Ecological conditions of dry streams in the Los Angeles region

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SOUTHERN CALIFORNIA COASTAL WATER RESEARCH PROJECT

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Intermittent streams; ephemeral streams; bioassessment; terrestrial arthropods; bryophytes; the California Rapid Assessment Method [CRAM]

Executive Summary

This report provides a preliminary summary of ecological conditions of twelve streams in the Los Angeles region assessed using indicators for dry intermittent and ephemeral streams. These indicators include terrestrial arthropods on the streambed, arthropods on riparian vegetation, and bryophytes (i.e., mosses) on the banks or channel bottom. Conditions were also assessed with the California Rapid Assessment Method, using modules appropriate for traditional riverine wetlands or for episodic streams, depending on the local conditions of each site. Datasets were supplemented with data collected from sites in the San Diego region, leading to a total of 93 sites with bryophyte data, and 32 sites with arthropod data.

Metrics are based on arthropod assemblages sensitive to human activity, underscoring the potential use of these indicators as bioassessment tools. For example, sites with high levels of human activity typically had fewer beetle, ant, and spider taxa than sites with low levels of human activity. Conversely, high-activity sites had higher proportions of non-native Argentine ants. These patterns were true for both streambed and riparian vegetation samples.

We classified 23 metrics as responsive or unresponsive based on differences in scores at high- versus low-activity sites, and further classified responsive metrics as increasers (i.e., those that increase in response to disturbance, like Argentine ant abundance) or decreasers (i.e., those that decrease in response, like ant, beetle, and spider richness). We then identified candidate assessment thresholds as the 25th percentile of values at low-activity sites for decreasing metrics, or the 75th percentile for increasing metrics. Passing these thresholds indicates likely good conditions, whereas failing these thresholds indicates potential degradation. Across the 12 sites in the Los Angeles region, we found that the typical site passed the threshold for 12 metrics, which is somewhat less than the typical low-activity site (i.e., 16 metrics). As expected, sites in less developed regions had more metrics indicating good conditions.

This pilot assessment shows the promise of biological indicators in dry intermittent and ephemeral streams. Future work will result in the development of indices with levels of accuracy, precision, and sensitivity that should support many needs in Water Board monitoring and management programs.

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INTRODUCTION

Intermittent and ephemeral stream-reaches comprise a large portion of stream-miles in the arid U.S. southwest, but at this time, we have few tools that can be used to assess their condition. Consequently, monitoring programs may overlook these streams, despite their importance in providing beneficial uses or protecting adjacent perennial waters. With an increasing population and global change leading to extreme floods and droughts, land managers need to understand how freshwater systems respond to human impacts and relate to our clean water supply. To understand these systems, we can monitor and assess the relationship between the biota and the rivers, lakes, wetlands, and streams that create the above-ground freshwater network. Determining the best way to assess these systems is integral to evaluating their health.

Non-perennial stretches of rivers are common features in headwater systems, but they can also 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. (2014) described non-perennial 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 non-perennial 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 non-perennial systems and their ability to function properly can greatly influence the health of entire watersheds.

Non-perennial streams are particularly abundant and widespread in drier regions of California. Most streams in California exhibit some degree of ephemeral flow (Levick et al. 2008; McKay et al. 2014; Goodrich et al. 2018). Despite their intrinsic values and importance to hydrologically connected waterbodies, they 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). Ephemeral streams (especially in desert locales) are under increasing pressure from development, including new urban/suburban and infrastructure projects, and, most recently, alternative energy production facilities (e.g., wind and solar) (Chiu et al. 2017). Assessment tools for ephemeral and intermittent streams are necessary to allow managers to prioritize streams for protection or restoration, assess impacts, and develop and evaluate performance standards for mitigation or remediation.

In this report, we describe results of an effort to apply bioassessment indicators to the dry phase of intermittent streams in the Los Angeles river to attain a preliminary understanding of the ecological conditions of these ecosystems. We identify bioassessment metrics based on terrestrial arthropod and bryophyte communities that have potential for use as assessment tools. We also use the California Rapid Assessment Method to evaluate habitat conditions of dry streams in the Los Angeles region. This study paves the way for assessing the conditions of streams in southern California, regardless of the presence of surface water.

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.

- **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.

- **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.

METHODS

Site selection and classification

Twelve sites in the Los Angeles region were identified for sampling under this project. To select sites, we examined outputs of models developed by Mazor et al. (2021; Figure 1). Briefly, those models predicted which stream segments in California were likely to require dry-stream assessment tools, and which were likely to have poor biological conditions. We identified nearly 3,000 potential stream segments in the Los Angeles region representing likely intermittent streams, from which 12 were selected for sampling.

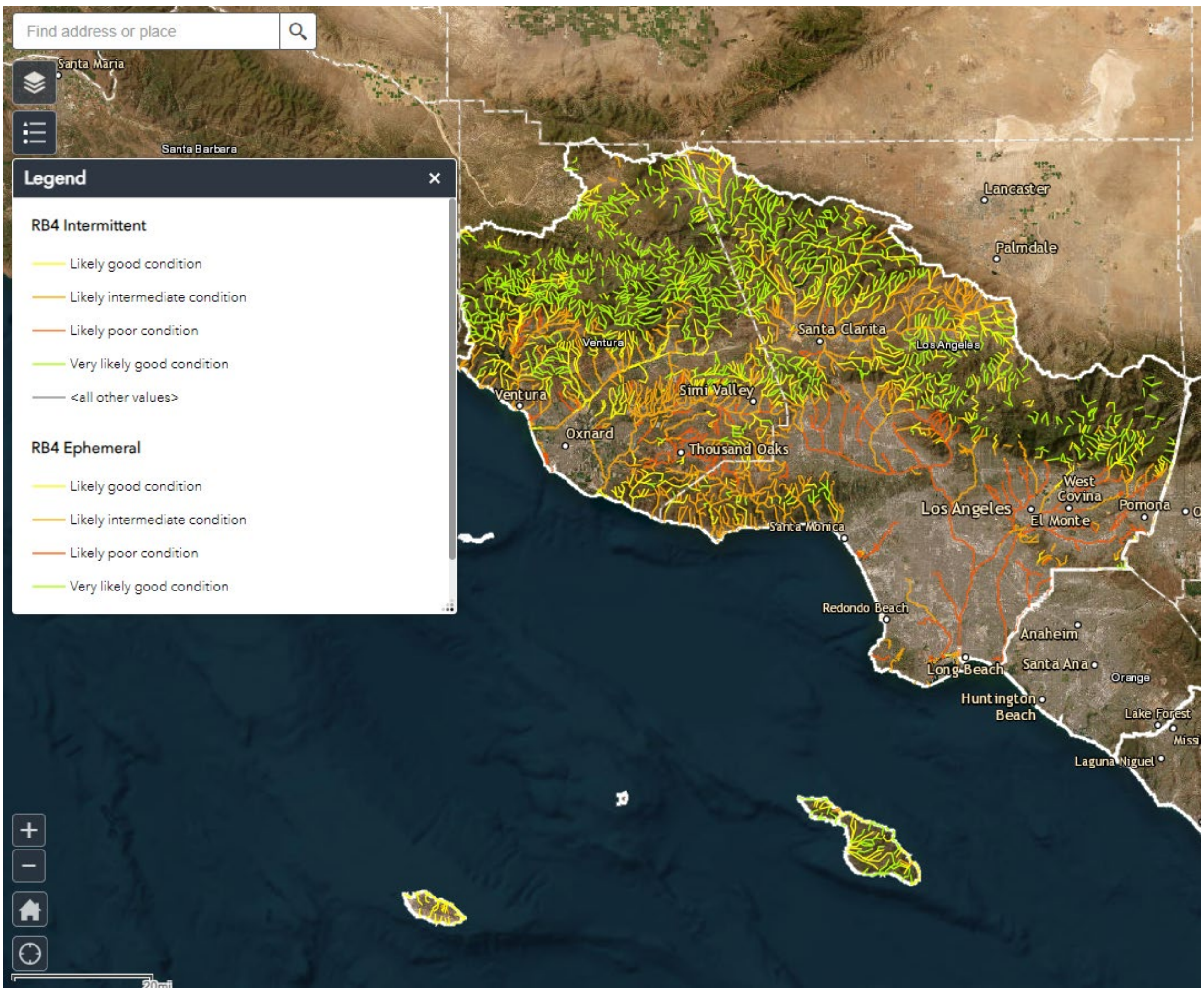

Figure 1. Model outputs that were used to select sampling sites for this study. Models are described in Mazor et al. (2021).

At each site, bioassessment samples were collected following the protocols of Robinson et al. (2018), as described below. The California Rapid Assessment Method (CRAM) was also conducted at these 12 sites. Additional arthropod and bryophyte data from the San Diego region collected following Robinson et al. (2018) was also used in this study. Combined with the Los Angeles region data, we have a combined set of 93 sites (Table 1; Figure 2). Bryophyte taxonomic data were available at all of these sites, whereas arthropod taxonomic data were available at 32 sites at the time of this report; additional taxonomic data from both the Los Angeles and San Diego regions are currently being analyzed and will be included in future analyses.

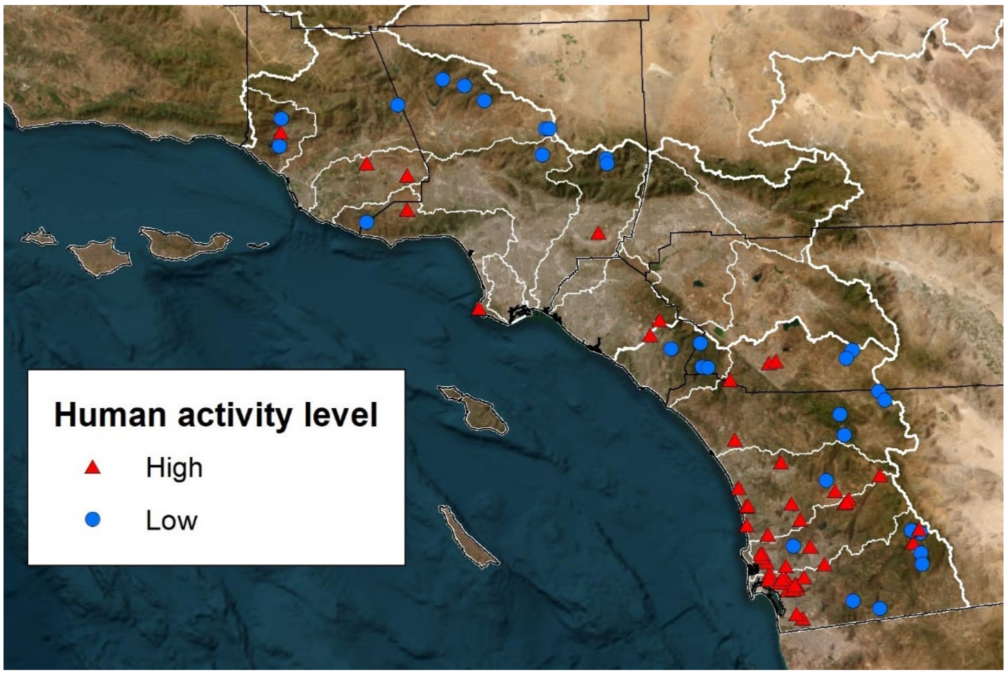

Figure 2. A map of sites used in this report. Blue circles indicate low-activity sites, whereas red triangles indicate high-activity sites.

Table 1. List of sites used in this report. B: Bryophyte data available. B, A: Bryophyte and arthropod data available. B, A, C: Bryophyte, arthropod, and CRAM data available.

StationCode	Station name	Latitude	Longitude	County	Human activity level	Sample date	Indicators
402COZYDL	Cozy Dell (COMID 17586480)	34.478976	-119.288622	Ventura	Low	7/10/2021	B, A, C
402LONVAL	Long Valley (COMID 17586712)	34.429690	-119.293523	Ventura	High	7/11/2021	B, A, C
403CLWCYN	Clear Water Canyon (COMID 17569817)	34.592845	-118.464667	Los Angeles	Low	7/4/2021	B, A, C
403KLEINE	Kleine Canyon (COMID 17569633)	34.616726	-118.562098	Los Angeles	Low	7/5/2021	B, A
403LACACR	Lower Aliso at Canyon Aliso Canyon Rd (COMID 17574575)	34.428088	-118.103987	Los Angeles	Low	7/14/2021	B, A, C
403TEXCYN	Texas Canyon Rd NF-5N14 (COMID 17570159)	34.536092	-118.377530	Los Angeles	Low	7/6/2021	B, A, C
403UACAFH	Upper Aliso Canyon at Angeles Forest Hwy (COMID 17574575)	34.427713	-118.087888	Los Angeles	Low	7/13/2021	B, A, C
404LUNADA	Beautify Lunada Bay (COMID 20366141)	33.768886	-118.417988	Los Angeles	High	7/16/2021	B, A, C
404SMMCON	Santa Monica Mountains Conservancy (COMID 20364797)	34.137264	-118.728986	Los Angeles	High	7/8/2021	B, A, C
405SJHILL	San Jose Hills (COMID 22523229)	34.039412	-117.878202	Los Angeles	High	7/15/2021	B, A, C
408ARYSIM	Arroyo Simi (COMID 17563962)	34.264145	-118.728421	Ventura	High	7/7/2021	B, A, C
408GRIMES	Grimes Canyon RD (COMID 17563718)	34.310135	-118.909653	Ventura	High	7/9/2021	B, A, C

StationCode	Station name	Latitude	Longitude	County	Human activity level	Sample date	Indicators
412SINGSP	Singing Springs (COMID 22514264)	34.331298	-118.120976	Los Angeles	Low	7/12/2021	B, A, C
902SGCGKR	Santa Gertrudis Creek at General Kearny Road	33.538940	-117.134137	Riverside	High	6/8/2021	B, A
904SAXONY	Unnamed Trib to Batiquitos on Saxony	33.078640	-117.284890	San Diego	High	8/1/2021	B, A
904UNTSE1	Unnamed Trib to San Elijo Lagoon 1	33.009290	-117.254028	San Diego	High	7/29/2021	B, A
904UNTSE2	Unnamed Trib to San Elijo Lagoon 2	33.009690	-117.245588	San Diego	High	8/2/2021	B, A
905SMCRAM	Santa Maria Creek Ramona	33.055700	-116.859198	San Diego	High	8/3/2021	B, A
905UNTGVC	Unnamed Trib to Green Valley Creek	33.015090	-117.053395	San Diego	High	7/31/2021	B, A
906UNTLPE	Unnamed Trib to Los Penasquitos Estuary	32.938610	-117.252962	San Diego	High	7/21/2021	B, A
906UPCAKS	Upper Poway Creek at Kittery Street	32.953570	-117.015461	San Diego	High	7/24/2021	B, A
907SDT163	Unnamed Trib to SD River along 163	32.757040	-117.159177	San Diego	High	7/20/2021	B, A
907SDTJHN	Unnamed Trib to SD River along Johnson	32.757160	-117.158623	San Diego	High	7/30/2021	B, A
907UNAACR	Unnamed Trib to Alvarado Creek at Alvarado Canyon Rd	32.783420	-117.085522	San Diego	High	7/28/2021	B, A
907UNTPCD	Unnamed Trib to SD River Park Center Drive	32.853180	-116.975835	San Diego	High	8/4/2021	B, A
907UTSVC1	Unnamed Trib to San Vicente Creek 1	33.008160	-116.820950	San Diego	High	8/5/2021	B, A

StationCode	Station name	Latitude	Longitude	County	Human activity level	Sample date	Indicators
907UTSVC3	Unnamed Trib to San Vicente Creek 3	33.024330	-116.799490	San Diego	High	8/4/2021	B, A
908PVCUPP	Upper Paradise Valley Creek	32.698230	-117.039209	San Diego	High	7/27/2021	B, A
908SSCBD1	Seventh Street Channel at Bonita Drive	32.693610	-117.080187	San Diego	High	7/19/2021	B, A
908UTSFC2	Unnamed Trib to South Fork Chollas 2	32.710381	-117.040369	San Diego	High	7/26/2021	B, A
910DENNRY	Dennery Canyon	32.587410	-117.019337	San Diego	High	7/22/2021	B, A
911TJPC2x	Pine Valley Creek at Noble Canyon Trailhead	32.853119	-116.522737	San Diego	High	7/18/2021	B, A
403R4SSCT	Sulphur Creek Tributary	34.377240	-119.298910	Ventura	Low	5/8/2019	B
403S00028	Trib to Piru Ck west of Canton Canyon Rd	34.524506	-118.764921	Ventura	Low	6/26/2019	B
404R4SASQ	Arroyo Sequit 0.27 miles upstream from Mulholland Hwy	34.090980	-118.911049	Los Angeles	Low	7/23/2019	B
405R4SSDC	Soldier Creek	34.312512	-117.832770	Los Angeles	Low	9/10/2019	B
405R4STSC	Tributary to Soldier Creek	34.292346	-117.832373	Los Angeles	Low	9/10/2019	B
801SANT1x	Santiago Canyon above education house	33.708850	-117.614560	Orange	High	8/10/2017	B
901AUDFOX	Fox Canyon	33.598743	-117.564667	Orange	Low	8/24/2019	B
901NP9BWR	Bluewater Canyon Creek 1	33.530630	-117.429080	Riverside	Low	8/5/2020	B
901NP9TNC	Tenaja Canyon	33.526506	-117.405504	Riverside	Low	8/2/2020	B
901UNTLCC	Unnamed Tributary to Long Canyon Creek Above San Juan	33.618052	-117.435405	Riverside	Low	8/4/2020	B

StationCode	Station name	Latitude	Longitude	County	Human activity level	Sample date	Indicators
901UPRAC1	Upper Aliso Creek 1	33.655730	-117.659090	Orange	High	8/3/2020	B
902DPCCT	Unnamed Cooper Canyon Tributary	33.418050	-116.650650	San Diego	Low	8/8/2020	B
902DPUCC1	Unnamed Tributary to Cahuilla Creek 1	33.575754	-116.761838	Riverside	Low	8/9/2020	B
902DPUCC2	Unnamed Tributary to Cahuilla Creek 2	33.546030	-116.791020	Riverside	Low	8/10/2020	B
902UDLVGR	Upper De Luz Creek Above Vuelta Grande Road	33.481379	-117.308525	Riverside	High	7/18/2020	B
902USGCBS	Upper Santa Gertrudis Creek at Butterfield Stage Road	33.545480	-117.103440	Riverside	High	7/20/2020	B
903DPUEFS	Upper East Fork San Luis Rey	33.384680	-116.626020	San Diego	Low	8/6/2020	B
903DPUWF1	Unnamed Tributary to West Fork San Luis Rey 1	33.336920	-116.824870	San Diego	Low	8/7/2020	B
903NP9PRC	Prisoner Creek ~0.1mi above San Luis Rey River	33.260410	-116.809170	San Diego	Low	8/22/2019	B
903UTLSLR	Unnamed Trib to Lower San Luis Rey	33.257680	-117.294090	San Diego	High	7/22/2020	B
904UNTEC3	Unnamed Trib to Escondido Creek 3	33.169010	-117.092940	San Diego	High	6/30/2020	B
905SDBDN9	Boden Canyon Creek (BOD)	33.093324	-116.897295	San Diego	Low	8/23/2019	B
906UNTSC1	Unnamed Trib to Soledad Canyon 1	32.902290	-117.160880	San Diego	High	7/8/2020	B
906UNTSC2	Unnamed Trib to Soledad Canyon 2	32.902524	-117.162600	San Diego	High	7/23/2020	B

StationCode	Station name	Latitude	Longitude	County	Human activity level	Sample date	Indicators
906UNTTC4	Unnamed Trib to Tecolote Creek 4	32.798770	-117.171440	San Diego	High	7/26/2020	B
906UNTTC6	Unnamed Trib to Tecolote Creek 6	32.818060	-117.192200	San Diego	High	7/28/2020	B
906UNTTC7	Unnamed Trib to Tecolote Creek 7	32.830270	-117.185100	San Diego	High	7/27/2020	B
906UNTTC8	Unnamed Trib to Tecolote Creek 8	32.830100	-117.197370	San Diego	High	7/29/2020	B
907NP9OSU	Oak Springs Canyon Upstream of Highway 52	32.855102	-117.051904	San Diego	Low	8/21/2019	B
907SRSD1x	San Diego River Headwaters above Highway 79	33.108780	-116.657580	San Diego	High	8/22/2019	B
907UNTFC1	Unnamed Trib to Forester Creek 1	32.786960	-116.915550	San Diego	High	7/3/2020	B
907UTSVC2	Unnamed Trib to San Vicente Creek 2	33.013240	-116.811610	San Diego	High	6/29/2020	B
908CCAEA1	Chollas Creek above Euclid Ave	32.737360	-117.086750	San Diego	High	7/5/2020	B
908LCCAWM	Laurel Creek in Maple Canyon	32.733860	-117.165620	San Diego	High	7/16/2020	B
908NFCDDR	North Fork Chollas Creek at Delevan Dr	32.721420	-117.117720	San Diego	High	7/15/2020	B
908PVCDST	Paradise Valley Creek upstream of Division Street	32.694240	-117.059590	San Diego	High	7/14/2020	B
908SFCCAB	South Fork Chollas Creek at Broadway	32.715050	-117.046910	San Diego	High	7/24/2020	B
908UNTCC1	Unnamed Trib to Chollas Canyon at Home Ave	32.736160	-117.091340	San Diego	High	7/25/2020	B

StationCode	Station name	Latitude	Longitude	County	Human activity level	Sample date	Indicators
908UNTCC2	Unnamed Trib to Chollas Canyon 2	32.736580	-117.106920	San Diego	High	7/6/2020	B
908UTSFC1	Unnamed Trib to South Fork Chollas 1	32.710250	-117.051280	San Diego	High	7/9/2020	B
909UNTSWR	Unnamed Trib to Sweetwater River at Lamar Park	32.740360	-117.007290	San Diego	High	7/4/2020	B
910DPUSCT	Unnamed Tributary to Sycamore Canyon	32.643630	-116.795750	San Diego	Low	7/11/2020	B
910UNTMAB	Unnamed Trib at Max Ave Ballfields	32.603790	-117.046870	San Diego	High	7/10/2020	B
911DPCMCC	Channing Meadow Creek Upstream of Cottonwood	32.813530	-116.490640	San Diego	Low	11/8/2020	B
911DPNMCC	Noble Mine Canyon Creek	32.886990	-116.489310	San Diego	Low	8/13/2020	B
911DPUCC5	Unnamed Tributary to Upper Cottonwood 5	32.771320	-116.486830	San Diego	Low	7/2/2020	B
911DPULCC	Unnamed Tributary to Lower Cottonwood Creek	32.611160	-116.680020	San Diego	Low	7/12/2020	B
911DPUPV2	Unnamed Tributary to Upper Pine Valley Creek 2	32.896980	-116.521510	San Diego	Low	8/15/2020	B
911GSCAPV	Granite Spring Canyon above Pine Valley Creek	32.897590	-116.528060	San Diego	Low	8/15/2020	B
911S00858	Indian creek ~1.2mi above Deer Park Rd.	32.902824	-116.493371	San Diego	High	8/12/2020	B

Site classification

We classified sites as experiencing high versus low levels of human activity by characterizing watershed conditions using GIS. First, we delineated watersheds for each site, and calculated a set of landscape metrics for each watershed, following the procedures described in Boyle et al. (2020). These metrics were compared to criteria used to identify reference sites for wadeable streams (Table 2; adapted from Ode et al. 2016). This process identified 34 potential low-activity sites. This set of sites was further screened by applying a watershed prioritization tool that identifies whether a stream reach is likely disturbed based on landscape metrics (Stein et al. 2022); 32 of the 34 previously identified sites were considered to be undisturbed, and thus were designated as "low-activity" sites in further analyses. Arthropod data were available at 7 of these 32 low-activity sites.

Table 2. Criteria to identify low-activity sites adapted from Ode et al. (2016). WS: Metric calculated at the watershed scale. 5K: Metric calculated for the area within the watershed within 5 km of the sampling location. 1K: Metric calculated for the area within the watershed within 1 km of the sampling location.

Landscape metric	Screen for low-activity sites
Urban or agricultural land use (WS, 5K, 1K)	<3%
Urban AND agricultural land use (WS, 5K, 1K)	<5%
Code 21 (i.e., developed open space; WS)	<10%
Code 21 (i.e., developed open space; 5K, 1K)	<7%
Road density (WS, 5K, 1K)	<2 km/km^2
Road crossings (WS)	<50
Road crossings (5K)	<10
Road crossings (1K)	<5
Dam distance (WS)	>10 km
Producer mines (5K)	0

Data collection

Biological indicators

Streambed arthropods

Following the protocol described in Robinson et al. (2018), field crews collected biological and physical habitat data at a total of 104 sites. At each site, crews designated a representative 160-m reach, which were separated into eight sections. In each section, crews collected arthropods from the streambed using ramped pitfall (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 24 hours to collect both diurnal and nocturnal arthropods, which were stored in jars along with the contents of the traps for later identification.

Riparian arthropods

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 later identification.

Bryophytes

Along with arthropods, California State University, Monterey Bay (CSUMB) collected bryophytes (moss) at each site (when possible or available), which were collected using a floristic approach (Newmaster et al. 2005; Robinson et al. 2018). They designated three mesohabitats: right and left banks and the channel. They designated 20 minutes to search for moss in each habitat and allotted 12 minutes to collect moss. Field crews collected up to a total of five samples of moss from each mesohabitat, collecting them by hand in a pattern from most diverse to least diverse patches in each microhabitat (e.g., soil, rock, or wood) present.

California Rapid Assessment Method (CRAM)

Field assessments were conducted at 12 sites using the California Rapid Assessment Method (CRAM) during June and July 2022 (Table 1). CRAM is a visual assessment of the condition and stressors affecting the physical and biological habitat. Both the episodic module (California Wetlands Monitoring Workgroup [CWMW] 2020) and the riverine module (CWMW 2013) were applied at each site, with the most appropriate module determined based on the vegetation and physical characteristics observed at each assessment area. Episodic streams exhibit short-duration, highly localized, and extremely variable (flashy) flow in response to rainfall events or dam releases, and most ephemeral streams are typically assessed with the episodic module. Intermittent streams [those that exhibit biological, hydrological, or physical characteristics commonly associated with conveyance of surface water or near-surface water for extended durations (i.e., several weeks to months)] are generally assessed with the standard riverine module. The episodic CRAM module uses many of the same measurements as the riparian module, but is less stringent in the scoring, thus final index values tend to be higher using the episodic module when both modules are applied at the same site.

CRAM is comprised of four attributes: buffer and landscape context, hydrology, physical structure, and biological structure. These attributes are aggregated into an overall index score, which ranges from 25-100 (most to least impacted).

The buffer and landscape context attribute assesses the amount and condition of the area adjacent to the stream channel that is in a natural state and protects the stream from stress and disturbances.

The hydrology attribute evaluates the source of water to the site during the dry season (e.g., natural, anthropogenic, eliminated), the state of the channel stability (whether the channel is degrading, aggrading, or at equilibrium), sediment transport (evidence of natural or altered sediment processes), and the ability of the stream to connect to the surrounding landscape under flood conditions.

The physical structure attribute measures the structural patch richness (the number of different types of physical surfaces or features that may provide habitat for aquatic, wetland, or riparian plant and animal species), and the topographic complexity (the spatial arrangement and interspersion of micro- and macro-topographic relief present within the channel that affects moisture gradients or that influence the path of flowing water).

The biotic structure attribute is based on plant metrics, including plant composition (the number of plant height layers, the number of co-dominant plant species, and the percent of co-dominant plant species that are classified as invasive), horizontal interspersion and zonation (the variety and interspersion of distinct plant zones), and vertical biotic structure (the degree of overlap among plant layers).

Data analysis

Bioassessment metric calculation

Bioassessment metrics were calculated for three assemblages: bryophytes, arthropods collected from ramp traps, and arthropods collected from vegetation (no metrics were calculated for combined assemblages). All taxonomic data were aggregated within a site, date, and collection method to a standardized level. Most bryophytes were identified to genus, and most arthropods to family, with ants and other select taxa, taken to species. Thirty-seven metrics were then calculated from the aggregated data. One bryophyte metric was calculated (i.e., bryophyte richness). For arthropods, an identical set of 18 metrics was calculated for each of the two collection methods (36 arthropod metrics total). Where possible, up to 4 metric formulations were calculated:

- Richness: The total number of taxa in a sample.
- Relative richness: The total number of taxa within a subgroup of arthropods in a sample, divided by the total number of taxa in a sample.

- Abundance: The total number of individuals in a sample.
- Relative richness. The total number of individuals within a subgroup of arthropods, divided by the total number of individuals in a sample.

The complete list of metrics is provided in Table 3.

Table 3. Bioassessment metrics evaluated in this study. Metric codes ending with _Rich are richness metrics. Metric codes ending with _RelRich are relative richness metrics. Metric codes ending with _Ab are abundance metrics. Metric codes ending with _RelAb are relative abundance metrics.

Assemblage	Group	Metric code
Bryophytes	Bryophytes	B_Rich
Ramp traps	Arthropods	R_Rich R_Ab
Ramp traps	Insects	R_Insects_Rich R_Insects_RelRich R_Insects_Ab R_Insects_RelAb
Ramp traps	Non-insect arthropods	R_Noninsects_Rich R_Noninsects_Ab
Ramp traps	Coleoptera, Aranea, and Formicidae (beetles, spiders, and spiders)	R_CAF_Rich R_CAF_RelRich R_CAF_Ab R_CAF_RelAb
Ramp traps	Coleoptera, Aranea, Formicidae, and Hemiptera (beetles, spiders, spiders, and true bugs)	R_CAFH_Rich R_CAFH_RelRich R_CAFH_Ab R_CAFH_RelAb
Ramp traps	*Linepithema humile* (Argentine ants)	R_LE_Ab R_LE_RelAb
Vegetation	Arthropods	V_Rich V_Ab
Vegetation	Insects	V_Insects_Rich V_Insects_RelRich V_Insects_Ab V_Insects_RelAb
Vegetation	Non-insect arthropods	V_Noninsects_Rich V_Noninsects_Ab
Vegetation	Coleoptera, Aranea, and Formicidae (beetles, spiders, and spiders)	V_CAF_Rich V_CAF_RelRich V_CAF_Ab V_CAF_RelAb
Vegetation	Coleoptera, Aranea, Formicidae, and Hemiptera	V_CAFH_Rich V_CAFH_RelRich

Assemblage	Group	Metric code
	(beetles, spiders, spiders, and true bugs)	V_CAFH_Ab V_CAFH_RelAb
Vegetation	*Linepithema humile* (Argentine ants)	V_LE_Ab V_LE_RelAb

Assessment of the Los Angeles region

Sites in the Los Angeles region were assessed by comparing metric values and CRAM scores to assessment thresholds. For each metric, we calculated the percent of sites meeting or not meeting the threshold. The approach for determining assessment thresholds for CRAM was comparable to standard, reference-based methods used for bioassessment indices, such as the California Stream Condition Index (Mazor et al. 2016). However, due to the general scarcity of data for the bioassessment metrics, a different approach was used. These approaches are described below.

Calculation of assessment thresholds

Bioassessment metrics

We performed a Wilcoxon nonparametric test of differences to compare median metric scores at low- versus high-activity sites. Metrics with significant differences ($p<0.1$) were considered responsive, whereas those with non-significant differences were considered unresponsive.

Responsive bioassessment metrics were classified as increasers (i.e., metrics that increase in response to disturbance) if the median metric value at high-activity sites was greater than the median metric value at low-activity sites, and they were classified as decreasers if the median value at high-activity sites was lower than at low-activity sites.

For increaser metrics, the 75th percentile of values at low-activity sites was used as a threshold to identify potentially degraded sites; sites with values above this value were considered potentially degraded. For decreaser metrics, the 25th percentile of values at low-activity sites was used as a threshold; sites with values below this threshold were considered potentially degraded.

To provide an overall assessment of a site, we calculated the number of bioassessment thresholds met (aggregating across all 3 assemblages); unresponsive metrics were excluded from this analysis. We then mapped this sum to identify areas where conditions were overall intact or degraded. We generated a boxplot comparing the number of thresholds met at high-activity versus low-activity sites.

CRAM

CRAM thresholds based on distributions of scores at reference sites have been previously published (e.g., Mazor et al. 2021), and these thresholds were used to assess CRAM data in this report (Table 4).

Table 4. Ranges of index scores for each condition class.

Index	Likely intact (≥30th percentile of reference)	Possibly altered (10th to 30th percentile of reference)	Likely altered (1st to 10th percentile of reference)	Very likely altered (<1st percentile of reference)
Episodic CRAM	≥79	73 to 79	65 to 73	<65
Riverine CRAM	≥81	76 to 81	68 to 76	<68

Results

Bioassessment metrics

Assessment thresholds for bioassessment metrics

Of the 37 bioassessment metrics we evaluated, 23 were considered responsive. Among these, 9 were metrics for ramp trap assemblages and 14 were for vegetation assemblages; the one bryophyte metric evaluated was not responsive. Twelve of the 23 responsive metrics were increasers, while 11 were decreasers. In general, metrics for the vegetation method were increasers, while those for the ramp traps were decreasers (Table 6). As expected, metrics based on the non-native Argentine ant (*Linepithema humile*; metrics containing “LE” in Table 5) were increasers.

Table 5. Metric responsiveness, as measured by Wilcoxon's W-statistic comparing median values at high- and low-activity sites. Metrics with p-values >0.1 were considered unresponsive. Metric direction was determined by comparing median values at high- and low-activity sites (shown in Table 6). Assessment thresholds indicate the minimum (for decreasing metrics) or maximum (for increasing metrics) value to indicate good ecological condition.

Metric	Wilcoxon W	Wilcoxon p	Metric responsiveness	Metric direction	Assessment threshold
B_Rich	849	0.361	Unresponsive	Decreasing	≥4.50
R_Rich	34.5	0.016	Responsive	Decreasing	≥15.00
R_Ab	38.5	0.027	Responsive	Decreasing	≥79.50
R_Insects_Rich	26	0.005	Responsive	Decreasing	≥11.5
R_Insects_RelRich	43	0.045	Responsive	Decreasing	≥0.72
R_Insects_Ab	33	0.014	Responsive	Decreasing	≥72.5
R_Insects_RelAb	53	0.121	Unresponsive	Decreasing	≥0.88
R_Noninsects_Rich	86	0.963	Unresponsive	Neither	None determined
R_Noninsects_Ab	100	0.584	Unresponsive	Increasing	≤12
R_CAF_Rich	20	0.002	Responsive	Decreasing	≥9.5
R_CAF_RelRich	59	0.201	Unresponsive	Decreasing	≥0.57
R_CAF_Ab	52	0.110	Unresponsive	Decreasing	≥44.5
R_CAF_RelAb	120	0.148	Unresponsive	Increasing	≤0.71
R_CAFH_Rich	30	0.009	Responsive	Decreasing	≥9.5
R_CAFH_RelRich	68	0.385	Unresponsive	Decreasing	≥0.59
R_CAFH_Ab	52.5	0.116	Unresponsive	Decreasing	≥45
R_CAFH_RelAb	120.5	0.138	Unresponsive	Increasing	≤0.71
R_LE_Ab	164.5	0.000	Responsive	Increasing	≤0.5
R_LE_RelAb	166.5	0.000	Responsive	Increasing	≤ 0
V_Rich	145.5	0.009	Responsive	Increasing	≤7.5
V_Ab	166	0.000	Responsive	Increasing	≤21.5
V_Insects_Rich	147.5	0.006	Responsive	Increasing	≤4
V_Insects_RelRich	110.5	0.305	Unresponsive	Increasing	≤0.8
V_Insects_Ab	168	0.000	Responsive	Increasing	≤7
V_Insects_RelAb	119	0.158	Unresponsive	Increasing	≤0.89

Metric	Wilcoxon W	Wilcoxon p	Metric responsiveness	Metric direction	Assessment threshold
V_Noninsects_Rich	118	0.166	Unresponsive	Increasing	≤3.5
V_Noninsects_Ab	123	0.110	Unresponsive	Increasing	≤10
V_CAF_Rich	127	0.074	Responsive	Increasing	≤5
V_CAF_RelRich	16	0.001	Responsive	Decreasing	≥0.65
V_CAF_Ab	158.5	0.001	Responsive	Increasing	≤17.5
V_CAF_RelAb	39	0.029	Responsive	Decreasing	≥0.74
V_CAFH_Rich	132	0.044	Responsive	Increasing	≤7
V_CAFH_RelRich	21.5	0.003	Responsive	Decreasing	≥0.93
V_CAFH_Ab	165.5	0.000	Responsive	Increasing	≤20
V_CAFH_RelAb	34.5	0.016	Responsive	Decreasing	≥0.99
V_LE_Ab	161	0.001	Responsive	Increasing	≤0
V_LE_RelAb	161	0.001	Responsive	Increasing	≤0

Table 6. Quantile metric values at high- and low-activity sites. Q25: 25th percentile. Q50: 50th percentile (median). Q75: 75th percentile. Metric abbreviations are shown in Table 3.

Human activity level	Metric	# sites	Q25	Q50	Q75
High	B_Rich	62	4	6	8
Low	B_Rich	31	4.5	7	9.5
High	R_Ab	25	40	60	127
Low	R_Ab	7	79.5	165	204.5
High	R_CAF_Ab	25	29	32	47
Low	R_CAF_Ab	7	44.5	69	145.5
High	R_CAF_RelAb	25	0.5	0.71	0.88
Low	R_CAF_RelAb	7	0.4	0.49	0.71
High	R_CAF_RelRich	25	0.46	0.5	0.6
Low	R_CAF_RelRich	7	0.57	0.57	0.61
High	R_CAF_Rich	25	5	7	8
Low	R_CAF_Rich	7	9.5	11	11.5
High	R_CAFH_Ab	25	29	33	48
Low	R_CAFH_Ab	7	45	70	146
High	R_CAFH_RelAb	25	0.52	0.75	0.91
Low	R_CAFH_RelAb	7	0.41	0.5	0.71
High	R_CAFH_RelRich	25	0.53	0.59	0.67
Low	R_CAFH_RelRich	7	0.59	0.64	0.67
High	R_CAFH_Rich	25	7	8	10
Low	R_CAFH_Rich	7	9.5	12	12.5
High	R_Insects_Ab	25	33	42	105
Low	R_Insects_Ab	7	72.5	155	193
High	R_Insects_RelAb	25	0.72	0.83	0.88
Low	R_Insects_RelAb	7	0.88	0.93	0.95
High	R_Insects_RelRich	25	0.58	0.67	0.75
Low	R_Insects_RelRich	7	0.72	0.75	0.78
High	R_Insects_Rich	25	6	9	11
Low	R_Insects_Rich	7	11.5	13	16
High	R_LE_Ab	25	6	17	41
Low	R_LE_Ab	7	0	0	0.5
High	R_LE_RelAb	25	0.08	0.44	0.61
Low	R_LE_RelAb	7	0	0	0
High	R_Noninsects_Ab	25	7	12	21
Low	R_Noninsects_Ab	7	7	10	12
High	R_Noninsects_Rich	25	2	4	6
Low	R_Noninsects_Rich	7	3.5	4	4.5
High	R_Rich	25	11	13	15

Human activity level	Metric	# sites	Q25	Q50	Q75
Low	R_Rich	7	15	18	19.5
High	V_Ab	25	65	96	169
Low	V_Ab	7	5	6	21.5
High	V_CAF_Ab	25	28	58	98
Low	V_CAF_Ab	7	4	6	17.5
High	V_CAF_RelAb	25	0.46	0.67	0.8
Low	V_CAF_RelAb	7	0.74	0.83	0.95
High	V_CAF_RelRich	25	0.45	0.5	0.58
Low	V_CAF_RelRich	7	0.65	0.75	0.9
High	V_CAF_Rich	25	5	6	8
Low	V_CAF_Rich	7	3	4	5
High	V_CAFH_Ab	25	54	83	149
Low	V_CAFH_Ab	7	5	6	20
High	V_CAFH_RelAb	25	0.87	0.93	0.98
Low	V_CAFH_RelAb	7	0.99	1	1
High	V_CAFH_RelRich	25	0.67	0.71	0.75
Low	V_CAFH_RelRich	7	0.93	1	1
High	V_CAFH_Rich	25	6	8	12
Low	V_CAFH_Rich	7	3.5	5	7
High	V_Insects_Ab	25	52	89	141
Low	V_Insects_Ab	7	2	4	7
High	V_Insects_RelAb	25	0.81	0.9	0.95
Low	V_Insects_RelAb	7	0.32	0.5	0.89
High	V_Insects_RelRich	25	0.67	0.71	0.75
Low	V_Insects_RelRich	7	0.52	0.57	0.8
High	V_Insects_Rich	25	5	8	12
Low	V_Insects_Rich	7	2	3	4
High	V_LE_Ab	25	2	34	77
Low	V_LE_Ab	7	0	0	0
High	V_LE_RelAb	25	0.04	0.31	0.62
Low	V_LE_RelAb	7	0	0	0
High	V_Noninsects_Ab	25	7	10	16
Low	V_Noninsects_Ab	7	1.5	5	10
High	V_Noninsects_Rich	25	2	4	5
Low	V_Noninsects_Rich	7	1	3	3.5
High	V_Rich	25	8	11	16
Low	V_Rich	7	3.5	5	7.5

Assessment of the Los Angeles region

For the most sensitive bioassessment metrics (i.e., abundance or relative abundance of Argentine ants in ramp trap samples; R_LE_Ab and R_LE_RelAb), 6 of the 32 sites (81%) were potentially degraded (Table 7). For the least sensitive metrics (i.e., richness of beetles, spiders, ants, and true bugs in vegetation samples; V_CAF_Rich and V_CAFH_Rich), 15 (47%) were potentially degraded. Across the 23 responsive metrics, the median number of potentially degraded sites was 21.

Table 7. Number of sites meeting assessment thresholds for 23 responsive metrics. Metric abbreviations are shown in Table 3.

Metric	# sites	# sites meeting threshold	% sites meeting threshold
V_CAF_Rich	32	17	53%
V_CAFH_Rich	32	17	53%
R_Rich	32	16	50%
V_CAF_RelAb	32	15	47%
R_Insects_RelRich	32	14	44%
R_Ab	32	13	41%
R_CAFH_Rich	32	13	41%
R_Insects_Ab	32	12	38%
V_Insects_Rich	32	12	38%
V_LE_Ab	32	11	34%
V_LE_RelAb	32	11	34%
V_Rich	32	11	34%
R_Insects_Rich	32	10	31%
V_CAF_Ab	32	9	28%
V_CAFH_RelAb	32	9	28%
R_CAF_Rich	32	8	25%
V_Ab	32	8	25%
V_CAF_RelRich	32	8	25%
V_CAFH_Ab	32	8	25%
V_CAFH_RelRich	32	8	25%
V_Insects_Ab	32	7	22%
R_LE_Ab	32	6	19%
R_LE_RelAb	32	6	19%

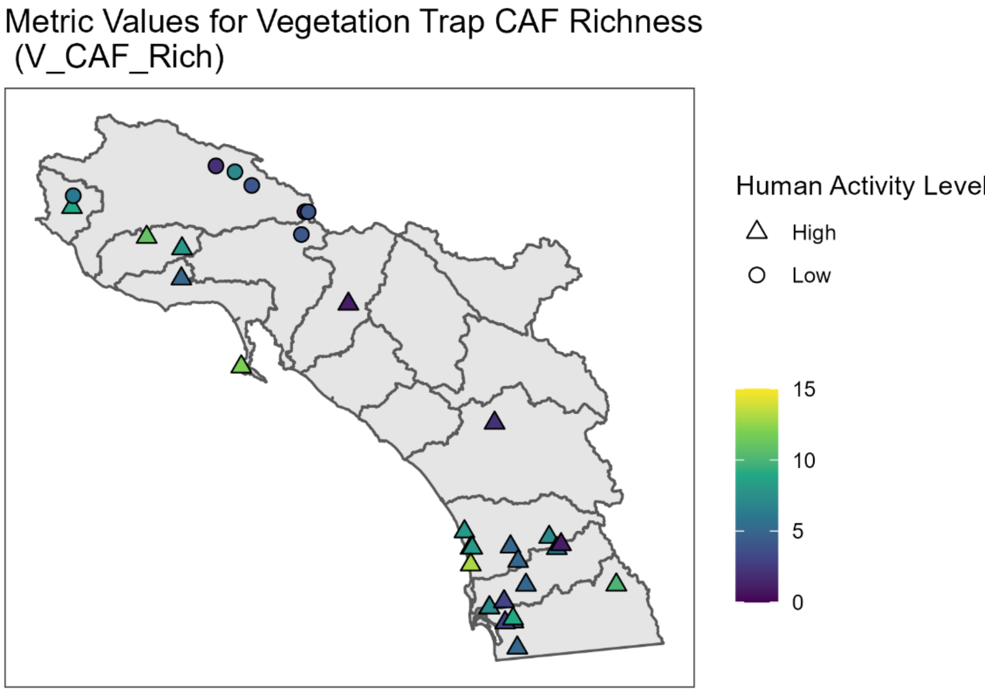

Figure 3. Map of sites showing richness of beetles, ants, and spiders in vegetation samples (V_CAF_Rich).

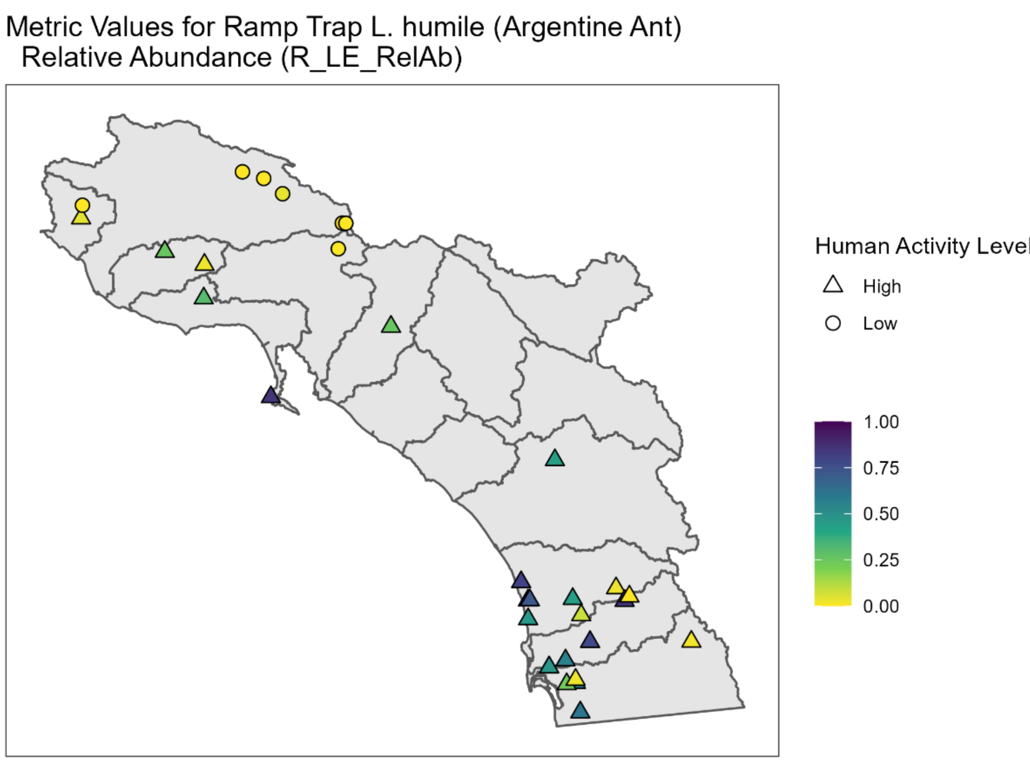

Figure 4. Map of sites showing relative abundance of Argentine ants in ramp traps. (R_LE_RelAb)

The number of metrics meeting thresholds ranged from a low of 1 to a high of 23 (i.e., all responsive metrics met). This number varied strongly between high- and low-activity sites. For example, among high-activity sites, the number of metrics indicating good conditions ranged from 1 to 17 (median: 5), whereas among low-activity sites, it ranged from 12 to 23 (median: 16; Figure 5). Within region 4, this number ranged from 2 to 23 (median: 12). Sites in undeveloped areas tended to have more metrics indicating likely good conditions (Figure 6).

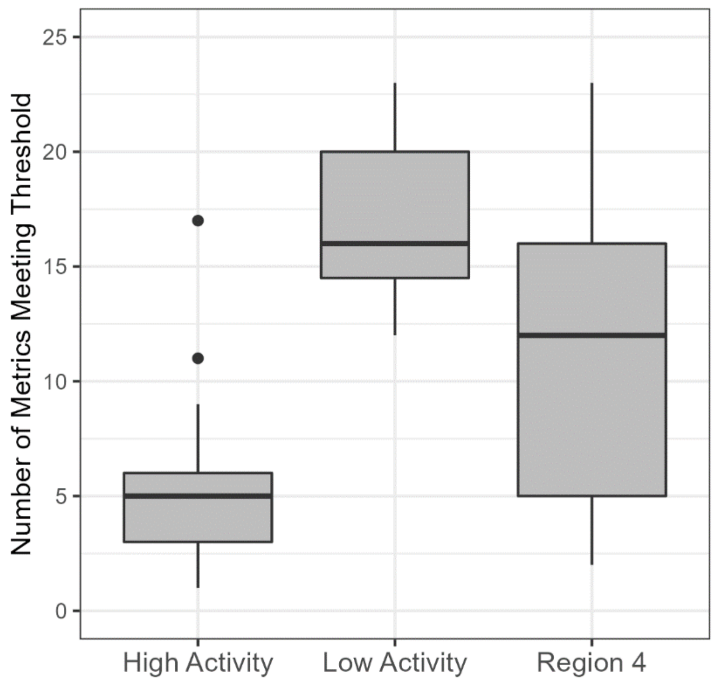

Figure 5. Number of metrics passed at high-activity sites, low-activity sites, and all sites within Region 4. The maximum possible value was 23 (i.e., the total number of responsive metrics).

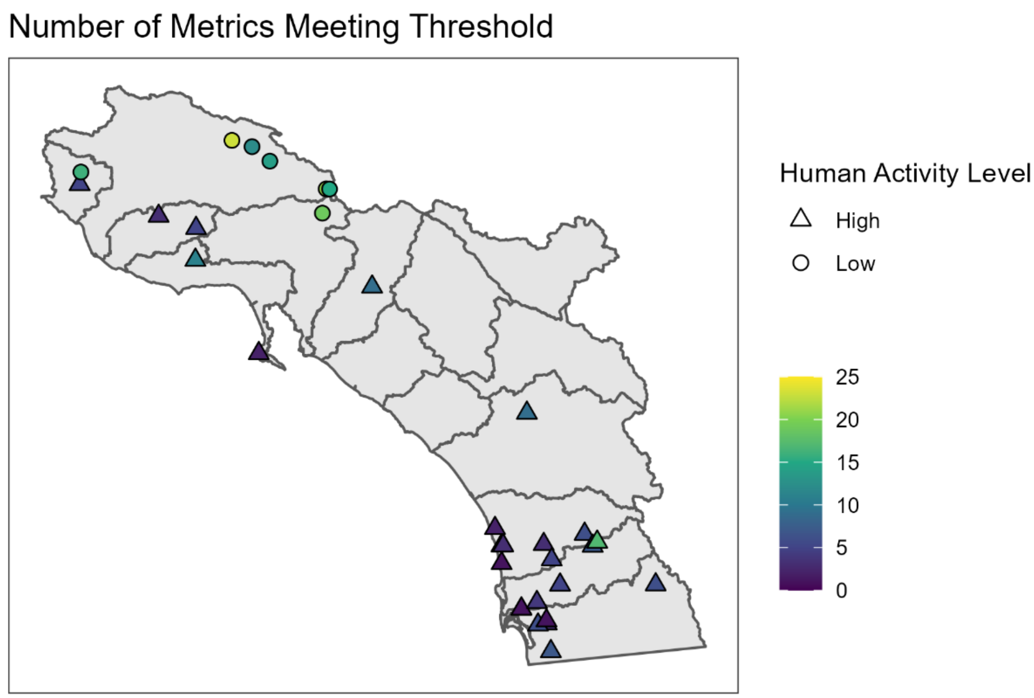

Figure 6. Map of sites showing the number of metrics indicating likely good ecological conditions.

CRAM

Assessment of the Los Angeles region

The episodic module was most appropriate to use at four sites, and the riverine CRAM module was most appropriate at eight sites (Table 8). The episodic sites tended to have a greater representation of upland plant species (e.g., *Eriogonum fasciculatum*, *Baccharis pilularis*) and had fewer or no water stains on cobbles and boulders. The geographic setting of the sites assessed using CRAM in this study varied, with two of the locations appearing to be restoration sites in urban areas, with new plantings of native vegetation (one site riverine, one site episodic), while four sites were non-restoration sites in urban or agricultural settings, and six sites were located in National Forests (Table 8).

CRAM index scores ranged from 57 to 100 (Table 8). Six (50%) of the sites had scores that were likely intact, and 6 of the sites were very likely altered (Table 8). None of the sites had scores in the two intermediate-condition categories. Sites that were very likely altered were those in urban or agricultural settings, while the likely intact sites were located within the Angeles or Los Padres National Forests (Figure 7). CRAM index scores were significantly negatively correlated with increasing levels of agriculture, urbanization, Code 21, paved road crossings, and road and railroad density (Spearman's rank correlation, $p<0.05$) with strong negative relationships for each of these stressors (rho < -0.60) (Figure 8; Table 9).

The CRAM metrics most likely to be impacted at the very likely altered sites were those related to the stream corridor and assessment area buffer. Stream corridor continuity (i.e., the physical, ecological, and hydrological continuity of the stream corridor and the habitat it provides to wildlife within 500 m upstream and downstream of the assessment area) had the lowest possible score at all six of the very likely altered sites, while buffer width had the lowest possible score at four of these sites. Buffer condition, percent of the assessment area with buffer, and the occurrence of invasive species within the assessment area were submetrics that had the lowest possible score at two of the very likely altered sites.

Table 8. Index scores for the California Rapid Assessment Method (CRAM) at each assessment location.

Station Code	Geographic Setting	Applied CRAM Module	CRAM Index Score	Condition relative to threshold
402COZYDL	National Forest	Riverine	85	Likely intact
402LONVAL	Urban	Riverine*	49	Very likely altered
403TEXCYN	National Forest	Riverine	84	Likely intact
403UACAFH	National Forest	Riverine	88	Likely intact
403CLWCYN	National Forest	Riverine	85	Likely intact
403LACACR	National Forest	Episodic	100	Likely intact
404SMMCON	Restoration - Urban	Riverine*	66	Very likely altered
404LUNADA	Urban	Episodic	63	Very likely altered
405SJHILL	Restoration - Urban	Episodic	63	Very likely altered
408GRIMES	Agricultural	Riverine*	47	Very likely altered
408ARYSIM	Urban	Riverine	57	Very likely altered
412SINGSP	National Forest	Episodic	87	Likely intact

* = Riverine module was the only applicable CRAM module. For other Riverine sites, both modules were applicable, but the Riverine module was preferred due to local vegetation and physical characteristics of the reach.

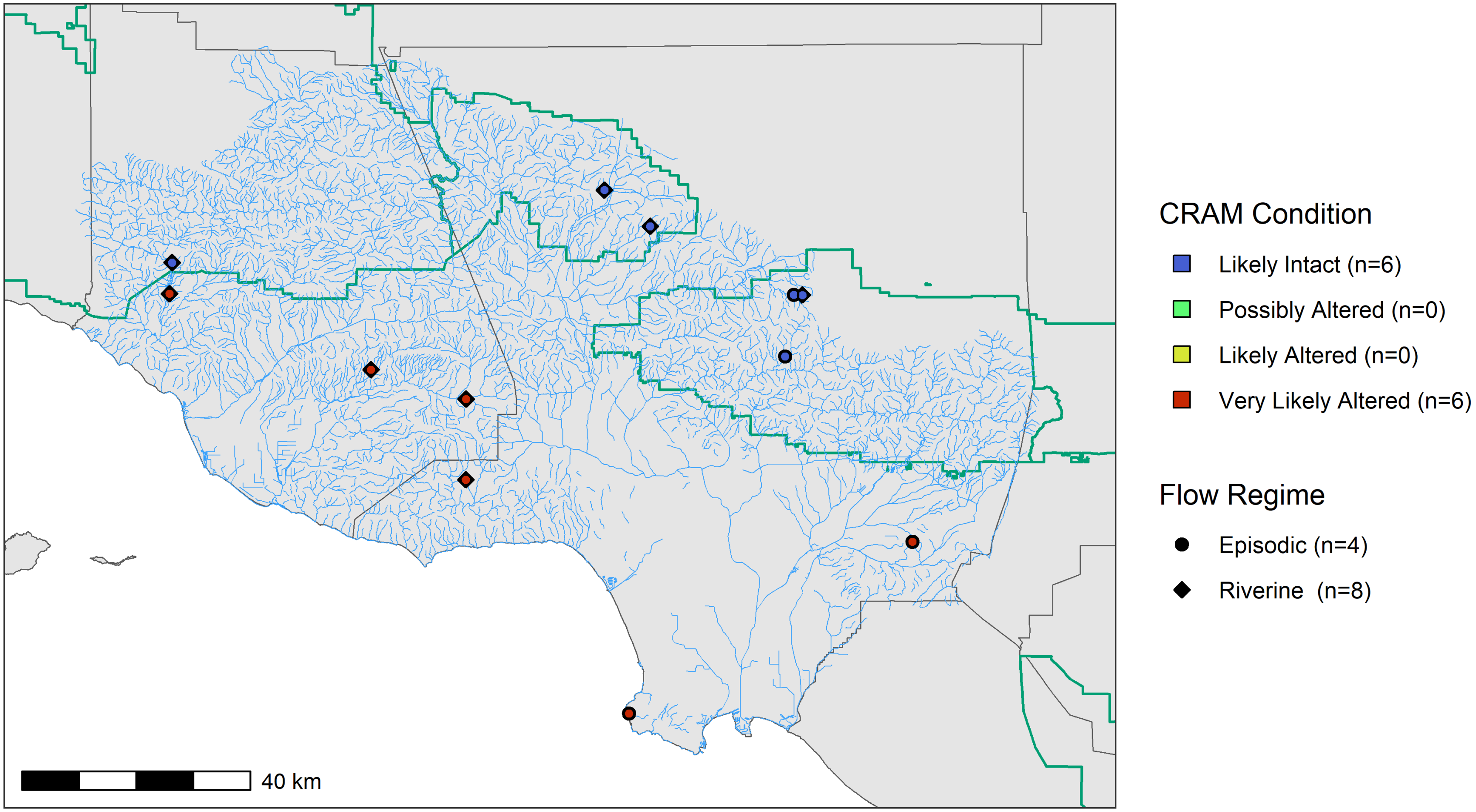

Figure 7. Map of CRAM condition and flow regime at Water Board Region 4 assessment sites. County lines (gray) are added for reference. National Hydrography Dataset Plus flowlines (NHD Plus, light blue) and National Forest boundaries (green) are also shown.

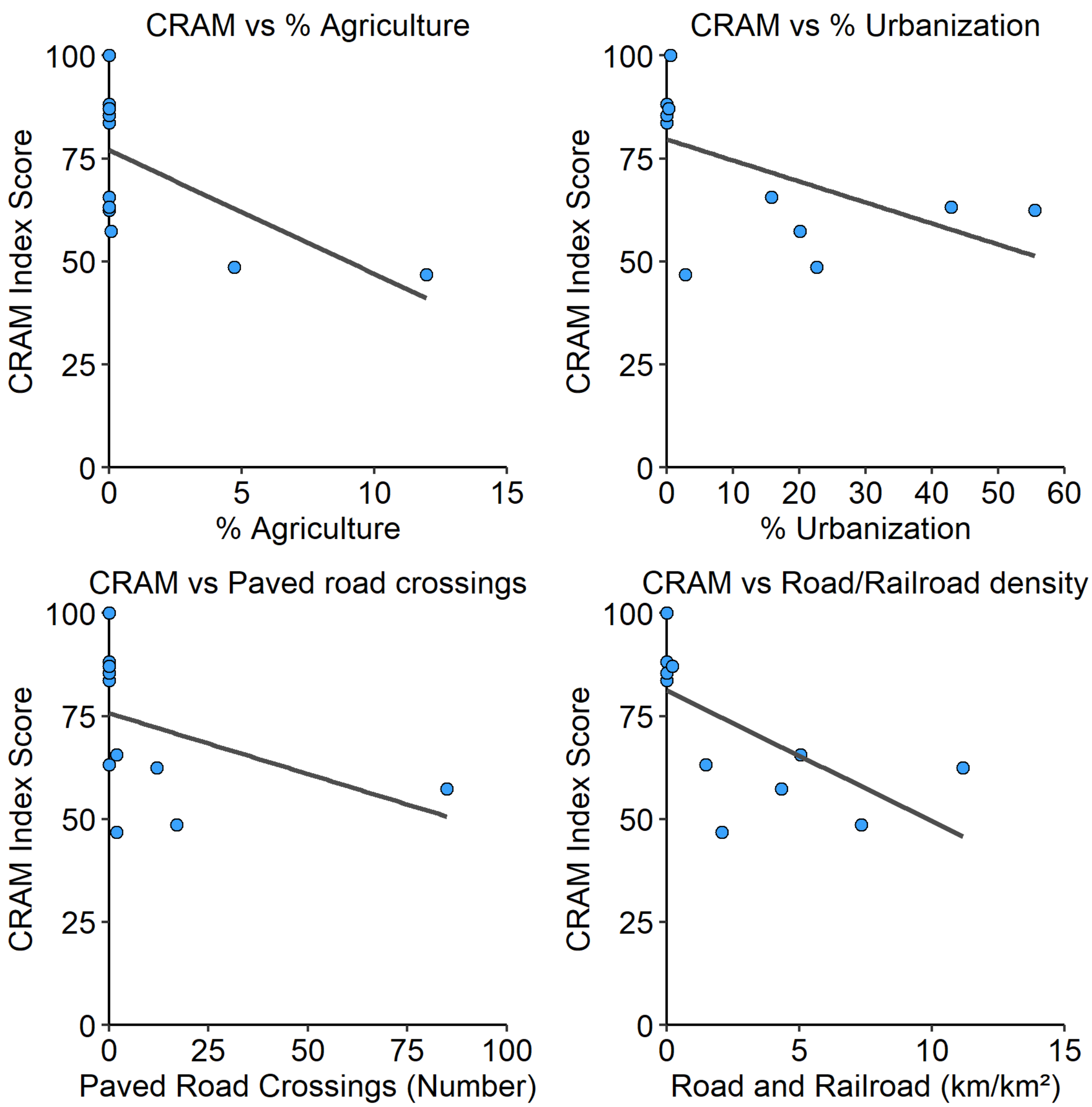

Figure 8. Relationship between CRAM index scores and landscape stressors at the watershed level. A locally weighted scatterplot smoothing trend line is added for reference.

Table 9. The relationship between CRAM index scores and the levels of landscape-related stress, identified using Spearman's rank correlation. WS = Watershed upstream of the assessment site.

Stressor	Number of Sites	p-value	rho
Number of mines (5 km)	12	0.11	-0.48
Dam distance (WS)	12	0.33	-0.31
% Agriculture (1 km)	12	0.02	-0.65
% Agriculture (5 km)	12	<0.01	-0.76
% Agriculture (WS)	12	<0.01	-0.76
% Urban (1 km)	12	0.01	-0.73
% Urban (5 km)	12	0.02	-0.65
% Urban (WS)	12	0.02	-0.66
% Agriculture + urban (1 km)	12	<0.01	-0.81
% Agriculture + urban (5 km)	12	0.02	-0.65
% Agriculture + urban (WS)	12	0.02	-0.66
% Code 21 (1 km)	12	<0.01	-0.76
% Code 21 (5 km)	12	<0.01	-0.81
% Code 21 (WS)	12	<0.01	-0.78
Paved road crossings (1 km)	12	0.01	-0.74
Paved road crossings (5 km)	12	<0.01	-0.79
Paved road crossings (WS)	12	<0.01	-0.79
Road and railroad density (1 km)	12	<0.01	-0.80
Road and railroad density (5 km)	12	<0.01	-0.83
Road and railroad density (WS)	12	<0.01	-0.77

CONCLUSIONS

Although this study is based on a limited (but soon to expand) dataset, it shows the promise of using biological indicators to assess the condition of dry intermittent and ephemeral streams — at least, with indicators based on arthropod assemblages. Further investigation is needed to determine if bryophytes may also serve as biological indicators, although the one metric we examined was unresponsive to human activity.

Both the bioassessment metrics and CRAM results show that about half of the sites within the Los Angeles region are potentially degraded, while the other half are likely in good condition. As expected, sites in good conditions are primarily found within undeveloped areas, which underscores the relationship between dry stream indicators and watershed conditions.

Further investigations are currently underway to further support the use of dry stream indicators of biological condition:

- Additional arthropod samples collected from both the Los Angeles and San Diego regions are currently under taxonomic analysis by the California Department of Fish and

Wildlife's Aquatic Bioassessment Lab. These additional data are expected to greatly expand the number of reference sites for which arthropod data are available, providing more robust measures of responsiveness. A larger data set may also allow further investigation of the relationship between dry stream arthropods and natural gradients, which can be used to reduce the influence of bias from natural environmental gradients (as is done with the California Stream Condition Index, Mazor et al. 2016).

- We are developing reach-scale measures of human activity derived from physical habitat data collected as part of the protocol in Robinson et al. (2018). We expect that reach-scale measures are even more important in screening reference sites than the watershed-scale measures we used here.
- We are expanding the list of candidate bioassessment metrics. We examined only a handful of candidate metrics for arthropods, and only one metric for bryophytes. We are developing a database of life-history traits (such as body size, feeding styles, longevity, and responses to desiccation or heat stress) that may provide more accurate, precise, and sensitive measures of ecological condition than the metrics we examined here.

These ongoing efforts will ultimately result in the development of a bioassessment with sufficient levels of performance that the Water Boards can use in monitoring or management programs where dry stream assessments are needed. These programs may include a wide range of applications, such as permit compliance, natural resource damage assessments, target setting for restorations or mitigation, and prioritizing sites for preservation or management intervention.

References

Boulton, A. J. 2014. Conservation of ephemeral streams and their ecosystem services: What are we missing?: Editorial. Aquatic Conservation: Marine and Freshwater Ecosystems 24:733–738.

Boyle, T. D., R. D. Mazor, A. C. Rehn, S. Theroux, M. W. Beck, M. Sigala, C. Yang, and P. R. Ode. 2020. Instructions for calculating bioassessment indices and other tools for evaluating wadeable streams in California: The California Stream Condition Index (CSCI), Algal Stream Condition Index (ASCI) and Index of Physical Integrity (IPI). SWAMP-SOP-2020-0001, Surface Water Ambient Monitoring Program, Sacramento, CA. (Available from: https://www.waterboards.ca.gov/water_issues/programs/swamp/bioassessment/docs/20201220_consolidated_sop.pdf)

California Wetlands Monitoring Workgroup (CWMW). 2013. California Rapid Assessment Method (CRAM), Riverine Wetlands Field Book, version 6.1. Page 45. CRAM module field book, San Francisco Estuary Institute, Richmond, CA. (Available from: https://www.cramwetlands.org/sites/default/files/2013.03.19_CRAM%20Field%20Book%20Riverine%206.1_0.pdf)

California Wetlands Monitoring Workgroup (CWMW). 2020. California Rapid Assessment Method (CRAM), Episodic Riverine Field Book, version 6.2. Page 64. CRAM module field book, San Francisco Estuary Institute, Richmond, CA. (Available from: https://www.cramwetlands.org/sites/default/files/Episodic%20Riverine%20CRAM%20Field%20Book_v6.2.pdf)

Chiu, M.-C., C. Leigh, R. Mazor, N. Cid, and V. Resh. 2017. Anthropogenic Threats to Intermittent Rivers and Ephemeral Streams. Pages 433–454 Intermittent Rivers and Ephemeral Streams. Elsevier.

Datry, T., N. Bonada, and A. J. Boulton. 2017. Conclusions: Recent Advances and Future Prospects in the Ecology and Management of Intermittent Rivers and Ephemeral Streams. Pages 563–584 Intermittent Rivers and Ephemeral Streams. Elsevier.

Datry, T., N. Bonada, and J. Heino. 2016. Towards understanding the organisation of metacommunities in highly dynamic ecological systems. Oikos 125:149–159.

Datry, T., S. T. Larned, K. M. Fritz, M. T. Bogan, P. J. Wood, E. I. Meyer, and A. N. Santos. 2014. Broad-scale patterns of invertebrate richness and community composition in temporary rivers: Effects of flow intermittence. Ecography 37:94–104.

Goodrich, D. C., W. G. Kepner, L. R. Levick, and P. J. Wigington. 2018. Southwestern Intermittent and Ephemeral Stream Connectivity. JAWRA Journal of the American Water Resources Association 54:400–422.

Levick, L. R., J. Fonseca, D. C. Goodrich, M. Hernandez, D. Semmens, J. C. Stromberg, R. A. Leidy, M. Scianni, P. Guertin, M. Tluczek, and W. G. Kepner. 2008. The Ecological and Hydrological

Significance of Ephemeral and Intermittent Streams in the Arid and Semi-arid American Southwest. Page 116. EPA/600/R-08/134 and ARS/23304, U.S. Environmental Protection Agency and USDA/ARS Southwest Research Center, Washington, D.C.

Mazor, R. D., J. Brown, E. D. Stein, J. R. Olson, M. D. Robinson, A. Caudillo, S. Johnson, G. Mak, C. Clarke, K. O'Connor, K. Hammerstrom, and R. Clarke. 2021. Development of an Assessment Framework for Dry Ephemeral and Intermittent Streams in California and Arizona. Page 84. Southern California Coastla Water Research Project Technical Report #1176 1176, Southern California Coastal Water Research Project, Costa Mesa, CA. (Available from: https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/1176_DryStreamsAssessmentFramework.pdf)

Mazor, R. D., A. C. Rehn, P. R. Ode, M. Engeln, K. C. Schiff, E. D. Stein, D. J. Gillett, D. B. Herbst, and C. P. Hawkins. 2016. Bioassessment in complex environments: Designing an index for consistent meaning in different settings. Freshwater Science 35:249–271.

McKay, L., T. Bondelid, T. Dewald, J. Johnson, R. Moore, and A. Rea. 2014. NHDPlus Version 2: User Guide. Page 173. U.S. Environmental Protection Agency. (Available from: https://nhdplus.com/NHDPlus/NHDPlusV2_home.php)

Messager, M. L., B. Lehner, C. Cockburn, N. Lamouroux, H. Pella, T. Snelder, K. Tockner, T. Trautmann, C. Watt, and T. Datry. 2021. Global prevalence of non-perennial rivers and streams. Nature 594:391–397.

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

Ode, P. R., A. C. Rehn, R. D. Mazor, K. C. Schiff, E. D. Stein, J. T. May, L. R. Brown, D. B. Herbst, D. Gillett, K. Lunde, and C. P. Hawkins. 2016. Evaluating the adequacy of a reference-site pool for ecological assessments in environmentally complex regions. Freshwater Science 35:237–248.

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

Pearce, J. L., D. Schuurman, K. N. Barber, M. Larrivée, L. A. Venier, J. McKee, and D. McKenney. 2005. Pitfall trap designs to maximize invertebrate captures and minimize captures of nontarget vertebrates. The Canadian Entomologist 137:233–250.

Robinson, M. D., T. Clark, R. D. Mazor, and J. R. Olson. 2018. Field protocol for assessing the ecological health of dry-phase non-perennial rivers and streams. Page 24. Central Coast Watershed Studies Report WI-2018-XX, California State University at Monterey Bay.

Sánchez-Montoya, M. M., K. Tockner, D. von Schiller, J. Miñano, C. Catarineu, J. L. Lencina, G. G. Barberá, and A. Ruhi. 2020. Dynamics of ground-dwelling arthropod metacommunities in intermittent streams: The key role of dry riverbeds. Biological Conservation 241:108328.

von Schiller, D., S. Bernal, C. N. Dahm, and E. Martí. 2017. Nutrient and Organic Matter Dynamics in Intermittent Rivers and Ephemeral Streams. Pages 135–160 Intermittent Rivers and Ephemeral Streams. Elsevier.

Stein, E. D., J. S. Brown, A. Canney, M. Mirkhanian, H. Lowman, K. O'Connor, and R. Clark. 2022. Prioritizing Stream Protection, Restoration and Management Actions Using Landscape Modeling and Spatial Analysis. Water 14:1375.

Steward, A. L., D. von Schiller, K. Tockner, J. C. Marshall, and S. E. Bunn. 2012. When the river runs dry: Human and ecological values of dry riverbeds. Frontiers in Ecology and the Environment 10:202–209.

Stubbington, R., R. Chadd, N. Cid, Z. Csabai, M. Miliša, M. Morais, A. Munné, P. Pařil, V. Pešić, I. Tziortzis, R. C. M. Verdonschot, and T. Datry. 2018. Biomonitoring of intermittent rivers and ephemeral streams in Europe: Current practice and priorities to enhance ecological status assessments. Science of The Total Environment 618:1096–1113.

Stubbington, R., and T. Datry. 2013. The macroinvertebrate seedbank promotes community persistence in temporary rivers across climate zones. Freshwater Biology 58:1202–1220.

Wyatt, K. H., A. R. Rober, N. Schmidt, and I. R. Davison. 2014. Effects of desiccation and rewetting on the release and decomposition of dissolved organic carbon from benthic macroalgae. Freshwater Biology 59:407–416.