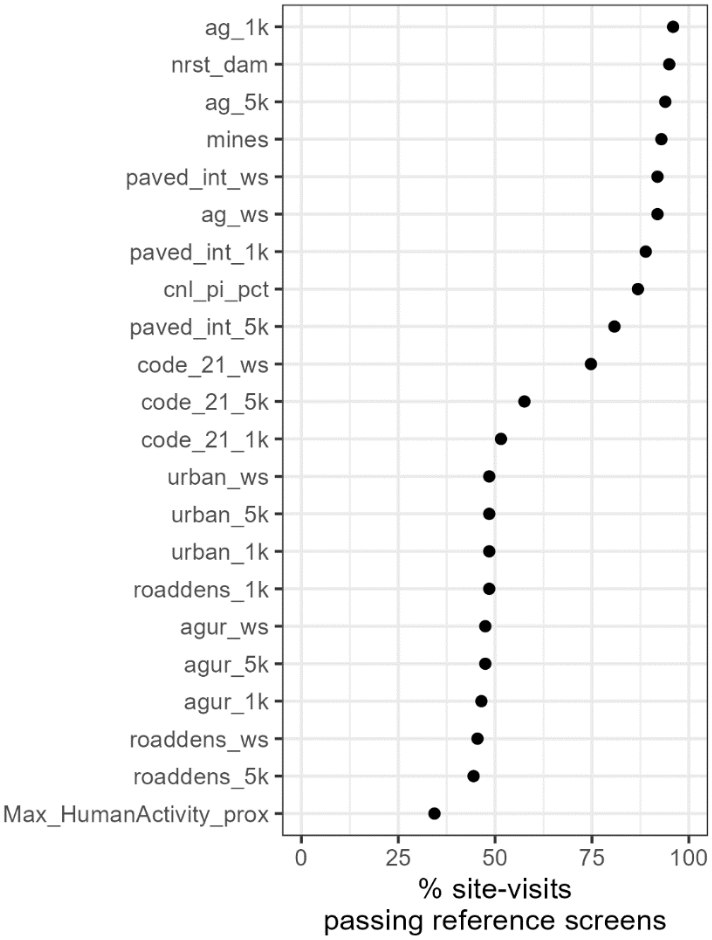

Figure 2. Sensitivity of reference screening criteria

Summary of biological data

A total of 53 bryophyte taxa and 183 arthropod taxa were identified (138 from streambed samples and 117 from riparian vegetation samples; 72 taxa were found using both collection methods). Overall, richness was greater in the streambed arthropod samples than in the other two types of samples (Table 9).

Table 9. Taxonomic richness of samples in this study. Numbers for bryophytes exclude the 7 samples where no bryophytes were observed.

Assemblage	**Minimum**	**Median**	**Maximum**
Bryophytes	1	6	14
Streambed arthropods	2	15	34
Riparian arthropods	1	11	23

Among bryophyte samples, the most common taxa were in the family Pottiaceae, followed by Bryaceae, both of which were found in more than 90% of samples (Figure 3). The next-most-common Bryophyte families (e.g., Fissidentaceae, Grimmaceae) were found in fewer than half of all samples. Bryaceae were also the most speciose group, containing 20 distinct taxa.

Among arthropod samples, Formicidae were the most common taxa collected from the streambed, occurring at 98% of samples (Figure 3). The next most common taxa in streambed samples were Diptera (93% of samples), Coleoptera (88%), and Hemiptera (77%). For arthropods sampled from vegetation, Hemiptera were the most common (91% of samples), followed by Formicidae (88%), Coleoptera (75%), and Thysanoptera (64%). Araneae were found in 30% of vegetation samples and 25% of streambed samples, making them relatively uncommon among arthropod taxa. Among streambed samples, Coleoptera were the most speciose group, containing 29 taxa (however, not all of these taxa may be distinct, and taxa left at the subfamily level were counted even if genera in those subfamilies were already counted). For vegetation samples, Hemiptera were the most speciose group, with 32 taxa.

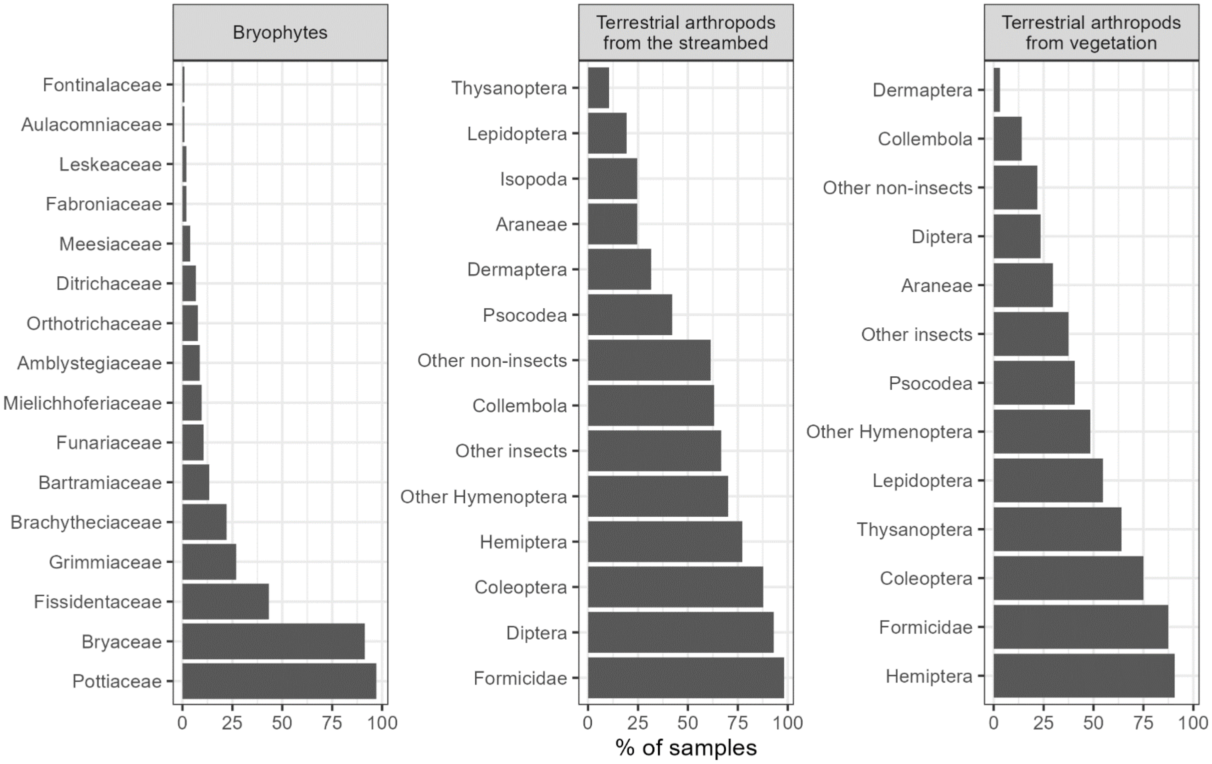

Figure 3. Frequency of collecting major groups of taxa across samples

Non-native taxa were common among the arthropods. By far, the most common nonnative taxon was the Argentine ant, *Linepithema humile*, which occurred in 61% of vegetation samples and 68% of riparian vegetation samples. The remaining nonnative taxa were only commonly observed in streambed samples. These taxa included the earwig *Euborellia* (30% of samples), the isopod *Porcellio laevis* (10% of samples) and ants in the genus *Cardiocondyla* (9% of samples). No non-native bryophyte taxa were identified based on this level of taxonomic resolution.

Review of trait completeness

Among arthropods, coverage of trait information varied widely by group and trait category (Table 10a). For example, native or synanthropic status was known for nearly 100% of all taxa, and functional feeding group was known for over 80% of the five most frequently observed groups of arthropods. Other traits had much more limited information. For example, dispersal was known for two-thirds of beetle taxa and over 40% of hemipteran taxa, but was minimally covered in other arthropod groups. In contrast, coverage of bryophyte taxa was much better, with the majority of taxa having coverage in all traits (Table 10b).

Table 10a. Percent of taxa within major groups of arthropods with trait information used to calculate metrics.

Group	# taxa	Body size	Functional feeding group	Dispersal	Nativeness or synanthropy	Stratum
Coleoptera	38	95	87	66	100	66
Hemiptera	37	68	89	41	100	46
Other insects	23	74	83	13	96	30
Formicidae	22	77	95	0	100	95
Araneae	8	100	100	0	100	0
Other Hymenoptera	8	13	38	0	100	0
Other non-insects	6	17	100	0	100	17
Lepidoptera	5	0	100	0	100	0
Isopoda	4	75	100	0	100	100
Collembola	3	100	100	0	100	0
Dermaptera	3	67	100	0	100	100
Diptera	3	0	0	0	100	0
Psocodea	1	100	100	0	100	0
Thysanoptera	1	100	100	0	100	0

Table 10b. Percent of taxa within major groups of bryophytes with trait information used to calculate metrics.

Family	# taxa	Growth form	Life strategy	Generation length	Hemeroby	Habitat	Moisture, light and acidity	Nutrients	Metals and salts	Climate
Pottiaceae	20	100	85	90	60	95	95	90	85	95
Other Families	9	89	78	78	78	89	89	89	67	89
Bryaceae	5	100	40	60	60	60	60	60	60	60
Grimmiaceae	5	100	100	80	100	100	100	100	100	100
Brachytheciaceae	4	100	100	100	100	100	100	100	100	100
Bartramiaceae	3	100	67	100	67	100	67	67	67	100
Funariaceae	3	100	100	100	67	100	100	100	100	100
Amblystegiaceae	2	100	100	100	100	100	100	100	100	100
Ditrichaceae	2	100	100	100	100	100	100	100	100	100

Ordination of biological data

Nonmetric multidimensional scaling showed that arthropod assemblages collected by traps (i.e., arthropods from the streambed) more easily distinguished samples high- and low-disturbance sites than did samples collected by other methods (Figure 4). For all assemblages, reference sites tended to have more homogenous composition (i.e., reference sites were clustered together in ordination space) compared to sites with more disturbance.

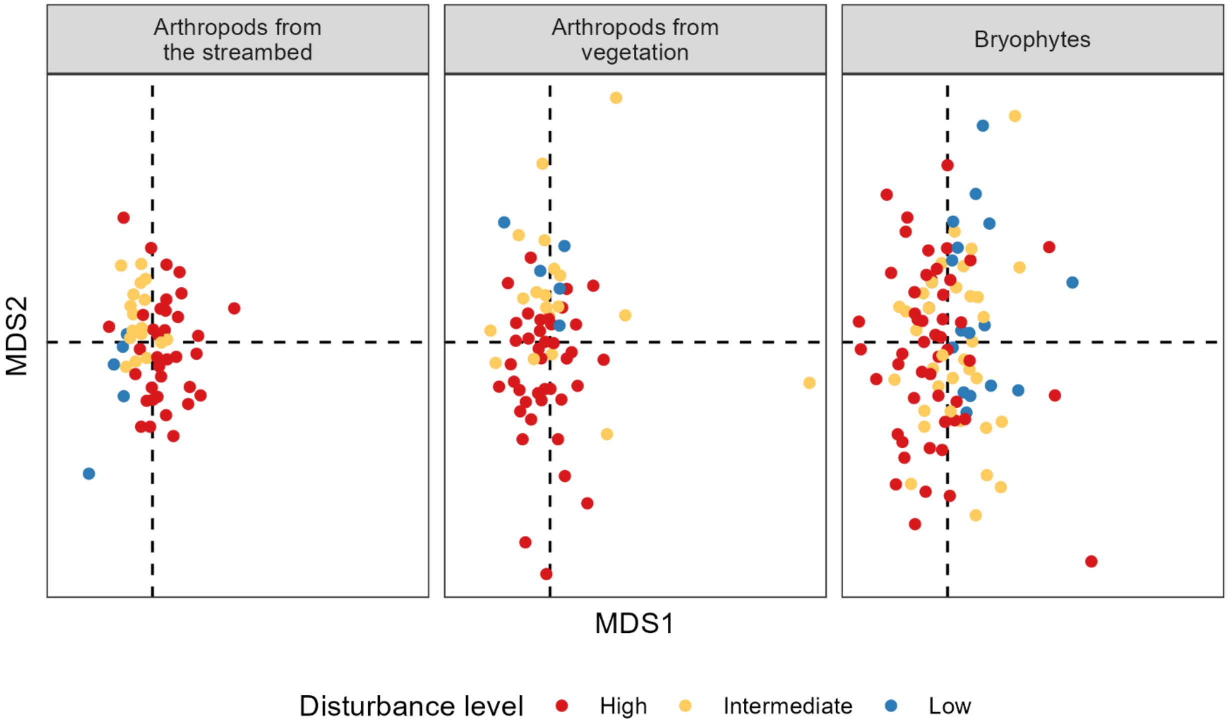

Figure 4. Nonmetric multidimensional scaling (MDS) plots of arthropod and bryophyte assemblages. Each point represents a sample.

Most major taxonomic groups did not show strong clustering in ordination plots (Figure 5a through c). Among streambed arthropod samples, several Formicidae had low scores on Axis 1, suggesting that they had higher abundance at low-disturbance sites. In contrast, other groups like Coleoptera, Araneae, and Hemiptera, were more evenly distributed across the ordination-space (Figure 5a). No clear patterns were evident for the arthropods on vegetation (Figure 5b). Among the Bryophytes, Brachytheciaceae, Grimmiaceae, and Pottiaceae were primarily grouped on the right side of Axis 1, indicating their predominance at low-disturbance sites (Figure 5c).

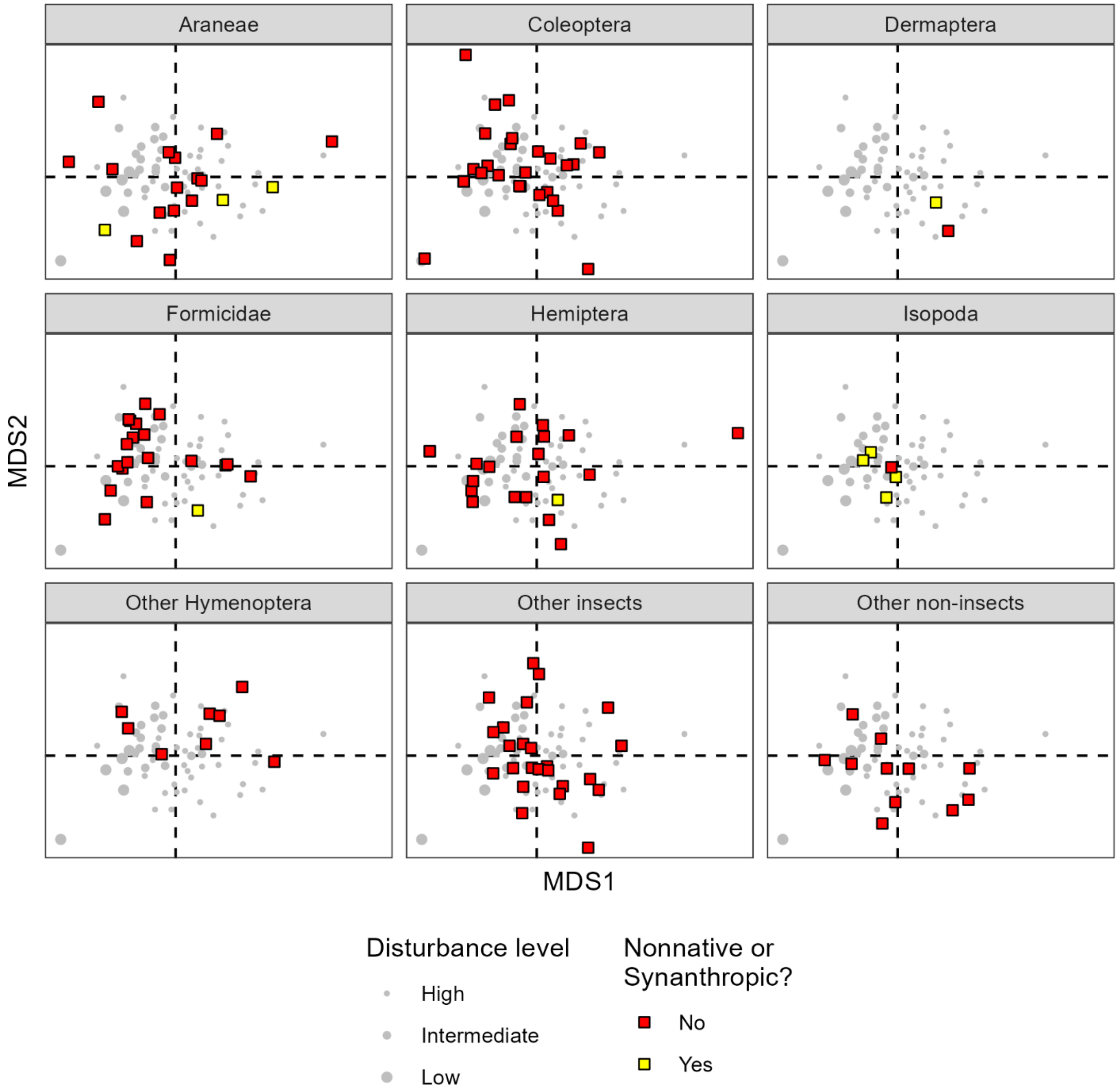

Figure 5a. Weighted average scores of taxa in MDS ordinations of arthropods on the streambed. Each square represents a taxon, with color indicating if the taxon is primarily nonnative or synanthropic (e.g., the Argentine ant, *Linepithema humile*). These squares overlay a set of gray circles representing samples.

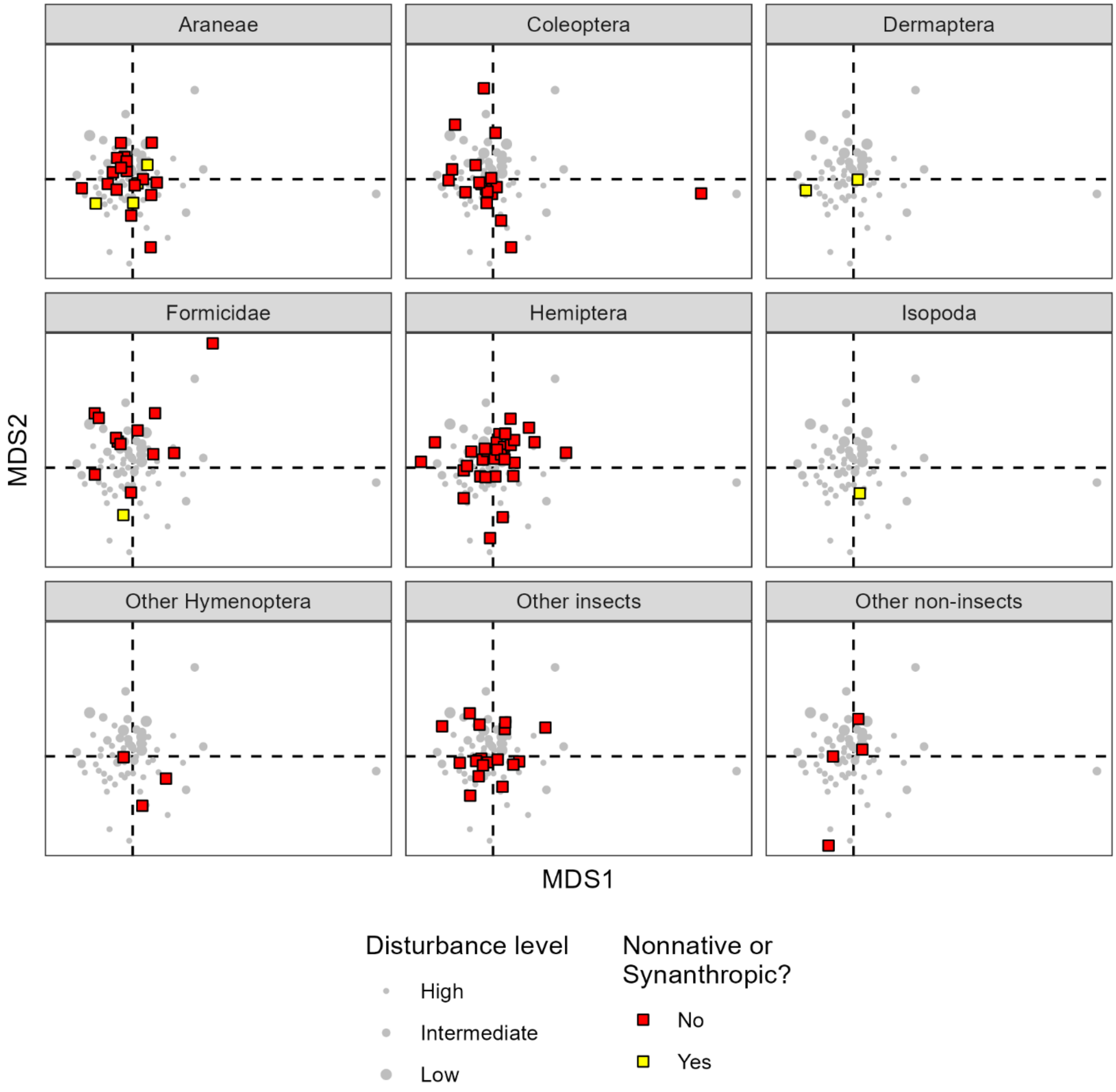

Figure 5b. Weighted average scores of taxa in MDS ordinations of arthropods on vegetation. Each square represents a taxon, with color indicating if the taxon is primarily nonnative or synanthropic (e.g., the Argentine ant, *Linepithema humile*). These squares overlay a set of gray circles representing samples.

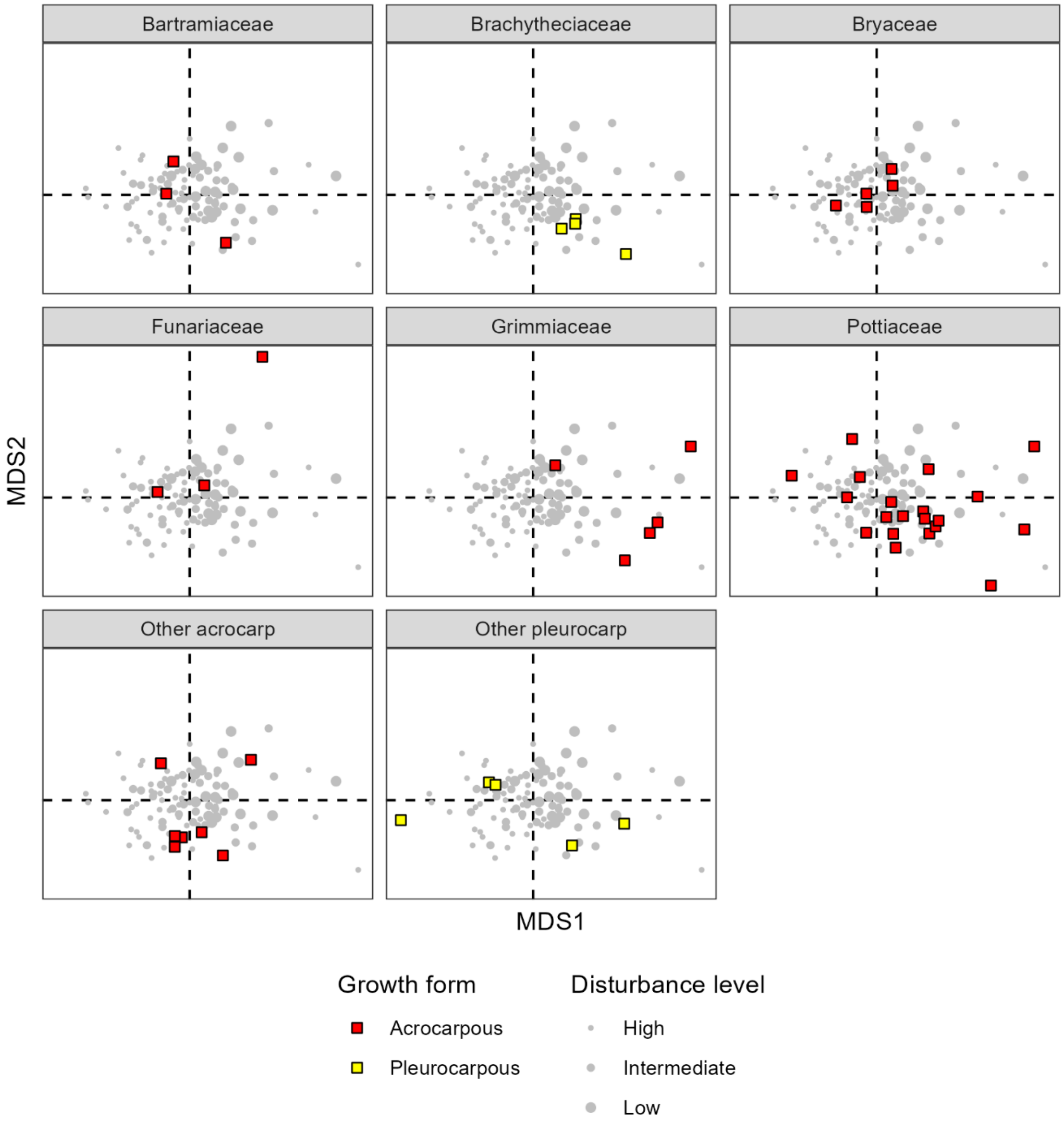

Figure 5c. Weighted average scores of taxa in MDS ordinations of bryophytes. Each square represents a taxon. These squares overlay a set of gray circles representing samples.

In general, biological, geospatial, and habitat metrics all had relatively strong relationships with ordination axis scores that were consistent with the distribution of high- versus low-disturbance sites (Figure 6a through c). For example, metrics related to nonnative taxa had strong, positive correlations with Axis 1 for the ordination of arthropods from the streambed or with Axis 2 for the ordination of arthropods from vegetation. Taxa with larger average body sizes were more common at less-disturbed sites for both arthropod assemblages. The richness of native Coleoptera, Araneae, and Formicidae had a particularly strong relationship with the major axis separating low-disturbance sites from other sites in both arthropod ordinations (Figure 6a and b). For the bryophyte ordination, the strongest correlations were observed for biological metrics related to climatic affinities or moisture, indicating that taxa more tolerant of arid conditions were more common at sites with high values on Axis 2, whereas those preferring cooler, wetter conditions were found at sites with low scores on Axis 2 (Figure 6c). Less-disturbed sites were also associated with higher values of metrics related to low heavy metal tolerance, low salinity tolerance, affinity for natural (vs. hemerobic) habitats, affinity for rocky substrate, and life strategies and certain life strategies (i.e., fugitive, colonist, and annual shuttle taxa).

Correlations between biological metrics and environmental metrics

In general, metrics related to arthropods from the streambed had stronger relationships with environmental metrics than metrics related to arthropods from vegetation, which in turn had stronger relationships than bryophyte metrics (Figure 7 through Figure 9). Metric formulation did not have a strong impact on arthropod metrics. In contrast, bryophyte metrics based on relative richness were much weaker than bryophyte metrics based on richness, perhaps reflecting the frequency of samples where few taxa had assigned traits (which can make it difficult to estimate relative richness metrics). The strongest relationships between biological metrics and environmental metrics were between metrics related to invasive or native species of arthropods versus metrics related to disturbance. Responses of selected metrics with the strongest correlations to geospatial and field-measured disturbance measures are shown in Figure 10. In general, arthropod metrics had stronger relationships with watershed-scale measures of disturbance, whereas bryophyte metrics had stronger relationships with field-based measures of disturbance.

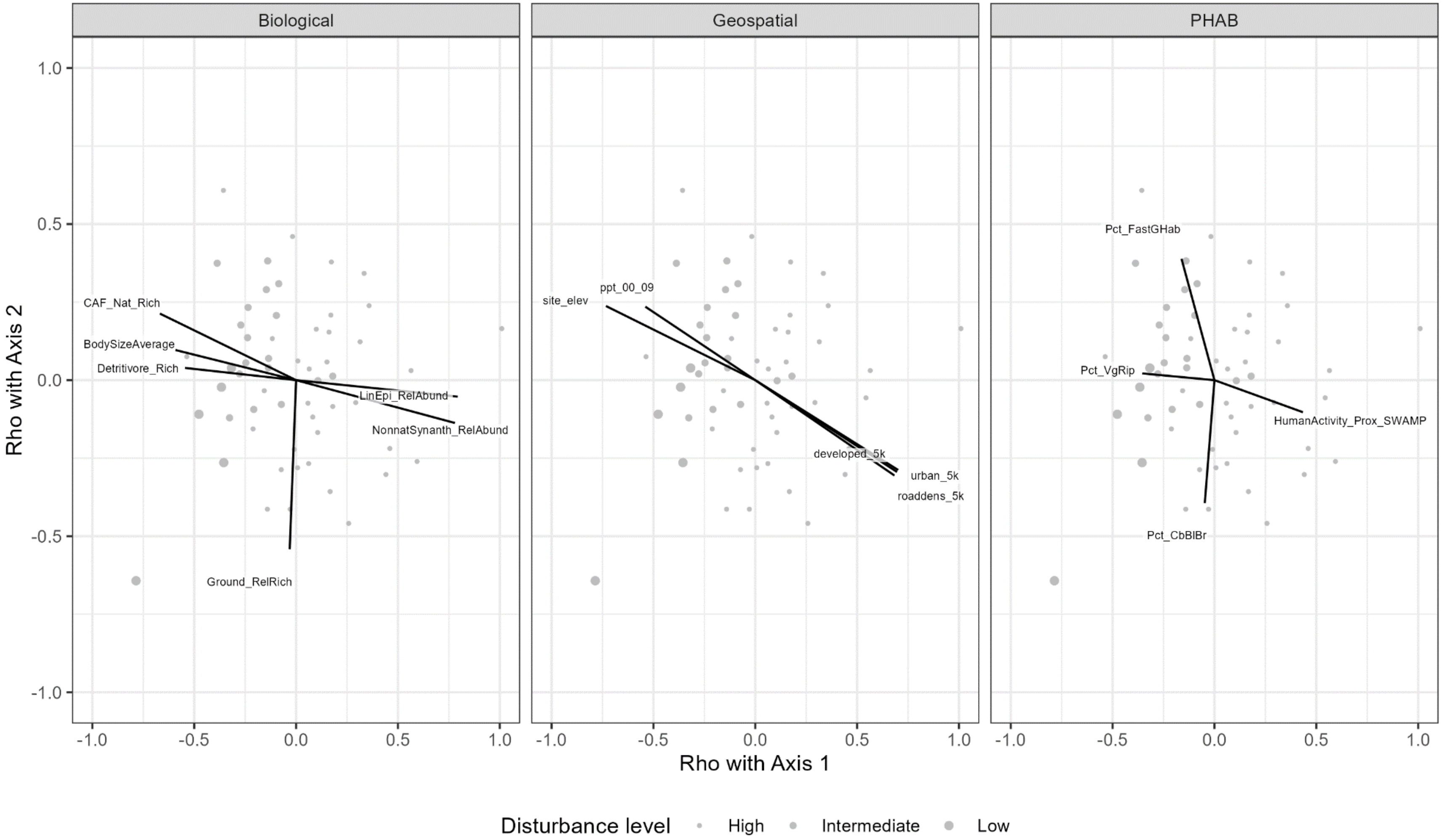

Figure 6a. Spearman rank correlations between selected biological, geospatial, or habitat metrics with axes of the ordination of arthropods from the streambed. Each metric is represented by a labeled vector; metric abbreviations are shown in Table 1 through Table 5. These vectors overlay a set of gray circles representing samples.

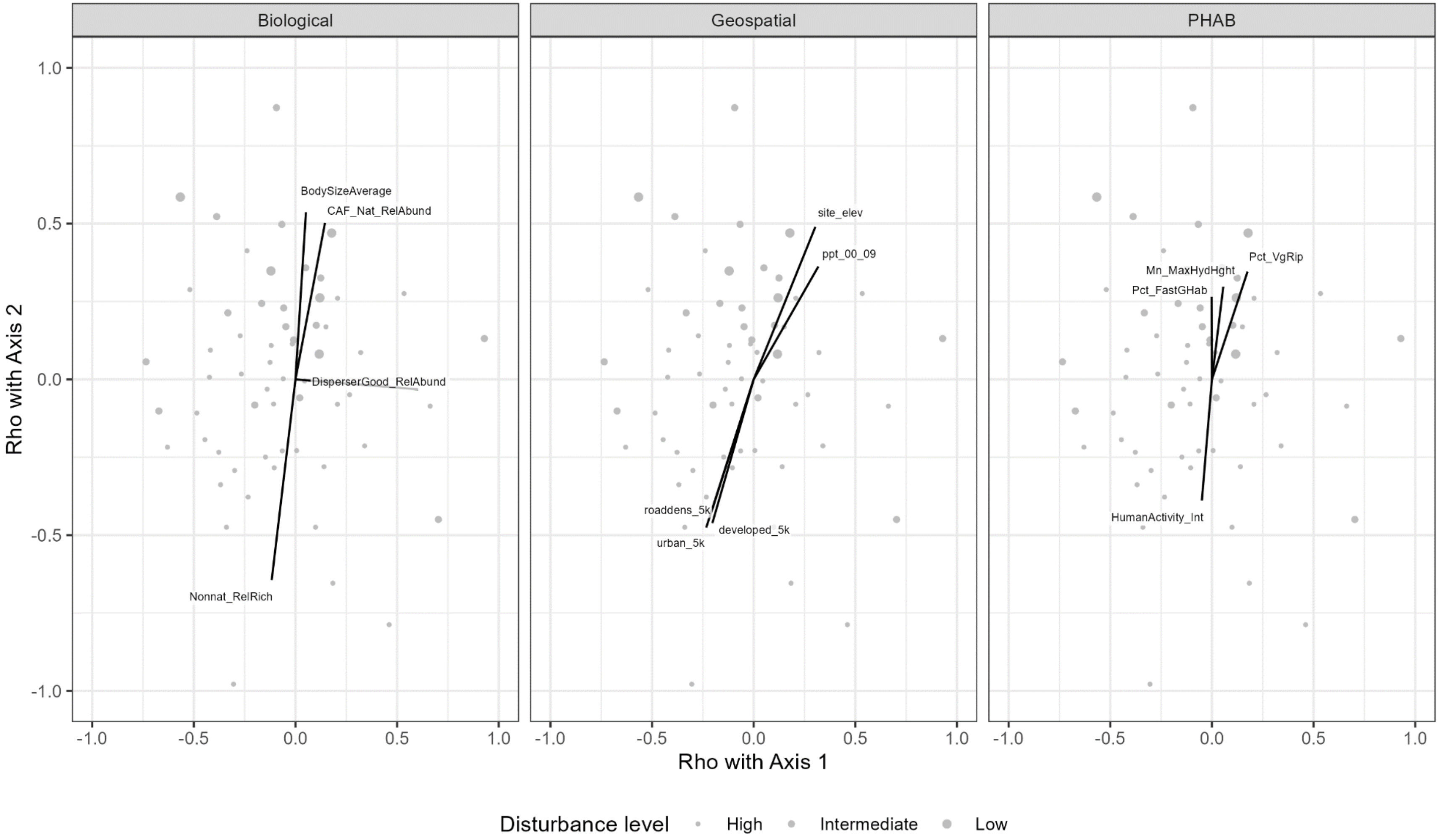

Figure 6b. Spearman rank correlations between selected biological, geospatial, or habitat metrics with axes of the ordination of arthropods from the vegetation. Each metric is represented by a labeled vector; metric abbreviations are shown in Table 1 through Table 5. These vectors overlay a set of gray circles representing samples.

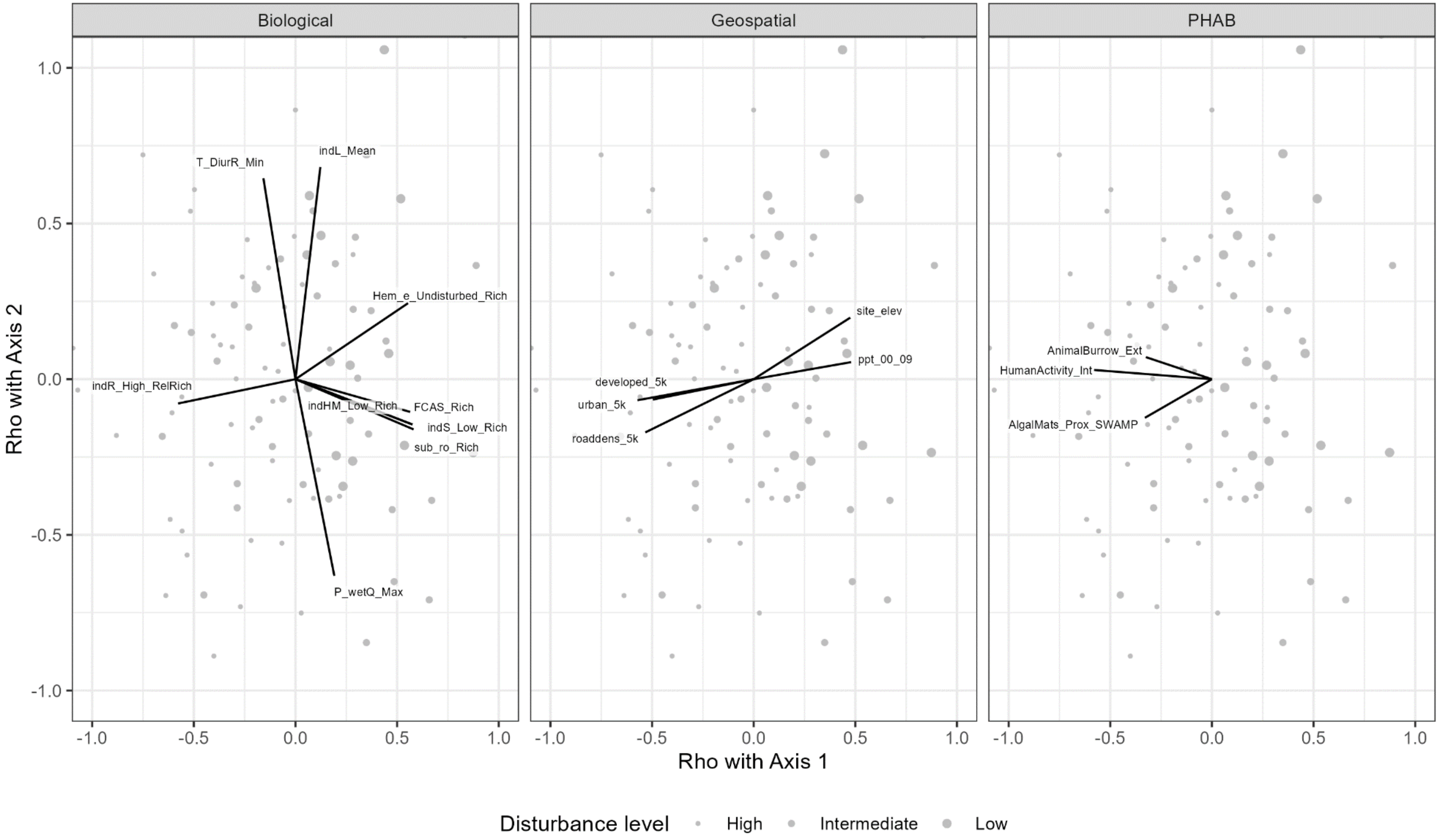

Figure 6c. Spearman rank correlations between selected biological, geospatial, or habitat metrics with axes of the ordination of bryophytes. Each metric is represented by a labeled vector; metric abbreviations are shown in Table 1 through Table 6. These vectors overlay a set of gray circles representing samples.

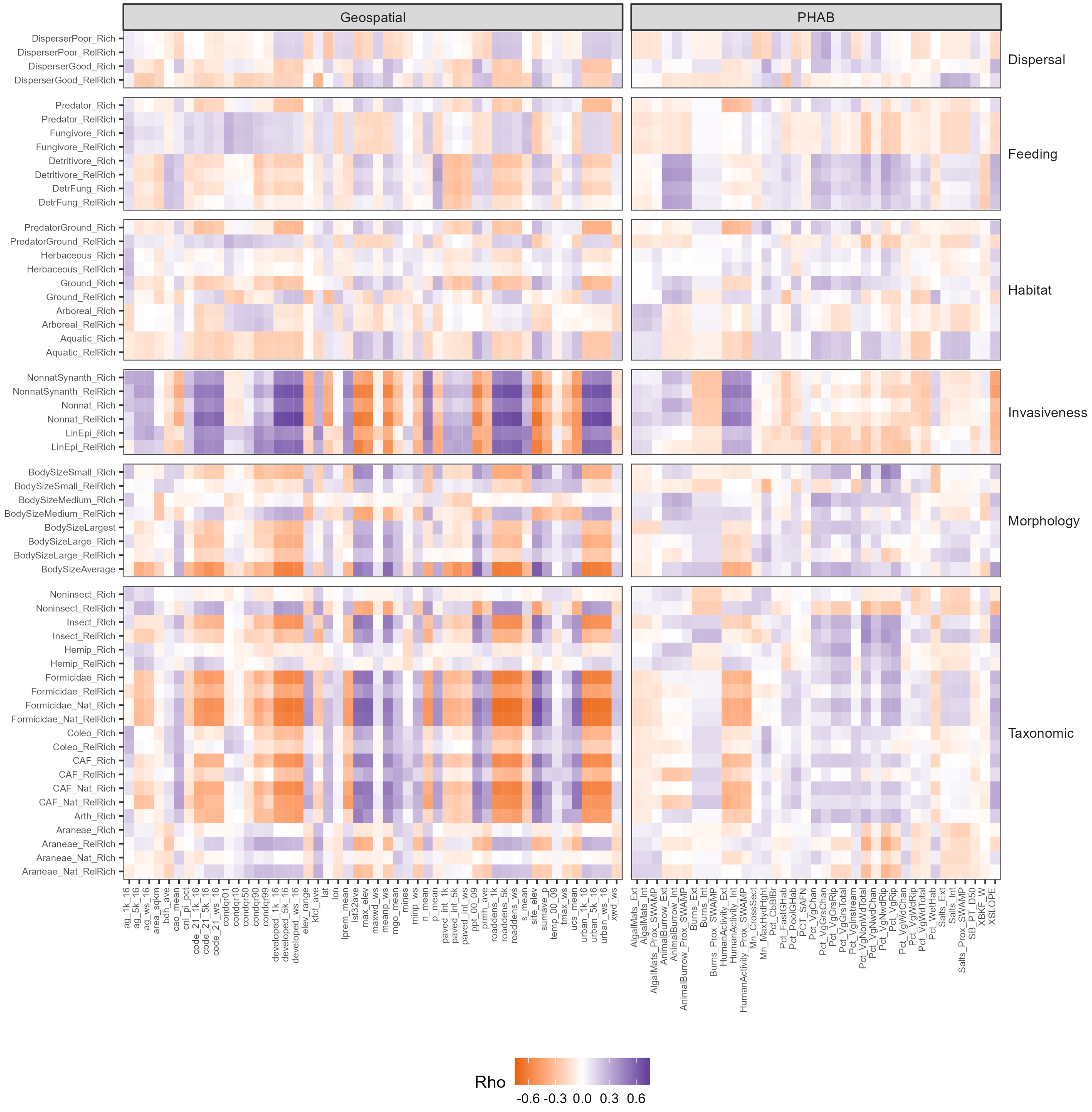

Figure 7a. A heatmap of Spearman rank correlations (Rho) between biological metrics calculated from arthropods on the streambed versus environmental metrics. This figure shows metrics based on richness, relative richness, and other non-abundance formulations.

Figure 7b. A heatmap of Spearman rank correlations (Rho) between biological metrics calculated from arthropods on the streambed versus environmental metrics. This figure shows metrics based on abundance and relative abundance formulations.

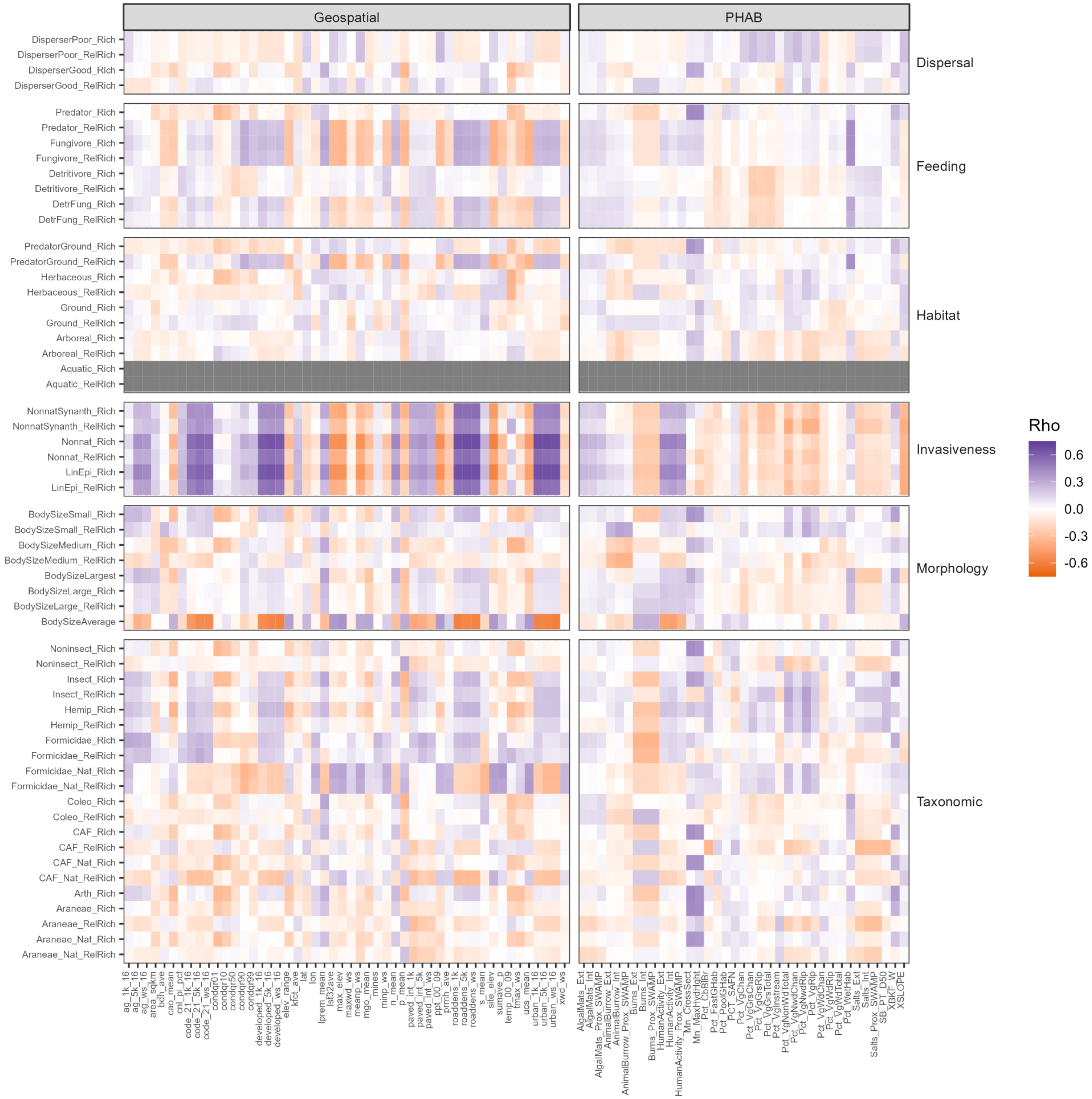

Figure 8a. A heatmap of Spearman rank correlations (Rho) between biological metrics calculated from arthropods on vegetation versus environmental metrics. This figure shows metrics based on richness, relative richness, and other non-abundance formulations.

Figure 8b. A heatmap of Spearman rank correlations (Rho) between biological metrics calculated from arthropods on vegetation versus environmental metrics. This figure shows metrics based on abundance and relative abundance formulations. Thermal tol.: Metrics based on thermal tolerance.

Figure 9a. A heatmap of Spearman rank correlations (Rho) between biological metrics calculated from bryophytes versus environmental metrics. This figure shows metrics based on richness formulations.

Figure 9b. A heatmap of Spearman rank correlations (Rho) between biological metrics calculated from bryophytes versus environmental metrics. This figure shows metrics based on relative richness formulations.

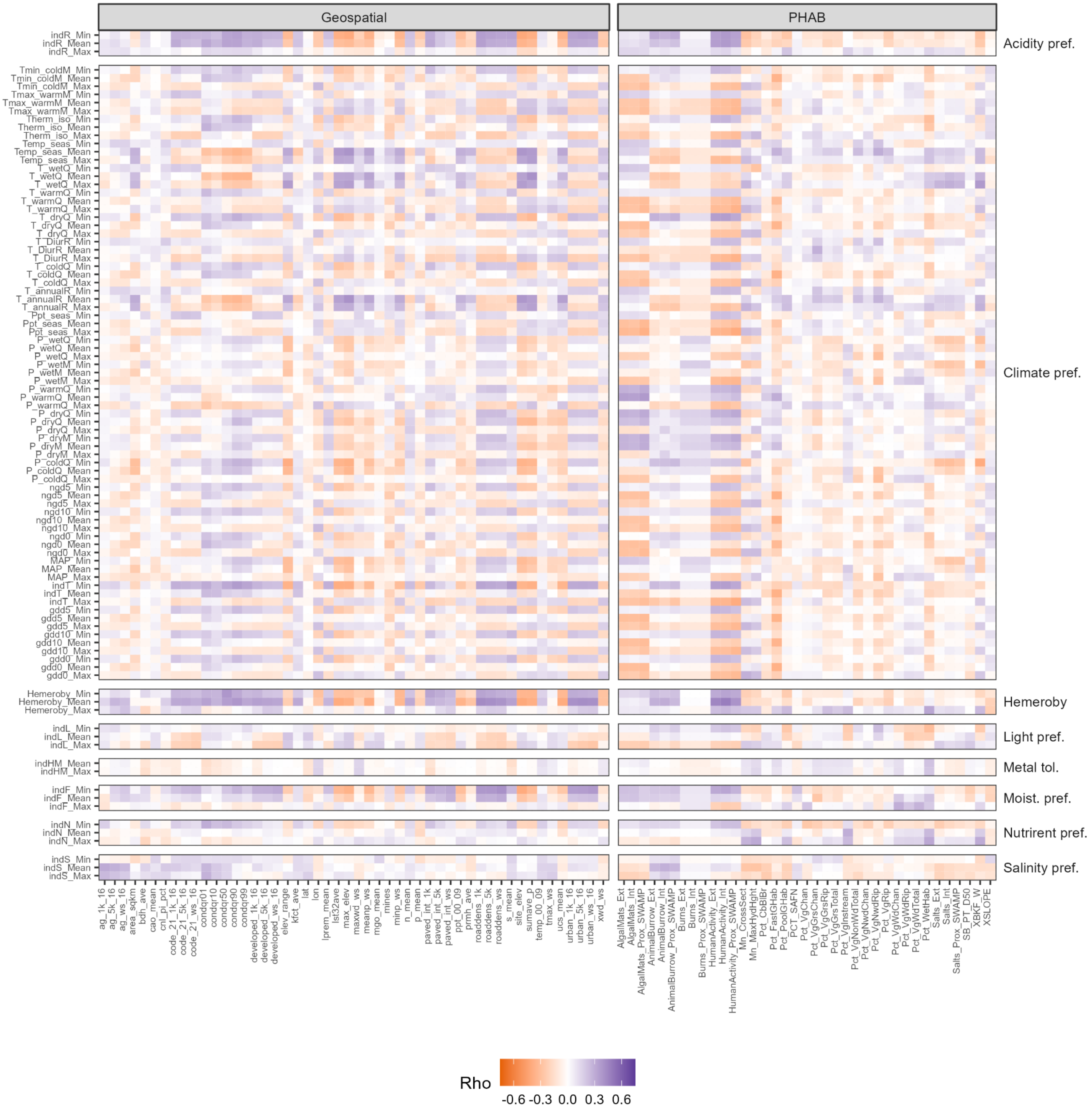

Figure 9c. A heatmap of Spearman rank correlations (Rho) between biological metrics calculated from bryophytes versus environmental metrics. This figure shows metrics based on formulations other than richness or relative richness.

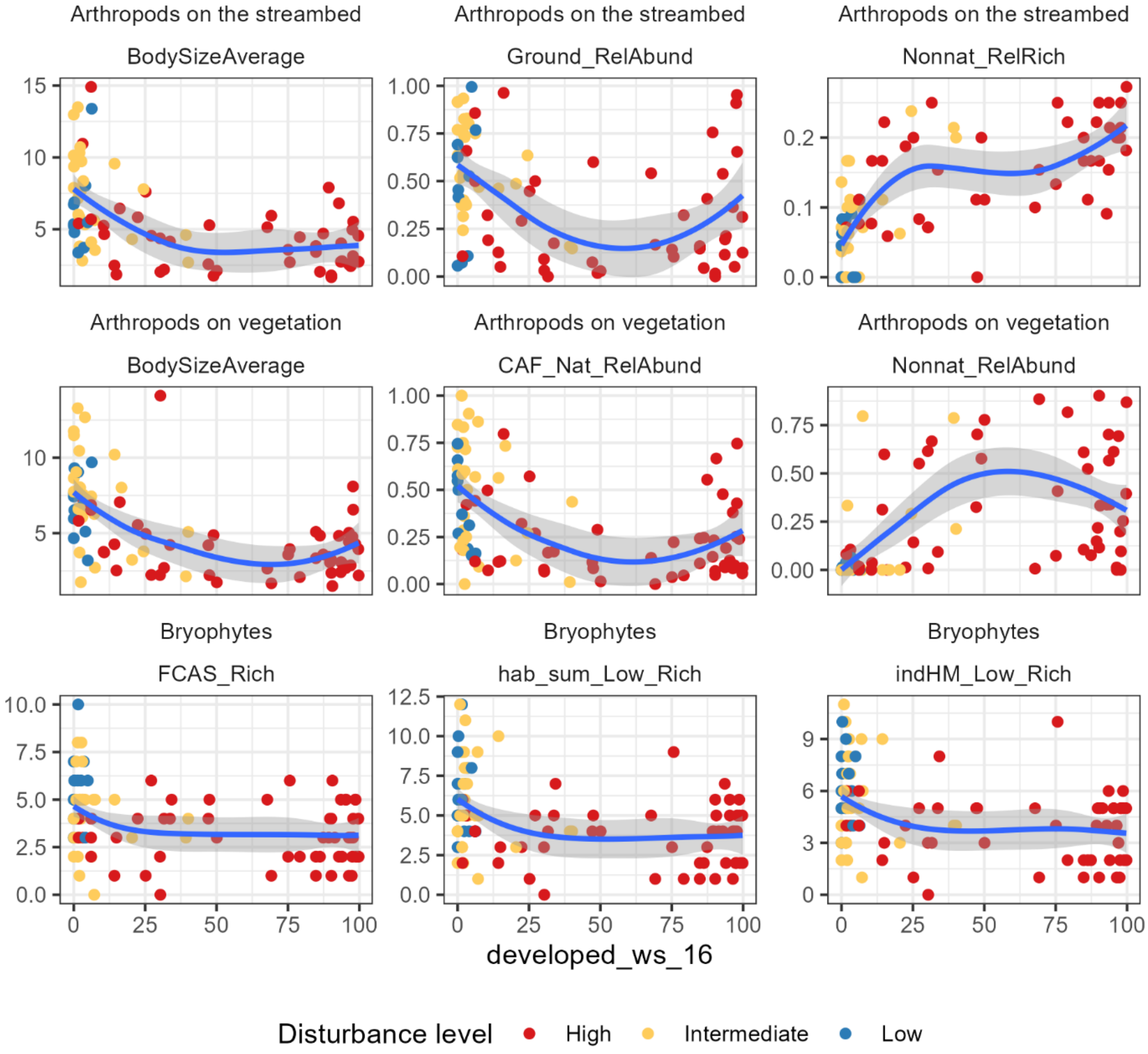

Figure 10a. Relationships between selected biological metrics at percent developed land in the watershed. Each dot represents a sample. The blue line is a fit from a general additive model calibrated using the default options in the geom_smooth function in the ggplot2 R package (Wickham 2016, R Core Team 2022).

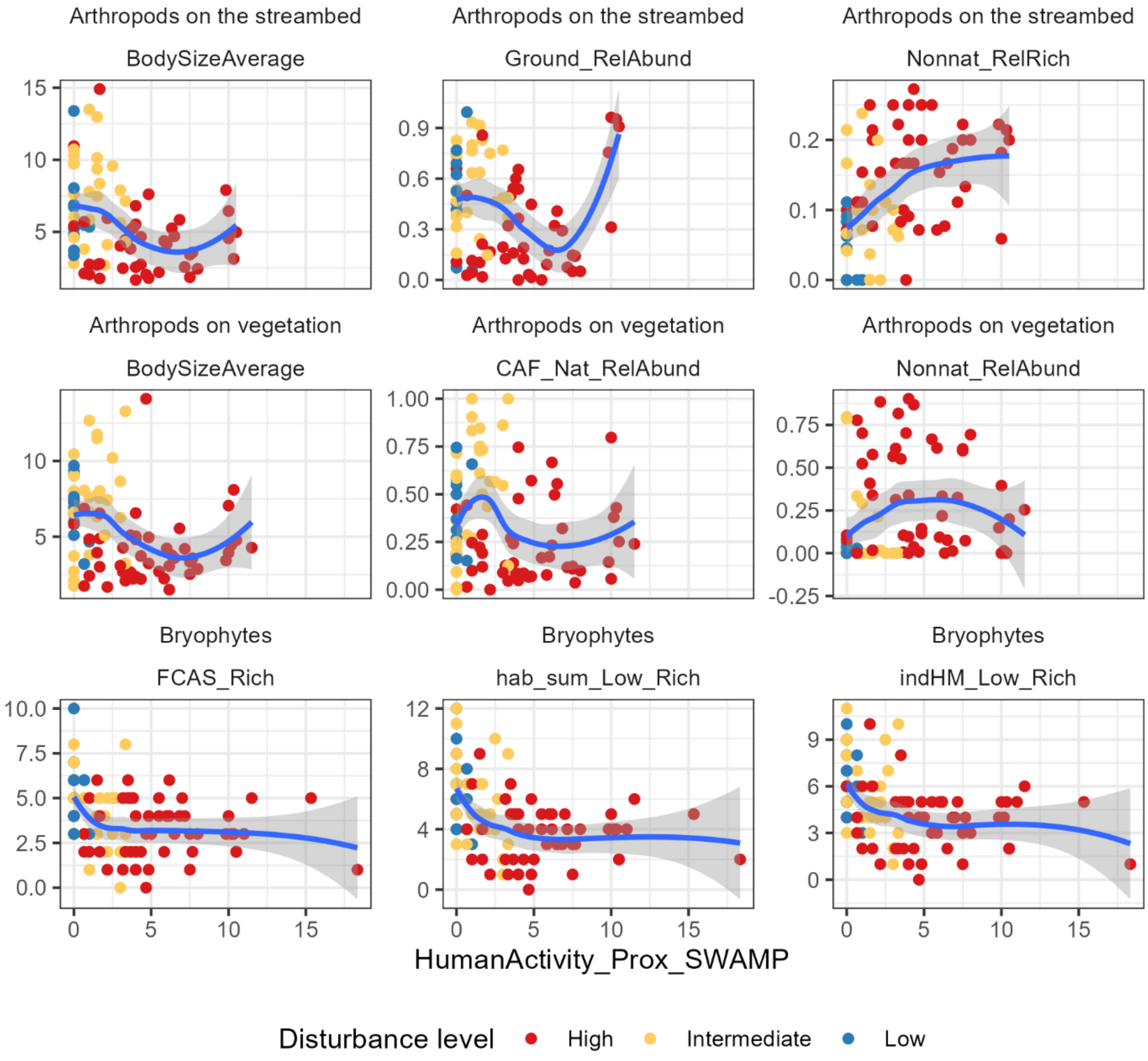

Figure 10b. Relationships between selected biological metrics at a field-measured disturbance metric (HumanActivity_Prox_SWAMP). Each dot represents a sample. The blue line is a fit from a general additive model calibrated using the default options in the geom_smooth function in the ggplot2 R package (Wickham 2016, R Core Team 2022).

Metric responsiveness

81 of the 414 biological metrics had significant (p<0.01) relationships with stress levels. 24% (i.e., 27 of 112) of metrics based on arthropods from the streambed had significant relationships, compared to 16% (18 metrics) of arthropods from vegetation and 18% of bryophyte metrics (36 of 200).

Metric form had a large impact on the frequency of responsive metrics (Table 11). For both bryophytes and arthropods from the streambed, richness metrics were most frequently responsive, whereas for arthropods from vegetation, relative abundance metrics were most frequently responsive. Among metric subtypes, invasiveness was most frequently responsive for both arthropod assemblages (75% of metrics for both groups), whereas taxonomic metrics were most frequently responsive for bryophyte metrics (57%), followed by substrate affinity (50%, Table 12).

Some metrics showed clear, linear relationships with stress levels. For example, the richness of bryophyte taxa restricted to two or fewer habitat types (i.e., hab_sum_LowRich) was greatest at low stress levels, intermediate at intermediate stress levels, and lowest at high stress levels (Figure 11). However, many metrics had similar values at low and intermediate stress levels compared to values at high stress levels (e.g., average body size in both assemblages); these metrics may be more useful for detecting high levels of degradation. No metrics had significant differences in mean values between sites with low versus intermediate stress levels at the p <0.01 level, compared to 83 metrics that had significantly different mean values between sites low and intermediate versus high stress levels.

Table 11. Responsiveness of biological metrics to stress levels, summarized by metric form. Significant responses were identified as p-values < 0.01 from an ANOVA of metric value versus stress level (i.e., low, intermediate, and high stress). Only richness, relative richness, abundance, and relative abundance metrics are included in this analysis. NA: Not applicable.

Assemblage	Richness	Relative richness	Abundance	Relative abundance	Overall
Arthropods from the streambed	36%	22%	14%	22%	24%
Arthropods from vegetation	11%	11%	0%	42%	16%
Bryophytes	41%	12%	NA	NA	18%

Table 12. Responsiveness of biological metrics to stress levels, summarized by metric subtype. Significant responses were identified as p-values < 0.01 from an ANOVA of metric value versus stress level (i.e., low, intermediate, and high stress). NA: Not applicable.

Metric subtype	Arthropods on the streambed	Arthropods on vegetation	Bryophytes
Dispersal	0%	0%	NA
Feeding	0%	0%	NA
Habitat	15%	0%	18%
Invasiveness	75%	75%	NA
Morphology	7%	21%	NA
Taxonomic	33%	14%	57%
Thermal tolerance	33%	17%	NA
Acidity affinity	NA	NA	60%
Generation time	NA	NA	17%
Growth form	NA	NA	25%
Heavy metal tolerance	NA	NA	33%
Hemeroby	NA	NA	38%
Life strategy	NA	NA	20%
Light affinity	NA	NA	40%
Moisture affinity	NA	NA	14%
Nutrient affinity	NA	NA	0%
Precipitation affinity	NA	NA	4%
Salt affinity	NA	NA	25%
Substrate affinity	NA	NA	50%
Temperature affinity	NA	NA	2%

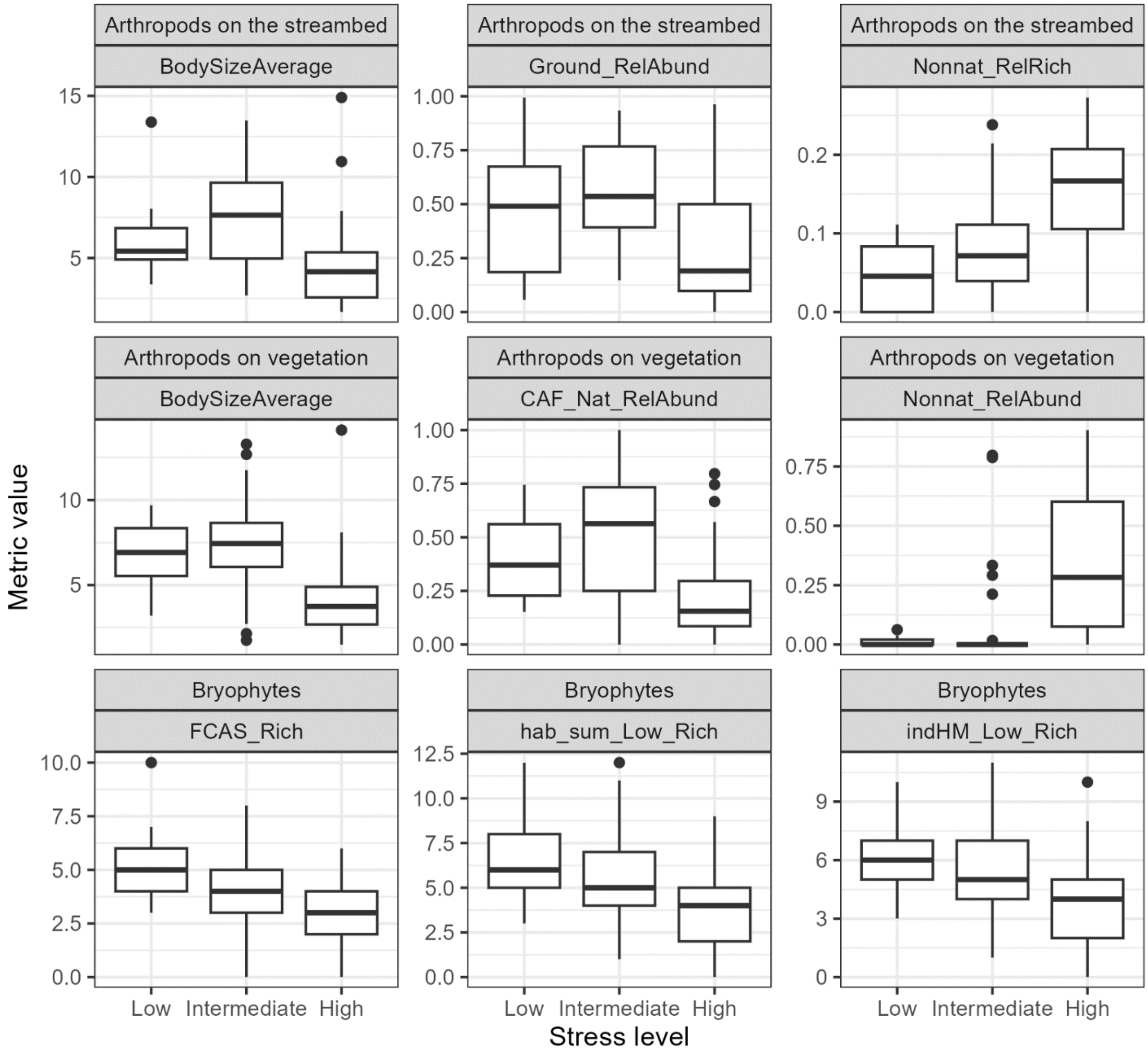

Figure 11. Boxplots showing responsiveness of selected biological metrics to stress levels. Metrics are defined in Table 5 and Table 6.

DISCUSSION & RECOMMENDATIONS

All three assemblages show potential value as indicators of ecological condition in dry intermittent and ephemeral streams, as each resulted in metrics with strong relationships with disturbance gradients. Thus, their potential for creating multimetric indices or other bioassessment tools is promising. Additional sampling efforts, specifically targeting additional reference sites (see below Recommendations), will yield a data set that should be sufficient for the development of an index.

Reference sites are a cornerstone of environmental monitoring programs because they can be used to set appropriate expectations for naturally variable analytes, including biological indicators (Reynoldson et al. 1997, Stoddard et al. 2006, Hawkins et al. 2010). This study represents an initial characterization of reference conditions in dry streambeds in southern California and is likely insufficient to fully capture the diversity of environmental gradients found in this region. For example, reference sites were almost exclusively in relatively high-elevation, high-gradient areas, even though intermittent and ephemeral streams are particularly common in the lower elevations of arid regions (Mazor et al. 2021b). Additional sampling will likely improve the environmental diversity represented within this initial reference data set.

Although the sampling effort required for streambed arthropods was more substantial than the other assemblages (in that sampling requires overnight deployment of traps; Robinson et al. 2018), they may have the greatest utility as biological indicators. In some settings, bryophyte populations may take several years to recover from a single sampling effort (personal observation), and thus sampling will be discontinued until a new, more sustainable approach to sample collection can be developed (e.g., using molecular methods based on smaller tissue samples). Finally, while arthropods from vegetation did yield a few highly responsive metrics, they tended to be less responsive than their equivalent metrics derived from streambed arthropod samples and were often duplicative. Thus, streambed arthropods should be prioritized above other assemblages for the development of a bioassessment index.

The most responsive arthropod metrics for both streambed and riparian vegetation assemblages related to nonnative or synanthropic species, such as the Argentine ant (*Linepithema humile*). This strong relationship could reflect this species' affinity for disturbed environments, as well as its well documented ability to alter the balance of native fauna, especially native arthropods (e.g., Kennedy 1998, Suarez et al. 1998, Bolger et al. 2000, Sanders et al. 2001, Hanna et al. 2015). In urban southern California, aridity of natural areas was associated with reduced invasions by non-native arthropods. In contrast, more irrigated suburban habitats had more invasive species. That is, water subsidies are associated with invasion by *Linepithmea humile, Euborelia annulipes,* and *Porcelio dilatatus* (Staubus et al. 2019). However, *Forficula auricularia* did not follow this trend. This affinity for moisture could mean that riparian areas associated with perennial or intermittent streams are more vulnerable to invasion than terrestrial upland habitats (e.g., chaparral) or riparian areas adjacent to ephemeral streams.

The ecological impacts of non-native earwigs have not been as well studied as those of invasive ants, and these were the second most frequently observed non-native taxon in our study, after Argentine ants. However, Barthell et al. (1998) showed that European earwigs (*Forficulua auricularia*) had potentially negative impacts on native cavity-nesting bees by displacing them from nests and rendering nests inaccessible with sticky barriers. In our study, *F. auricularia* was not observed, although *Euborellia* could have similar impacts. Two species are known in California (i.e., *E. annulipes* and *E. cinctocollis*), and both are predaceous on other arthropods (Langston and Powell 1975). Therefore, they could affect native arthropods through direct predation.

Apart from status as a native, invasive, or synanthropic species, most arthropod traits did not show a strong relationship with measures of stress. A notable exception was arthropod body size, with larger taxa being associated with less disturbed conditions. This is consistent with research on arthropods in dry streams in Australia (Steward et al. 2018, 2022) and England (R. Stubbington, personal communication). It is possible that physical disruption of the streambed eliminates interstitial spaces where large-bodied taxa can find refuge. Better documentation of typical body sizes of dry stream arthropods would likely benefit index development. However, other traits should also be explored, such as those reflecting ecological affinities for substrate conditions (which can be directly altered by water quality conditions during the wet phase), and trophic relationships (which may reflect ecosystem functions, such as processing of organic material in dry streambeds).

In contrast with arthropods, several bryophyte trait-based metrics showed strong relationships with stress gradients, likely reflecting the close relationships between bryophytes and substrate conditions (Gecheva and Yurukova 2014). Traits based on metal tolerance and salinity show particularly good potential. Disappointingly, traits reflecting nutrient affinities did not show a strong relationship with disturbance; however, because nutrient concentrations in streambed substrate were not measured, it is unknown whether the data set adequately represented a nutrient gradient sufficient to see a response in bryophyte assemblages.

Statewide Program Recommendations

SWAMP is developing a plan for the assessment of nonperennial rivers and streams across all of California. This plan should address the need to assess these rivers when they are both wet dry. These needs include:

1. Exploration of classification methods for nonperennial rivers (e.g., ephemeral, regularly flowing intermittent, seldomly flowing intermittent), and the development of tools (including field-based tools) to assign dry and flowing streams to these classes.
2. Validation or adaptation of California's reference criteria developed for perennial streams (Ode et al. 2016) for application to dry intermittent and ephemeral streams.
3. Development or validation of ecological health assessment tools for both the wet and dry phases.
4. Examination of stress-response relationships that explore the role of streamflow duration in vulnerability to stress, as well as the different sensitivities of the dry versus wet phases of nonperennial streams.
5. Development of a method to integrate assessments made during both the wet and dry phases of a stream.

Additional needs may be identified by the SWAMP bioassessment workgroup and may be added to the forthcoming plan. Recent and ongoing research is already underway to address the first two needs (e.g., Mazor et al. 2014, 2021, 2023a, Lane et al. 2017). This study primarily addresses the second of these needs—to develop ecological health assessment tools for the dry phase of intermittent and ephemeral streams. However, this study has focused on southern California and excludes large portions of the state, including many major Ecoregions, some of which are dominated by nonperennial streams (e.g., the Sonoran and Mojave deserts).

In order to advance the development of these assessment tools, we identify several areas where additional research or data collection will be helpful.

<u>Expand data collection at reference sites</u>

Data from reference sites enable the characterization of reference conditions, which is the cornerstone of most bioassessment methods (Reynoldson et al. 1997, Stoddard et al. 2006, Hawkins et al. 2010, Ode et al. 2016). The reference data set should sufficiently characterize key natural gradients known to relate to biological composition. The present study suggests that rainfall and elevation may be appropriate factors to focus on. Reach-scale flow duration may be a more important factor given its strong relationship to biotic composition (Fritz et al. 2020), although watershed factors can serve as proxies for more difficult to measure hydrologic characteristics. A goal should be to represent ephemeral streams, intermittent streams with relatively short flow durations/infrequent flows, and intermittent streams with more regular, longer duration flows.

Because of the small size of the data set, we cannot be confident that the reference criteria screens in Table 7 are appropriate for dry phase assessments outside of southern California. Thus, reference site identification should be approached in an iterative manner in which these screens are re-evaluated and refined with progressively larger data sets to ensure that the biological response to residual disturbance in the reference data set is sufficiently minimized (e.g., following Ode et al. 2016).

Focus data collection efforts on streambed arthropods

Although all three assemblages in the present study show some potential for the development of biological indicators, we recommend focusing on streambed arthropods. First, this assemblage had the greatest number of metrics that were responsive to disturbance gradients (Table 11). Second, we advise against continued sampling of bryophytes following the protocol of Robinson et al. (2018) because populations did not appear to recover from sampling for several years in certain locations. Third, streambed arthropods have a conceptually direct relationship to stream condition. In contrast, arthropods on riparian vegetation may be only indirectly reflecting in-stream conditions as mediated through the plant community (which may in turn yield a better measure of ecological health, e.g., Westwood et al. 2021). Finally, focusing on a single assemblage will reduce costs. At the time of this study, the laboratory costs of analyzing terrestrial arthropod samples is substantially greater than aquatic benthic macroinvertebrate samples (due to the greater expertise required to make identifications). Thus, focusing on a single assemblage could greatly increase the number of sites that could be sampled with a limited amount of resources.

Develop alternative methods for sampling bryophytes

As noted above, the protocol of Robinson et al. (2018) appeared to greatly reduce populations of bryophytes in certain locations, with no recovery observed for several years post sampling. Thus, the current method may not be suitable for large-scale application. Molecular identification methods may be less destructive because they require comparatively small tissue samples than typically collected for morphological identification. Preliminary studies show that DNA reference libraries for California’s bryophytes are suitable for genus-level identification (Mazor et al. 2023b).

Gather additional reach-scale stressor data at sites along disturbance gradients

The present study examined responses to stress measured at the watershed scale (e.g., % development in the watershed) and reach scale (e.g., proximity of human activity). Future data collection should gather additional stressor data to better characterize stress-response relationships. Sediment quality would be a good stressor to measure because it can be used to investigate the relationship between water quality during the wet phase and ecological conditions during the dry phase. We recommend focusing on pyrethroids in sediment because these pesticides are widely used in both urban and agricultural settings. Alternatively, pollutants related to urban transport or oil production (e.g., heavy metals, polycyclic aromatic hydrocarbons) may also help characterize sediment quality gradients. A key objective of this data collection (as well as the relationship between wet and dry-phase measurements of health) is to determine the extent to which dry-phase indicators can be used to assess wet-phase water quality, and the potential for improving ecological conditions in either phase through water quality improvements.

Investigate relationships between wet and dry phase measures of health

Data collection efforts should target intermittent streams where wet-phase bioassessment has previously occurred, at both reference and disturbed sites. This dataset will allow direct comparisons of stream condition measured by dry-stream indicators to index scores for the California Stream Condition Index (CSCI) for benthic macroinvertebrates (Mazor et al. 2016) and the Algal Stream Condition Indices (ASCIs) for diatoms or for diatoms combined with soft-bodied algal taxa (Theroux et al. 2020). A framework should be developed for combining these indicators from both wet- and dry-phase assessments into an integrated measure of a stream's ecological health.

Improve trait databases for terrestrial indicators

For arthropods, some traits had very poor coverage (Table 10); however, this coverage was the result of only a limited review of the scientific literature. A more intensive review will be beneficial. Based on this study, we recommend focusing on life cycle/generation times, thermal tolerance, diet, body size or other morphological characteristics. Given their frequency in the data set, additional effort should focus on Coleoptera and Hemiptera. For bryophytes, coverage of California taxa in European databases (Bernhardt-Römermann et al. 2018, Simmel et al. 2021, Van Zuijlen et al. 2023b) was good. However, the appropriateness of these traits for California can be validated with additional review of the scientific literature or prioritizing for funding in future studies.

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APPENDIX A. SITES USED IN THE STUDY

Table A1. List of sites used in the study, with available data indicated. RB: Regional board. Bryos: Bryophytes. PHAB: Physical habitat using Robinson et al. (2018). BMI: Benthic macroinvertebrates (collected on a different date). Diatoms: benthic diatoms (collected on a different date). SBA: Benthic soft-bodied algal taxa (collected on a different date). Int.: Intermediate stress level.

StationCode	Sample date	RB	Lat	Long	Stress level	Arthropods from traps	Arthropods from vegetation	Bryos	PHAB	BMI	Diatoms	SBA
402COZYDL	7/10/2021	4	34.47876	-119.28814	Int.	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
402LONVAL	7/11/2021	4	34.42973	-119.29337	High	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
402R4SSCT	9/11/2018	4	34.37747	-119.29893	Int.	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
402R4SSCT	5/8/2019	4	34.37747	-119.29893	Int.	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
403CLWCYN	7/4/2021	4	34.59174	-118.46412	Int.	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
403KLEINE	7/5/2021	4	34.61659	-118.56207	Int.	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
403LACACR	7/14/2021	4	34.42817	-118.10384	Int.	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
403S00028	9/11/2018	4	34.52451	-118.76493	Int.	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
403S00028	6/26/2019	4	34.52451	-118.76493	Int.	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
403TEXCYN	7/6/2021	4	34.53638	-118.37716	Int.	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
403UACAFH	7/13/2021	4	34.42756	-118.08826	Low	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
404LUNADA	7/16/2021	4	33.76912	-118.41726	High	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
404R4SASQ	9/12/2018	4	34.09101	-118.91113	Int.	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
404R4SASQ	7/23/2019	4	34.09101	-118.91113	Int.	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
404R4SLVC	9/13/2018	4	34.14410	-118.70065	High	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
404SMMCON	7/8/2021	4	34.13782	-118.73011	High	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
405R4SSDC	9/10/2019	4	34.31251	-117.83275	Low	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
405R4STSC	9/10/2019	4	34.29231	-117.83238	Int.	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
405SJHILL	7/15/2021	4	34.03984	-117.87917	High	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
408ARYSIM	7/7/2021	4	34.26427	-118.72710	High	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
408GRIMES	7/9/2021	4	34.31070	-118.90781	High	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE

StationCode	Sample date	RB	Lat	Long	Stress level	Arthropods from traps	Arthropods from vegetation	Bryos	PHAB	BMI	Diatoms	SBA
412SINGSP	7/12/2021	4	34.33251	-118.12083	Int.	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
801SANT1x	8/10/2017	8	33.70885	-117.61456	High	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE
801SANT1x	8/25/2019	8	33.70885	-117.61456	High	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE
801SHDCYN	7/27/2017	8	33.61987	-117.78564	Int.	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
901AUDFOX	7/26/2017	9	33.59874	-117.56467	Low	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
901AUDFOX	8/24/2019	9	33.59874	-117.56467	Low	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
901EMRCYN	8/11/2017	9	33.55738	-117.80311	Low	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
901LAUREL	7/28/2017	9	33.58551	-117.76368	Int.	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
901NP9BWR	8/5/2020	9	33.53063	-117.42908	Int.	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
901NP9CSC	8/9/2017	9	33.59190	-117.52160	Low	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE
901NP9TNC	8/2/2020	9	33.52651	-117.40550	Int.	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
901SJVERD	8/10/2017	9	33.53280	-117.55060	Int.	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
901UNTLCC	8/4/2020	9	33.61805	-117.43541	Int.	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
901UPRAC1	8/3/2020	9	33.65573	-117.65909	High	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
902DPCCT	8/8/2020	9	33.41805	-116.65065	Low	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
902DPUCC1	8/9/2020	9	33.57575	-116.76184	Low	FALSE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
902DPUCC2	8/10/2020	9	33.54603	-116.79102	Low	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
902LNGCYN	7/30/2017	9	33.50990	-117.14470	High	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
902SGCGKR	6/8/2021	9	33.53894	-117.13414	High	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
902SMAS2x	7/31/2017	9	33.45641	-116.97191	Low	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
902UDLVGR	7/18/2020	9	33.48138	-117.30853	Int.	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
902UPPWSC	7/21/2020	9	33.66910	-117.08456	High	TRUE	TRUE	FALSE	TRUE	FALSE	FALSE	FALSE
902USGCBS	7/20/2020	9	33.54548	-117.10344	High	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
902WRMSPC	7/30/2017	9	33.52961	-117.18200	High	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
903DPUEFS	8/6/2020	9	33.38468	-116.62602	Low	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
903DPUWF1	8/7/2020	9	33.33692	-116.82487	Low	TRUE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
903NP9PRC	8/7/2017	9	33.26041	-116.80917	Int.	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE
903NP9PRC	8/22/2019	9	33.26041	-116.80917	Int.	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE

StationCode	Sample date	RB	Lat	Long	Stress level	Arthropods from traps	Arthropods from vegetation	Bryos	PHAB	BMI	Diatoms	SBA
903SLFRCx	8/7/2017	9	33.34398	-116.88170	Int.	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE
903UTLSLR	7/22/2020	9	33.25768	-117.29409	High	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
903UTMSLR	7/18/2020	9	33.36475	-117.15947	Int.	TRUE	TRUE	FALSE	TRUE	FALSE	FALSE	FALSE
904SAXONY	7/31/2020	9	33.07864	-117.28489	High	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
904SAXONY	8/1/2021	9	33.07864	-117.28489	High	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
904UNTEC3	6/30/2020	9	33.16901	-117.09294	High	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
904UNTSE1	7/29/2021	9	33.00929	-117.25403	High	TRUE	TRUE	FALSE	TRUE	FALSE	FALSE	FALSE
904UNTSE2	8/2/2021	9	33.00969	-117.24559	High	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
905SDBDN9	8/1/2017	9	33.09332	-116.89730	Int.	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE
905SDBDN9	8/23/2019	9	33.09332	-116.89730	Int.	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE
905SMCRAM	8/3/2021	9	33.05570	-116.85920	High	TRUE	TRUE	FALSE	TRUE	FALSE	FALSE	FALSE
905UNTGVC	7/31/2021	9	33.01509	-117.05340	High	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
906SLCFGC	8/2/2017	9	32.89201	-117.18096	High	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
906UNTLPE	7/21/2021	9	32.93861	-117.25296	Int.	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
906UNTSC1	7/8/2020	9	32.90229	-117.16088	High	FALSE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
906UNTSC2	7/23/2020	9	32.90252	-117.16260	High	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
906UNTTC4	7/26/2020	9	32.79877	-117.17144	High	FALSE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
906UNTTC6	7/28/2020	9	32.81806	-117.19220	High	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
906UNTTC7	7/27/2020	9	32.83027	-117.18510	High	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
906UNTTC8	7/29/2020	9	32.83010	-117.19737	High	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
906UPCAKS	7/24/2021	9	32.95357	-117.01546	High	TRUE	TRUE	FALSE	TRUE	FALSE	FALSE	FALSE
907DPFMUS	7/30/2020	9	32.83530	-117.06421	Int.	FALSE	TRUE	FALSE	TRUE	FALSE	FALSE	FALSE
907NP9OSU	8/3/2017	9	32.85510	-117.05190	High	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
907NP9OSU	8/21/2019	9	32.85510	-117.05190	High	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
907SDT163	7/20/2021	9	32.75704	-117.15918	High	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
907SDTJHN	7/30/2021	9	32.75716	-117.15862	High	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
907SRSD1x	8/6/2017	9	33.10878	-116.65758	Int.	FALSE	FALSE	TRUE	TRUE	TRUE	FALSE	FALSE
907SRSD1x	8/22/2019	9	33.10878	-116.65758	Int.	FALSE	FALSE	TRUE	TRUE	TRUE	FALSE	FALSE

StationCode	Sample date	RB	Lat	Long	Stress level	Arthropods from traps	Arthropods from vegetation	Bryos	PHAB	BMI	Diatoms	SBA
907UNAACR	7/28/2021	9	32.78342	-117.08552	High	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
907UNTFC1	7/3/2020	9	32.78696	-116.91555	High	FALSE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
907UNTPCD	8/4/2021	9	32.85318	-116.97583	High	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
907UTSVC1	8/5/2021	9	33.00816	-116.82095	High	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
907UTSVC2	6/29/2020	9	33.01324	-116.81161	High	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
907UTSVC3	8/4/2021	9	33.02433	-116.79949	Int.	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
908CCAEA1	7/5/2020	9	32.73736	-117.08675	High	FALSE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
908CHI805	8/3/2017	9	32.71904	-117.10724	High	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
908LCCAWM	7/16/2020	9	32.73386	-117.16562	High	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
908NFCDDR	7/15/2020	9	32.72142	-117.11772	High	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
908PVCDST	7/14/2020	9	32.69424	-117.05959	High	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
908PVCUPP	7/27/2021	9	32.69823	-117.03921	High	TRUE	TRUE	FALSE	TRUE	FALSE	FALSE	FALSE
908SFCCAB	7/24/2020	9	32.71505	-117.04691	High	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
908SSCBD1	7/19/2021	9	32.69361	-117.08019	High	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
908UNTCC1	7/25/2020	9	32.73616	-117.09134	High	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
908UNTCC2	7/6/2020	9	32.73658	-117.10692	High	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
908UTSFC1	7/9/2020	9	32.71025	-117.05128	High	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
908UTSFC2	7/26/2021	9	32.71038	-117.04037	High	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
909UNTSWR	7/4/2020	9	32.74036	-117.00729	High	FALSE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
910DENNRY	7/22/2021	9	32.58741	-117.01934	Int.	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
910DPUSCT	7/11/2020	9	32.64363	-116.79575	Int.	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
910UNTMAB	7/10/2020	9	32.60379	-117.04687	High	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
911DPCMCC	11/8/2020	9	32.81353	-116.49064	Low	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
911DPNMCC	8/13/2020	9	32.88699	-116.48931	Low	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
911DPUCC5	7/2/2020	9	32.77132	-116.48683	Low	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE
911DPULCC	7/12/2020	9	32.61116	-116.68002	Int.	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
911DPUPV2	8/15/2020	9	32.89698	-116.52151	Int.	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE
911GSCAPV	8/15/2020	9	32.89759	-116.52806	Int.	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE

StationCode	Sample date	RB	Lat	Long	Stress level	Arthropods from traps	Arthropods from vegetation	Bryos	PHAB	BMI	Diatoms	SBA
911NP9ATC	8/5/2017	9	32.76824	-116.41757	Low	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE
911S00858	8/12/2020	9	32.90282	-116.49337	Int.	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE
911S01142	8/4/2017	9	32.73548	-116.65268	Low	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE
911TJPC2x	8/5/2017	9	32.85312	-116.52274	High	FALSE	FALSE	TRUE	TRUE	TRUE	FALSE	FALSE
911TJPC2x	8/21/2019	9	32.85312	-116.52274	High	FALSE	FALSE	TRUE	TRUE	TRUE	FALSE	FALSE
911TJPC2x	7/18/2021	9	32.85312	-116.52274	High	TRUE	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE

APPENDIX B. HUMAN ACTIVITIES RECORDED DURING PHYSICAL HABITAT ASSESSMENTS

The following human activities are noted during physical habitat assessments. These data are used to calculate the human activity intensity, extent, and proximity metrics:

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