Final Report on Bioassessment in Nonperennial Streams

Report to the State Water Resources Control Board

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Southern California Coastal Water Research Project
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Overview

Despite comprising large portions of stream length in coastal Southern California, nonperennial streams are often excluded from most monitoring programs because it is unclear if existing assessment tools can be used to accurately identify them and evaluate their condition. When they are sampled, it is unclear whether assessment tools developed for perennial systems produce scores that accurately reflect condition of non-perennial streams. To address this uncertainty, the Stormwater Monitoring Coalition directed a study in the San Diego region to evaluate the extent of nonperennial streams in the region, as well as the applicability of the Southern California Index of Biotic Integrity (IBI) for use in nonperennial streams. This study showed that, despite some limitations, available tools can be used to assess the health of at least some nonperennial streams.

Nonperennial streams are defined as streams that lack surface flow for at least several days per year in most years. This definition encompasses a large variety of streams, from ephemeral washes and headwaters that flow for only a few hours after rain events, to those with sustained flows lasting nearly all year (and even more than a year with adequate rainfall). The findings of this report may only apply to nonperennial streams that flow for sufficient duration to all establishment of benthic invertebrate communities (i.e. several weeks during the spring or summer months).

Extent of Nonperennial Streams

Based on ground-truthed field estimates from ambient monitoring programs, nonperennial streams comprise 59% of stream-length in the South Coast region of California and 73% of the streams in the San Diego region, which is substantially less than estimates from the National Hydrography Dataset (NHD) Plus (i.e., 81 and 85%, respectively). Nonperennial streams were found to be relatively extensive in open space and agricultural settings, whereas many urban streams appeared to have been perennialized. The majority of disagreements between field-based estimates and the NHD Plus were observed for streams in the urbanized coastal plain.

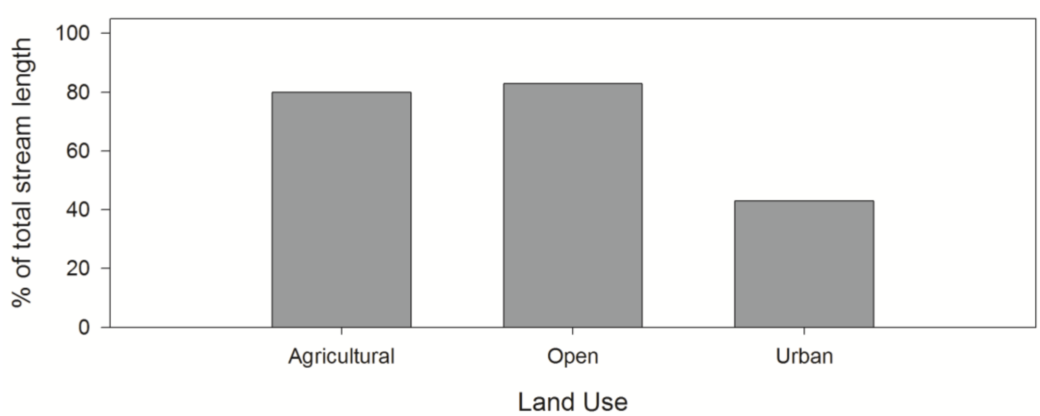

Figure E1. Extent of nonperennial stream length in Southern California.

Applicability of the Index of Biotic Integrity to Nonperennial Streams

Despite the effects of nonperennial flow on benthic community structure, the Southern California IBI can be used to assess the condition of nonperennial streams. Nonperennial streams support benthic macroinvertebrate communities that are distinct from those found in perennial streams. Many of the life history traits that macroinvertebrates use to survive in nonperennial streams (such as tolerance of low oxygen or high conductivity conditions, or rapid life-cycles) are similar to those used to survive in degraded streams. In the past, concerns have been raised that indices designed to identify degraded streams (such as the IBI) may give false indications of impairment at nonperennial streams under natural conditions. At sites included in this study, no such false indications were observed.

The IBI accurately assessed the condition of some nonperennial streams that had flow long enough to all establishment of benthic communities, as indicated by the comparability of IBI scores at minimally stressed perennial and nonperennial sites. That is, nonperennial flow alone did not preclude high IBI scores at low stress sites in this study, and all low-stress sites had scores well above the threshold for identifying streams in poor quality (i.e,. 39). Furthermore, IBI scores declined with increasing stress at nonperennial streams, indicating that the IBI can identify poor biological condition at nonperennial streams. However, future adjustments (e.g., changes in scoring thresholds or metrics) may be required to apply the IBI to the full diversity of nonperennial stream types, such as streams with short flow durations. Additional sampling at a large number (at least 50) of nonperennial reference sites is necessary to determine if such adjustments are needed.

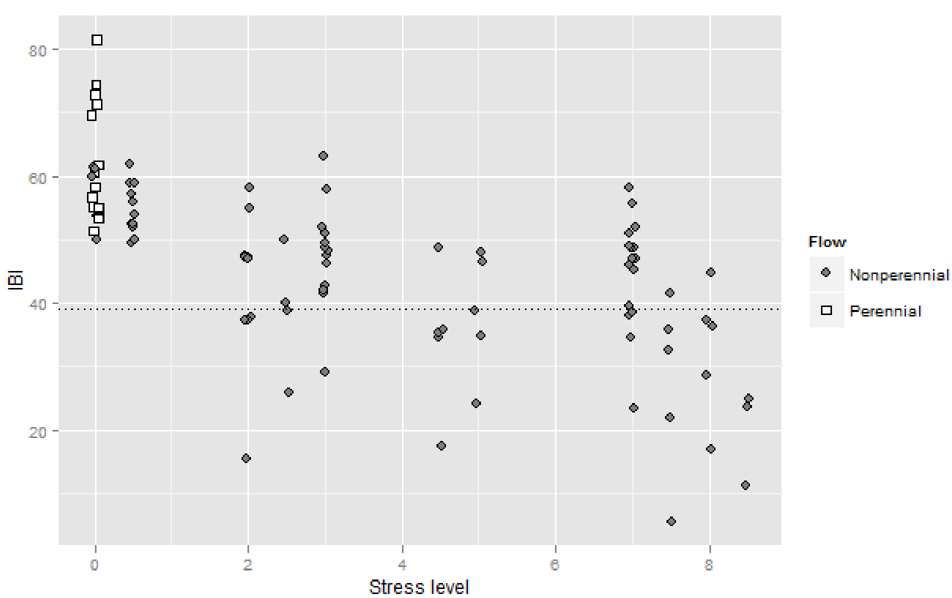

Figure E2. IBI scores declined with stress at nonperennial streams. Each point represents one sample. Gray circles represent nonperennial sites, and white squares represent perennial sites. The dashed line represents the threshold for identifying nonreference condition. Stress was quantified as the sum of evident (score 0.5) and major (score 1.0) stressors, identified by the California Rapid Assessment Method's Stressor Checklist (Collins et al 2008).

Sensitivity of the Index of Biotic Integrity to Changes in Flow

IBI scores were robust to declines in flow at minimally stressed sites. However, decreases in flow were associated with declines in IBI scores at moderately and highly stressed sites, suggesting that nonperennial streams can be particularly sensitive to flow modifications. Few other consistent trends with habitat or chemistry variables were observed, and instead reflected site- or year-specific phenomena, rather than a predictable environmental change that occurs during stream trying.

Conclusions and Recommendations

Although limited to a small number of sites, this study illustrates that nonperennial streams can be incorporated into routine bioassessment programs with little modification of current protocols, provided that surface flow persists for sufficient duration to allow establishment of benthic macroinvertebrate communities. Because existing bioassessment programs mandate several minimum flow conditions that are consistent with this requirement (e.g.., flow sustained at least 4 weeks since last storm, wetted width at least 1 m for 50% of the reach; flow sufficient to operate a d-frame net), no adjustments to these protocols are justified. Furthermore, the large extent of nonperennial streams in the San Diego Region makes their inclusion more relevant if watershed managers are to truly understand the health of their watersheds.

The following considerations are recommended to improve the assessment and management of nonperennial streams:

1. Develop a flexible approach to characterize flow regimes at nonperennial sites.
    - An approach that can characterize the intra- and inter-annual variability in flow regimes has many applications to watershed management, and creates more useful maps for planning and survey design. This approach could lead to the development of a map or a rapid field assessment protocol that identifies the status of a stream reach along a flow gradient from perennial to nonperennial.
2. Include nonperennial streams that meet the minimum flow criteria in routine and ambient bioassessment programs, such as the Perennial Stream Assessment and compliance monitoring, using existing sampling protocols and assessment tools (such as the IBI).
    - Data from this study do not support modifying the IBI. In its current form, the IBI can correctly identify streams in reference condition, even for streams with nonperennial flow. Furthermore, the IBI responds to stress in an expected manner, indicating that it may be useful in evaluating degradation at nonperennial streams. Data from additional sites are needed to establish the general applicability of this finding beyond the limited sites sampled for this study.
3. Establish a program to monitor reference nonperennial sites that capture the full gradient of natural flow regimes under multiple climatic conditions.

- Although California has initiated a robust program to monitor perennial reference streams (Ode and Schiff 2009), data from nonperennial reference streams are minimal, and only three minimally stressed sites were included in this study.

4. Include assessments of hydrologic disturbances when trying to identify possible causes of low IBI scores.

    - Nonperennial streams may be uniquely sensitive to altered hydrology, and as this study revealed, routine bioassessment protocols are inadequate to identify some hydrologic stressors. Routine deployment of water loggers or flow gages/meters may help detect hydrologic disturbance patterns. Channel erosion associated with hydromodification also has the potential to be used as an indicator of hydrologic disturbance.

Introduction

Although nonperennial streams comprise large portions of watersheds in California, they are not well understood, and are often excluded from bioassessment programs (such as the California Water Resources Control Board's Perennial Stream Assessment (PSA), Ode et al. 2011, or the Stormwater Monitoring Coalition's (SMC's) stream monitoring program in Southern California, Mazor et al. 2011). This exclusion is motivated by uncertainty about the extent and location of nonperennial streams, as well as uncertainty about the validity of assessment tools (such as the Southern California Index of Biotic Integrity (IBI); Ode et al. 2005) that were developed and validated with perennial streams. As a result, these ambient condition surveys are incomplete, and regulatory programs (such as NPDES or 401) have limited ability to evaluate stream health.

One of the more fundamental challenges to managing nonperennial streams is as simple as knowing where they are. Maps that correctly identify the location of perennial and nonperennial streams do not exist for most of California. One of the most widely used maps of stream networks, the National Hydrography Dataset Plus (NHD Plus; USGS and USEPA 2006), designates stream segments as perennial or intermittent, although the accuracy of these designations has not held up to scrutiny, particularly in parts of California and the arid West (e.g., Hall et al. 1998, Hughes et al. 2011, Ode 2011). These designations were based on a variety of sources, including flow gauges, aerial photographs, and best professional judgment. Because data availability varies widely from stream to stream, consistency in these designations is low. As a result of these limitations, few stream surveys that require identification of perennial and nonperennial streams (e.g., the PSA, SMC, and national programs like the EPA's Environmental Monitoring and Assessment Program; Peck et al. 2006) make use of the designations provided by the NHD Plus, and instead rely on a more intensive field reconnaissance to make these designations.

Nonperennial streams present a challenging environment for benthic macroinvertebrates, as both the abiotic and biotic conditions change dramatically. As water levels recede, chemical concentrations and pollutants (if present) may magnify and increase toxicity. Temperature, pH, and dissolved oxygen concentration can fluctuate over short time periods (Gasith and Resh 1999). Biotic pressures can also intensify, as predation and competition become more important as space and resources become limited (Robson et al. 2011). These changes may lead to differences in community composition between the end and beginning of the sampling season, as this phenomenon has been documented in numerous studies in California (e.g., Bêche et al. 2006, Mazor et al. 2009) and elsewhere (e.g., Morais et al. 2004; Bogan and Lytle 2007, 2011).

Many of the life history traits that benthic macroinvertebrates use to survive in nonperennial streams (such as tolerance of low oxygen or high conductivity conditions) are similar to those used to survive in polluted streams. Therefore, indices designed to identify polluted streams (e.g., the IBI) may give false indications of impairment at nonperennial streams under natural conditions. Mazor et al. (2009) found that two bioassessment indices (a multimetric and a multivariate index) identified impairment in two minimally disturbed nonperennial streams in northern California, although the sampling methods used were not identical to those used to develop the evaluated indices. Morais et al. (2004) found that intra-annual variability in bioassessment was particularly high in nonperennial streams in Portugal, meaning that both false positive and false negative findings of impairment may be increased in nonperennial streams. The present study represents the first evaluation of a bioassessment index in nonperennial streams in California.

The purpose of this study was to determine if standard assessment tools developed for perennial streams can be applied to nonperennial streams, focusing on the San Diego hydrologic region. Specifically, this study addressed the following questions:

1. What is the extent of nonperennial streams?
    a. How accurately does the NHD Plus represent these streams?
2. Does the IBI accurately assess the condition of nonperennial streams?
    a. Are IBI scores at low stress nonperennial sites comparable to low stress perennial sites?
    b. Do IBI scores decline with increased stress at nonperennial sites?
3. Are IBI scores consistent over time?
4. How do changes in environmental conditions affect nonperennial streams?
    a. Do certain environmental variables exhibit consistent trends?
    b. Are these trends associated with changes in IBI scores?

The first question was addressed by verifying the accuracy of the NHD Plus designations using data from surveys and field reconnaissance. The last three questions were addressed by collecting benthic macroinvertebrate samples from perennial and nonperennial streams over the course of a season (and at a subset of sites over multiple seasons). Hydrologic conditions, water chemistry, and physical habitat were also sampled to address the fourth question.

Scope

This study focused on nonperennial streams in the San Diego region that had sustained flows through April in the year of sampling. A great variety of streams considered “nonperennial” can be found in the San Diego region, including those that flow for only a few days following rain events. The findings of this study are limited to only a small portion of the spectrum of nonperennial streams, and may not apply to other stream types or streams throughout the state.

Question 1: What is the extent of nonperennial streams?

Nonperennial streams comprise 59% of stream-length in the South Coast region of California, and 73% of the streams in the San Diego region. These streams are relatively more extensive in open space and agricultural settings, and many urban streams appear to have been perennialized.

The true extent of nonperennial streams was estimated using reconnaissance data from probabilistic surveys conducted in the region. These surveys included the regional program of the Stormwater Monitoring Coalition, as well as statewide surveys by the California Water Resources Control Board (e.g., Perennial Stream Assessment), and the Environmental Monitoring and Assessment Program (EMAP), by the Environmental Protection Agency. These estimates were then compared to the total intermittent stream length estimated from the NHD Plus. In order to identify possible causes for disagreements with the NHD Plus, site visits were conducted in the late summer of 2007.

Analysis of Survey Data

In order to estimate the extent of nonperennial streams from survey data, the proportion of sites identified as nonperennial within each stratum (defined by stream order, land use, and watershed) was multiplied by the total length of streams in that stratum, derived from the NHD Plus. All weight calculations were conducted using the *spsurvey* package in R version 2.11.1 (Kincaid and Olsen, www.epa.gov/nheerls/arm; The R Foundation for Statistical Computing, http://www.r-project.org/). A total of 1747 discrete reconnaissance events were evaluated from Southern California, representing over 25,000 km.

These surveys indicate that, although the NHD Plus estimates that 90% of streams in the South Coast region are nonperennial based on remote mapping, the survey-estimated extent is lower, at 59%. At 73% the extent of nonperennial streams is greater in the San Diego Region is greater than other parts of Southern California (e.g., 49% of the Los Angeles Region and 55% of the Santa Ana Region), perhaps due to the lack of high elevation peaks where snow can accumulate (Figure 1).

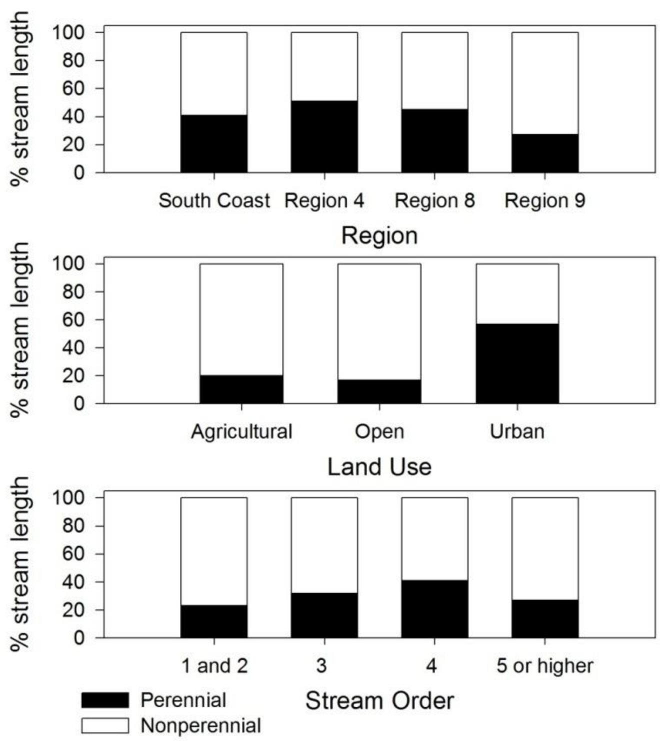

Figure 1. Extent of perennial and nonperennial stream length by region, land use, and stream order.

Within the San Diego Region, the distribution of nonperennial streams was strongly associated with land use. The majority (i.e., 57%) of stream length in urban areas were perennial, compared to much smaller extents in agricultural and open areas (i.e., 20 and 17%, respectively). The association with stream order was weaker, as headwater streams (i.e., stream orders 1 and 2) were relatively less perennial than larger streams (i.e., 77% at headwater streams vs. 68 and 59% at 3rd and 4th order streams, respectively). However, nonperennial streams were relatively common (73%) in highest order streams, perhaps reflecting loss to groundwater in these lower positions in the watershed (Figure 1).

Disagreements with the NHD Plus

Disagreements with the NHD Plus were somewhat common, occurring at 26% of the 1747 reconnaissance events. Of these disagreements, 74% were perennial sites that were considered intermittent by the NHD Plus, and the majority of these disagreements occurred in the urbanized coastal plain (Figure 2).

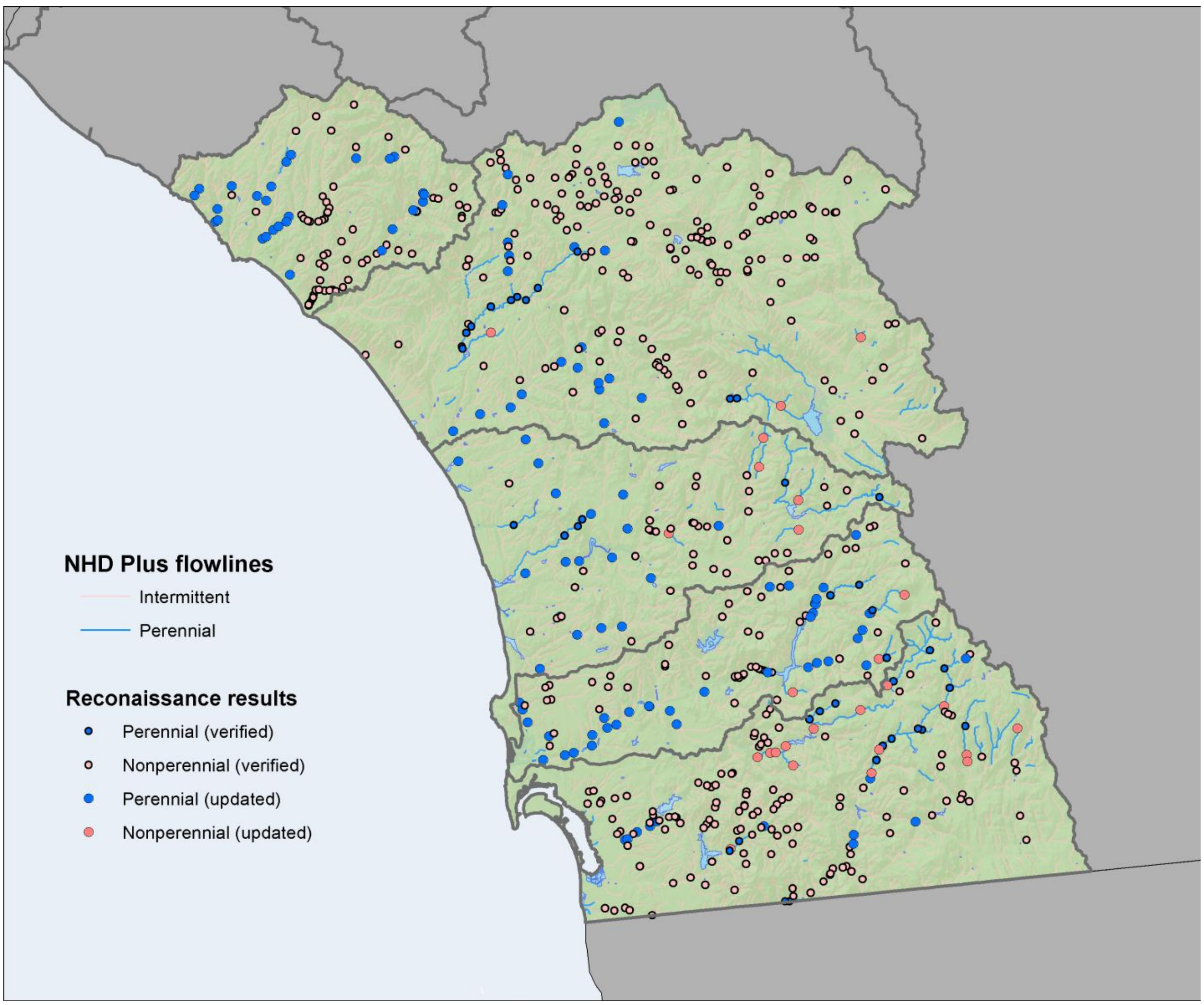

Figure 2. Location of reconnaissance events in the San Diego Region.

A recent study also indicated large disagreements with the NHD Plus in the extent of nonperennial streams in California, particularly in the South Coast (Ode 2011). Like the present study, Ode estimated that slightly more than half of the South Coast's total stream length was perennial. Although relationships with land use were not explicitly investigated, it also noted that disagreements were most common in urbanized regions (like the Central Valley and the South Coast).

Sources of Disagreements with the NHD Plus

In order to identify possible reasons for disagreements between reconnaissance data and the NHD Plus, site visits were conducted during the summer of 2007. This summer followed a record drought (e.g., Lindbergh Field received only 3.85 inches of rain between October 2006 and September 2007, which is 36% of normal). Therefore, streams that were flowing during these site visits can be considered truly perennial with high confidence.

Disagreements seem to come from three major sources: 1) The limitation of the approach used by the NHD Plus; 2) the limitations of the data produced by the surveys; and 3) genuine changes in the true flow status of some of these streams.

The limits of the flow designations of the NHD Plus have been widely documented (e.g., Hall et al. (1998). A fundamental limitation to the NHD Plus is that it uses a dichotomous designation (i.e., perennial vs. intermittent) for an entire stream segment, which may be several kilometers long. This approach cannot accurately reflect spatial heterogeneity (e.g., segments with both perennial and nonperennial portions), nor can it reflect temporal heterogeneity (e.g., sites that are perennial in some years, nonperennial in others). The location and dates of some of the reconnaissance events suggest that both limitations have led to disagreements. Third, the dichotomous approach used by the NHD Plus prevents it from reflecting the gradient of different flow conditions that exist in the real world. For example, it is impossible to distinguish between a stream that flows 6 or more months a year (such as San Juan Creek in Caspers Park) from one that flows for a few days following major rainstorms (such as the Armargosa River), nor from a stream where the flow varies on a daily basis due to management activities (such as the mainstem of the Santa Ana River, Trabuco Creek in Aliso Viejo).

The primary limits of the reconnaissance data used in this study is that much of it was based on very limited information, and each survey used slightly different definitions of perenniality. For example, the earliest reconnaissance data was derived from the EPA's nationwide Environmental Monitoring and Assessment Program (EMAP; Peck et al. 2006), which defined perennial streams as those flowing at the time of sampling. At the other extreme, the SMC's Southern California-based program defined perennial streams as those that flow through the end of the hydrologic year (i.e., September 30). Although the SMC's definition is much closer to a true definition of perenniality, it requires substantially more site-specific information than would be possible with a national survey like EMAP, or even a statewide survey like the PSA. These limitations can be easily surmounted through standardization of the reconnaissance process, which has recently begun for the SMC and PSA programs.

The preponderance of perennial streams in urban areas probably reflects the conversion of waterbody types, caused by either discharges of imported water directly to the stream (e.g., below wastewater treatment plants), or indirectly through increased runoff of imported water. Site visits in 2007 revealed a striking example of the latter at Jeronimo Creek, a tributary of the San Juan Creek, designated in the NHD Plus as intermittent (COMID 20348371). Despite the historic antecedent drought, the stream was flowing on September 12, 2007 (Figure 3A). The point of perennialization could be observed where storm drains join the creek (Figure 3B).

Figure 3. Jeronimo Creek, September 12, 2007. A) Flow is readily observable at this site, despite the fact that less than four inches of rain had fallen within the past 12 months. B) Perennial flow is evident at the point where storm drains discharge into the stream.

Implications for Management and Conservation

Despite the large extent of nonperennial streams in the San Diego Region, data from this study suggest large scale type conversion resulting in loss of nonperennial streams. If open and agricultural regions can be considered a baseline for pre-urban San Diego, the shift from ~80% nonperennial to 43% nonperennial represents a large scale conversion of waterbody type that has so far received little attention. Aquatic biota naturally adapted to nonperennial streams (e.g., Anna et al. 2008) may not be able to survive in perennialized systems. An analysis of the historical ecology of the watersheds of the San Diego region may produce a more appropriate baseline for assessing this loss, as well as more accurate reference standards for perennialized streams.

Question 2: Does the Southern California Index of Biotic Integrity (IBI) accurately assess the condition of nonperennial streams?

Results from this study suggest that the IBI is valid for at least some nonperennial streams, as scores at low stress nonperennial sites were comparable to scores at low stress perennial sites. The IBI responds to stress in an expected manner. However, adjustments may be required to apply the IBI to full diversity of nonperennial stream types. Additional sampling at a large number (at least 50) of nonperennial reference sites is necessary to determine if such adjustments are needed.

The validity of the IBI in nonperennial streams was assessed in two ways:

1. Are scores low stress nonperennial sites similar to those at reference perennial sites?
2. Do scores respond to a stressor gradient in an expected manner?

To answer these questions, SWAMP bioassessment protocols were used to sample benthic macroinvertebrates at twelve nonperennial sites and three perennial reference sites (data for the perennial sites was provided by SWAMP's Reference Condition Management Program). Each site was sampled at least three (and up to eight) times in one season, and three sites were sampled over multiple years. At a subset of sites, continuous data loggers were deployed to measure water level and temperature throughout the course of the study. Locations of sampled sites are shown in Figure 4, and are summarized in Table 1. Standard SWAMP protocols (Ode 2007) were used to collect benthic macroinvertebrate.

At each site, benthic macroinvertebrate community data were used to calculate IBI scores (Ode et al. 2005). Scores were compared to the threshold for determining nonreference condition (i.e., 39, or two standard deviations below the reference mean).

Table 1. Summary of sites sampled in the study.

Site	Name	Flow status	Stress score	County	Watershed area (km^2)	Elevation (m)	Gradient	Ecoregion
AC	Agua Caliente Creek	Nonperennial	0.5	San Diego	46	918	<1%	Mountains
AN	South Fork Santa Ana River	Perennial	0.0	San Bernardino	11	2447	>2%	Mountains
AS	Arroyo Seco	Nonperennial	2.5	Riverside	34	494	<1%	Xeric
BC	Bear Canyon	Perennial	0.0	Los Angeles	65	639	>2%	Mountains
CC	Carney Canyon	Nonperennial	0.5	San Diego	19	312	>2%	Xeric
CD	Cedar Creek	Perennial	0.0	San Diego	55	522	>2%	Xeric
CV	Cañada Verde	Nonperennial	4.5	San Diego	14	954	>2%	Mountains
NC	Noble Canyon	Nonperennial	2.0	San Diego	39	1169	>2%	Xeric
OF	Ortega Falls	Nonperennial	7.5	Riverside	16	575	>2%	Xeric
PC	Pine Valley Creek	Nonperennial	5.0	San Diego	74	1132	<1%	Xeric
SJ	San Juan Mainstem	Nonperennial	8.0	Orange	103	181	<1%	Xeric
SR	San Diego River Headwaters	Nonperennial	3.0	San Diego	2	1038	>2%	Mountains
SY	Santa Ysabel Creek	Nonperennial	7.0	San Diego	32	902	1 to 2%	Mountains
TC	Trabuco Creek	Nonperennial	8.5	Orange	58	237	1 to 2%	Xeric
TE	Temescal Creek	Nonperennial	0.0	San Diego	22	333	>2%	Xeric

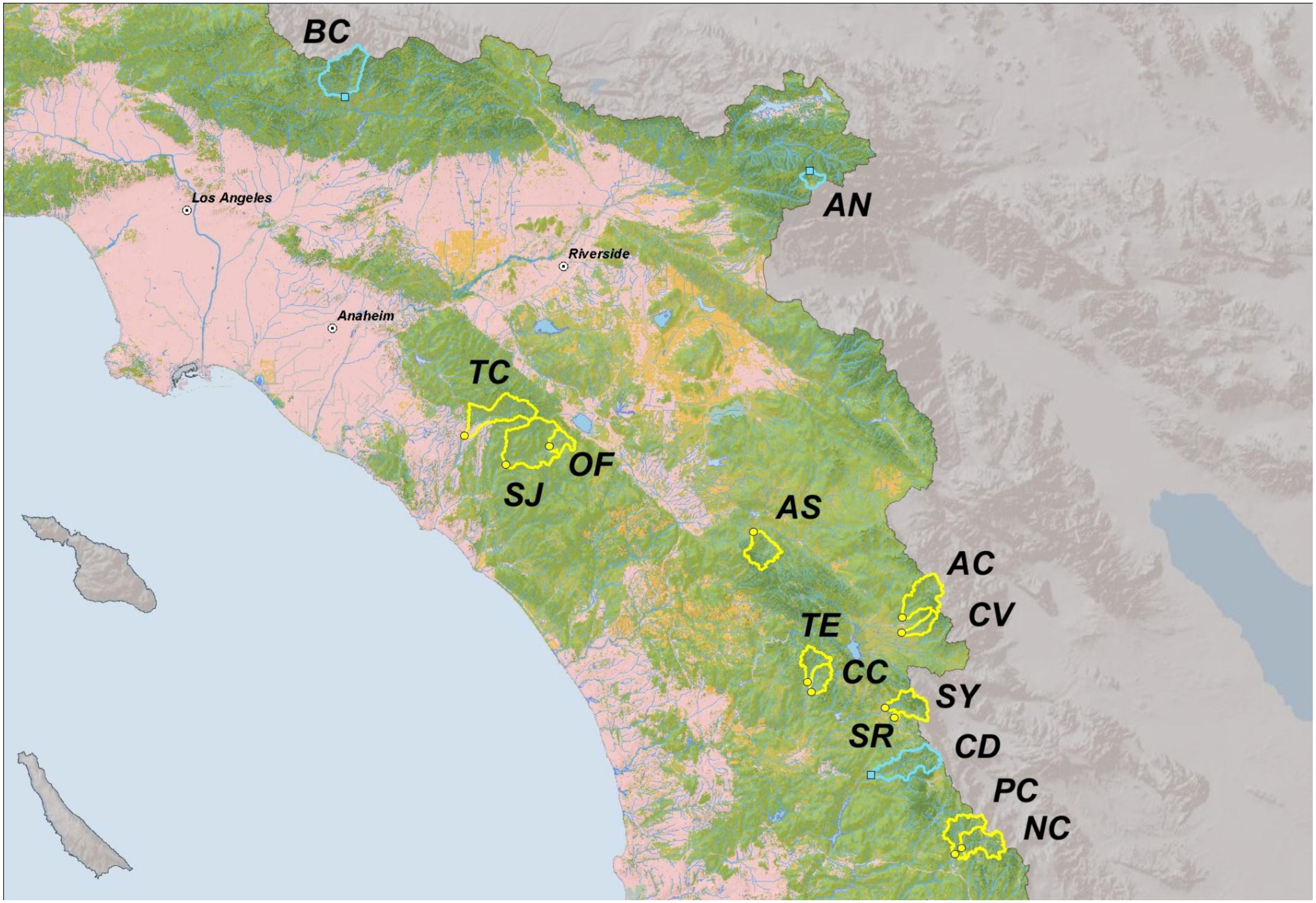

Figure 4. Yellow watersheds are nonperennial sites, and blue watersheds are perennial sites. Urban land is indicated with pink; agricultural land is indicated with orange; and open space is indicated with green.

Nonperennial sites were initially selected to represent a gradient of stress using best professional judgment, but were assigned to stress classes (low, moderate, and high stress) using the CRAM Stressor Checklist (Collins et al. 2008). A total of 50 stressors were evaluated for each site. A stressor was given a score of 0.5 if the stressor was likely to have a negative impact on the stream, and a score of 1 if the impact was likely to be large. The distribution of scores was examined to identity four groups (Figure 5). Low stress sites are those with scores less than 1. Moderately low stress sites are those with scores between 2 and 4. Moderately high stress sites are those with scores between 4 and 6. High stress sites are those with scores between 6 and 9. Scores are summarized in Appendix 1. Site descriptions are provided below. Photos documenting site characteristics over the course of the study are provided in Appendix 2.

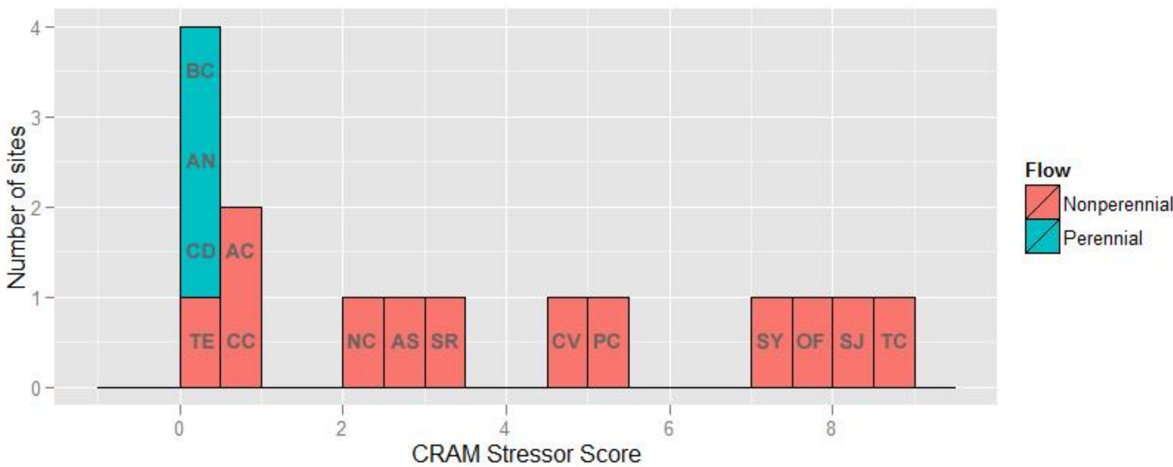

Figure 5. Distribution of stressor scores at sampled sites. Based on this distribution, four classes of sites were identified: Low stress sites (BC, AN, CD, TE, AC, and CC), moderately low stress sites (NC, AS and SR), moderately high stress sites (CV and PC), and high stress sites (SY, OF, SJ, and TC).

Low Stress Perennial Sites

Bear Creek (BC) is a tributary of the Los Angeles River. It is located high in the San Gabriel Mountains, and has a streambed comprised of large boulders and cobbles, with extensive riffle habitat.

South Fork Santa Ana (SA) is located entirely within the San Gorgonio Wilderness in the San Bernardino Mountains. The site is surrounded by meadows dominated by sedges and corn lilies.

Cedar Creek (CC) is a tributary to the San Diego River in the Laguna Mountains, and is the closest geographically to the nonperennial sites in the study.

Low Stress Nonperennial Sites

Aqua Caliente Creek (AC) is a sandy, low-gradient stream in the San Luis Rey watershed, east of Lake Henshaw. The substrate is extremely unstable, and can be observed to move under baseflow conditions.

Carney Canyon (CC) is a tributary of Temescal Creek, which drains into Santa Ysabel Creek, and is part of the San Dieguito watershed. It is a high gradient creek, although portions of the reach are low gradient and filled with sediment, possibly due to the 2009 Witch Fire.

Temescal Creek (TE) is a tributary of Santa Ysabel Creek, and is part of the San Dieguito Watershed. Much of the streambed is high gradient, and is comprised of very large boulders, which may harbor perennial aquatic refugia during the summer. Although the surrounding area is heavily grazed, and cattle are not deliberately excluded site, there was little evidence that they approach the creek, perhaps due to the difficulty in navigating the boulders.

Moderately Low Stress Nonperennial Sites

Arroyo Seco (AS) is a tributary of the Santa Margarita River. The channel is unconfined and unstable, with a streambed comprised of sand and small boulders. The gradient is relatively low. Although the watershed is completely protected within the Agua Tibia Wilderness, data from water level loggers, plus an observed flooding event (6/2/2008) suggest that flows are managed at this site, preventing it from being considered a reference site.

Major stressors: Unnatural flow regime

Noble Canyon (NC) is a high gradient, bedrock-dominated canyon in the Tijuana watershed, draining the Laguna Mountains. Historically, extensive mining occurred upstream of the site, and legacy roads from that era (now mostly used for recreational purposes) may affect the stream. This stream dried abruptly and unexpectedly in 2009, suggesting that flows may be managed at this site, preventing it from being considered a reference site.

Major stressors: Unnatural flow regime.

San Diego River headwaters (SR) is a high gradient stream in a secluded portion of the Santa Ysabel Open Space Preserve. The channel is narrow and confined, and contains small cascades, as well as flatter, more cobble-dominated portions. Although the watershed is entirely undeveloped, grazing impacts are severe.

Major stressors: Cattle grazing

Moderately High Stress Nonperennial Sites

Cañada Verde (CV) is a narrow, steep stream in the San Luis Rey watershed, east of Lake Henshaw. Grazing impacts are severe, and many dozen cattle were observed passing through the site, forcing the postponement of one sample event. The Pacific Crest Trail passes through the entire reach.

Major stressors: Cattle grazing, recreational impacts.

Pine Valley Creek (PC) is a low gradient tributary to the Tijuana River, with a sandy, unstable substrate. Light levels of rural residential surround the site, although much of the watershed is undeveloped.

Major stressors: Light urban runoff, stream crossings, and recreational impacts (equestrian).

High Stress Nonperennial Sites

Santa Ysabel Creek (Syed et al.) is a moderately low gradient stream in the Santa Ysabel Open Space Preserve. Grazing impacts are more severe here than at any other site in the study, with bank collapse, nutrient enrichment, and elimination of riparian vegetation being the most obvious impacts. Much of the surrounding vegetation is non-native annual grass. Hikers have easy access to the creek from nearby trails, and some impacts from recreation (e.g., litter) was evident. Although some of the substrate is sandy, there are a few areas of cobbles and boulders, as well as bedrock outcrops.

Major stressors: Cattle grazing (intense), recreational impacts

Ortega Falls (OF) is a tributary of San Juan Creek, located high in the Santa Ana mountains. Light rural development immediately surrounds the site. Water levels loggers indicate that diversions occur on a nightly basis. The stream is very high gradient, with extensive bedrock outcrops. Macrophytes (particularly *Ranunculus aquatilis* and *Mimulus guttatus*) are more abundant at this site than others in the study,

Major stressors: Unnatural flow regime, light urban runoff, possible nutrient enrichment, stream crossings.

San Juan Creek (SJ) is the largest watershed in the study. It is low gradient and sandy, with a few small boulders, and occurs just downstream of San Juan canyon. Algae growth, particularly *Cladophora* sp. is extensive, suggesting nutrient enrichment. Water levels loggers indicate that diversions occur on a nightly basis.

Major stressors: Unnatural flow regime, light urban runoff, nutrient enrichment, invasive species (mosquito fish and crayfish), road crossings, and recreational impacts.

Trabuco Creek (TC) is a tributary of San Juan Creek. This site receives urban runoff from Rancho Santa Margarita, but not enough to perennialize the flow. Patches of heavy algae growth were observed,. The stream is relatively low gradient, and the substrate is comprised of sand and small boulders. Invasive New Zealand Mudsnails *(Potamopyrgus antipodarum)* were observed within 0.5 km of the site, but never within the sampling reach.

Major stressors: Moderate urban runoff, recreational impacts, transportation infrastructure, possible nutrient enrichment.

Question 2a: Are IBI scores at low stress nonperennial sites comparable to low stress perennial sites?

Flow status alone does not preclude high IBI scores, as all low stress nonperennial sites had scores above the threshold for identifying reference condition. However, because only three low stress nonperennial sites were sampled in this study, it is not clear whether other low stress nonperennial sites would have similar scores.

IBI scores were high at both perennial and nonperennial low stress sites (Figure 6). The three low stress nonperennial sites have IBI scores that are comparable to perennial reference sites, and no sample was observed below the threshold of 39. The means for the two types of sites (perennial: 61.9 ± 10.7 standard deviation; nonperennial low stress: 55.6 ± 3.1) was not significantly different (p=.69), although power was low with only 3 sites in each group (power = 0.08). The within-site variability at low stress nonperennial sites was similar to perennial sites (i.e., mean within-site standard deviation was 2.9 at perennial sites, and 3.9 at low stress nonperennial sites).

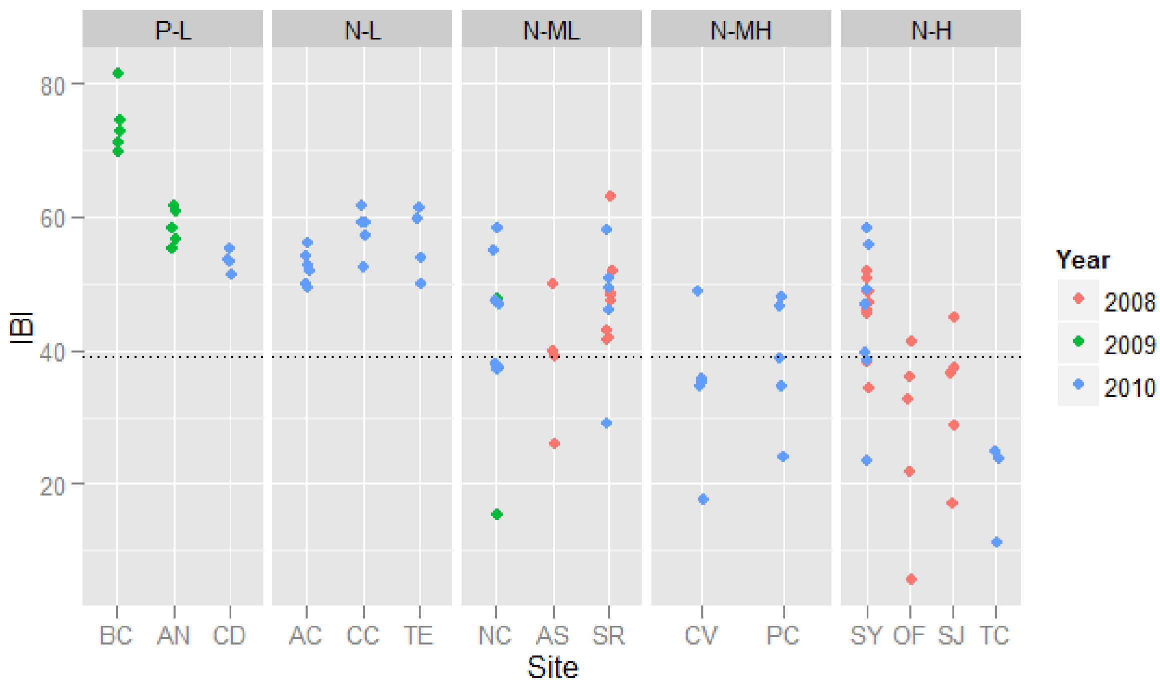

Figure 6. IBI scores at each sample in the study. Each panel represents a different flow and stress class (P-L: Perennial, low stress; N-L: Nonperennial, low stress; N-ML: Nonperennial, moderately high stress; and N-H: Nonperennial, high stress). The dotted horizontal line represents the threshold for identifying nonreference condition.

Question 2b: Do IBI scores decline with increased stress at nonperennial sites?

As expected, mean IBI scores declined, and the frequency of IBI scores in nonreference condition increased, as stress increased.

IBI scores responded to stress at nonperennial sites in an expected manner. That is, mean scores declined as site quality declined. For example, low stress sites had higher mean IBI scores than moderately low stress sites (i.e., 43.3), which in turn were higher than moderately high stress sites (i.e., 33.4) and high stress sites (31.4). In fact, with the exception of SY (a relatively high scoring site, more typical of the moderately low stress sites), all high stress sites had scores well below the reference threshold (mean of 26.8, excluding SY). Figure 6, Table 2.

Table 2. Mean IBI scores and standard deviation (SD) at study sites. n: Number of samples. n > 39: Number of samples with scores greater than 39 (i.e., the threshold for identifying reference condition).

Site	Mean IBI	SD	n	n > 39
Perennial				
Low stress	61.1	10.7		
BC	73.9	4.6	5	5
AN	58.6	2.7	5	5
CD	53.3	1.5	4	4
Nonperennial				
Low stress	55.6	3.1		
TE	57.2	5.1	5	5
AC	52	2.6	6	6
CC	57.6	3.9	5	5
Moderately low stress	43.3	4.7		
NC	43.0	12	10	6
AS	38.7	9.8	4	2
SR	48.2	8.4	13	12
Moderately high stress	33.4	3.7		
CV	30.8	8.9	5	1
PC	36.1	9.4	5	2
High stress	31.4	10.6		
SY	45.1	9.0	16	12
OF	27.5	14.2	5	1
SJ	32.8	10.5	5	1
TC	20.0	5.1	3	0

Question 3: Are IBI scores consistent over time?

IBI scores were relatively stable at low stress nonperennial sites, but slightly more variable than those at low stress perennial sites. Variability increased with stress, and negative trends in IBI scores were evident in some of the more highly stressed sites.

Examination of scores over the three-year time period of this study indicated that IBI scores were steadiest at low stress sites, particularly at perennial sites (Figure 7). In neither perennial nor nonperennial low stress sites was a directional trend evident. In contrast, sharp declines were observed at several stressed sites (e.g., OF, AS, SJ), and erratic fluctuations at others (e.g., CV, NC). Therefore, it appears that IBI scores are stable at sites with low stress, at least at nonperennial sites represented in the study, but that scores decline at some stressed sites over the course of the season.

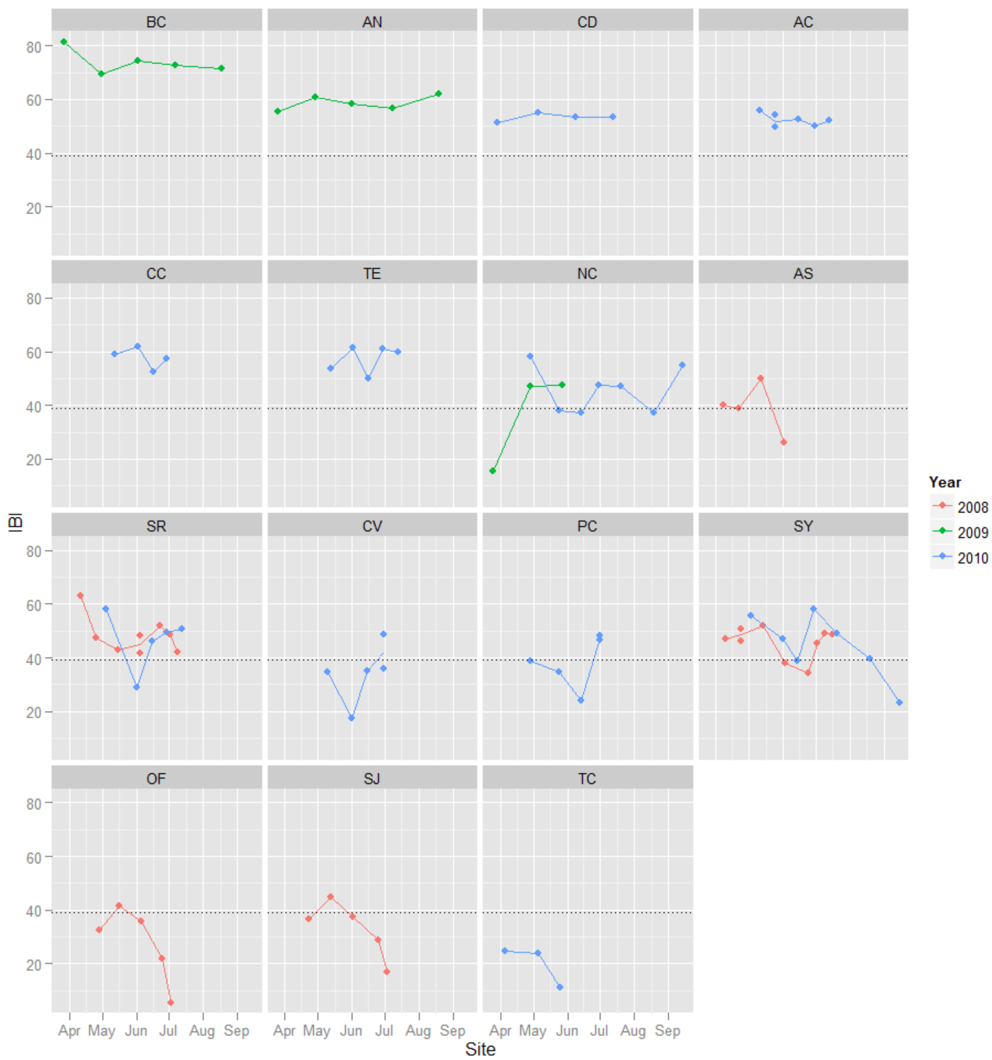

Figure 7. Trends in IBI scores at each of the sites. From top left to bottom right, panels are in order of increasing stress. Where replicates were collected, individual values are shown, but the trend line reflects the mean value.

At two of the sites that were resampled over two years (SR and SY), a mid-spring decline in IBI scores was followed by an early summer increase, and this pattern was similar in both years of sampling, although no individual metrics appeared to drive this pattern. The consistent response over multiple years suggests this is a real pattern, and not an artifact of the inherent variability in the IBI. The third replicated site (NC) did not display similar patterns in each year, perhaps due to the different hydrologic regimes observed each year (explained below).

Scores for the aggregate IBI was more stable than component metric values (Figure 8). In some cases, declines in some metrics were offset by increases in others, but the pattern was not consistent across sites. For example, a decline in the % Intolerant metric was offset by an increase in the % Collectors metric at CD, but at CC, % Collectors declined and instead was offset by an increase in % Non-Insect Taxa.

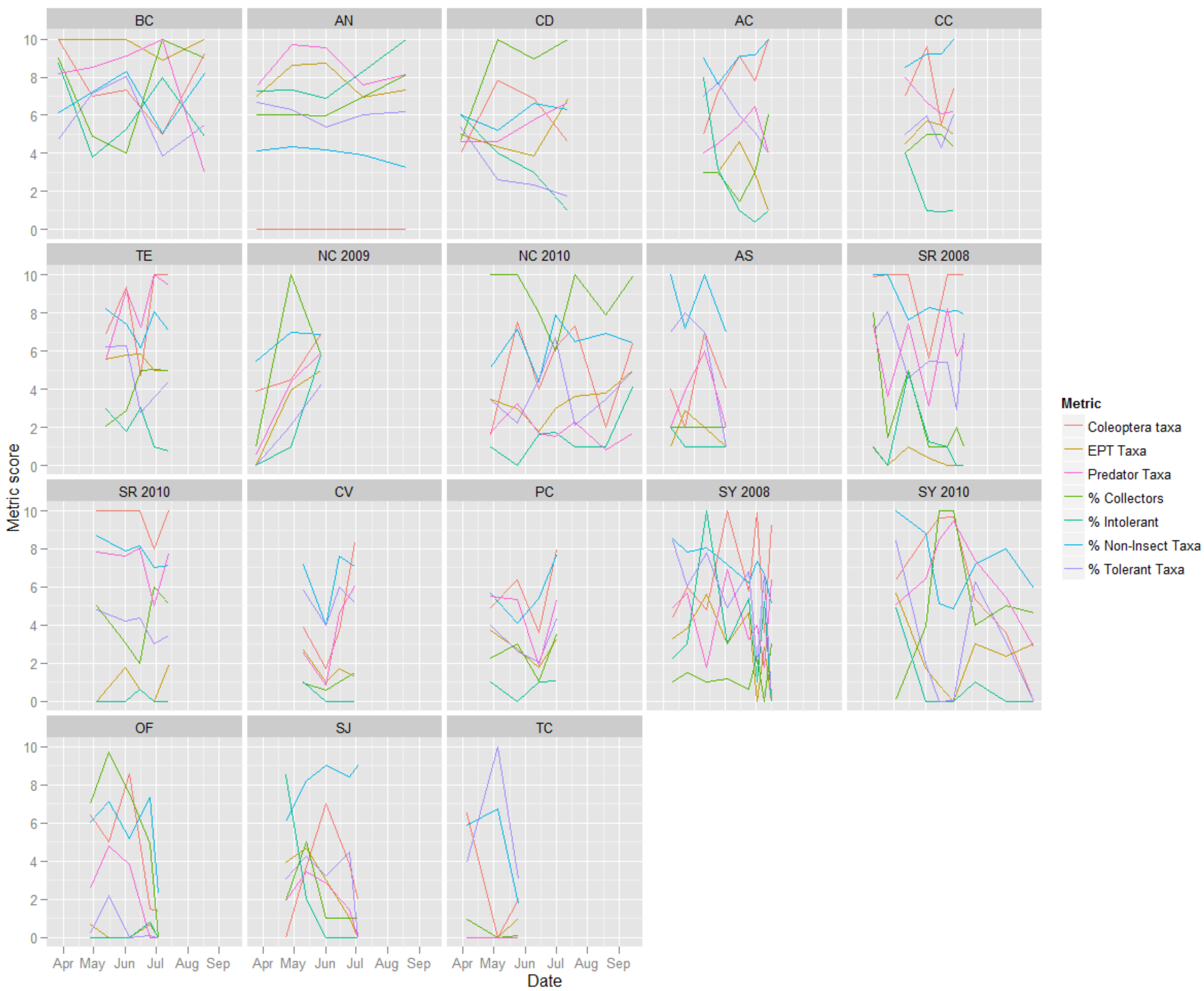

Figure 8. Trends in metric scores at each site. From top left to bottom right, panels are in order of increasing stress. Each metric is plotted as a separate line.

Question 4: How do changes in environmental conditions affect nonperennial streams?

Few consistent trends were observed, and most environmental variables exhibited site- and year-specific behaviors. At high stress sites, variables related to water available (e.g., flow, % fast water) were associated with declines in IBI scores, as were % sands and fines and % macroalgae cover, although to a lesser degree.

Although some environmental conditions were not expected to change over the sampling period (e.g., development in the watershed, bank morphology), other environmental variables (e.g., water hydrology, water chemistry, and many components of physical habitat) were measured at each sampling event. In order to relate these factors to biological condition, trends in each variable were first characterized at each site, and then they were correlated to IBI scores.

General patterns observed for environmental variables are summarized in Table 3, indicating differences between perennial and nonperennial streams, temporal trends observed, relationships with stress, and relationship with IBI scores. Although some data are presented in graphs in the body of this report, more are presented in Appendix 3.

Table 3. Summary of observations for trends in environmental variables

Environmental variable	Differences between perennial and nonperennial streams	Temporal trends observed	Relationship with stress	Relationship with IBI scores
Hydrology				
- Flow	More variable at nonperennial	Declined at all sites over time	Intermittent drying at stressed sites	Decreased flow associated with declines in IBI scores at high stress sites
Water chemistry				
- Specific conductivity	Higher at nonperennial	Site- and year-specific increases	Increases with stress	Negative association, but not related to trends
- Total N	Low at all perennial. High at some nonperennial.	No consistent pattern	Higher values observed at all stress levels, but more common at high stress sites.	No relationship observed
- Dissolved Copper	No data from perennial sites	No pattern observed	Low at all sites	No relationship observed
Physical habitat				
Substrate				
- % sands and fines	Sandier at nonperennial streams	Site-specific trends observed	No pattern observed	Increases associated with declines in IBI scores at high stress sites
- % bedrock	No pattern observed	Increases at some nonperennial sites	No pattern observed	No relationship observed
Microhabitats				
- % fast water	No pattern observed	Mostly decreases, but site- and year- specific increases observed	No pattern observed	Increases weakly associated with declines in IBI scores at high stress sites
- Instream habitat complexity	Higher at perennial sites	Site-specific. High year-to-year consistency.	No pattern observed	No relationship observed
Productivity				
- % macroalgae cover	No pattern observed	Site-specific.	No pattern observed	Increases weakly associated with declines in IBI scores at high stress sites
- % microalgae cover	No pattern observed	Site-specific.	No pattern observed	No pattern observed
Riparian vegetation				
- % stream shading	Higher at perennial	Site-specific, but usually steady or increase	Declines with stress	Positive association, but not related to trends
- % lower and upper canopy cover	Higher at perennial	Site-specific, but usually steady or increase	Declines with stress	Positive association, but not related to trends

Hydrologic Conditions

Hydrologic conditions were evaluated using a combination of data sources: continuous data loggers, direct measurements, and visual observation during site visits. Continuous water level loggers were deployed at a subset of sites, at the first sampling event and retrieved at the final sampling event (with the exception of NC, where the logger was deployed for several months after sampling ended). At BC, AN, CD, and NC, water level was determined by correcting for air pressure measured by a second logger deployed at the site above the water line. At the other sites, nearby weather stations were used to correct for air pressure. Direct measurements of stream discharge was conducted at most sampling events by measuring water velocity using an electromagnetic or propeller-type velocity meter , though flotation time using a neutrally buoyant object was used when conditions were too slow or shallow for the velocity meter. Finally, hydrologic conditions were evaluated through site visits to determine when streams were flowing. All three sources of data were used to identify periods when the reaches contained flowing water, and when they were dry (or intermittently dry), with visual observation being given the highest priority, followed by direct measurements.

Water chemistry

At a subset of sites, several water chemistry parameters were measured. These analytes include field measures (such as specific conductivity), nutrients (such as total nitrogen), and dissolved metals (such as dissolved copper). Because a large number of constituents was assessed, a few representative analytes were selected for inclusion in this report.

Physical habitat

Standard SWAMP protocols (Ode et al. 2007) were used to sample physical habitat data, but with a few key modifications for the study. First, transects were established at fixed locations that did not vary over the course of the study. Therefore, if the amount of wetted area within the reach retracted, some transects were excluded from sampling. Sampling continued at a site if at least 5 transects were wet. In contrast, current practices of programs like the SMC is to reduce transect distance if an entire reach is not available for sampling. Thus, sampling extended well beyond the period at which a site would be rejected for sampling due to lack of wet habitat. Second, certain aspects of physical habitat were assumed to be stable, and were only measured on one sampling event per year: slope, gradient, bank width, and bank height. Third, the algae cover components of physical habitat were added in 2009 and 2010, following the publication of standard operating procedures for these analytes (Fetscher et al. 2009).

Physical habitat data were summarized using a beta version of SWAMP's data reporting module and by hand calculation of selected metrics that characterize substrate (% sands and fines; % bedrock), instream habitat (% fast water; instream habitat complexity), algal productivity (% macroalgae cover; % microalgae cover), and riparian vegetation (% stream shading; % lower and upper canopy cover).

Question 4a: Do certain environmental variables exhibit consistent trends?

Most environmental variables did not show consistent trends over time, and trends that were observed were typically site- and year-specific.

Hydrologic Conditions

Intra-annual trends

Examination of the water level data revealed different patterns at the sites (Figure 9). Even among the three perennial sites, patterns were divergent. For example, the hydrograph at SA was stable, with water levels hardly fluctuating over the entire study period, suggesting a steady supply of groundwater at this site. In contrast, water levels at BC and CD declined over the summer, but appeared to approach a steady baseflow by July, suggesting that although groundwater inputs are important in these streams, they are dominated by surface runoff. Among the nonperennial sites, SY, SR, and NC showed relatively stable flows that ended abruptly. In contrast, SJ and OF both showed periods of large fluctuations, during which the streams dried on a nightly basis. Although the cause of these fluctuations was not determined, it was inferred that they reflected non-natural hydrologic regimes, and may be caused by regular groundwater diversions near these sites. Similar patterns were also evident at AS, but without the nightly drying or rapid fluctuations, although a few short flood events (also suggestive of human influence) are also evident in the water level data.

Loggers identified hydrologic stressors at sites that would not have been detected by site visits alone. Specifically, sites AS, SJ, and OF had intermittent periods of dryness, or periods of rapidly fluctuating water levels. Site visit alone (as might be expected under traditional bioassessment protocols) would not have revealed that these drying events occurred (Figure 9). Because loggers reflect water level at a point instead of at a reach, they sometimes indicate water retained in a wet pool from a reach that has gone dry (e.g., the end of the record at SR in Figure 9), or reflect dry conditions prior to the last day of sampling (e.g., SJ in Figure 9).

Loggers also provided information on temperature regimes. Patterns in water temperature were generally similar to flow regimes, with groundwater-dominated systems (e.g., AN, early CD) characterized by cooler, less variable water temperature than those dominated by surface water (e.g., late CD). At AS and SJ, large temperature fluctuations coincided with intermittent drying events, but this pattern was not evident at OF. Both SJ and SY—two sites with minimal riparian shading—had larger temperature fluctuations than other sites throughout the entire period when loggers were deployed.

Inter-annual trends

A surprising level in year-to-year variability in flow was evident at the three sites sampled over multiple years: NC, SY, and SR. All three sites dried by mid-July in their first year of sampling (2008 for SR, SY and 2009 for NC). However, in 2010, flow at NC did not decline by mid-September, and flow at SY was greatly reduced but still continuous. SY would likely have gone dry within a couple of weeks without rain, although flow at NC would have likely persisted much longer. At SY, the change probably reflects climatic variability, as 2010 was a much wetter year (10.6” vs. 3.9” in 2008 at Lindbergh Airport), with rainfall lasting later in the spring and starting earlier in the fall than was observed in 2008 (personal observation). In contrast, the cause of the drying event at NC in 2009 was not determined, though natural variability is less likely, as this stream was not known to local land managers to go dry. In contrast to both these sites, SR dried in July in both years it was sampled.

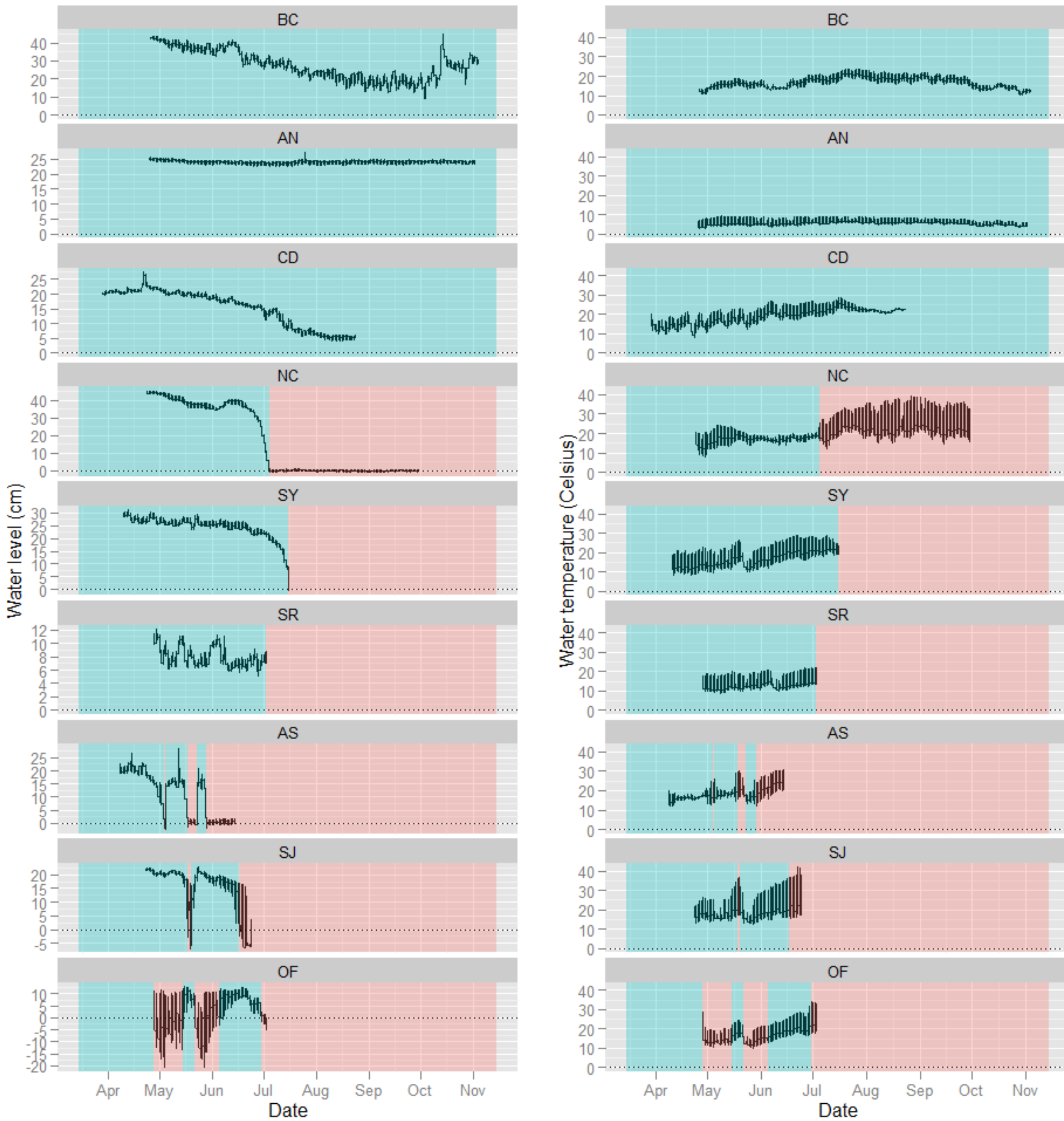

Figure 9. Water levels (left) and temperatures (right) at a subset of sites. Panel color indicates inferred flow status: blue indicates wet periods, and pink indicates dry (or fluctuating) periods. Data for SY, SR, AS, SJ, and OF were from 2008. Data for BC, SA, and NC were from 2009. Data for CD were from 2010.

Water Chemistry Conditions

Intra-annual trends

Conductivity was generally higher at the nonperennial sites (~400 to 800 uS/cm) than at the perennial sites (~100 to 400 uS/cm). Increasing trends were evident at a few sites in certain years, but conductivity was stable at other sites (including all perennial sites). Stress level was not associated with any particular pattern, as increases in conductivity were observed at low and high stress sites alike (Figure 10).

Ambient nutrient concentrations were low at most sites, although higher concentrations (e.g., > 1 mg/L) were sometimes observed. Concentrations were consistently low at all perennial sites, as well as in most samples from low stress nonperennial sites (with the final sample from AC being a conspicuous exception). Sharp declines from high concentrations were evident at AS and TC (Figures in Appendix 3).

Dissolved copper concentrations were low at all sites and samples in the study, although generally above method detection limits. At most sites, the concentration varied between 0 and 1 ug/L, although a concentration of 5 ug/L was observed at the initial date of sampling at the most urban site (TC; Figures in Appendix 3).

Inter-annual trends

Data were generally inadequate to evaluate inter-annual trends in most water chemistry analytes. However, available data again showed a surprising degree of variability. For example, although conductivity was similar at SR and NC in both years they were sampled, SY showed different trends. In 2008 (a relatively dry year), conductivity increased over the course of the study, while in 2010 (a relatively wet year), conductivity remained near its initial value for the entire duration (Figure 10).

Inter-annual trends for total Nitrogen and dissolved Copper were not evident. Large increases in total nitrogen followed by decreases were observed at two heavily grazed sites (SR and SY) in 2010, but concentrations were much lower and more steady at these sites in 2008. Copper concentrations were low in all years it was sampled. Concentrations at SY were similar in both 2008 and 2010, but at SR they were higher in 2010 than 2008 (Figures in Appendix 3).

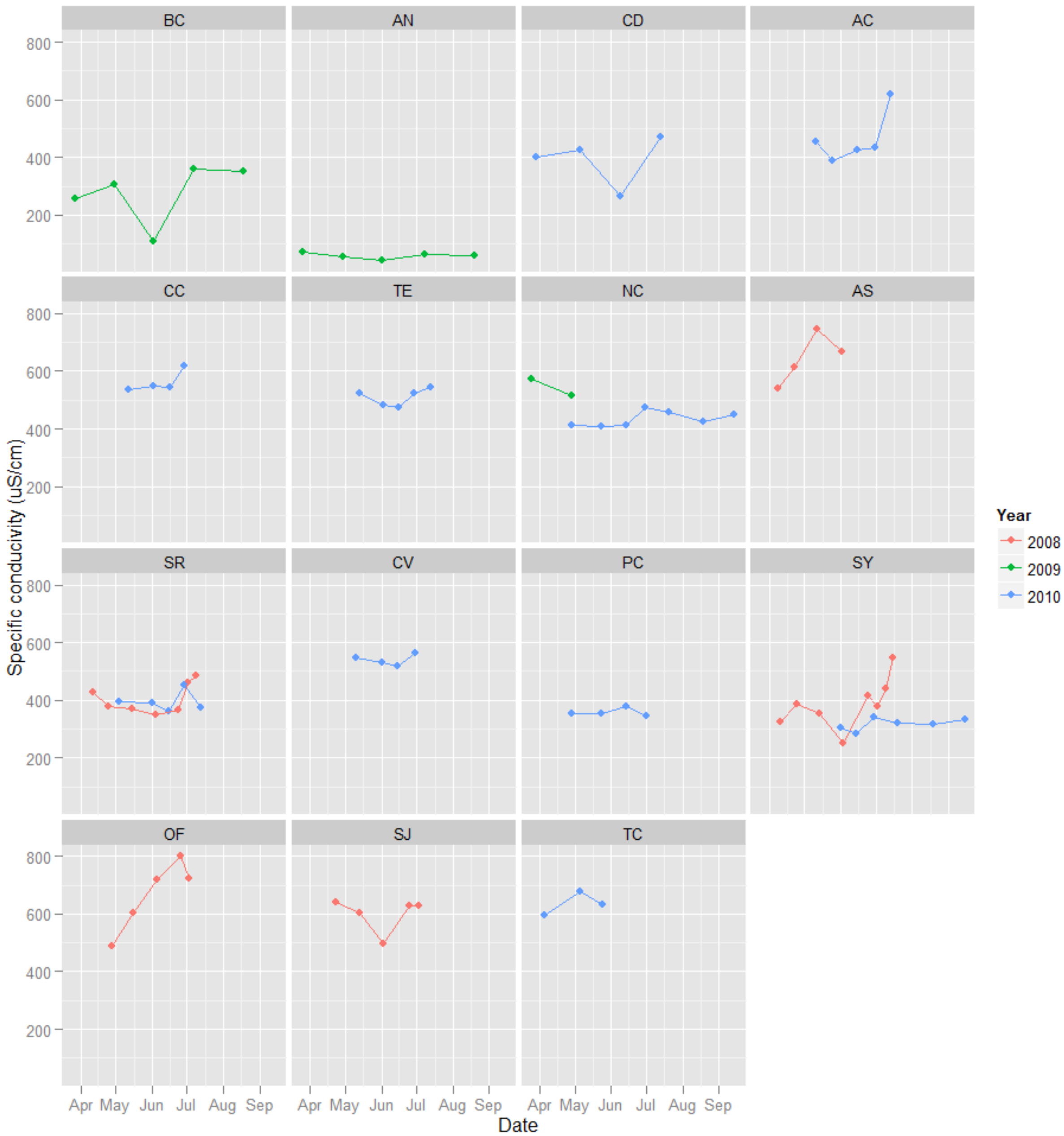

Figure 10. Trends in conductivity at each site and year.

Physical Habitat Condition

Intra-annual trends

Substrate - Substrate at perennial streams was relatively coarse, and the amount of smaller particles (i.e., % sands and fines was always below 40% at these sites) was stable over the course of the study. In contrast, substrate was overall finer in nonperennial streams. The % sands and fines metric fluctuated considerably at these sites, both from event to event and year to year. A sharp increase was evident at AC, and a sharp decrease was evident at AS, but most sites showed no overall trend towards finer or coarser substrate. These changes more likely reflect shifts and changes in the wet portion of the streambed over time, as opposed to actual changes in the streambed composition, which is unlikely to have changed in the absence of a major scouring event or other geomorphological disturbance during the course of the study (Figures in Appendix 3).

In contrast to fine particles, the percent of the streambed comprised of bedrock was steady at most sites, but increased at others. Several sites had no (or very little) bedrock, and the bedrock metric changed very little over the course of the study (e.g., AC, PC, TC, as well as the perennial site AN). In contrast, nonperennial sites underlain by extensive bedrock showed an increase in this metric over the course of the study (most sharply at OF, but also at CC, NC, SR, and SY). In contrast, perennial sites underlain by bedrock showed very different behaviors. At site BC, this metric varied around a narrow range (~8% to 12%). Variability at CD was extremely high (ranging from ~5% to 40%), and could not be attributed to any cause (Figures in Appendix 3).

Microhabitats As expected, the amount of fast water habitat (e.g., riffles) declined over the course of the study at most sites, although these trends were both site and year specific. The amount of fast water microhabitats is driven both by the availability of water, as well as site-specific microtopography of the streambed, which may explain why a few increases were observed (most notably at AC, where % fast water habitat increased before completely disappearing at the end of the study). Most of these increases were observed early in the study period (Figure 11).

Instream habitat complexity (measured as a modified version of EMAP's XFC_NAT metric, Kaufmann et al. 1999) was lower and more stable in nonperennial sites than perennial sites. This metric, which quantifies the availability of cover from natural features (e.g., woody debris, algae, macrophytes, boulders, tree roots, etc.) was generally over 100 at perennial sites, and lower at most nonperennial sites (with the exception of OF, where it fluctuated between 100 and 175). This metric was stable or fluctuated around a constant value at one perennial site (CD), and all nonperennial sites, with the exception of TC, where a large increase was driven by growth of filamentous algae (Figures in Appendix 3).

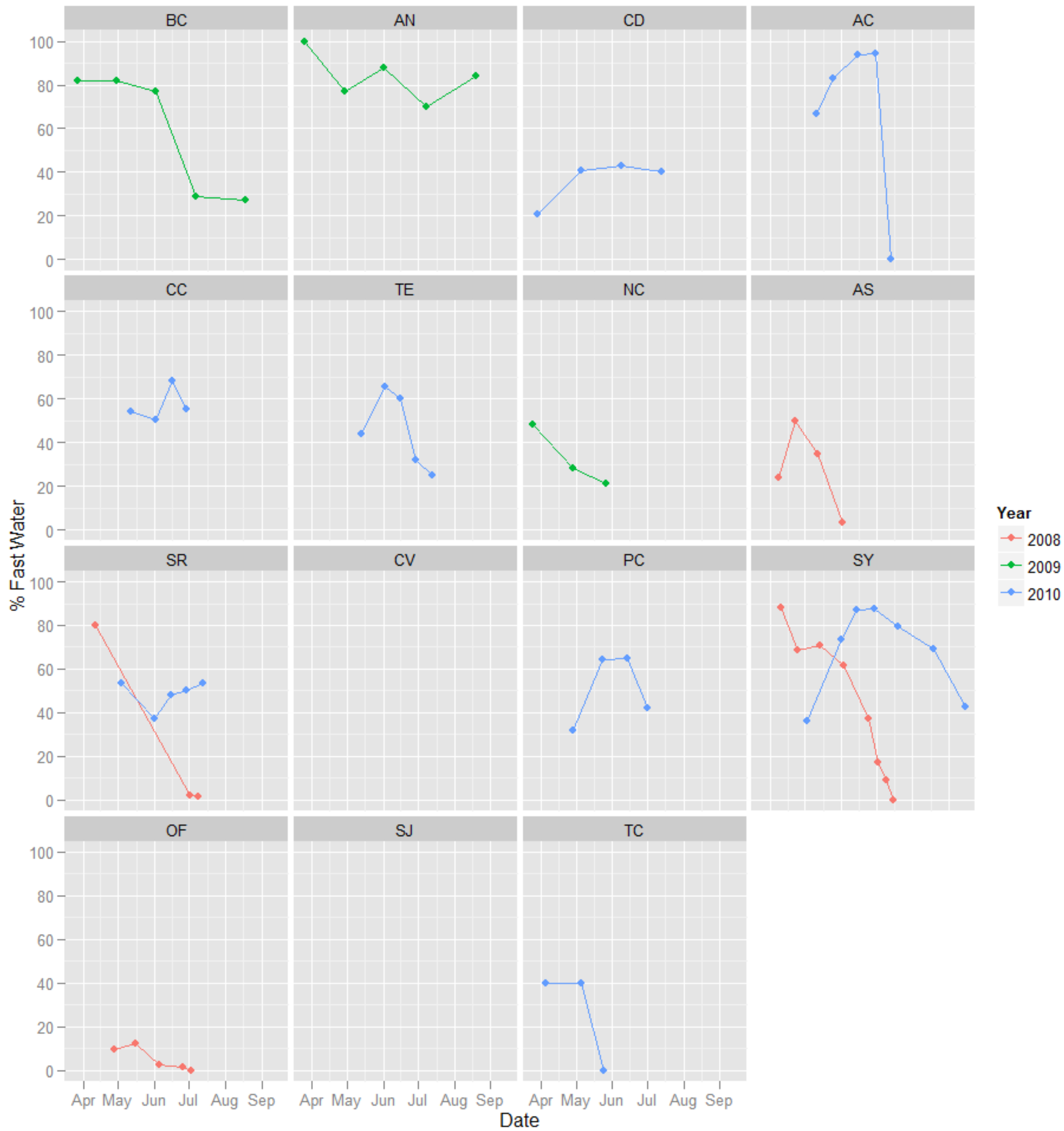

Figure 11. Trends in the amount of fast-water habitat at each site and date.

Productivity Productivity was measured as both macro- and microalgae cover of the streambed in samples collected in 2009 and later. Microalgae cover was almost always lower than macroalgae cover. These two metrics tracked each other closely at most sites, with a few exceptions. At CC, AC, and TE, macroalgae cover increased at the end of sampling, while microalgae cover remained low (or declined at NC). Only at TC did micro- and macroalgae cover show a converse relationship. Mid-season increases in macroalgae cover were evident at two perennial sites (i.e., BC and AN), while the opposite pattern was observed at CD and several nonperennial sites (e.g., CC, PC, and SR; Figure 12).

Riparian vegetation Riparian vegetation was assessed as both stream shading and vegetative cover in the riparian zone. As might be expected, shading was steady or increased at sites over the course of sampling as vegetation grew. This increase was dramatic at CD, and gradual at SY (where disturbance by cattle grazing limits riparian vegetation growth). Site OF was an exception to this pattern, as most of the stream shading came from emergent macrophytes, which began to die back towards the end of sampling (Figures in Appendix 3).

Riparian vegetation in the lower and upper canopies (i.e., over 0.5 m high) was generally higher at the perennial streams, but this metric was variable at these sites. At nonperennial sites, riparian vegetation was either low and steady over the course of sampling (e.g., SY, CC), or showed slight increases (e.g., AC, PC). A steady decline was only observed at TC, where the drop in riparian cover could be attributed to a retraction of the wetted width away from the vegetated margins of the stream (Figures in Appendix 3).

Inter-annual trends

With few exceptions, most physical habitat metrics displayed low year-to-year variability. The most notable exception was % fast water, which at site SY declined in 2008 (a relatively dry year), but showed a steady increase followed by a decrease in 2010 (a relatively wet year). It is possible that the stream actually displayed the same patterns in both years, but these changes were delayed in 2010 because of the higher rainfall. Therefore, the initial rise in fast water habitat was missed in 2008 at SY (and, perhaps, other sites in the study) because it occurred before the initiation of sampling (Figure 11).

No inter-annual data were available to examine year-to-year differences in algae productivity.

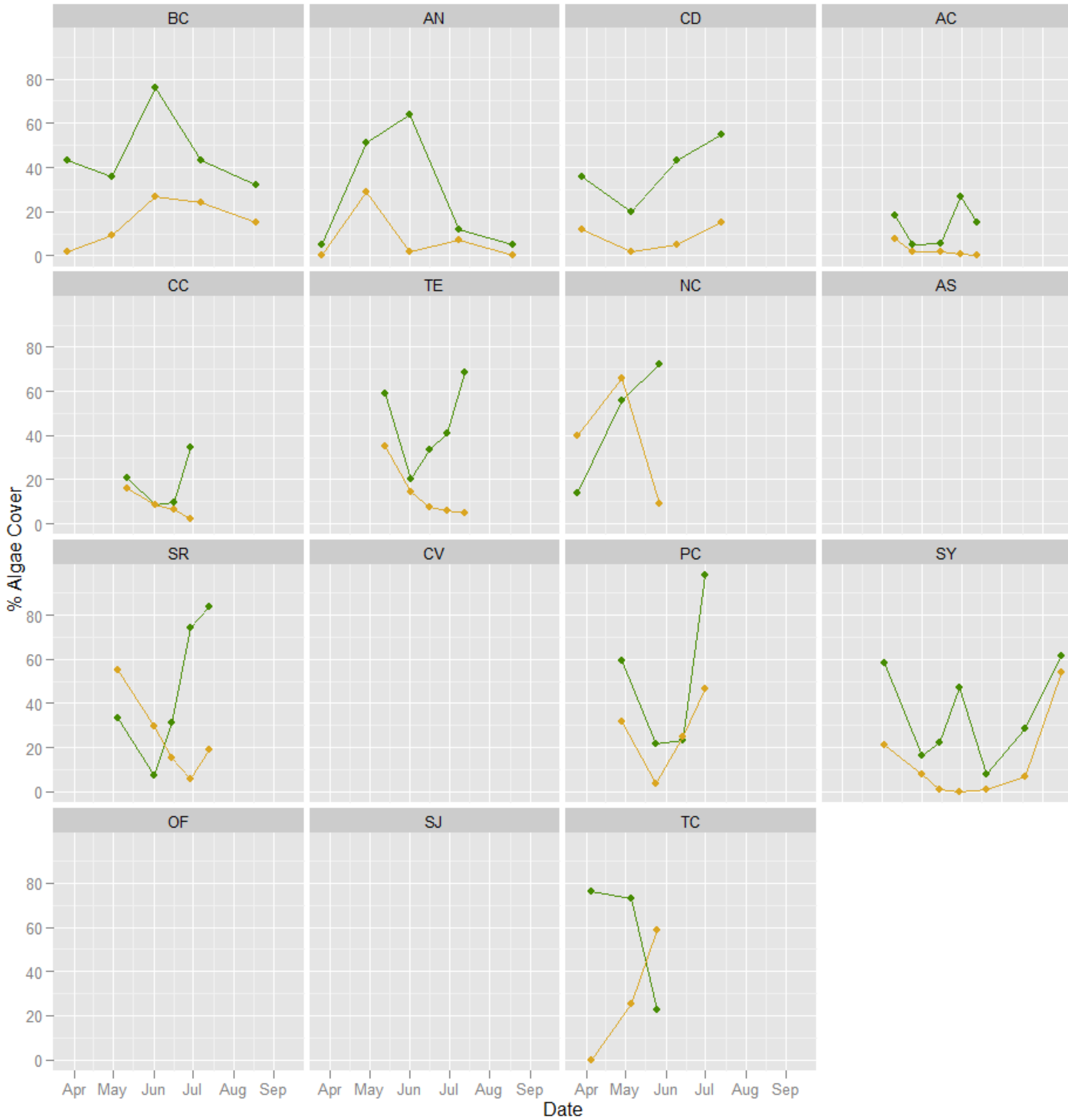

Figure 12. Trends in algae cover at each site and sampling event. In contrast to Green is macroalgae, gold is microalgae. Data for NC were collected in 2009, and data for SR and SY were collected in 2010.

Question 4b: Are trends in environmental condition associated with changes in IBI scores?

Most changes in environmental condition were not associated with changes in IBI scores. Flow and % fast water habitat were exceptions, but only at high stress sites. This lack of strong associations is due to the relative stability of IBI scores at low stress sites, and because consistent trends in environmental condition were rarely observed.

Environmental variables were plotted against IBI scores to see if there was a relationship between these factors and biological condition. Simple scatterplots are presented for clarity and ease of interpretation. However, they may reflect spurious relationships driven by differences among sites, rather relationships between trends. Therefore, trajectories were also plotted (one trajectory per site and year). Consistent, diagonal movement of trajectories was considered evidence in support of an association between the changes in the environmental variable and changes in the IBI score.

Hydrologic Conditions

At low and moderate stress sites, no relationship between discharge and IBI scores was evident. At highly stressed sites, scores declined when flow was ~0.75 cfs or lower. This pattern suggests that there is no critical flow at which the IBI is valid at unstressed and moderately stressed sites, but at highly stressed sites, higher flows are associated with higher IBI scores (Figure 13).

Declines in IBI score are roughly aligned with intermittent drying episodes at some, but not every site where they occurred (Figure 14). For example, a large decline in IBI scores at AS occurred after a ~5 day dry period in late May, and at SJ following a shorter drying event of ~1 day (also in late May). However, the first inferred drying event at AS was less than 1 day in early May, and preceded an increase in IBI scores. Drying events at OF occurred throughout the study period, and it is not possible to determine if scores were higher before these events occurred. At SR, the data logger indicated locally dry conditions, although the reach was sampled twice after date, as the majority of the reach was still flowing during site visits. Although IBI scores declined slightly after that the logger indicated dry conditions, these scores were consistent with natural variability observed at the site earlier in the season.

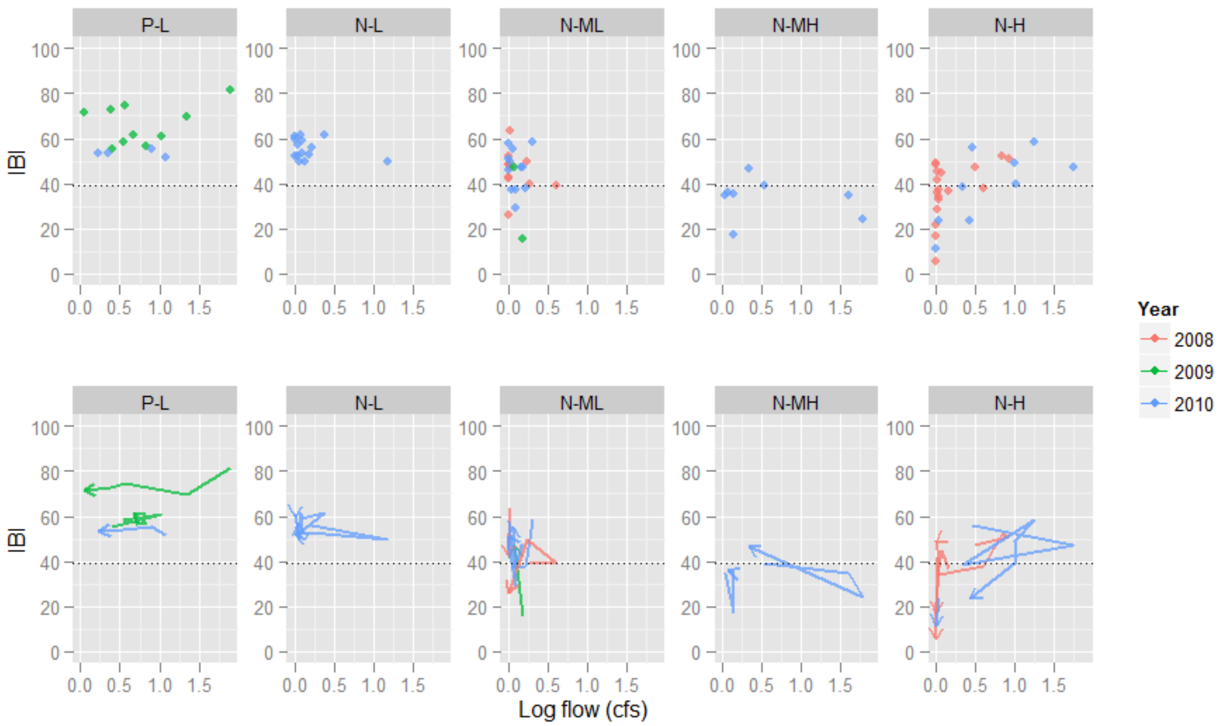

Figure 13. IBI scores relative to flow measured during sampling events. Each panel represents a different flow and stress class: P-L: perennial, low stress sites; N-L: nonperennial, low stress sites; N-ML: nonperennial, moderately low stress sites; N-MH: nonperennial, moderately high stress sites; N-H: nonperennial, high stressed sites. Each point in the top panels represents a different sampling event, and each trajectory in the bottom panel represents a different site and year.

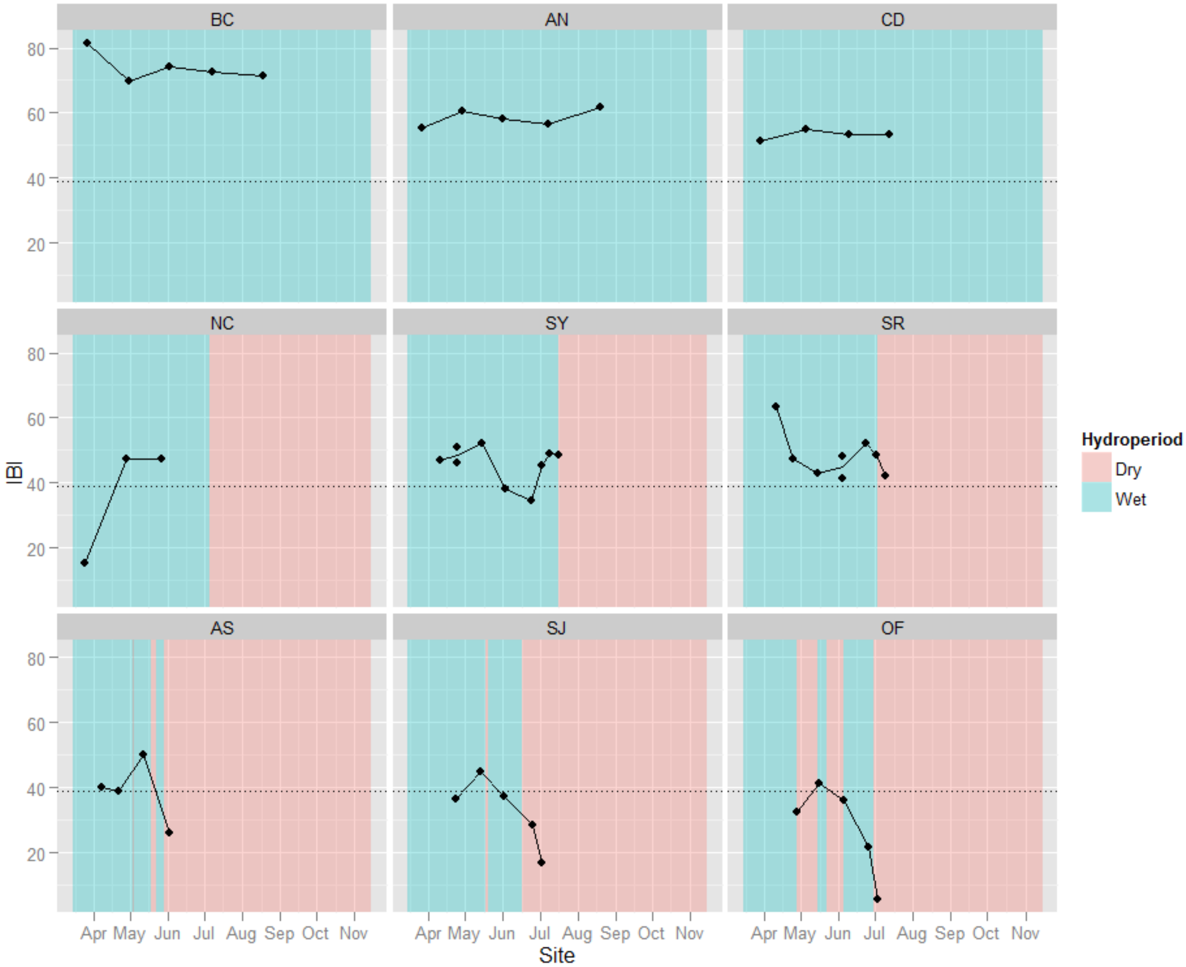

Figure 14.Trends in IBI score, overlaying water level data from continuous data loggers.

Water Chemistry Conditions

Conductivity showed a strong, negative relationship with IBI scores, although this relationship was driven by site-specific differences, and not trends. No relationships with other water chemistry variables were evident, although ranges in concentrations of total Nitrogen and dissolved Copper were generally low, even at stressed sites (Figure 15).

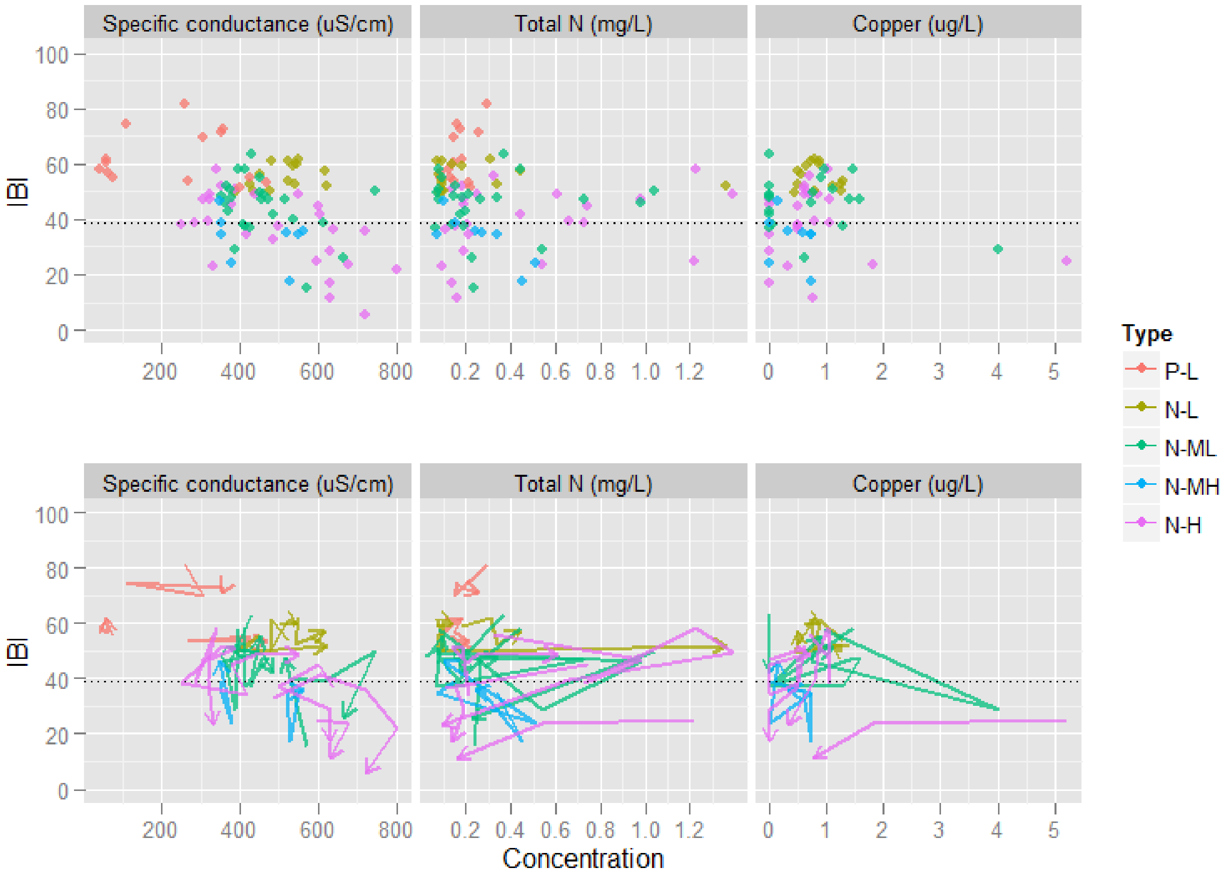

Figure 15. IBI scores versus three water chemistry analytes. Color indicates the flow and stress class of each site: P-L: perennial, low stress; N-L: nonperennial, low stress; N-ML: nonperennial, moderately low stress; N-MH: nonperennial, moderately high stress; and N-H, nonperennial, high stress. Each point in the top panels represents a different sampling event, and each trajectory in the bottom panel represents a different site and year.

Physical Habitat Conditions

Several habitat metrics showed moderately strong positive or negative relationships with IBI scores, but most of these relationships reflected site differences rather than association of trends (Figure 16). Exceptions to this pattern include % sands and fines and % fast water habitat, both of which declined with time and IBI scores at high stress nonperennial sites, and to a lesser extent % macroalgae cover (which increased with time and decreased with IBI scores, but only at two high stress nonperennial sites). Other metrics that showed strong linear or wedge-shaped relationships with IBI scores (e.g., % shading, mean canopy cover) reflect differences among sites, rather than trends over time, as most of the trajectories did not move in a consistent direction along both variables.

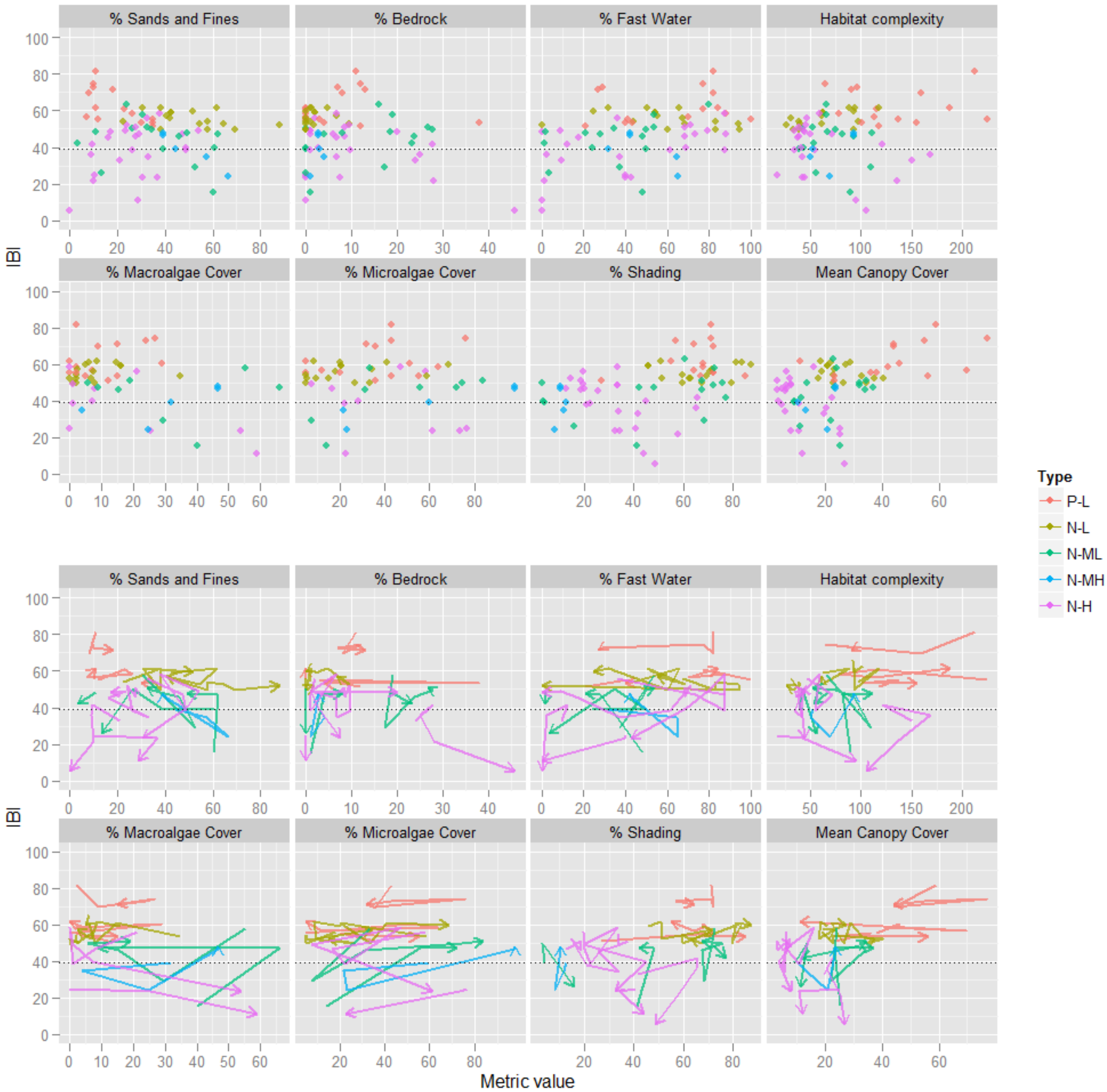

Figure 16. Correlations (top two rows) and trajectories (bottom two rows) between selected habitat metrics and IBI scores. Each point in the top rows represents a different sampling event, and each trajectory in the bottom rows represents a different site and year.

Conclusions and Recommendations

Although limited to a small number of sites, this study illustrates that nonperennial streams can be incorporated into routine bioassessment programs with little modification of current protocols. Furthermore, the large extent of nonperennial streams in the San Diego region makes their inclusion all the more relevant if watershed managers are to truly understand the health of their watersheds.

Key findings

- Nonperennial streams are extensive, but declining in urban areas
  Almost three quarters of the total stream length in the San Diego is nonperennial, but this number drops to less than half of urban streams. Furthermore, the preponderance of disagreements with designations in the NHD Plus also suggests that urbanization has converted nonperennial streams to perennial streams.

- Nonperennial streams are important biological resources that support beneficial uses
  As this study demonstrates, nonperennial streams support aquatic life, and require management in order to protect beneficial uses.

- Flow regimes are highly variable, both within and across years
  Even the small number of sites included in this study exemplified a large gradient of intermittent stream types, including those with long sustained flows, as well as short-lived streams that dried repeatedly over a single season. Furthermore, two of the three sites selected for sampling across multiple years were perennial or semi-perennial in the second year of sampling, suggesting that flow status can change at many sites, depending on antecedent climatic conditions.

- Nonperennial flow status does not preclude high IBI scores.
  IBI scores ≥ 39 (which is typically considered the threshold for poor quality streams) were observed at several samples from nonperennial streams, and at all samples from low stress nonperennial streams. Therefore, it is unlikely that nonperennial status alone results in low IBI scores.

- Stress increases variability in IBI scores in nonperennial streams
  Both perennial and nonperennial low stress sites showed remarkably low variability in IBI scores. However, variability increased as stress increased, and downward trends in IBI scores were evident at some of the most highly stressed sites in the study. Data from stressed perennial streams were not available for this study.

- Inter-annual variability in IBI scores was low at two of the three sites where sampling occurred over multiple years
  Although only assessed at three sites, IBI scores followed nearly identical trajectories at two of them, indicating a surprisingly high level of inter-annual consistency.

- Many changes in physical habitat and water chemistry are site and year specific.
  Several water chemistry analytes and physical habitat metrics did not show clear trends over the course of the sampling season, and those that did sometimes showed different trends at different sites and even different trends within a site in different years.

- Few environmental changes were rarely associated with changes in IBI scores.
  In general, changes in environmental condition were not associated with changes in IBI scores. IBI scores declined with flow at high stress sites, but flow and IBI scores were not related at sites with low or moderate stress.

Recommendations

- Develop a non-binary approach to characterize flow regimes at nonperennial sites.
  A tool that can characterize the intra- and inter-annual variability in flow regimes would have many applications to watershed management. For example, it might be used to characterize perenniality gradients as probability of drying under certain climatic conditions. This tool could also be used to create maps that would then form the framework for ambient surveys, such as the PSA, or to assess hydromodification and anthropogenic modification of flow regimes. Such a tool is fundamental to proper management of nonperennial streams, and is essential for implementing several of the following recommendations.

- Include nonperennial streams in routine and ambient bioassessment programs, such as the PSA and compliance monitoring.
  Incorporating nonperennial streams in routine and ambient monitoring programs is essential to many of SWAMP's objectives for managing surface waters. As the state moves towards a watershed-based approach to management, it cannot adequately protect perennial waters without protecting nonperennial streams. Not only do these comprise the majority of stream length in several regions of the state, but they are also typically located at the interface between terrestrial and aquatic systems, where many stressors are first introduced into a watershed.

- Establish a program to monitor reference nonperennial sites that capture the full gradient of natural flow regimes under multiple climatic conditions.
  As mentioned earlier, although the IBI appears to be valid for the nonperennial streams included in this study, a larger network of reference streams is needed to answer further questions, such as:
    - Are mean IBI scores of reference nonperennial sites equivalent to reference perennial streams?
    - Does that equivalency depend on antecedent flow conditions?

    - How far along the spectrum of nonperenniality (from long sustained, like most of the sites in this study to highly ephemeral streams (such as episodic channels) can benthic macroinvertebrates be used to assess condition (with the IBI or other indices)?

  Although SWAMP has initiated a robust program to monitor perennial reference streams (Ode and Schiff 2009), data from nonperennial reference streams are minimal. Creating a comparable program for nonperennial streams may be necessary for generating these data. Like the Reference Condition Management Program (RCMP), a comparablenonperennial program should select sites to represent key natural gradients (such as elevation, substrate, and watershed size). Perhaps even more important than for the RCMP, a nonperennial reference program should emphasize repeated sampling (both intra- and inter-annual) to understand the role of temporal variability in nonperennial streams.

- Use existing sampling protocols and indices (such as the IBI) for assessing nonperennial streams, at least until a reference network can be developed.
  Data from this study do not support modifying the IBI, and that it may correctly identify streams in reference condition, regardless of flow status. However, variability of IBI scores was higher at low stress nonperennial sites than at low stress perennial sites, suggesting that alternative thresholds may be warranted. However, the scope of this study was limited to only 12 nonperennial sites, of which only 3 were low stress. Additional reference sampling may reveal if further refinements to the IBI are necessary. The IBI may not work as well in nonperennial streams with flow regimes or environmental characteristics not represented in this study. In particular, nonperennial streams with very short or even ephemeral flow regimes were not represented, and the validity of the IBI cannot be assumed to be correct for these streams. Indeed, research from other Mediterranean-climate regions has shown that intermittent and ephemeral streams have highly distinct communities, and require their own assessment indices (Anna et al. 2008).

  SWAMP's existing standard protocols and recommended index periods are sufficient to ensure that nonperennial streams can be adequately assessed. That is, if flow is sufficient for sampling within the index period, data from nonperennial streams may be interpreted with existing tools and analytical approaches.

- Include assessments of hydrologic disturbances when trying to identify possible causes of low IBI scores.
  Nonperennial streams may be uniquely sensitive to altered hydrology, and as this study revealed, routine bioassessment protocols are inadequate to identify some hydrologic stressors. Continuous water level loggers should be deployed in bioassessment programs where possible, particularly in stressor identification studies.

- Develop an index to evaluate physical habitat data.
  The high variability in physical habitat metrics makes it difficult to associate changes in the habitat with biological condition, particularly for small studies with low statistical power. Although the biological metrics that comprise the IBI also showed high variability, the composite IBI itself was remarkably stable (at least at low stress sites). This reduction in variability is one of the key benefits to aggregating metrics into a multimetric index. A composite multimetric index for physical habitat may have similar properties, and allow for more effective analysis of relationships between biology and habitat, when used in conjunction with analysis of individual habitat metrics. Such an index would have applications to perennial streams as well, and also provide a new tool for stressor identification.

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Appendix 1. Stressor Scores

A1-1. Total scores and hydrologic stressors

Stressor	BC	AN	TC	AC	CV	CC	TE	NC	SY	CD	OF	SJ	AS	SR	PC
TOTAL	0	0	8.5	0.5	4.5	0.5	0	2	7	0	7.5	8	2.5	3	5
Hydrologic stress (TOTAL)	0	0	1	0	0	0	0	1	0	0	2.5	2	2	0	1
Point source	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nonpoint source	0	0	1	0	0	0	0	0	0	0	1	0.5	0	0	0.5
Flow diversions or unnatural inflows	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dams	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Flow obstruction	0	0	0	0	0	0	0	0	0	0	0.5	0.5	0	0	0.5
Weir or drop structure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Inlet/channel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Engineered channel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dike or levees	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Groundwater extraction	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0
Ditches	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Actively managed hydrology	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

A1-2. Physical structure stressors

Stressor	BC	AN	TC	AC	CV	CC	TE	NC	SY	CD	OF	SJ	AS	SR	PC
Physical structure stress (TOTAL)	0	0	3	0.5	1	0.5	0	0.5	1.5	0	2.5	2.5	0.5	1	1.5
Filling or dumping	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grading	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plowing or disking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Resource extraction	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0
Vegetation management	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Excessive sediment or debris	0	0	0	0.5	0	0.5	0	0	0	0	0	0.5	0.5	0	1
Excess runoff	0	0	1	0	0	0	0	0	0	0	1	0.5	0	0	0
Nutrient impairment	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
Heavy metal impairment	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0
Pesticides or trace organics	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bacteria and pathogens	0	0	0.5	0	1	0	0	0	1	0	0.5	0.5	0	1	0.5
Trash or refuse	0	0	1	0	0	0	0	0	0.5	0	0	0	0	0	0

A1-3. Biotic stressors

Stressor	BC	AN	TC	AC	CV	CC	TE	NC	SY	CD	OF	SJ	AS	SR	PC
Biotic stress	0	0	1	0	2	0	0	0.5	4	0	0.5	1.5	0	1	1
Grazing	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0.5
Human visitation	0	0	1	0	1	0	0	0.5	1	0	0.5	1	0	0	0.5
Non-native vertebrates	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sapling removal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Removal of woody debris	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Treatment of non-native plans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pesticides	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biological extraction or stocking	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0
Lack of vegetation management to conserve natural resources	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Lack of treatment of invasive plants	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0

A1-4. Buffer and landscape stressors

Stressor	BC	AN	TC	AC	CV	CC	TE	NC	SY	CD	OF	SJ	AS	SR	PC
Buffer and landscape stress	0	0	3.5	0	1.5	0	0	0	1.5	0	2	2	0	1	1.5
Urban residential	0	0	1	0	0	0	0	0	0	0	0.5	0.5	0	0	0.5
Industrial	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Military	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dams	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dryland farming	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Row crop ag	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Orchards	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Feedlots	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dairies	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ranching	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0
Transportation	0	0	1	0	0	0	0	0	0	0	1	0.5	0	0	0.5
Sports fields and urban parks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Passive recreation	0	0	1	0	0.5	0	0	0	0.5	0	0.5	0.5	0	0	0.5
Active recreation	0	0	0.5	0	0	0	0	0	0	0	0	0.5	0	0	0
Physical resource extraction	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bio resource extraction	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 2. Photo Documentation of Environmental Change and Condition

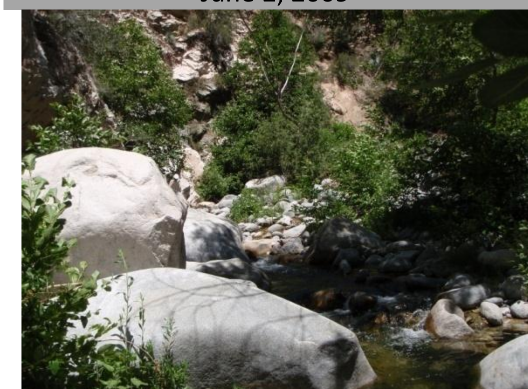
This appendix presents photo documentation of changes in site condition that were collected during each sample event. In addition, photos documenting some of the stressors affecting sites, as well as wildlife that were observed during the study, are included to provide information about the biological resources that these streams support.

March 27, 2009

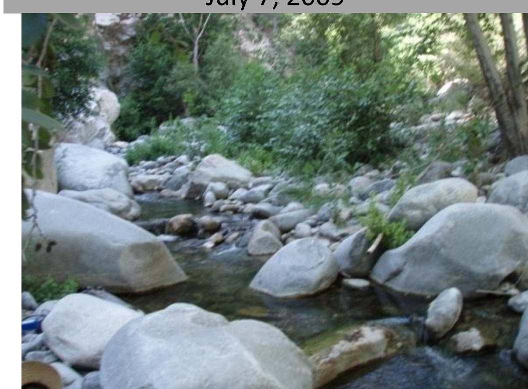
April 30, 2009

[Not available]

June 2, 2009



July 7, 2009



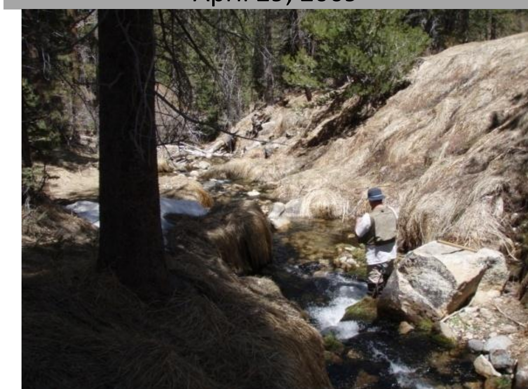
August 18, 2009

[Not available]

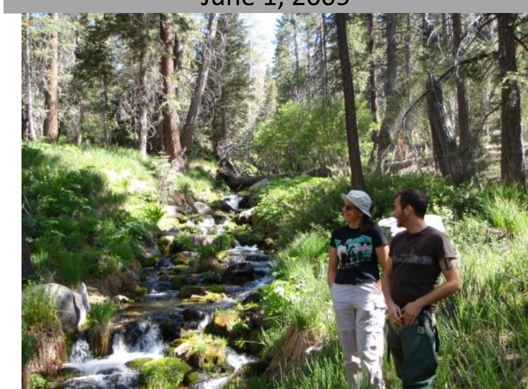
Bear Creek (BC) 2009

March 26, 2009

April 29, 2009



June 1, 2009



July 8, 2009

August 19, 2009

[Not available]

South Fork Santa Ana River (SA) 2009

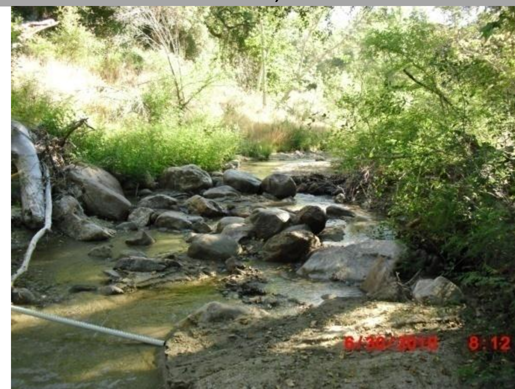
March 29, 2010
[Not available]
May 5, 2010
[Not available]
June 9, 2010

July 13, 2010
[Not available]

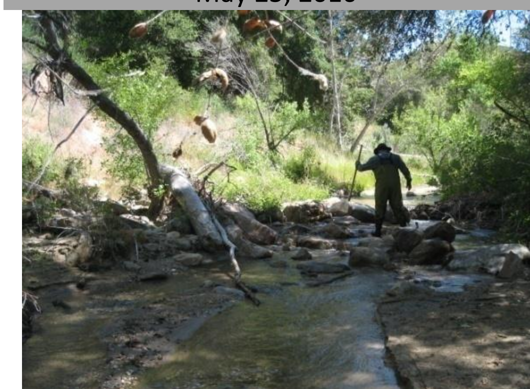
Cedar Creek (CD) 2010

May 11, 2010

June 30, 2010



May 25, 2010



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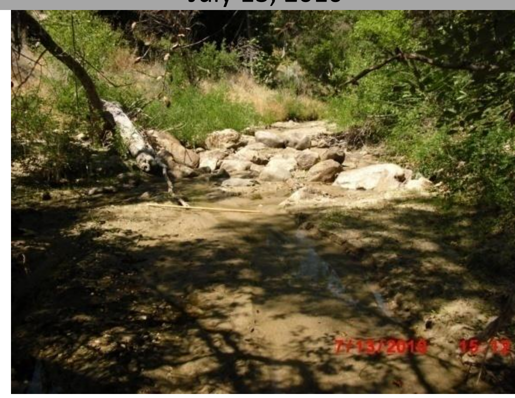


June 15, 2010

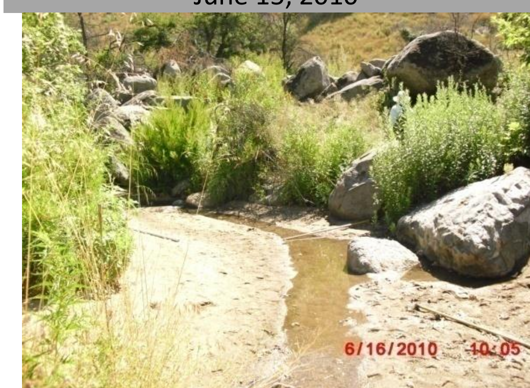
Agua Caliente Creek (AC) 2010

May 12, 2010

Arroyo Toad, 5/12/10

June 2, 2010

June 15, 2010



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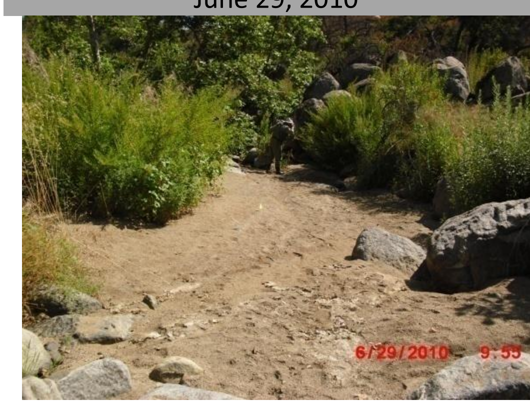
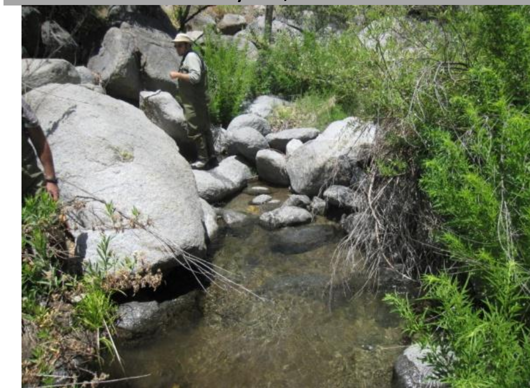


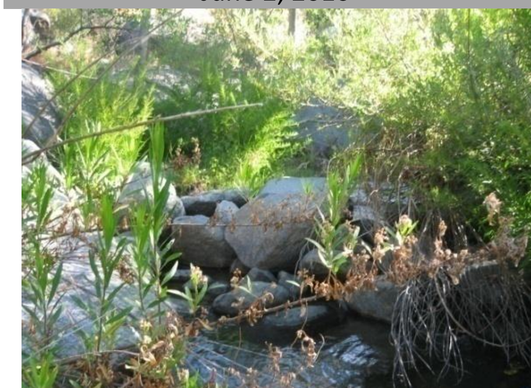
Carney Canyon (CC) 2010

May 13, 2010



June 29, 2010

June 2, 2010



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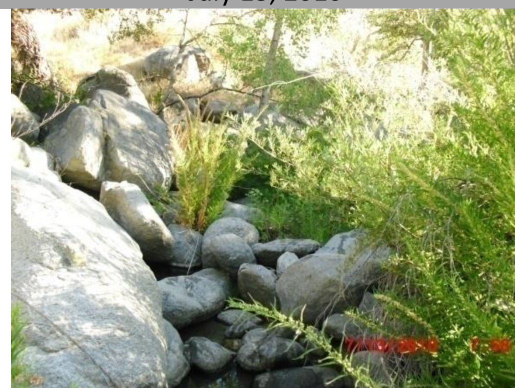
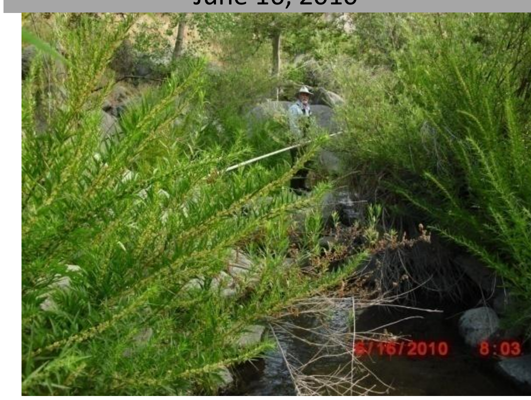


June 16, 2010

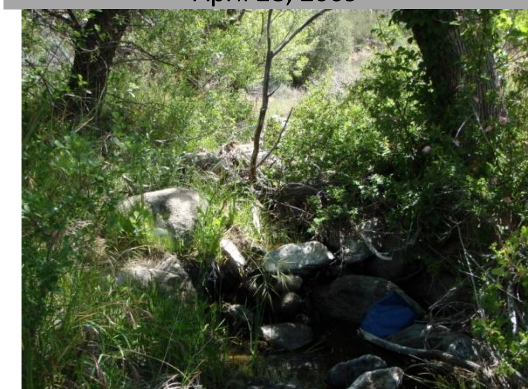


Rosy Boa, 5/13/10

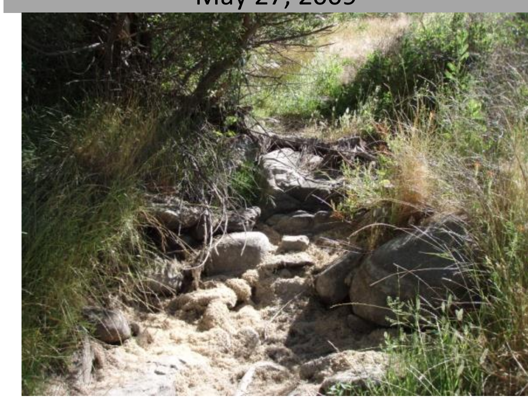
Temescal Creek (TE) 2010

March 25, 2009

April 28, 2009



May 27, 2009

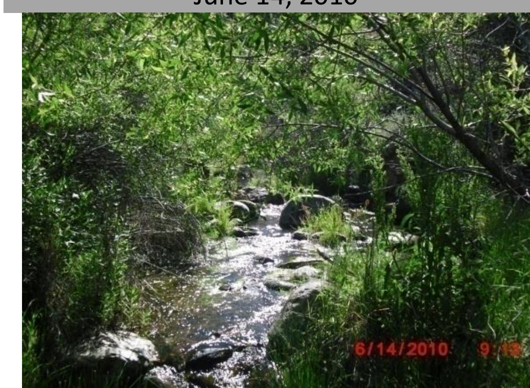


Noble Canyon (NC) 2009

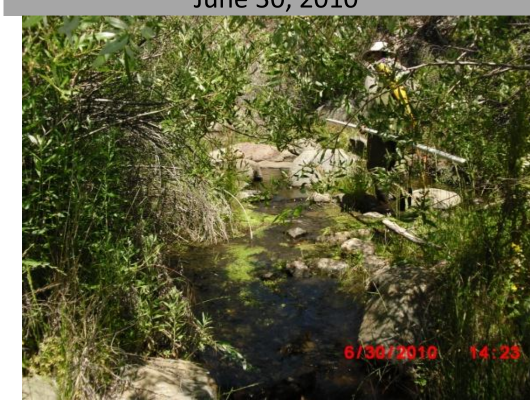
April 28, 2010

May 24, 2010

June 14, 2010

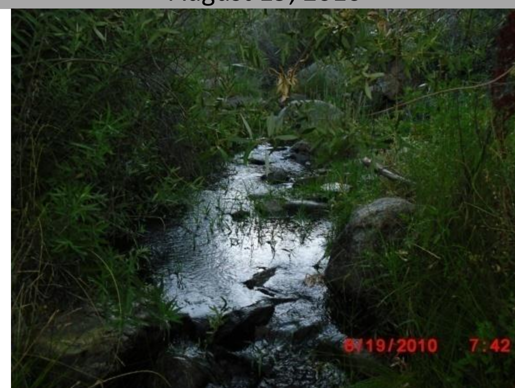


June 30, 2010

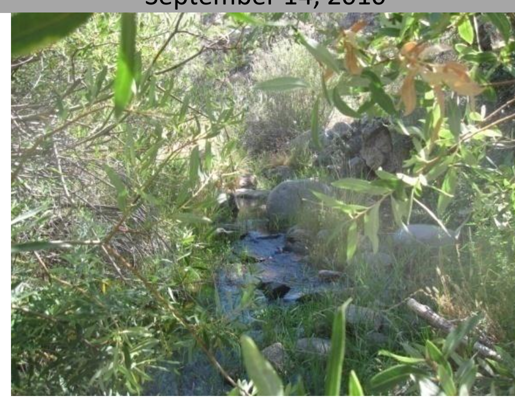


July 20, 2010

August 19, 2010



September 14, 2010



Noble Canyon (NC) 2010

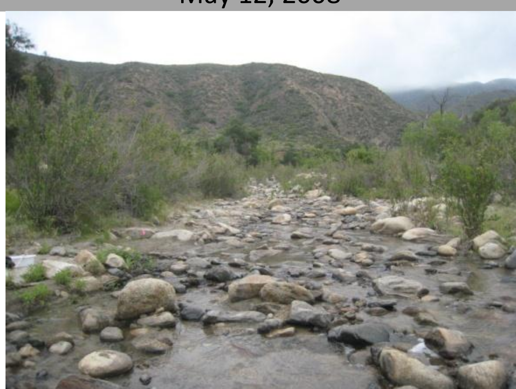
April 8, 2008

California tree frog 4/8/08

April 22, 2008

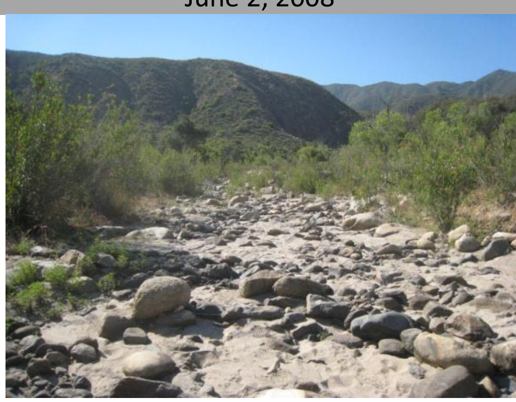
Damselfly nymph 6/2/08

May 12, 2008



Site of water loss 6/2/08

June 2, 2008



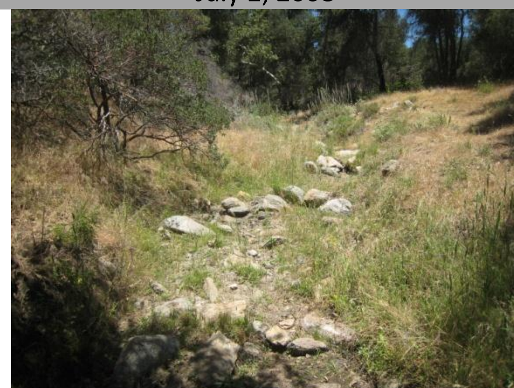
Arroyo Seco (AS) 2008

April 11, 2008

June 23, 2008

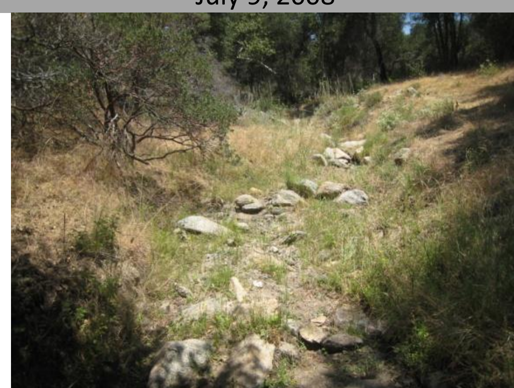
April 25, 2008

July 2, 2008

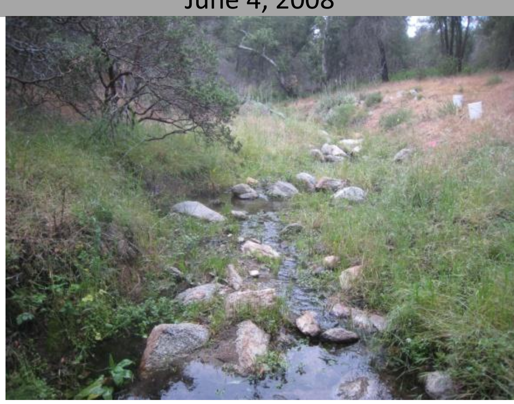


May 15, 2008

July 9, 2008

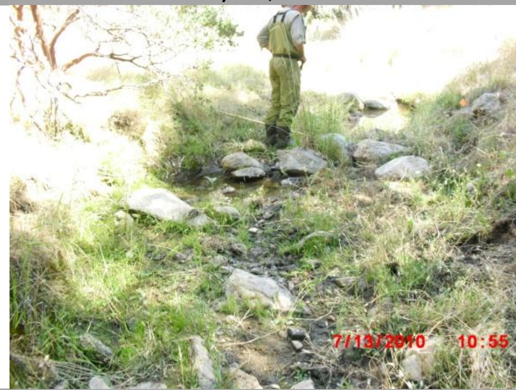
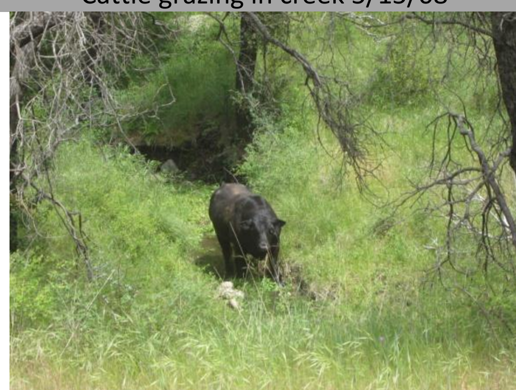
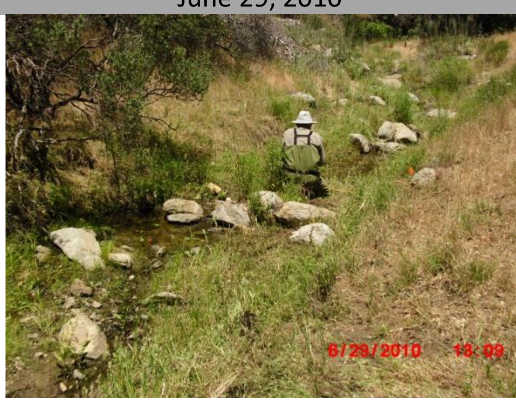


June 4, 2008



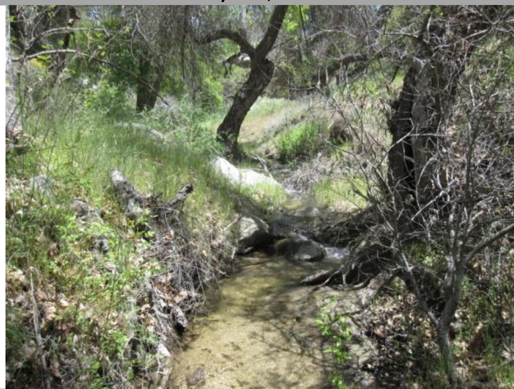
California kingsnake 6/23/08

San Diego River Headwaters (SR) 2008

May 4, 2010	July 13, 2010
	
June 1, 2010	July 2, 2008
	
June 15, 2010	Cattle grazing in creek 5/15/08
	
June 29, 2010	Baetid mayfly 4/11/08
	

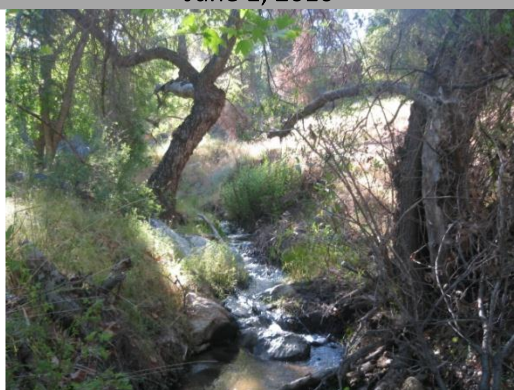
San Diego River Headwaters (SR) 2010

May 10, 2010

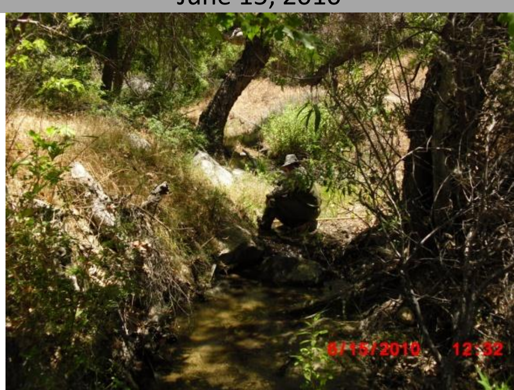


Cattle grazing in the creek 5/25/10

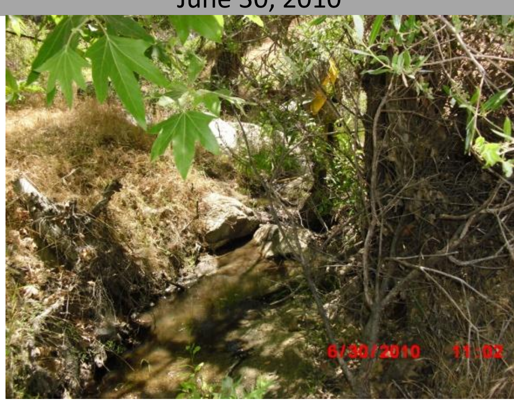
June 1, 2010



June 15, 2010



June 30, 2010



Cañada Verde (CV) 2010

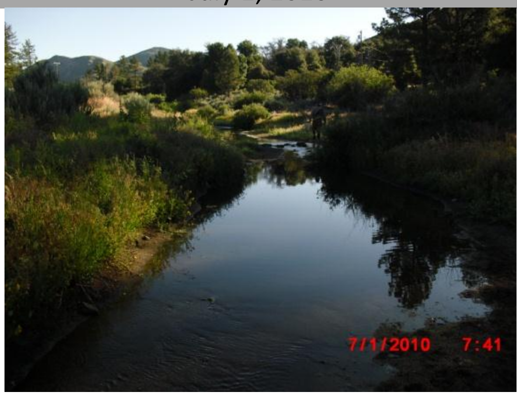
April 28, 2010

Arizona crossing downstream of reach 4/28/10

May 24, 2010

June 14, 2010

July 1, 2010



Pine Valley Creek (PC) 2010

April 10, 2008

April 24, 2008

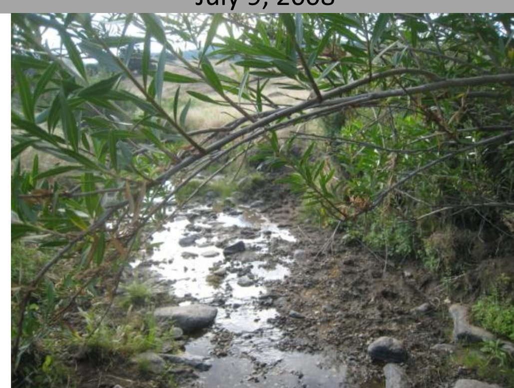
May 14, 2008

June 3, 2008

June 24, 2008

July 2, 2008

July 9, 2008



Juy 16, 2008

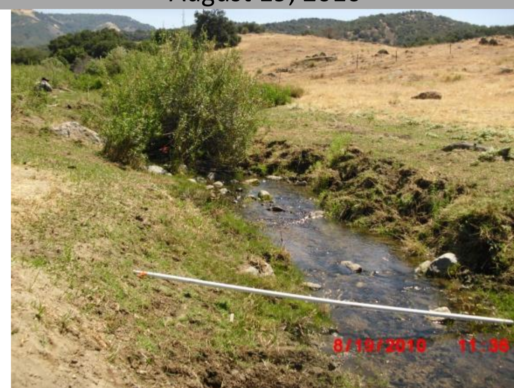
Santa Ysabel Creek (SY) 2008

May 3, 2010

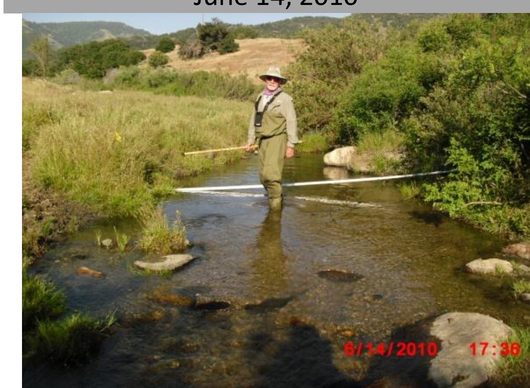
July 20, 2010

June 1, 2010

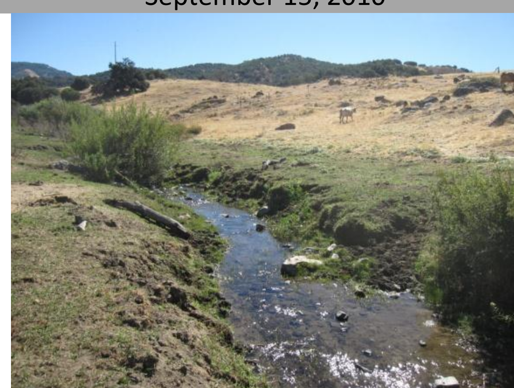
August 19, 2010



June 14, 2010



September 15, 2010



June 29, 2010

Grazing in creek 12/7/2007

Santa Ysabel Creek (SY) 2010

April 28, 2008

July 3, 2008

May 16, 2008

Adult stonefly 5/16/08

June 5, 2008

Dense macrophyte growth 6/5/08

June 25, 2008

Ortega Falls (OF) 2008

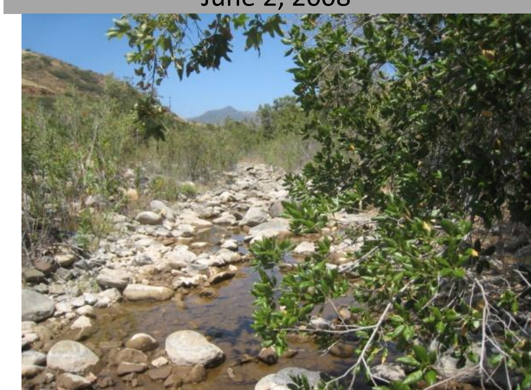
April 23, 2008

July 3, 2008

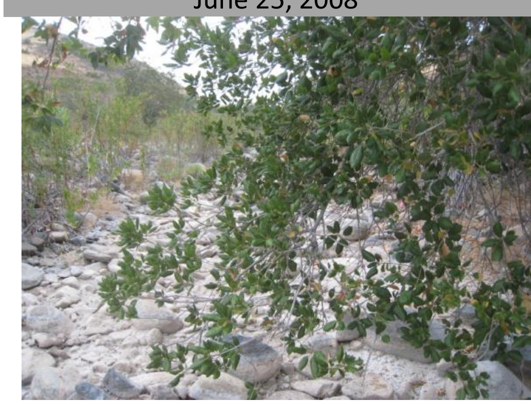
May 13, 2008

Heavy algae growth 6.2.08

June 2, 2008



June 25, 2008



San Juan Creek (SJ) 2008

April 5, 2010

May 5, 2010

May 25, 2010

Trabuco Creek (TC) 2010

Appendix 3. Trends in Environmental Variables

Figure A3-1. Water levels (left) and temperatures (right) at a subset of sites. Panel color indicates inferred flow status: blue indicates wet periods, and pink indicates dry (or fluctuating) periods. Data for SY, SR, AS, SJ, and OF were from 2008. Data for BC, SA, and NC were from 2009. Data for CD were from 2010. Because that loggers reflect water level at a point instead of a reach, they sometimes indicate water retained in a wet pool in a reach that has gone dry (e.g., the end of the record at SR), or reflect dry conditions prior to the last day of sampling (e.g., SJ).

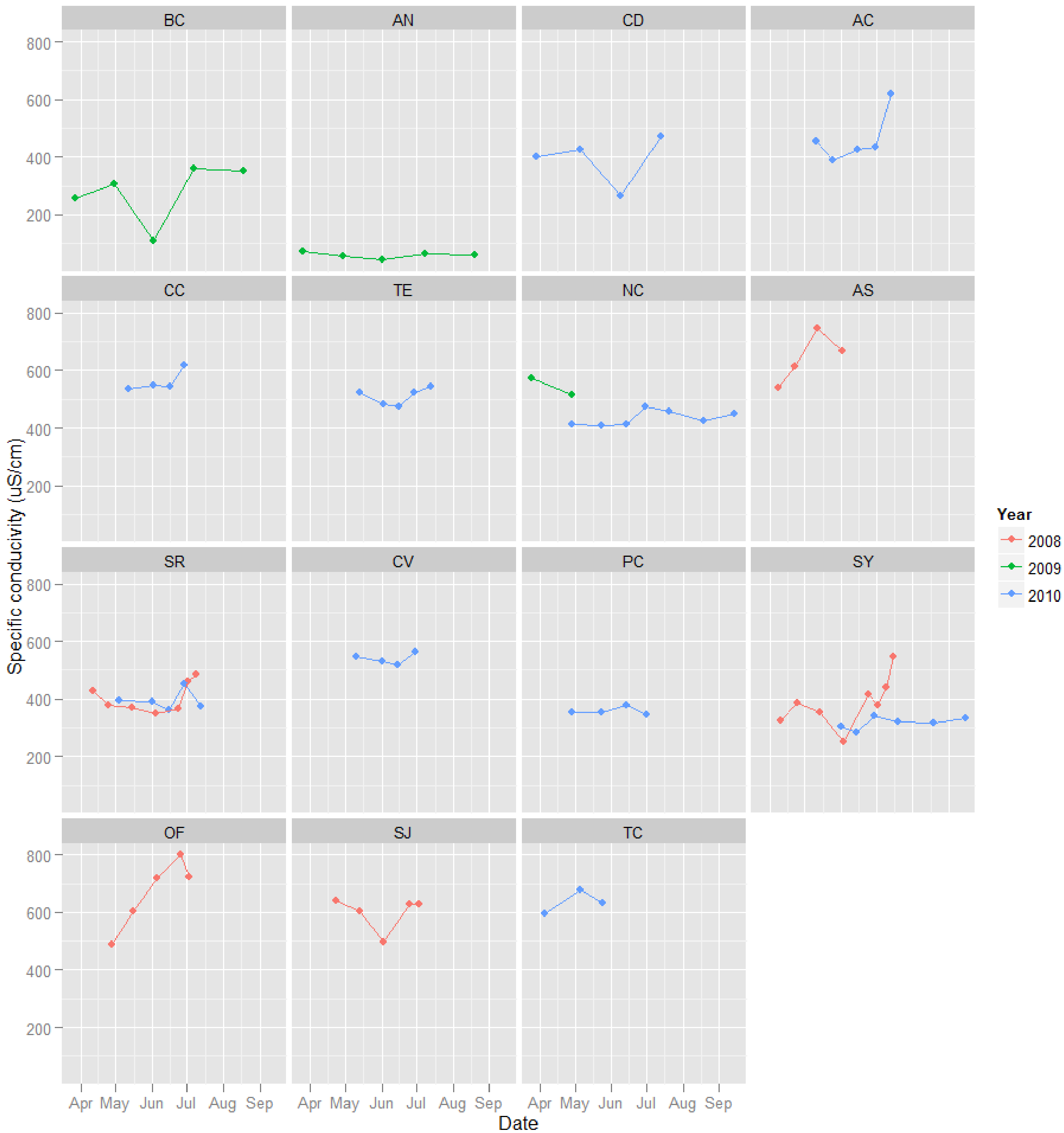


Figure A3-2. Trends in conductivity at each site and year. Line color reflects the year of sampling.

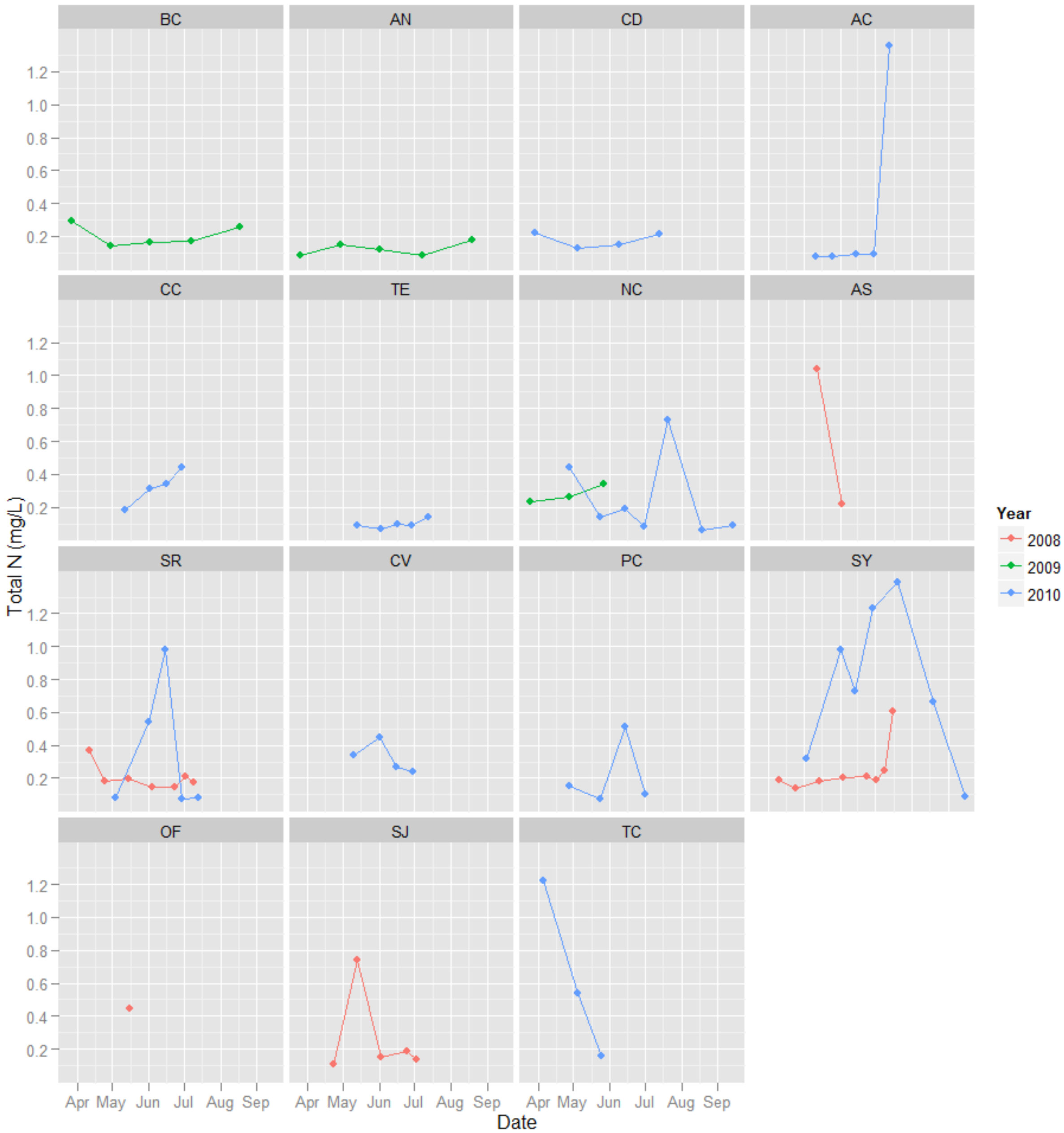


Figure A3-3. Trends in total N at each site and year. Line color reflects the year of sampling.

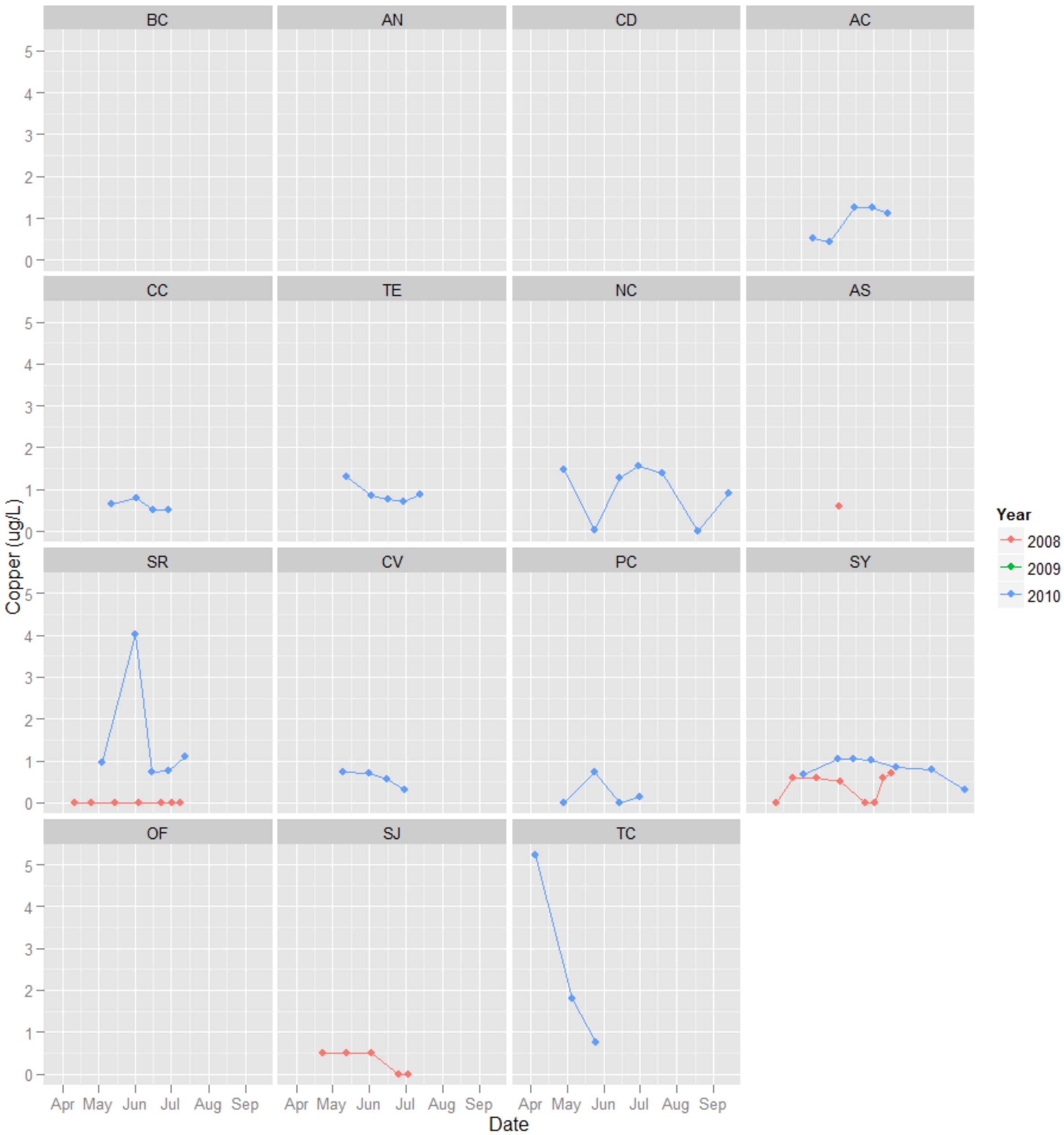


Figure A3-4: Trends in dissolved copper at each site and year. Line color reflects the year of sampling.

Figure A3-5. Trends in % sands and fines at each site and date. Line color reflects the year of sampling.

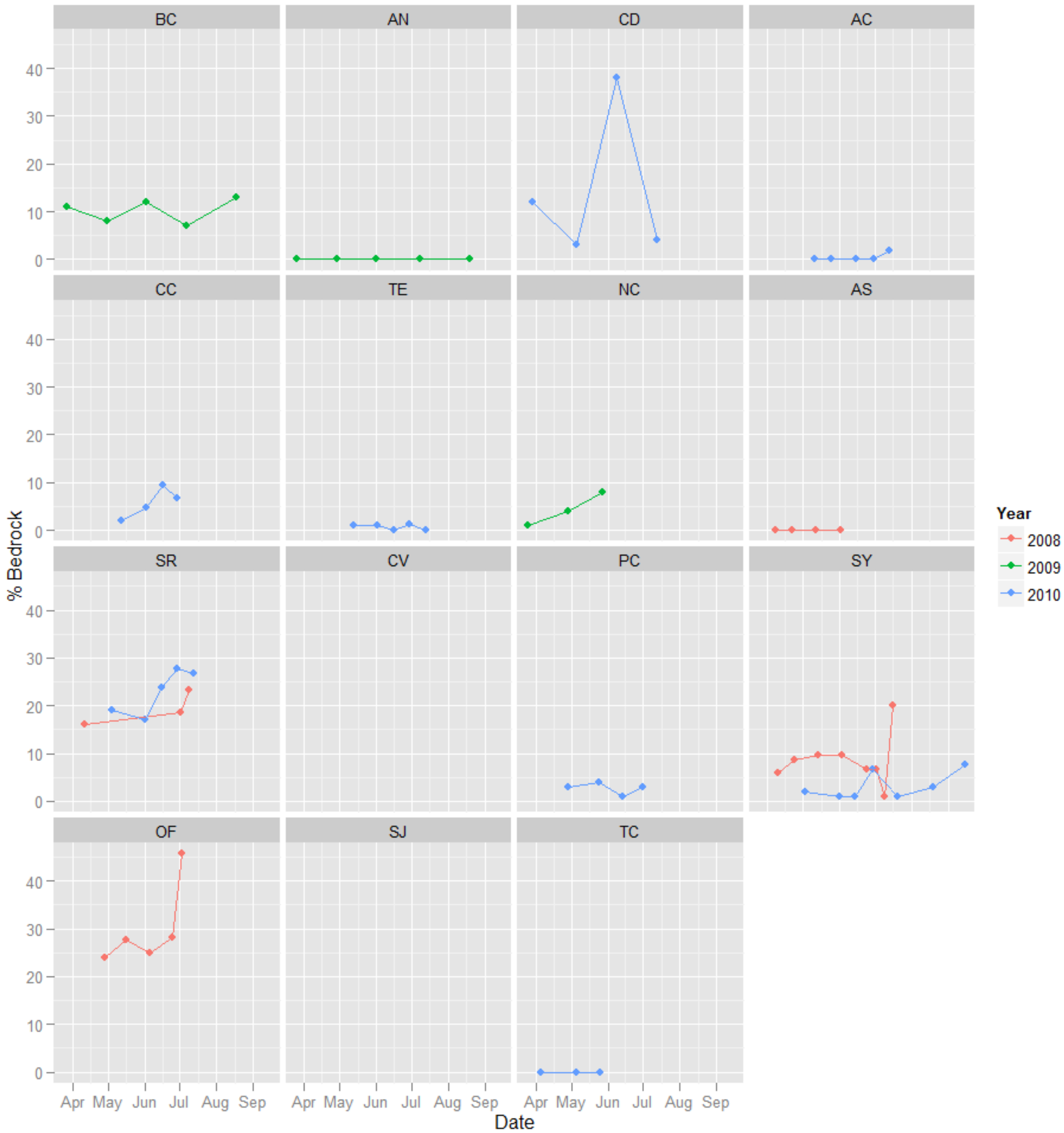


Figure A3-6. Trends in % bedrock for each site and date. Line color reflects the year of sampling.

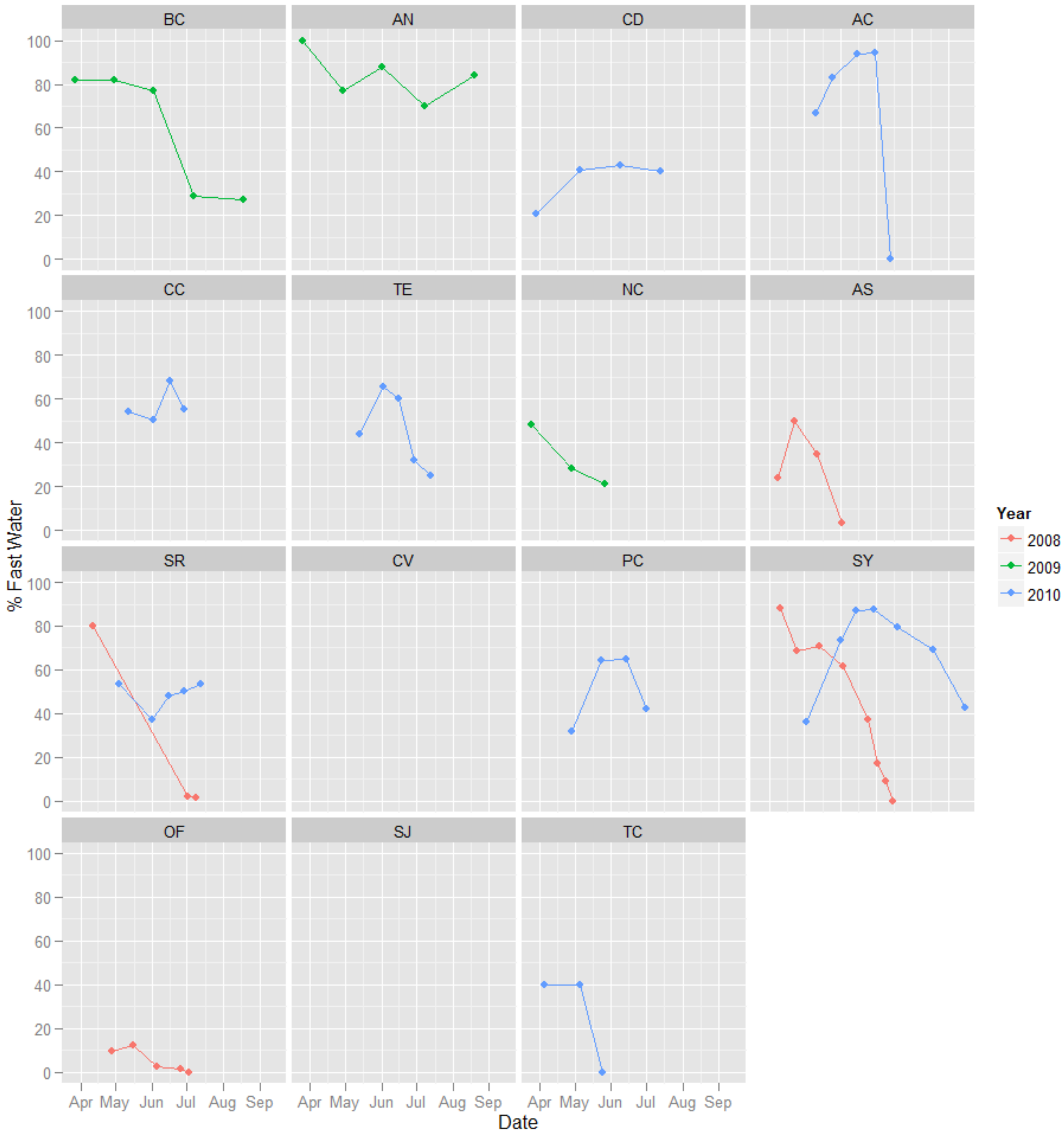


Figure A3-7. Trends in the amount of fast-water habitat at each site and date. Line color reflects the year of sampling.

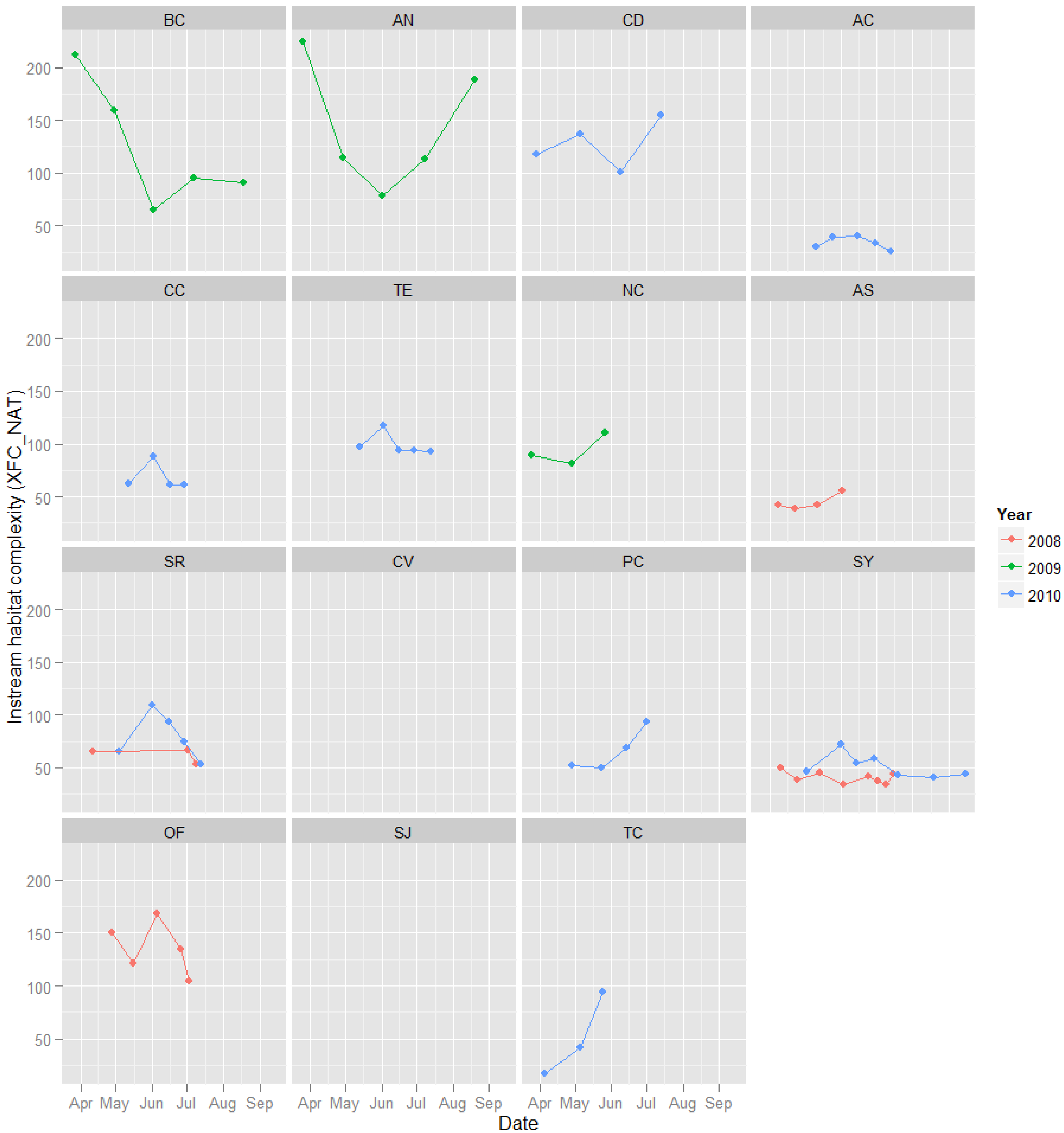


Figure A3-8. Trends in instream habitat complexity at each site and date. Line color reflects the year of sampling.

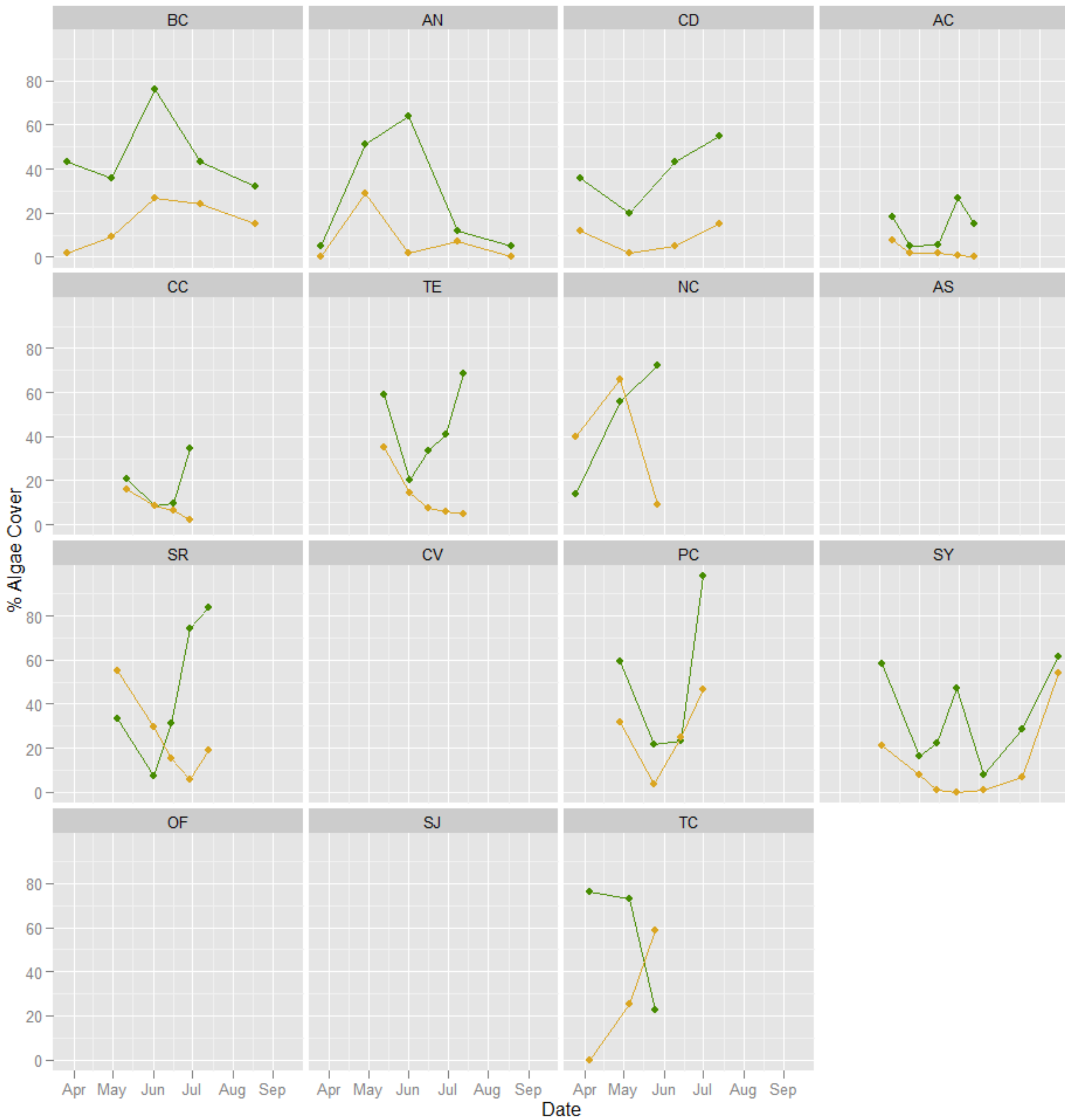


Figure A3-9. Trends in algae cover at each site and sampling event. In contrast to Green is macroalgae, gold is microalgae. Data for NC were collected in 2009, and data for SR and SY were collected in 2010.

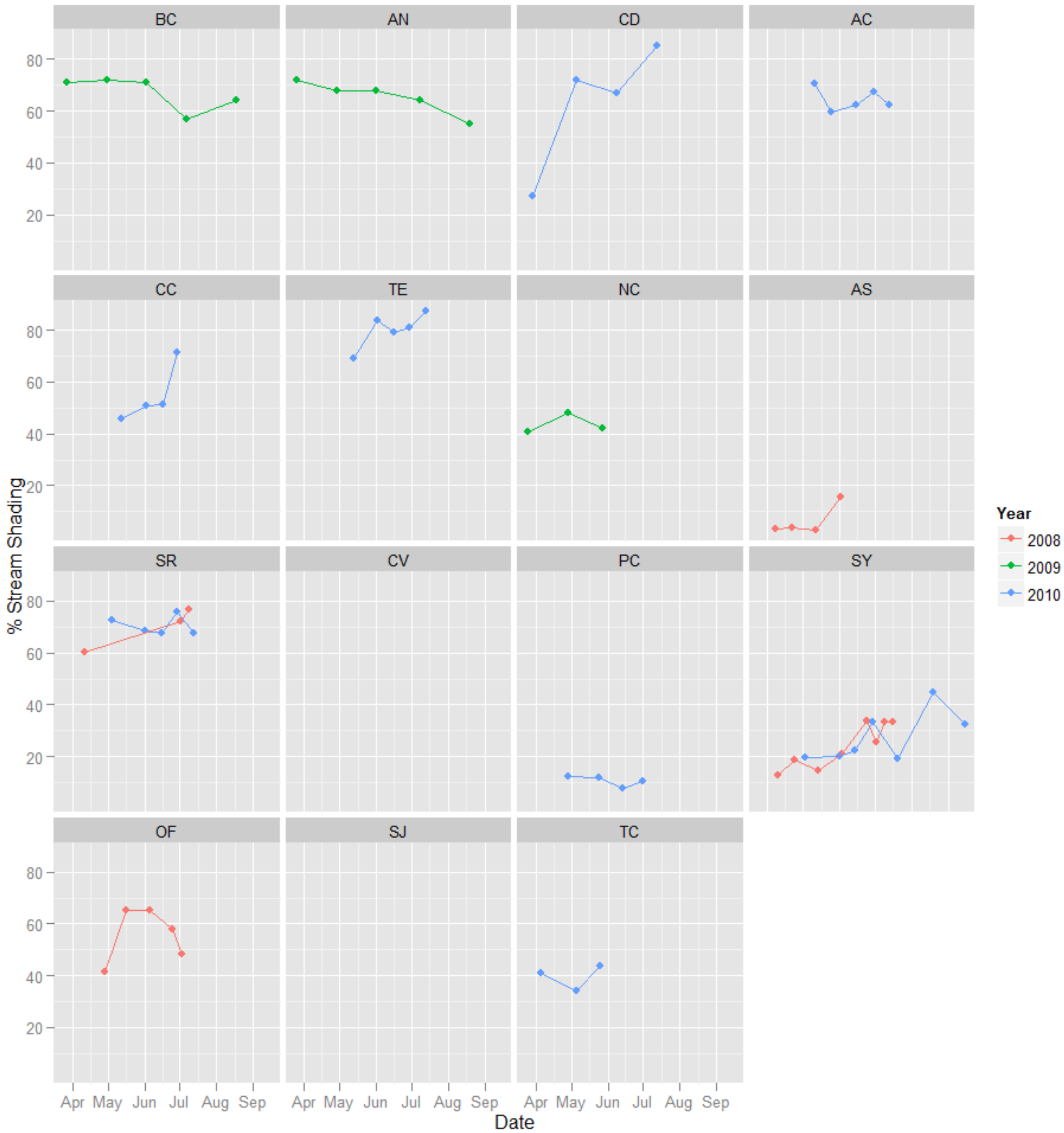


Figure A3-10. Trends in stream shading for each site and date. Line color reflects the year of sampling.

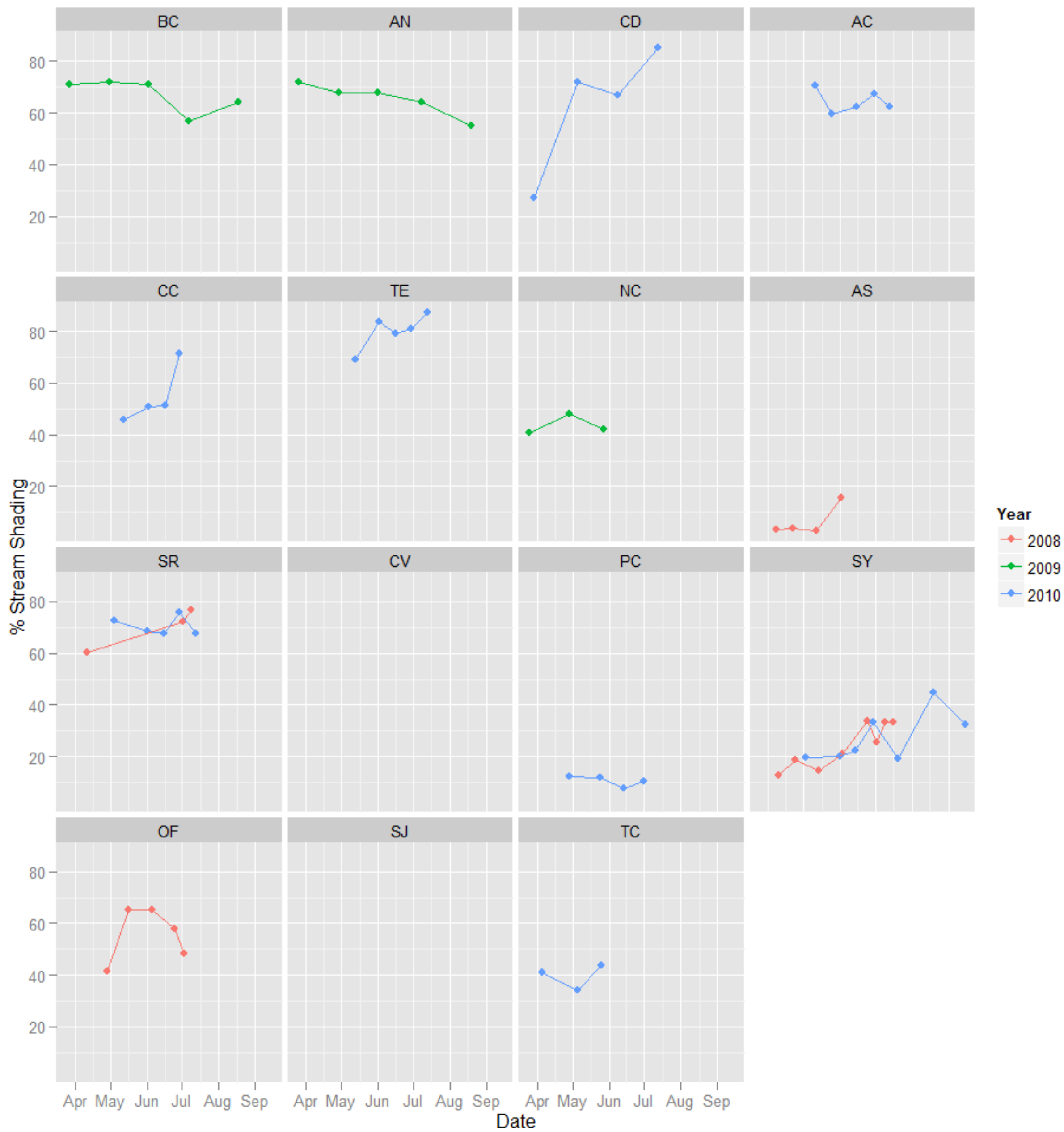


Figure A3-11. Trends in stream shading for each site and date. Line color reflects the year of sampling.

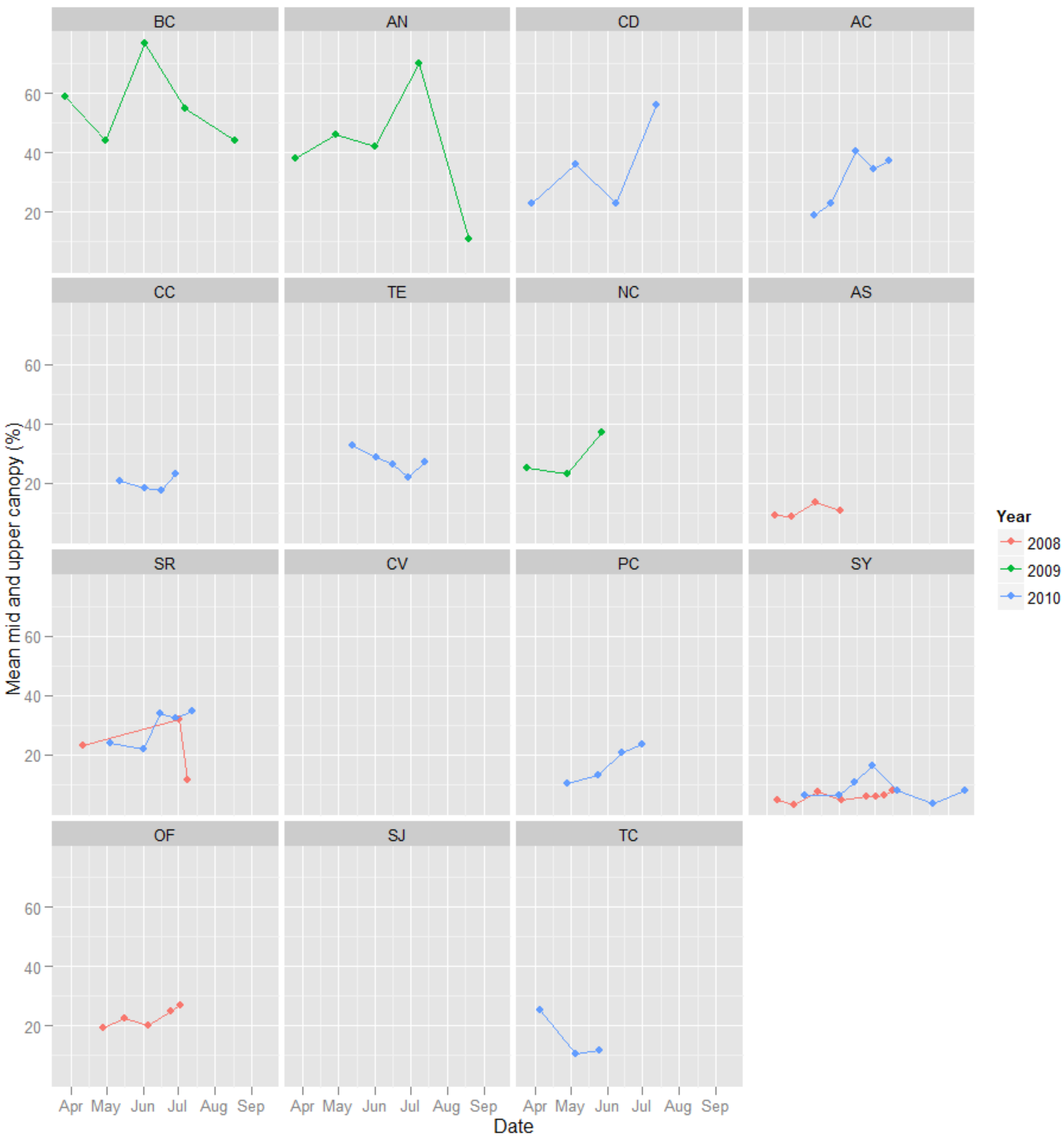


Figure A3-12. Trends in riparian vegetation for each site and date. Line color reflects the year of sampling.