An assessment of the biological condition of streams in the San Francisco Bay

Raphael D. Mazor

Jeffrey S. Brown

SOUTHERN CALIFORNIA COASTAL WATER RESEARCH PROJECT

Technical Report 1419

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Southern California Coastal Water Research Project, Costa Mesa, CA

June 2025

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ACKNOWLEDGMENTS

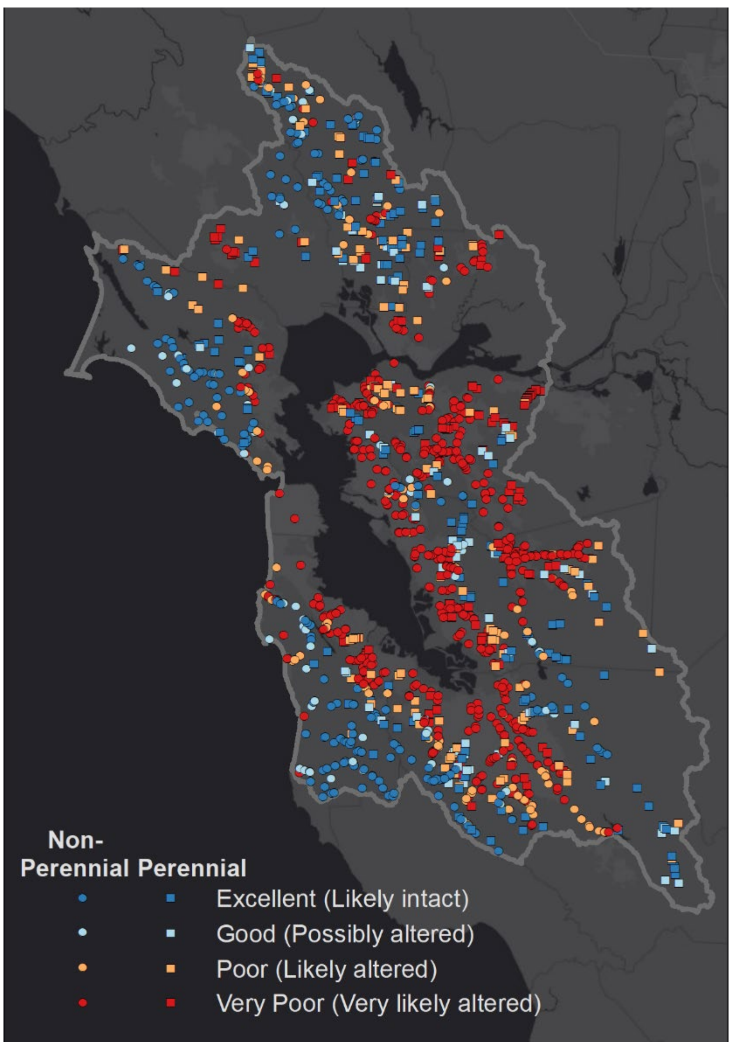
This report is a revised version of a manuscript that was completed with funding provided by the Regional Water Quality Control Board – San Francisco Region under State Water Resources Control Board Agreement 19-078-270. This report is also available at https://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/water_quality.html, along with associated material from the Water Board.

Executive Synthesis

How were stream conditions measured?

For over two decades, state and local agencies have conducted bioassessments at more than 1500 sites in the San Francisco Bay Area. This report represents an effort to bring these data together and produce a comprehensive assessment of wadeable streams in the region. A total of 2,418 bioassessment samples from large and small wadeable nontidal streams throughout the Bay Area.

Biological conditions were measured with the California Stream Condition Index (CSCI), which is based on the composition of benthic macroinvertebrates, and the Algal Stream Condition Index (ASCI) based on benthic diatoms or based on diatoms plus soft-bodied algal taxa. Physical habitat conditions were evaluated with the Index of Physical-habitat Integrity (IPI), as well as channel modification status. These indices were evaluated by comparing scores to reference-based thresholds; in the case of intermittent streams, CSCI scores were compared to provisional thresholds based on scores at intermittent reference streams in northern California. Eutrophication status was assessed with measures of organic matter accumulation (i.e., benthic chlorophyll-a and ash-free dry mass), as well as water quality parameters (i.e., total nitrogen, total phosphorus, pH, and dissolved oxygen). Other water quality parameters that were evaluated include major ions (i.e., sulfate, chloride, and specific conductivity) and—in a small number of samples—metals (i.e., selenium, copper, nickel, and zinc).



Overall condition of streams in the bay area

In sum, 36% of sampled streams within the Bay Area were in good or excellent ecological condition, as indicated by CSCI scores within the range of natural variation. High-scoring sites were primarily located in undeveloped areas, such as the East Bay Hills, the San Mateo coast, and western Marin. In contrast, streams that were likely or very likely altered were more common in urban areas, such as the lower elevations in the North, East, and South Bays.

Regional assessments can reflect the ecological conditions perennial and intermittent streams by using appropriate thresholds

This study represents a new approach to evaluating a region comprised of a blend of perennial streams (i.e., those with year-round flow) and intermittent streams (i.e., those that cease to flow during the dry season). Previous studies have shown that within northern California, reference streams (that is, streams with minimal disturbance due to human activity) receive lower bioassessment index scores where flows are intermittent, compared to reference streams where flows are perennial (summarized in Mazor et al. 2024). This difference suggests that assessment thresholds based on perennial streams may lead to incorrect conclusions about the condition of intermittent streams in the Bay Area as being worse than they are.

In this study, CSCI scores were assessed using different threshold values for perennial and intermittent streams. These thresholds were determined by examining the statistical variation in scores at minimally disturbed reference sites (as defined by Ode et al. 2016b) with perennial versus intermittent flows, and therefore they provide a scientifically defensible and unbiased way to assess streams with different flow regimes. Index scores can be interpreted the same way in both perennial and intermittent streams: a score above a reference-based threshold indicates that a stream is in good or excellent biological condition, whereas a score below a reference-based threshold indicates that a stream is in poor or very poor condition. The CSCI threshold applied to perennial stream was 0.79, whereas a threshold of 0.61 was applied to intermittent streams; in both cases, these values were calculated as the 10th percentile of scores at reference sites with perennial or intermittent flow regimes. The same 10th percentile reference threshold was used at both perennial and intermittent streams for ASCI-D (i.e., 0.86) and IPI (i.e., 0.84).

The approach used in this study demonstrates a way to include intermittent streams in monitoring and management programs that focus on biointegrity measures using the same indices used in perennial streams. However, the 0.61 threshold for intermittent should be considered provisional and likely to change as more data are collected from intermittent reference streams. Additional monitoring will allow an investigation of whether the 0.61 value is relevant for all of northern California's intermittent streams, or if these streams should be evaluated based on stream types (e.g., intermittent streams in different ecoregions), each having its own value. For illustrative purposes, this study employed a simple approach (i.e., one value for all northern California intermittent streams), but further data analysis may point towards a different approach.

Halleck Creek, an intermittent reference site in Marin County

Arroyo Hondo Creek, a perennial reference site in Santa Clara County

Overall, 47% of intermittent streams in the Bay Area were considered to be in good or excellent biological condition, and these streams were more often located in the upper watersheds, where both urban land use and perennial flows are less common.

Multiple indicators provide a more comprehensive picture of stream condition

Although this study focused primarily on stream condition as measured by the CSCI (a bioassessment index based on benthic macroinvertebrate community composition), an Algal Stream Condition Index (ASCI) was also used, based on diatoms (ASCI-D). Although both share many of the same advantages that characterize bioassessment indices (such as their ability to reflect the combined impact of all stressors affecting a waterbody), there are many advantages to using them in tandem. The CSCI is particularly responsive to habitat degradation, whereas the ASCI responds strongly to changes in water quality. Therefore, using them together provides greater confidence in understanding conditions of a stream.

In this study, the two indices were well correlated, with 75% of samples being in the same condition class (good or excellent vs. poor or very poor) for the CSCI compared to the ASCI. The ASCI was overall more sensitive than the CSCI; for example, the CSCI placed 36% of sites in good or excellent condition, whereas the ASCI-D only placed 22%.

	CSCI Good or excellent	CSCI Poor or very poor
ASCI-D Good or excellent	16%	6%
ASCI-D Poor or very poor	19%	59%

What are conditions like in modified channels?

Many streams in urban or agricultural portions of the Bay Area have been modified to improve flood protection or their ability to convey water. These long-term modifications, which include channel straightening, recontouring, or hardening of bed or banks, reduce the habitat quality for aquatic life, as reflected by lower bioassessment index scores. Within Santa Clara county, 36% of stream channels in this study were considered modified, and one-quarter of these had artificially hardened streambeds.

Most modified channels have low bioassessment index scores compared to unmodified channels. Accounting for streamflow, only 10% of modified channels were considered to be in good or excellent condition, compared to 50% of natural channels. Scores were similar for both hard- and soft-bottom modified channels. Only 9% of hard-bottom channels and 11% of soft-bottom channels were in good or excellent condition; the rest were poor or very poor.

San Leandro Creek, a hard-bottom channel in Alameda County

Arroyo Mocho, a soft-bottom modified and straightened channel in Alameda County.

What stressors contribute to poor conditions?

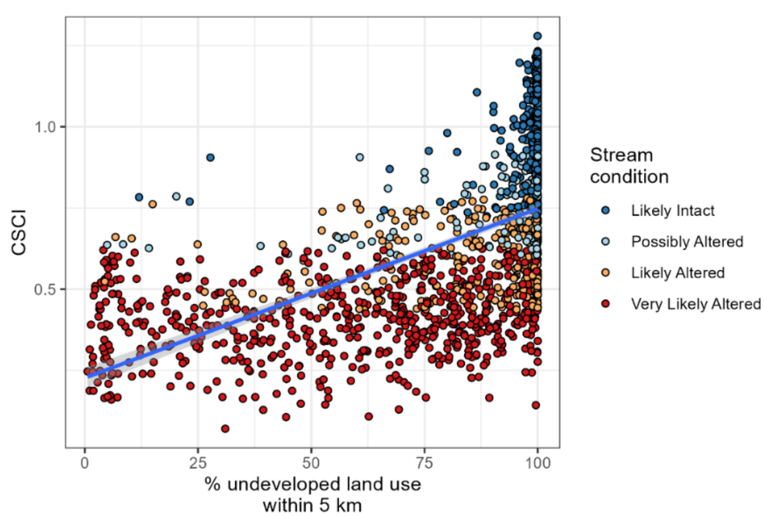
Channel modification and eutrophication are strongly associated with poor biological conditions. For example, low CSCI scores were nearly twice as common at sites where total nitrogen or chlorophyll-a exceeded natural levels, compared to sites where these eutrophication indicators were similar to natural levels. Risks from channel modification and poor habitat quality were similarly large. In general, algal index scores were more strongly associated with water quality than habitat quality. For example, elevated sulfate, specific conductivity, and nitrogen were a greater risk than channel modification.

Stressors with the greatest risk for impacts to bioassessment index scores

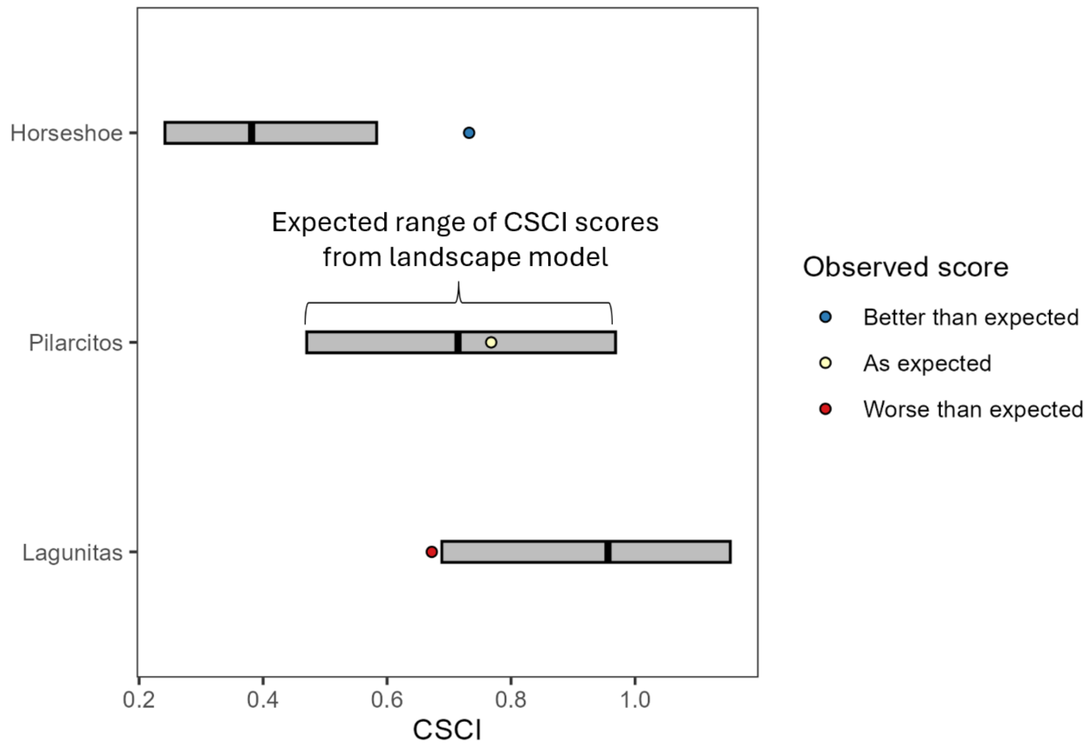
Top 5 risks for low CSCI scores	Top 5 risks for low ASCI scores
1. Benthic ash-free dry mass (organic matter) 2. Poor habitat quality (Index of physical-habitat integrity score) 3. Total nitrogen 4. Channel modification 5. Chloride	1. Sulfate 2. Benthic ash-free dry mass (organic matter) 3. Total nitrogen 4. Specific conductivity 5. Poor habitat quality (Index of physical-habitat integrity score)

Landscape is strongly associated with stream condition

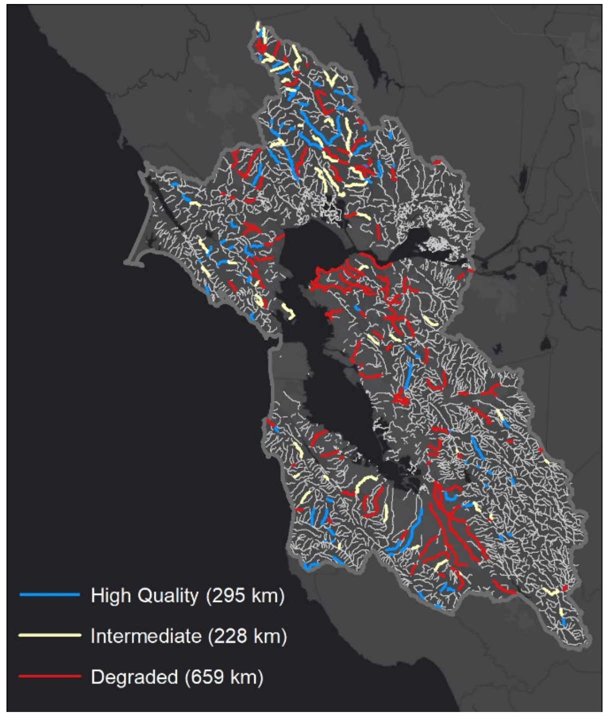
Landscape alteration was one of the best predictors of biological condition. Both local- and watershed-scale measures of non-natural land use were strongly correlated with declines in bioassessment index scores.



Models that predict bioassessment index scores, such as the Stream Classification and Prioritization Explorer (SCAPE) tool, can identify sites that score much better or worse than would be expected, given the landscape setting. In the example below, three sites with very similar CSCI scores could be prioritized for different actions by comparing the observed score to the range of likely scores predicted by the SCAPE model. For example, Lagunitas Creek might be prioritized over Pilarcitos Creek for restoration because it scored much worse than sites that drain similarly undeveloped watersheds. In contrast, Horseshoe Creek might be prioritized for protection because it scored much better than other sites with similarly urbanized watersheds.

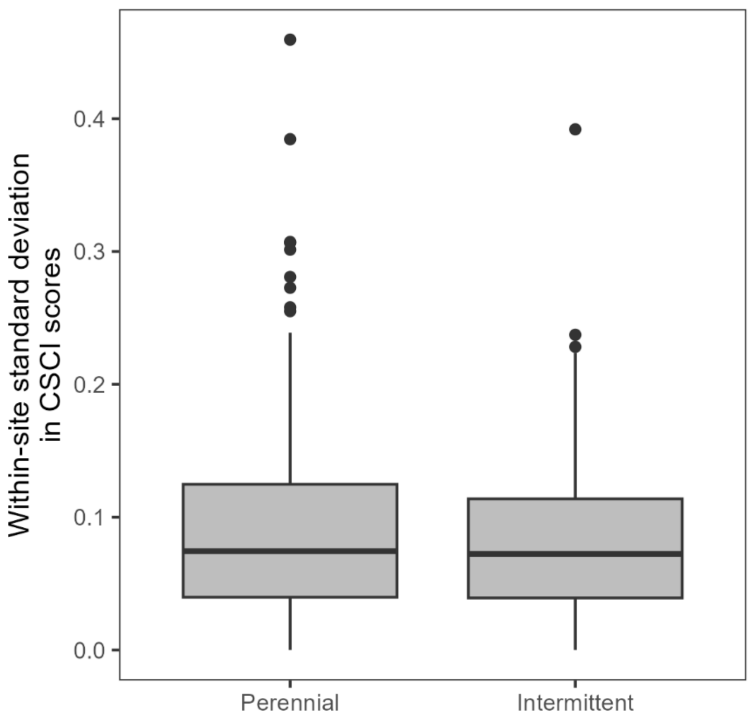


The importance of sampling multiple locations



Although assessment reaches are typically less than 200 m long, management decisions are typically made on much larger stream segments. Typically, only one location within a reach is sampled (if any). However, thanks to extensive and ongoing bioassessment activities in the Bay Area, several longer stream segments have been sampled in multiple locations, allowing managers to identify high quality streams where conditions are consistently good or excellent, or degraded streams where conditions are consistently poor or very poor. In the Bay Area, nearly 300 km of streams could be identified as having consistently good stream conditions, compared to over 650 km where conditions were consistently degraded. Although most high-quality streams are located in undeveloped areas, some extend into urban areas, such as Saratoga Creek in Santa Clara county. Some management decisions (e.g., listing of impaired waterbodies in the Integrated Report) are based on stream segments that are substantially larger than the typical bioassessment reach (which is 150 m), and thus conditions may vary within a segment.

Variability of sites across time



The high frequency of sampling in the Bay Area also provides insight into how bioassessment scores vary over time. At sites with repeated sampling events, most CSCI scores varied less than 0.1 across, with a small handful of sites showing higher levels of variation. There were no differences between perennial and intermittent sites.

This study is not intended to endorse the use of specific thresholds or waterbody classifications in policy or regulatory programs. Rather, the intention is to illuminate how streamflow duration and channel modification can influence decisions regarding the boundaries between reference and non-reference conditions.

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INTRODUCTION

Streams and wetlands are essential elements of the Bay Area's natural heritage. They also work in many ways to protect and enhance water quality throughout the region. Streams and wetlands, and the water that flows through them, shape the landscape as they support the ecological processes all human, plant, and animal watershed residents depend on. Aquatic and terrestrial habitats associated with streams and wetlands provide critical habitat for diverse plant and animal communities. Vegetated riparian and wetland corridors protect and enhance water quality. Healthy stream and wetland systems store flood waters, provide flood control during large storm events, and recharge groundwater. The federal Clean Water Act requires that the biological communities in water be protected.

The San Francisco Bay Area Regional Water Quality Control Board has collected bioassessment data from the region over several decades. Bioassessment index scores have been calculated using appropriate data (the California Stream Condition Index [CSCI], the Algal Stream Condition Index [ASCI], and the Index of Physical-habitat Integrity [IPI]. This report analyzes these data to answer key questions about the condition of wadeable streams in the Bay Area, such as:

- Question 1: What proportion of stream sites have scores indicating good and poor conditions across the region?
- Question 2: How do scores from different indices correspond to each other?
- Question 3: What stressors are associated with variability in index scores and are potential causes of poor biological conditions?

To answer the first question, we estimated the extent of streams with high biointegrity index scores, applying different assessment thresholds that depended on whether the stream was perennial or intermittent. We compared conditions in different geographic regions of the Bay Area, as well as in different channel types (e.g., natural vs. modified channels with hardened streambeds vs. modified channels with soft streambed). To answer the second question, we estimated the concordance among condition classes estimated by each index, as well as the strength of correlations among index scores. To address the third question, we calculated the relative risk of poor bioassessment index scores when thresholds for common stressors were exceeded.

METHODS

Samples

Samples were collected from 1,432 wadeable stream sites within the jurisdiction of the San Francisco Bay Regional Water Quality Control Board (Water Board Region 2) between 4/30/1998 and 6/17/2021, under a number of bioassessment programs lead by the State and Regional Waterboards (such as the Regional Board's Surface Water Ambient Monitoring Program, the Perennial Streams Assessment, and the Reference Condition Monitoring Program), as well as the Regional Monitoring Program led by the Bay Area Stormwater Agencies Association and a number of county-based stormwater monitoring programs (Table 1). Under these programs, benthic macroinvertebrates, diatom and soft-bodied algae, and chemistry samples were collected according to the methods of Ode et al. (2016a) or similar methods (Peck et al. 2006). Although benthic macroinvertebrates were collected at all sampling events, other indicators were only available at a subset of samples.

Table 1. Source of bioassessment data. Modified Parent Project designations from CEDEN (California Environmental Data Exchange Network) that are associated with the bioassessment monitoring data in this report.

Parent Project	Number of Sampling Events
BASMAA RMC	546
SWAMP San Francisco Bay Regional Water Board Monitoring	399
Pre-2012 county stormwater program, Contra Costa	328
Pre-2012 county stormwater program, Napa	192
Pre-2012 county stormwater program, Santa Clara	132
Pre-2012 county stormwater program, Alameda	120
Pre-2012 county stormwater program, Marin	116
Alameda Creek Aquatic Resource Monitoring	60
San Mateo Creek Aquatic Resource Monitoring	56
Pre-2012 county stormwater program, Sonoma	40
SWAMP Perennial Stream Surveys	40
Pre-2012 county stormwater program, San Mateo	38
DFW_ABL_Monitoring	31
RWB2 Zone 7 Bioassessment Monitoring	27
SWAMP California Monitoring and Assessment Program	27
SWAMP Reference Condition Management Plan	27
ICARE BMI Surveys	26
Other	236

Indicators

Benthic macroinvertebrate samples were scored with the California Stream Condition Index (CSCI; Mazor et al. 2016), and benthic algal samples were scored with the Algal Stream Condition Index for Diatoms (ASCI-D; Theroux et al. 2020). Habitat data were scored with the Index of Physical-habitat Integrity (IPI; Rehn et al. 2018). All indices assess condition relative to reference conditions.

The CSCI, ASCI-D, and IPI are ratios, with scores close to 1 indicating natural conditions that are similar to reference. Lower scores are indicative of a greater deviation from expectations at minimally impacted reference sites. Scores > 1 are interpreted to indicate greater physical complexity than predicted for a site given its natural environmental setting. For sites with multiple same-day field replicates, the maximum index score was used; taking the maximum value is common practice because the higher score better represents the biodiversity that a reach can support (Beck and Mazor 2020). For replicates taken across multiple sampling dates, a mean score was used under the assumption that the average represents the long-term conditions in a channel. Note that the IPI may be updated because of concerns about inadequate sensitivity of the current version of the index.

Stressors

Water quality stressors

Chemistry measurements used in this study included total nitrogen (TN), total phosphorus (TP), specific conductivity, stream algae ash free dry mass (AFDM), temperature, dissolved oxygen, and benthic chlorophyll a. Total nitrogen was measured directly as TN or was calculated as the sum of nitrate, nitrite and total Kjeldahl nitrogen. Total phosphorus was directly measured. For data analysis, non-detects for each analyte were treated as equal to half the reporting level (Table 2). The average chemistry value was calculated for each site across replicates and revisits. Nutrient measurements were excluded from data analysis if the samples were collected outside the typical bioassessment sampling timeframe (April-July), if they were analyzed using Hach field test kits, or if they were collected during a specific week that had a high frequency of failed laboratory quality criteria (6/12/2017-6/21/2017).

Table 2. Methods and reporting levels used for chemistry measurements. Ranges of reporting levels and method detection limits were evaluated only for samples indicated as "nondetect" or "detected not quantified".

Analyte	Method	Range in Reporting Levels	Range in Method Detection Limits
TN	EPA 300.0, EPA 300.1, EPA 351.1, EPA 351.2, EPA 351.3, EPA 353.2, EPA 353.3, QC 10107041B, QC 10107044B, QC 10107062E, SM 4500-N C v22, SM 4500-N CM v21, SM 4500-N org C, SM 4500-NH3 C v20, SM 4500-NO2 B, SM 4500-NO2 B v20, SM 4500-NO3 D v20, SM 4500-NO3 E, SM 4500-NO3 F, SM 4500-NO3 I v21, WRS 34A.2, WRS 40A.2	0.005 – 0.7 mg/L	0.001 – 0.4 mg/L
TP	EPA 365.1M, EPA 365.3, QC 10115011D, QC 10115012B, SM 4500-P BE, SM 4500-P E, SM 4500-P H, WRS 34A.2	0.01 – 0.2 mg/L	0.004 – 0.05 mg/L
AFDM	CALTEST B-AFDW, EcoAnalysts SOP Algae Biomass, EPA 160.4, WRS 73A.1, WRS 73A.3	0.198 – 78.1 g/m^2	0.198 – 78.1 g/m^2
Specific conductivity	Field measurement, with no method indicated	Not indicated	Not indicated
Temperature	Field measurement, with no method indicated	Not indicated	Not indicated
Dissolved oxygen	Field measurement, with no method indicated	Not indicated	Not indicated
Chlorophyll a	EPA 446.0, SM 10200 H, SM 10200 H-2ab, SM 10200 H-2b, WRS 71A.1	1.08 – 3242 mg/m^2	1.08 – 1275 mg/m^2

Geospatial stressors

Geospatial characteristics of the watershed were calculated for every site. These metrics were calculated for the entire watershed, as well as 5-km and 1-km clips of the upstream catchment. Metrics included agricultural, urban, and developed open space (e.g., lawns, parks, roadsides, and cemeteries, "code 21") land cover in the National Landcover Dataset (Jon Dewitz 2024), as well as road density.

Data analysis

Question 1: Ecological conditions of streams in the Bay Area

Indicator thresholds

All index scores were classified into condition classes based on ranges derived from statewide reference distributions (Table 3). Condition was further divided into an “intact” rating (combination of “likely intact” and “possibly altered” categories, i.e., ≥10th percentile reference threshold) and a “degraded” rating (combination of “likely altered” and “very likely altered” categories, i.e., < 10th percentile reference threshold), as described in Mazor et al. (2016) and Theroux et al. (2020).

Because flow duration can potentially affect biointegrity index scores (Mazor et al. 2024), different thresholds were used for perennial and naturally intermittent streams. For the CSCI and ASCI, thresholds for perennial streams came from the original publications that describe these indices (CSCI: Mazor et al. 2016, ASCI Theroux et al. 2020). Provisional CSCI thresholds for intermittent streams came from a study by Mazor and others (2024), reproduced in Table 4. In that study, thresholds for intermittent streams were calculated as percentiles of scores at intermittent reference sites, following the same methods used for perennial streams (Mazor et al. 2016). Although these intermittent thresholds have different numeric values from perennial thresholds, they have similar interpretation because they were derived the same way. Thus a perennial reach with a CSCI score of 0.95 and an intermittent reach with a score of 0.85 are both considered “likely intact” because their scores are within the natural range of variability of undisturbed perennial and intermittent sites, respectively.

This study used a provisional CSCI threshold for intermittent streams (i.e., 0.61) that was calculated from a set of 38 intermittent reference sites, 27 of which were located within the San Francisco Bay Area. The rest were located in the Sierra Nevada foothills, the Central Coast, and the interior portions of the North Coast (Table 4). A threshold of 0.74 would have been used if the threshold were calculated from sites within Region 2 alone. A handful of intermittent reference sites outside Region 2 had substantially lower CSCI scores than those within the region, leading to this observed difference in estimates of the 10th percentile (i.e., 0.74 vs 0.61; Mazor et al. 2024). Additional research is needed to develop a data-driven approach for determining which intermittent streams in northern California should use an adjusted value, and how much of an adjustment is needed.

Thresholds for the IPI and ASCI-D did not vary based on flow duration. IPI thresholds came from Rehn et al. (2018) and ASCI-D thresholds came from Theroux et al. (2020).

Table 3. Ranges of index scores for each condition class. Thresholds for perennial streams came from Mazor et al. (2016) for the CSCI and from Theroux et al. (2020) for the ASCIs. Provisional thresholds for intermittent streams in northern California came from Mazor et al. (2024)

Index	Excellent (Likely intact; ≥30th percentile of reference)	Good (Possibly altered; 30th to 10th percentile)	Poor (Likely altered; 10th to 1st percentile)	Very poor (Very likely altered; <1st percentile)
CSCI (Perennial)	≥0.92	0.79 to 0.92	0.63 to 0.79	<0.63
CSCI (Intermittent, provisional)	≥0.73	0.61 to 0.73	0.44 to 0.61	<0.44
ASCI-D	≥0.94	0.86 to 0.94	0.75 to 0.86	<0.75
IPI	≥0.94	0.84 to 0.94	0.71 to 0.84	<0.71

Table 4. Summary statistics of index scores at regularly flowing (RFI) and seldomly flowing (SFI) intermittent reference streams. N: Number of unique sites. SD: Standard deviation of index scores. Q30, q10, and q01: 30th, 10th, and 1st percentiles of scores at reference sites (empirical estimates and estimates assuming normal distributions are both provided). Results for regions in Northern California should be considered provisional while analyses are undergoing updates. (Reproduced from Mazor et al. 2024).

Region	Flow status	Index	n	Mean	SD	q30 (normal)	q10 (normal)	q01 (normal)
Regional Board 2	RFI	ASCI_D	6	0.96	0.07	0.92	0.87	0.80
Regional Board 2	RFI	ASCI_H	6	0.95	0.04	0.93	0.90	0.85
Regional Board 2	RFI	CSCI	27	0.89	0.11	0.83	0.74	0.62
Regional Board 5	RFI	ASCI_D	9	1.11	0.10	1.06	0.98	0.87
Regional Board 5	RFI	ASCI_H	9	1.04	0.09	1.00	0.93	0.84
Regional Board 5	RFI	CSCI	10	0.63	0.13	0.56	0.47	0.33
Regional Board 7	RFI	ASCI_D	10	1.04	0.07	1.00	0.95	0.88
Regional Board 7	RFI	ASCI_H	10	1.02	0.06	0.98	0.94	0.87
Regional Board 7	RFI	CSCI	10	0.88	0.09	0.83	0.77	0.67
Regional Board 9	RFI	ASCI_D	35	0.97	0.15	0.89	0.77	0.61
Regional Board 9	RFI	ASCI_H	35	0.98	0.16	0.90	0.77	0.61
Regional Board 9	RFI	CSCI	43	0.96	0.10	0.91	0.83	0.73

Region	Flow status	Index	n	Mean	SD	q30 (normal)	q10 (normal)	q01 (normal)
Regional Board 9	SFI	ASCI_D	7	1.02	0.14	0.95	0.85	0.71
Regional Board 9	SFI	ASCI_H	7	1.00	0.10	0.94	0.86	0.76
Regional Board 9	SFI	CSCI	7	0.86	0.07	0.82	0.76	0.69
Northern regions (1, 2, 3, 5)	RFI	ASCI_D	16	1.05	0.12	0.98	0.90	0.78
Northern regions (1, 2, 3, 5)	RFI	ASCI_H	16	1.00	0.08	0.96	0.90	0.81
Northern regions (1, 2, 3, 5)	RFI	CSCI	38	0.82	0.16	0.73	0.61	0.44
Southern regions (7, 9)	RFI	ASCI_D	45	0.99	0.14	0.91	0.80	0.66
Southern regions (7, 9)	RFI	ASCI_H	45	0.99	0.15	0.91	0.80	0.65
Southern regions (7, 9)	RFI	CSCI	53	0.94	0.10	0.89	0.82	0.71
Southern regions (7, 9)	SFI	ASCI_D	8	1.03	0.13	0.96	0.87	0.73
Southern regions (7, 9)	SFI	ASCI_H	8	1.01	0.10	0.95	0.88	0.78

Region	Flow status	Index	n	Mean	SD	q30 (normal)	q10 (normal)	q01 (normal)
Southern regions (7, 9)	SFI	CSCI	8	0.85	0.07	0.81	0.76	0.69
All regions (1, 2, 3, 5, 7, and 9)	RFI	ASCI_D	61	1.00	0.14	0.93	0.83	0.68
All regions (1, 2, 3, 5, 7, and 9)	RFI	ASCI_H	61	0.99	0.13	0.92	0.82	0.69
All regions (1, 2, 3, 5, 7, and 9)	RFI	CSCI	91	0.89	0.14	0.82	0.71	0.56
All regions (1, 2, 3, 5, 7, and 9)	SFI	ASCI_D	8	1.03	0.13	0.96	0.87	0.73
All regions (1, 2, 3, 5, 7, and 9)	SFI	ASCI_H	8	1.01	0.10	0.95	0.88	0.78
All regions (1, 2, 3, 5, 7, and 9)	SFI	CSCI	8	0.85	0.07	0.81	0.76	0.69

Assessment subpopulations

Index scores were used to assess the overall condition of subpopulations of the Bay Area defined in various ways: county, reference status, flow duration class, and channel modification status (county-level analyses are presented in the Appendix). For each subpopulation, we visually examined raw index scores using boxplots and maps, and condition classes were examined with stacked bar plots. To investigate the contribution and potential interactions between reference status and flow regime, two-way analysis of variance (ANOVA) tests were conducted. Because there were unequal numbers of sites in each of the four classes, an ANOVA unequal sample size type III test was used.

County, reference status, and flow duration classes were provided by staff from the Regional Board. Reference status was evaluated following the process described by Ode et al. (2016b); this approach defines reference streams as streams with minimally altered watersheds (evaluated through a geographic information system), and no evidence of human disturbance near the assessment reach (noted by field crews or in aerial imagery).

Flow duration status followed definitions used by the US Environmental Protection Agency (Fritz et al. 2020). Perennial streams flow year-round in most years, but may cease to flow during droughts. Intermittent stream typically flow for several months, and the flow is sustained by groundwater discharge or snowmelt for at least part of the year; intermittent streams may flow year-round during wet years, or not flow at all during droughts. In the Bay Area and other parts of California with a Mediterranean climate, intermittent streams typically flow seasonally during the Winter and Spring, and dry during the summer (Gasith and Resh 1999). Ephemeral streams flow only in immediate response to rain events, typically for no more than a few weeks; due to their short duration of stream flow, ephemeral streams are not sampled by most bioassessment programs, and none of the sites in this study were classified as ephemeral.

Channel modification was determined through direct observation of channel bed and bank materials (referred to in this document as the Direct Observation approach) and classified channels as natural (that is, unmodified), modified hard-bottom, or modified soft-bottom. Channel modification information was only available for sites in Santa Clara County. Hardening features include rip-rap, concrete, or other erosion-resistant materials, and needed to affect at least 25% of the reach-length to affect classification.

Table 5. Sample distribution among subpopulations for CSCI. Flow duration and reference status were not available for every site. Channel modification status was only available for a subset of sites in Santa Clara county.

Classification	Subpopulation	Number of sites	Number of samples
Entire region	Bay Area	1432	2276
County	Alameda	320	475
County	Contra Costa	245	504
County	Marin	124	248
County	Napa	188	246
County	San Francisco	2	2
County	San Mateo	177	289
County	Santa Clara	310	409
County	Santa Cruz	2	3
County	Solano	36	37
County	Sonoma	28	63
Flow duration	Perennial	925	1520
Flow duration	Intermittent	507	756
Reference status	Reference	92	162
Reference status	Non-reference	1340	2114
Channel modification	Natural	150	220
Channel modification	Soft	67	87
Channel modification	Hard	22	27

Evaluation of landscape constraints

In addition to comparing CSCI scores to the assessment thresholds, we compared them to ranges expected for watersheds with comparable levels of watershed alteration. Thus, sites with poor CSCI scores could be further categorized based on their relative performance. Ranges of expected scores were derived from the Stream Classification and Priority Explorer tool (SCAPE, Beck et al. 2019). The SCAPE tool is based on a quantile random forest model that predicts scores for a site given watershed characteristics, such as urban or agricultural land cover or road density. The model can predict the typical score (i.e., the 50th percentile), likely lower limits (e.g., the 10th percentile), and likely upper ranges (e.g., the 90th percentile). By comparing these ranges to a threshold (e.g., the 10th percentile of reference scores), stream segments where biological conditions could be constrained by watershed development can be identified (Table 6).

Table 6. Categories of stream segments defined by the SCAPE tool. qN: Nth percentile (e.g., q50 is the 50th percentile of predictions by the SCAPE tool).

SCAPE category	Definition
Very likely unconstrained	q10 ≥ 0.79
Likely unconstrained	q10 < 0.79 but q25 ≥ 0.79
Possibly unconstrained	q25 < 0.79 but q50 ≥ 0.79
Possibly constrained	q50 < 0.79 but q75 ≥ 0.79
Likely constrained	q75 < 0.79 but q90 ≥ 0.79
Very likely constrained	q90 < 0.79

In addition, we compared observed CSCI scores from sites to ranges predicted for the stream segments on which they were located. Scores were classified as follows:

- "Substantially better than expected" when CSCI scores were >q90;
- "Better than expected" when CSCI scores were between q75 and q90;
- "As expected" when CSCI scores were between q25 and q75;
- "Worse than expected" when CSCI scores were between q10 and q25;
- "Substantially worse than expected" when CSCI scores were <q10.

We summarized the distribution of scores for major assessment subpopulations.

Aggregating sites to stream segments

Because many management decisions are made at larger spatial scales than an individual 150-m bioassessment sampling reach, we aggregated scores across multiple sites within stream segments of the National Hydrography Dataset Plus (McKay et al. 2014). Thus, managers could identify which stream segments are overall in good condition and which are degraded based on multiple sampling locations. In this approach, stream segments were classified as "High Quality" when all sites within the segment had CSCI scores indicating good or excellent conditions, "Degraded" when >50% of sites had CSCI scores indicating poor or very poor conditions, or "Intermediate" when the segment did not meet the other two criteria. Segments with a single sampling location were included in the analysis; these segments could only be classified as "high quality" or "degraded", but not "intermediate."

Within-site variability of CSCI scores

In order to evaluate the variability of CSCI scores at sites where repeat visits had occurred, we calculated coefficients of variation within sites and averaged them within groups defined by flow duration and reference status. We used boxplots to visualize this variation.

Question 2: How do indices correspond to each other?

We evaluated concordance among condition indices in two ways. First, we examined raw scores by creating scatter plots and calculating Spearman's rho calculation coefficients. Second, we examined the categorical condition classes by creating contingency tables.

Question 3: What stressors are associated with variability in index scores?

Stressor associations with biological conditions were evaluated in two ways. First, we examined Spearman rho correlations between stressor values and bioassessment index scores. In addition, we calculated correlation coefficients within classes of streams defined by level of urbanization in the upstream watershed within 1 km (specifically, 0 to 5%, 5 to 10%, and greater than 10% urban landcover).

Second, we calculated the relative risk for each stressor (Van Sickle et al. 2006). Relative risk is the frequency of poor index scores at stressed sites (e.g., sites with contaminant levels above a threshold) compared to the frequency at sites where the stressor is absent. Analyses were completed using the *epitools* package in R.

Relative risk analysis requires thresholds to classify sites as stressed or unstressed. Some stressor thresholds were derived from appropriate literature, while others were identified by calculating the 90th percentile of values observed at sites in the Bay Area that met California's criteria for reference sites (Ode et al. 2016b). All thresholds in this analysis were used for the purposes of exploring the relationships between stressors and biological condition, and they may not be appropriate for regulatory applications. Thresholds are presented in Table 7.

Table 7. Thresholds used for assessing relative risk. Some thresholds were derived from reference sites in the present study; for these thresholds, n indicates the number of reference sites used in analyses. Thresholds for metals were not adjusted for hardness.

Indicator	Threshold	Source
Alkalinity	20000 mg/L	USEPA 1986
Chloride	250 mg/L	USEPA 1986
Sulfate	250 mg/L	USEPA 1986
Arsenic	150 µg/L	USEPA 2000
Cadmium	2.2 µg/L	USEPA 2000
Chromium	180 µg/L	USEPA 2000
Copper	9 µg/L	USEPA 2000
Nickel	2.5 µg/L	USEPA 2000
Lead	52 µg/L	USEPA 2000
Selenium	5 µg/L	USEPA 2000

Indicator	Threshold	Source
Zinc	120 µg/L	USEPA 2000
Dissolved oxygen	5 mg/L	San Francisco Bay Basin Plan 2024 (WARM)
Dissolved oxygen	7 mg/L	San Francisco Bay Basin Plan 2024 (COLD)
pH	6.5 to 8.5	San Francisco Bay Basin Plan 2024
Total Nitrogen	0.54 mg/L	Bay Area reference sites (n = 26)
Total Phosphorus	0.16 mg/L	Bay Area reference sites (n = 49)
Benthic ash-free dry mass	51.4 g/m^2	Bay Area reference sites (n = 48)
Benthic chlorophyll-a	40.1 mg/m^2	Bay Area reference sites (n = 49)
Specific conductivity	704 uS/cm	Bay Area reference sites (n = 63)

Relative risk was applied to the water quality indicators in Table 7, to channel modification status, and to habitat quality (based on having an IPI score above or below the 10^{th} percentile of reference, as presented in Table 3). Geospatial indicators were not included in relative risk analysis.

RESULTS

Question 1: Ecological conditions of streams in the Bay Area

Conditions of streams in the region

Most locations in Water Board Region 2 had CSCI and ASCI-D scores below the 10th percentile reference threshold, indicating degraded conditions (i.e., poor or very poor); Table 8, Figure 1 to Figure 5). Degraded conditions were identified at 64% of sites for CSCI and 78% of sites for ASCI-D. In contrast to the CSCI and ASCI scores, IPI scores were above the 10th percentile reference threshold at the majority of sites in Water Board Region 2 (73%), indicating that intact or possibly altered physical habitat conditions were widespread.

Table 8. Summary of index scores in Water Board Region 2.

Index	Number of sites	% Likely intact (Excellent)	% Possibly altered (Good)	% Likely altered (Poor)	% Very likely altered (Very poor)	Mean	SD
CSCI	1,432	23	10	18	46	0.63	0.26
ASCI-D	753	13	9	17	61	0.72	0.18
IPI	607	56	17	11	16	0.90	0.24

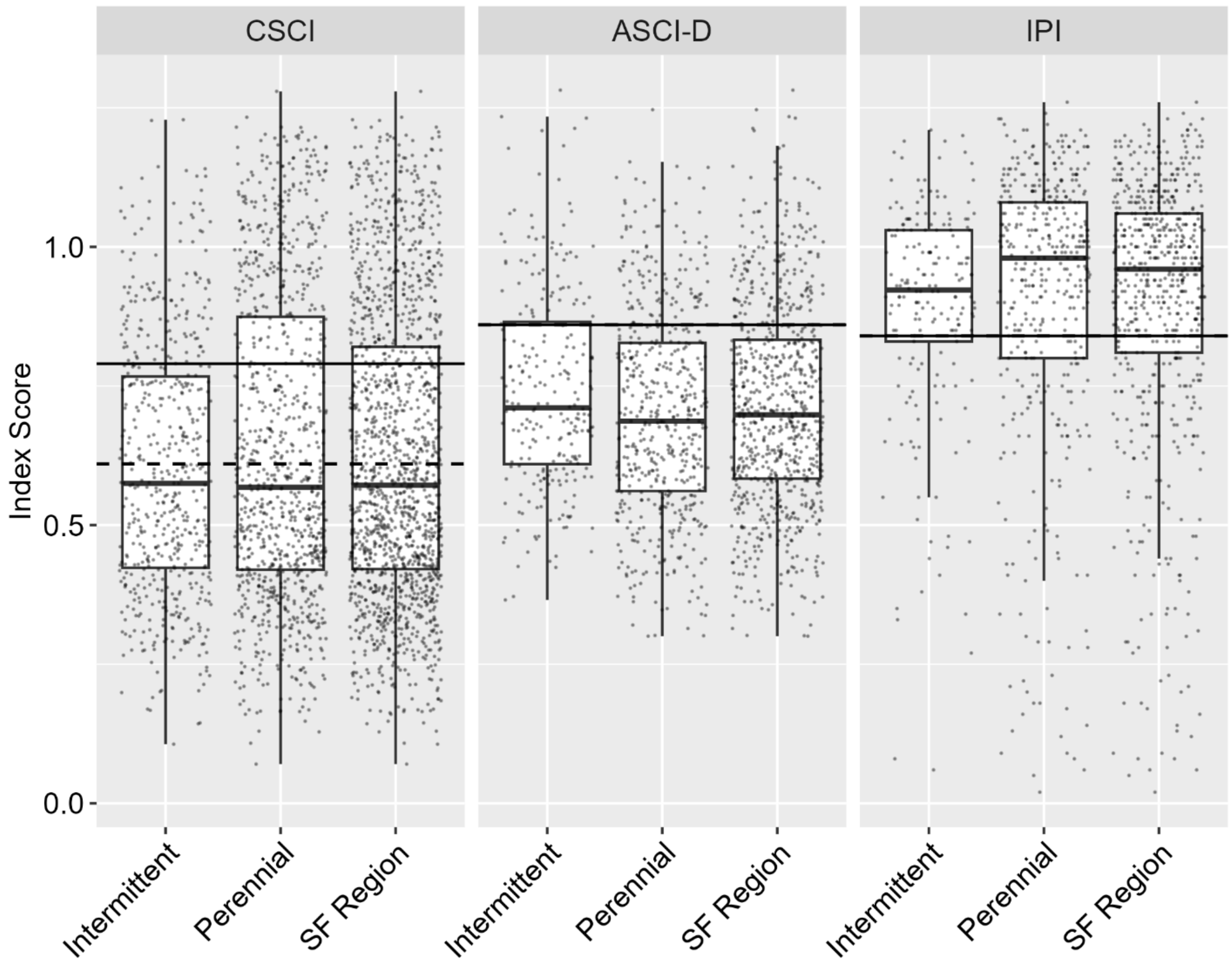


Figure 1. Bioassessment index scores in intermittent and perennial streams, and in the San Francisco Bay Area region as a whole. Each point represents the score at a sampling location. The horizontal lines are the 10th percentile reference thresholds (perennial threshold is solid and the provisional intermittent threshold is dashed).

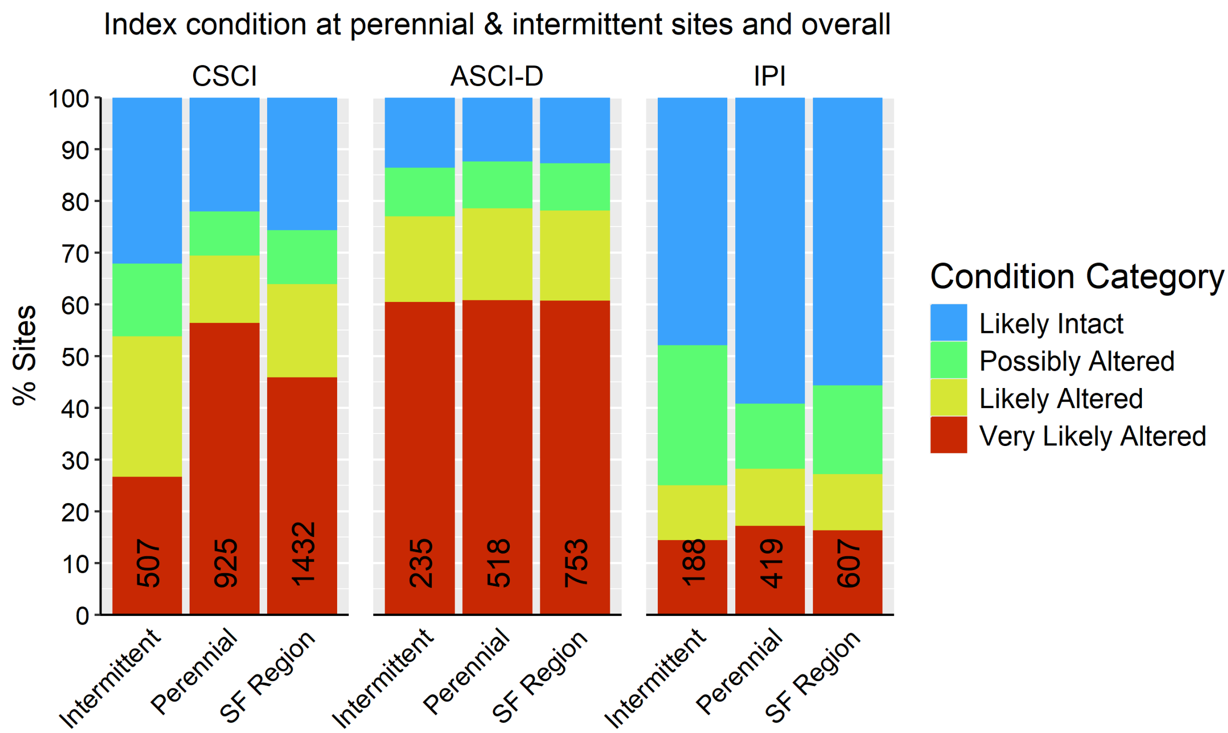
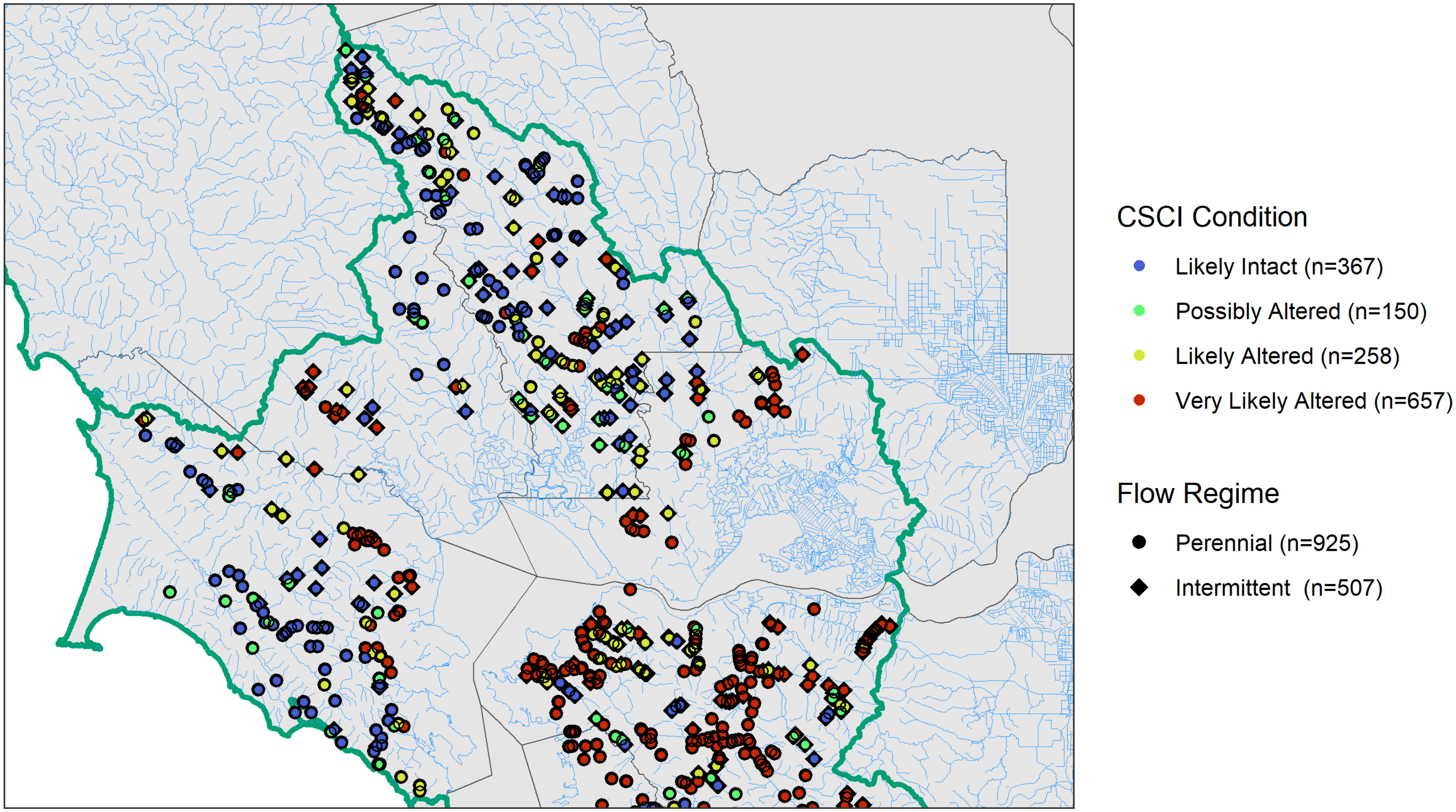


Figure 2. CSCI condition by flow regime and total Water Board Region 2. The numbers in the plot indicate the total number of sites per flow regime or San Francisco Region.


CSCI Condition
Likely Intact (n=367)
Possibly Altered (n=150)
Likely Altered (n=258)
Very Likely Altered (n=657)
Flow Regime
Perennial (n=925)
Intermittent (n=507)

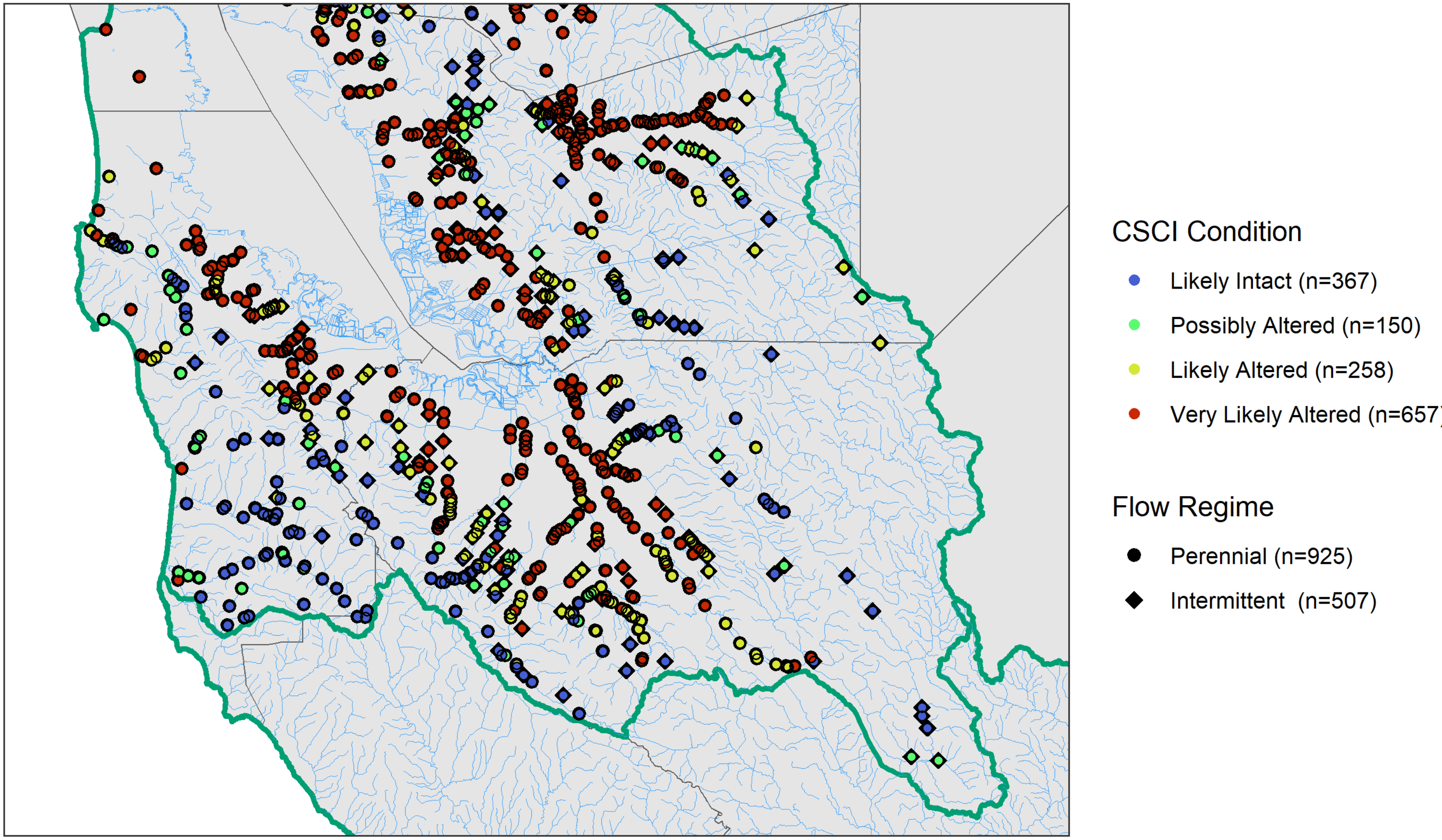
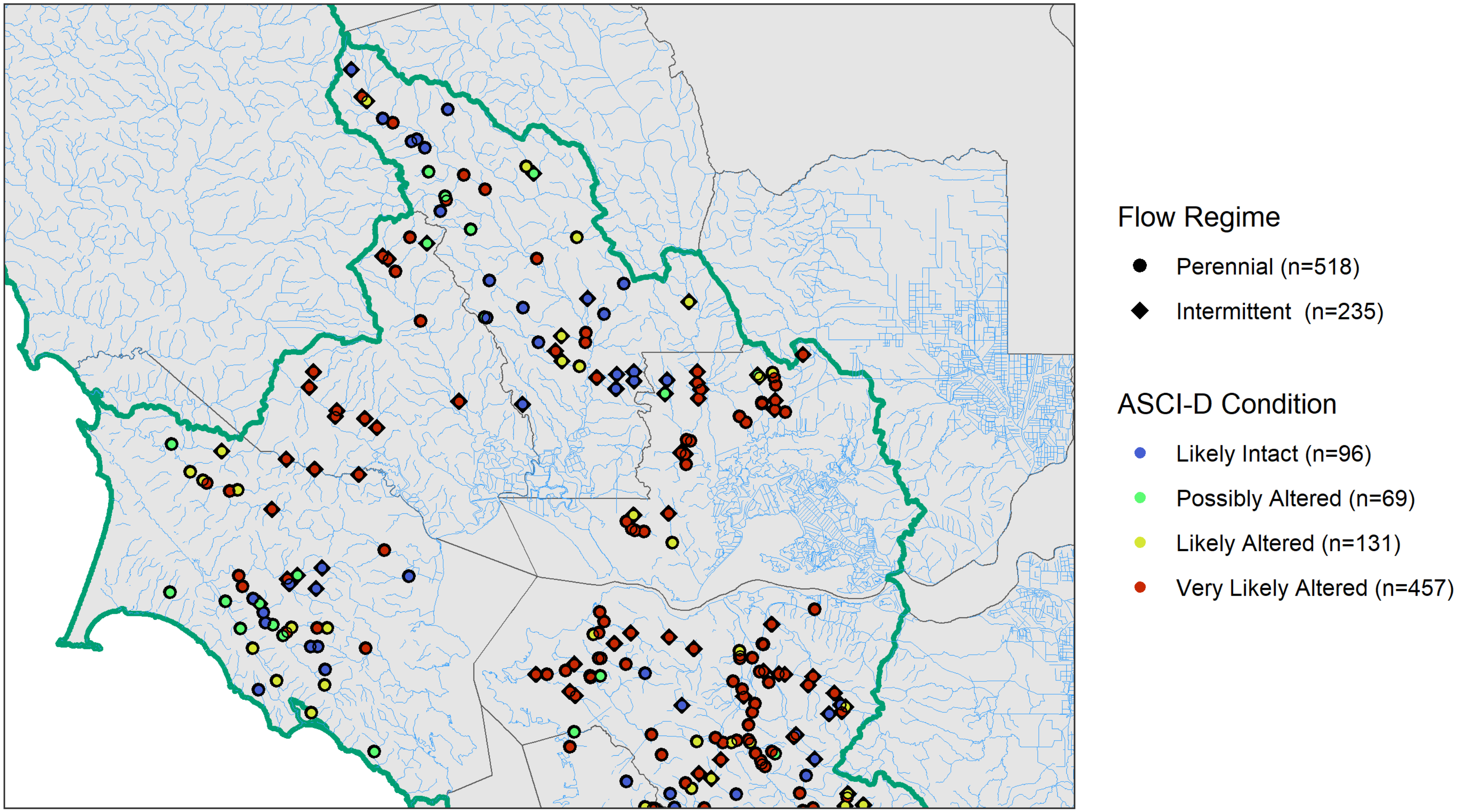


Figure 3. Map of CSCI condition by county in Water Board Region 2. National Hydrography Dataset Plus (NHD Plus) flowlines are also shown. The green lines indicate Regional Water Board boundaries while grey lines are county boundaries.


Flow Regime
Perennial (n=518)
Intermittent (n=235)
ASCI-D Condition
Likely Intact (n=96)
Possibly Altered (n=69)
Likely Altered (n=131)
Very Likely Altered (n=457)

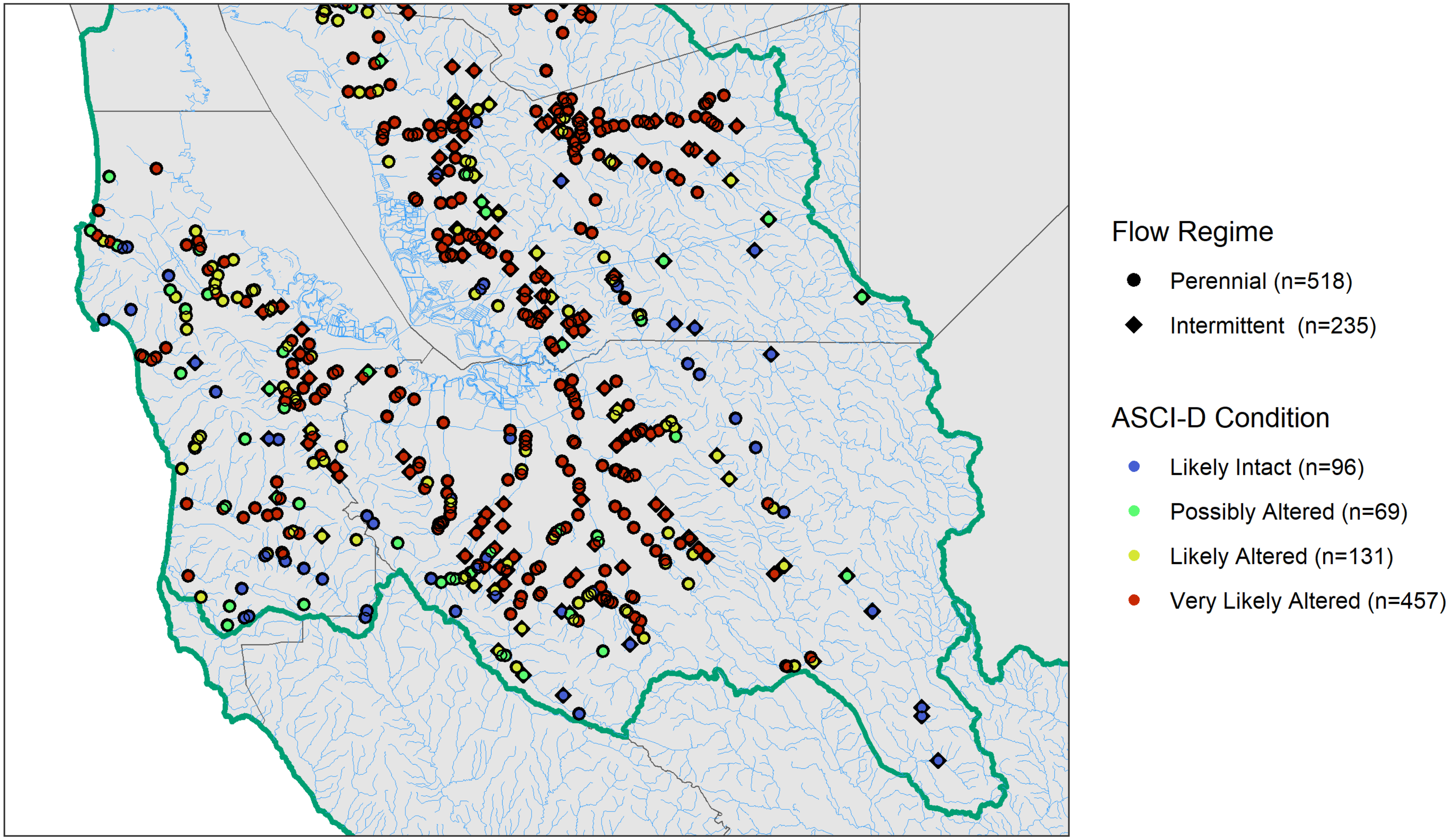
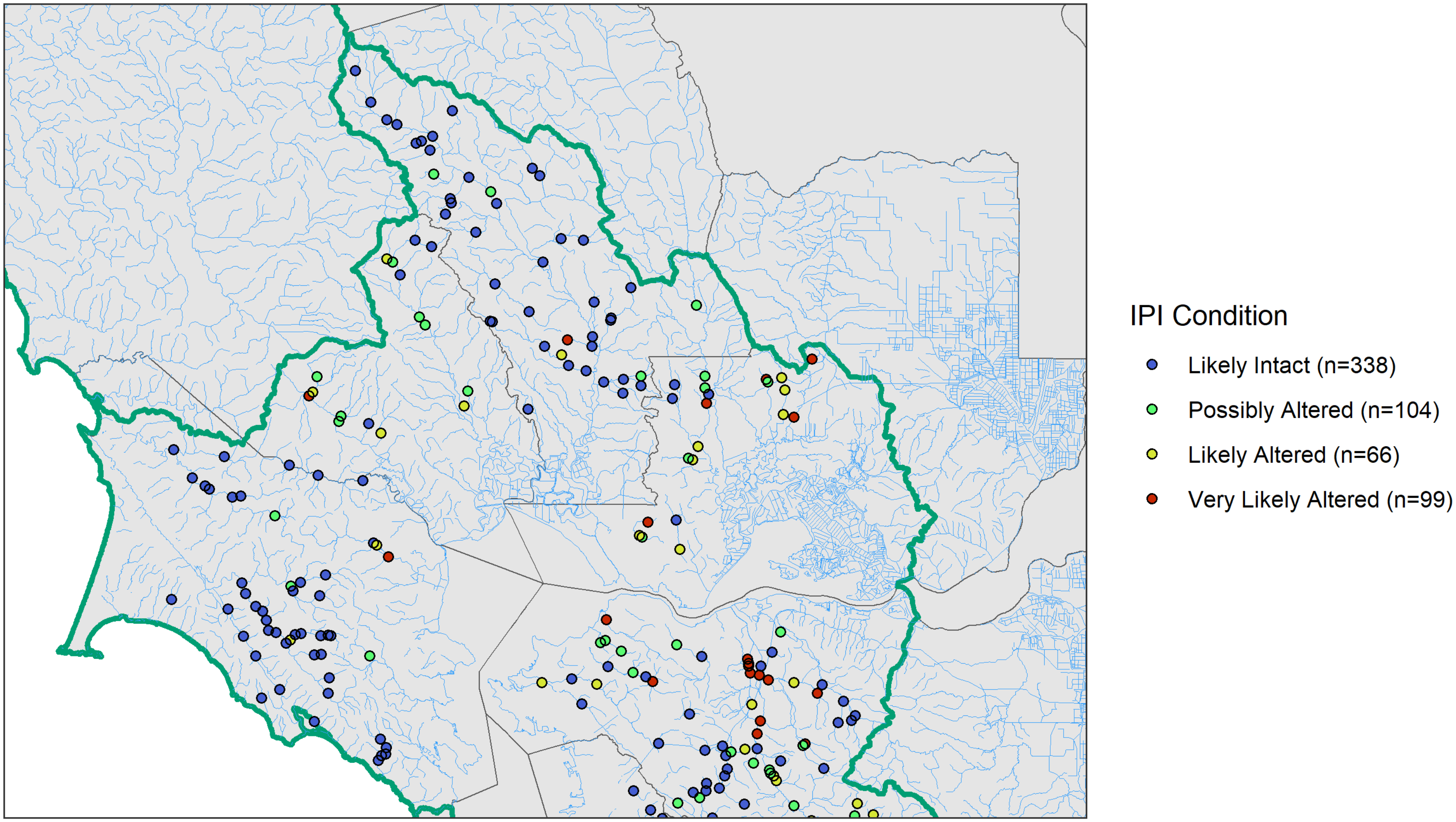


Figure 4. Map of ASCI-D condition by county in Water Board Region 2. National Hydrography Dataset Plus (NHD Plus) flowlines are also shown. The green lines indicate Regional Water Board boundaries while grey lines are county boundaries.


IPI Condition
Likely Intact (n=338)
Possibly Altered (n=104)
Likely Altered (n=66)
Very Likely Altered (n=99)

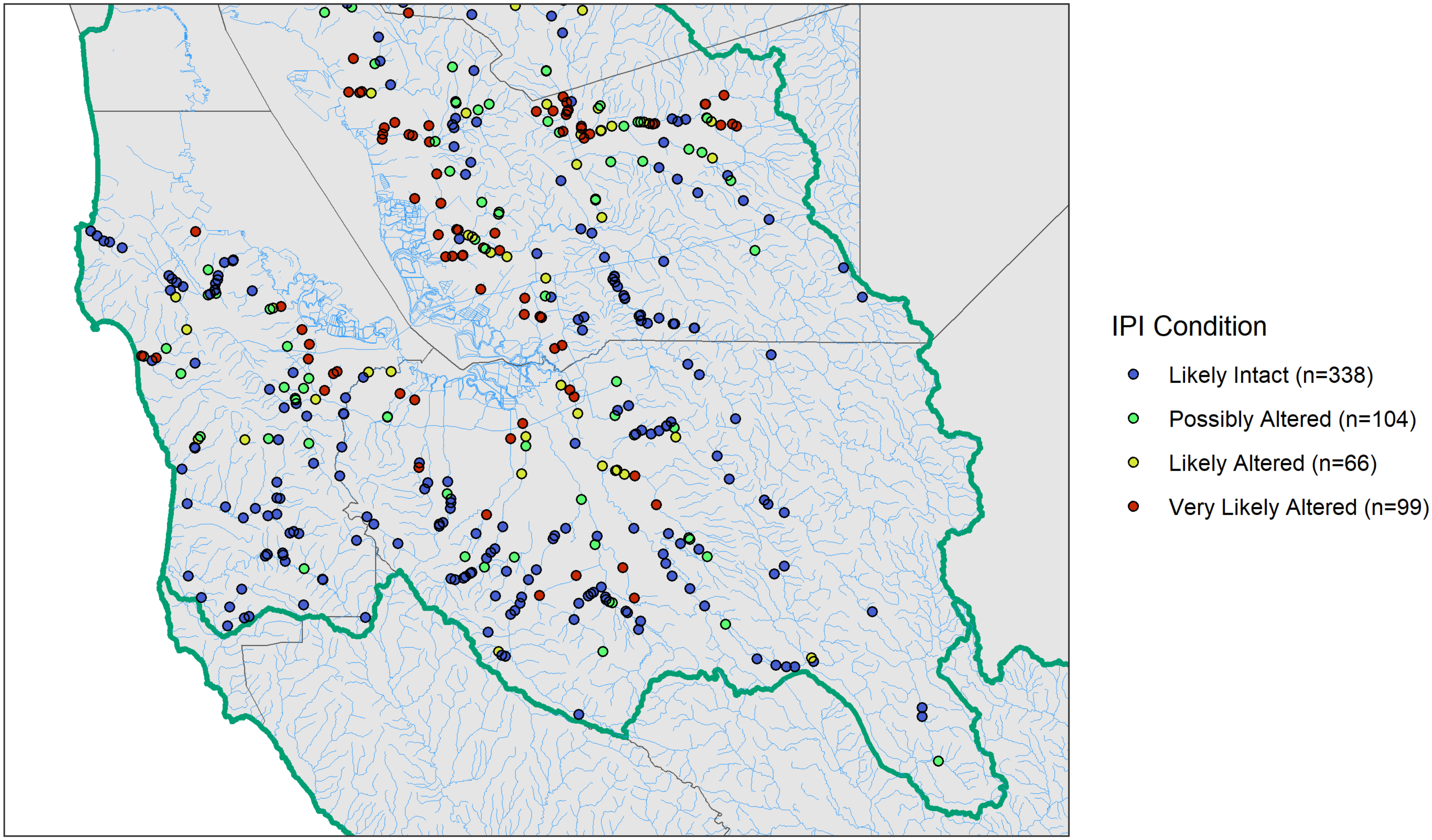


Figure 5. Map of IPI condition by county in Water Board Region 2. National Hydrography Dataset Plus (NHD Plus) flowlines are also shown. The green lines indicate Regional Water Board boundaries while grey lines are county boundaries.

Conditions of perennial and intermittent streams

Median scores were significantly higher at reference sites compared with scores at non-reference sites for all five indicators (Figure 6 to Figure 8, Table 10). For example, among perennial streams the median CSCI score was 0.99 at reference sites compared to 0.55 at non-reference sites.

Flow regime (perennial vs intermittent) did not appear to be related to index scores for CSCI (Figure 6, Table 10). There was, however, a significant difference in CSCI scores associated with flow regime within reference sites, with a higher mean score for perennial reference sites (CSCI = 1.00) than for intermittent reference sites (CSCI = 0.87).

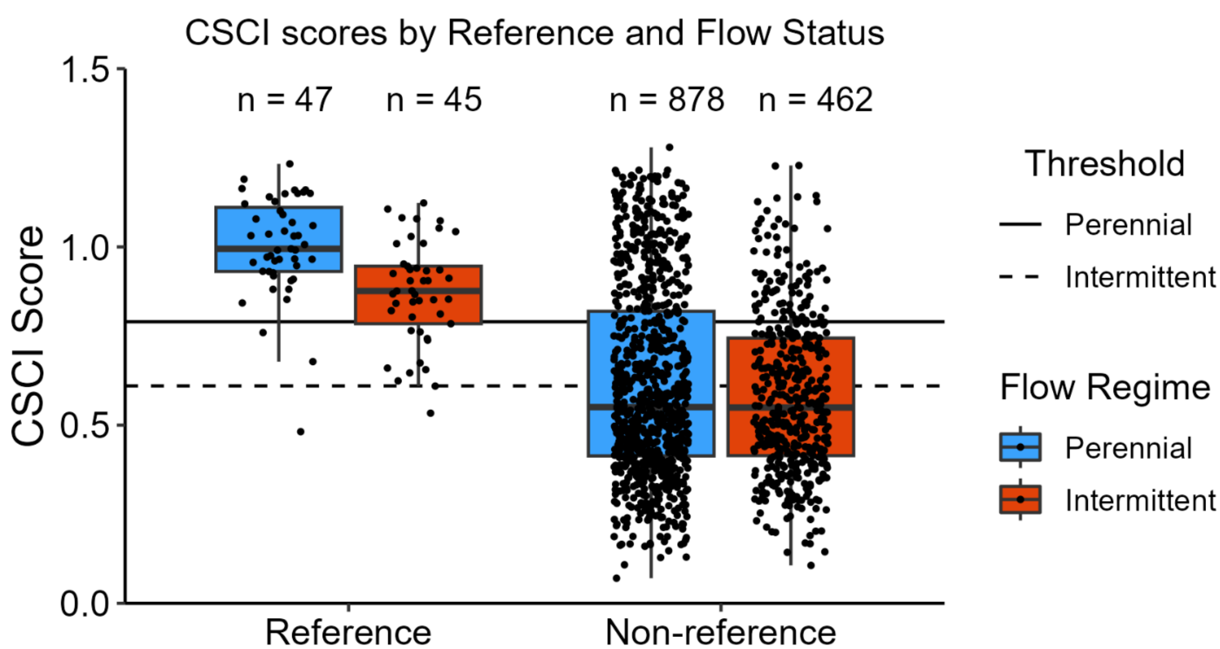


Figure 6. CSCI scores by reference and surface water flow regime. Each point represents the score at a sampling location. The horizontal lines are the 10th percentile reference thresholds perennial (0.79) and intermittent sites (0.61, provisional).

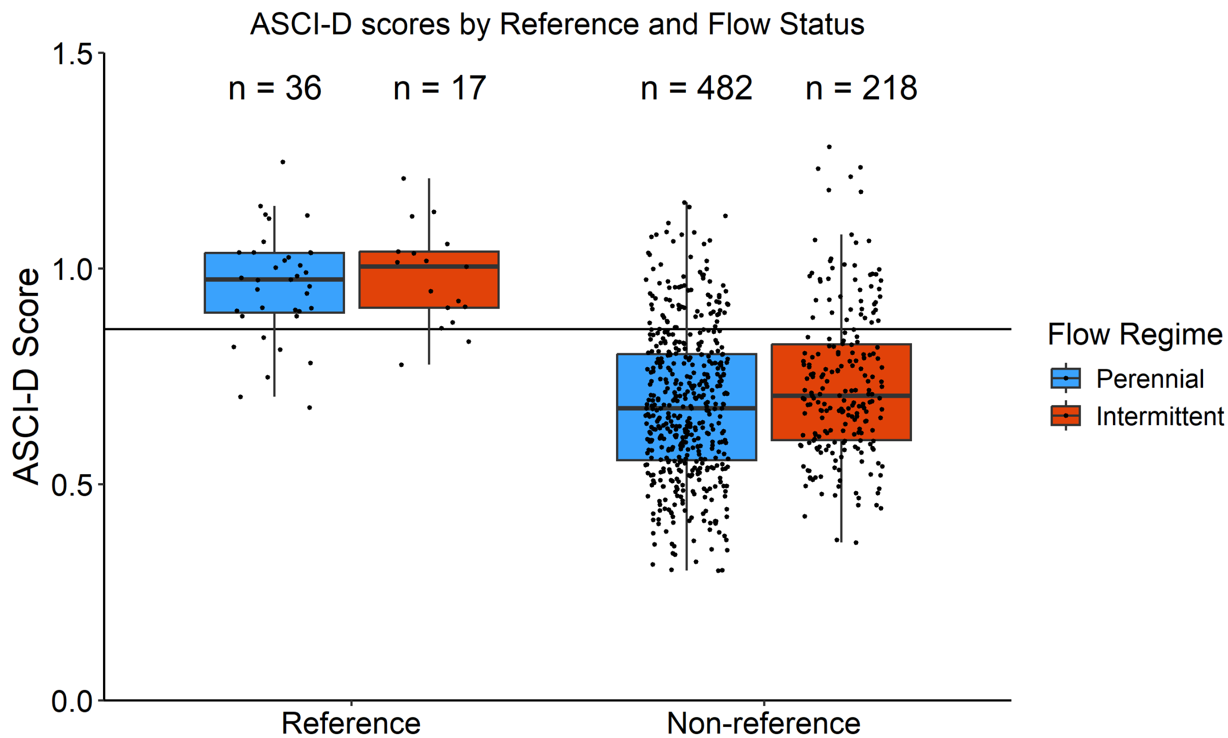


Figure 7. ASCI-D scores by reference and surface water flow regime. Each point represents the score at a sampling location. The horizontal line is the 10th percentile reference threshold (0.86)

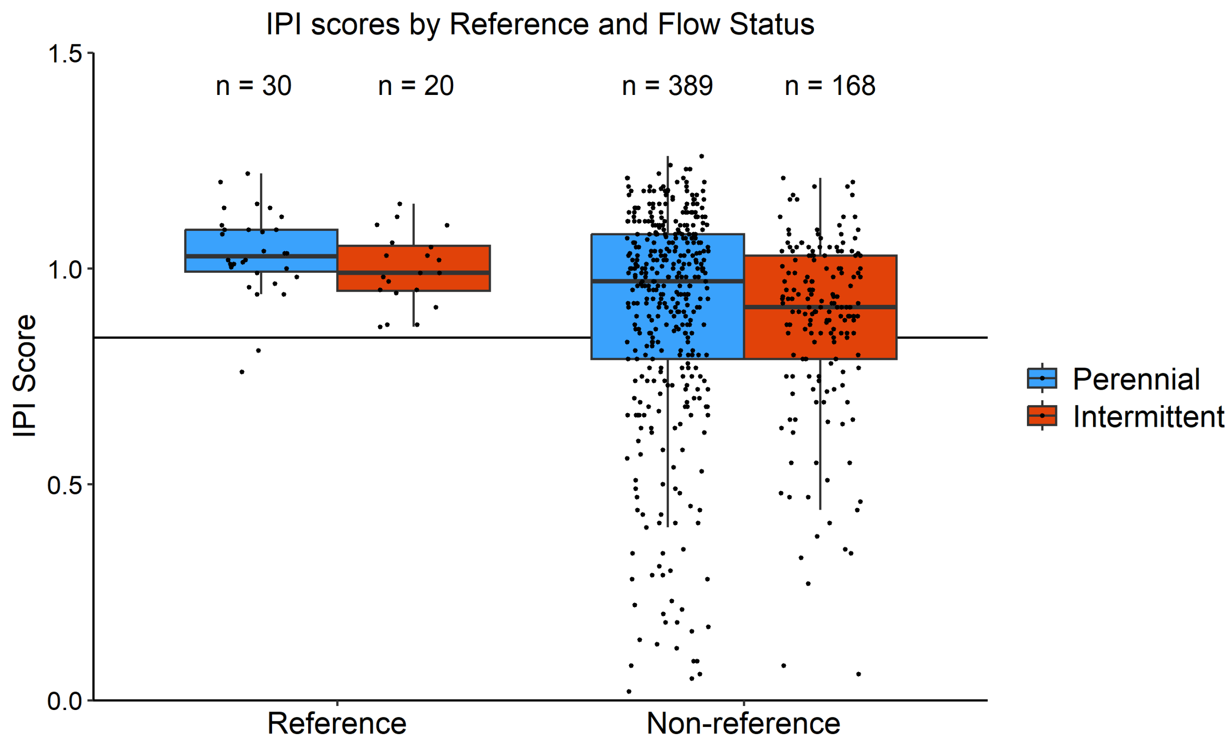


Figure 8. IPI scores by reference and surface water flow regime. Each point represents the score at a sampling location. The horizontal line is the 10th percentile reference threshold (0.84).

Table 9. Summary of the distribution of data for CSCI and ASCI-D by reference status and flow regime. C.I. = confidence interval, Q = quantile (normalized).

Indicator	Reference Status, Flow Regime	Mean	Std Dev	Upper 95% C.I.	Lower 95% C.I.	Q01	Q10	Q30
CSCI	Reference, Perennial	1.00	0.14	1.04	0.96	0.68	0.82	0.93
CSCI	Reference, Intermittent	0.87	0.14	0.91	0.83	0.54	0.69	0.79
CSCI	Non-reference, Perennial	0.62	0.27	0.64	0.60	-0.01	0.27	0.48
CSCI	Non-Reference, Intermittent	0.58	0.22	0.60	0.56	0.07	0.30	0.46
ASCI-D	Reference, Perennial	0.96	0.12	1.00	0.92	0.67	0.80	0.89
ASCI-D	Reference, Intermittent	0.98	0.12	1.04	0.93	0.71	0.83	0.92

Indicator	Reference Status, Flow Regime	Mean	Std Dev	Upper 95% C.I.	Lower 95% C.I.	Q01	Q10	Q30
ASCI-D	Non-reference, Perennial	0.68	0.17	0.70	0.67	0.28	0.46	0.59
ASCI-D	Non-Reference, Intermittent	0.73	0.17	0.76	0.71	0.33	0.51	0.64

Note: Negative results are possible for normalized quantile estimates.

Table 10. Results of Wilcox rank-sum tests comparing index scores between flow regime categories for reference sites, flow regime categories, and reference status categories.

Index	Reference Perennial vs Reference Intermittent	Perennial vs Intermittent	Reference vs Nonreference
CSCI	$p = 5.4 \times 10^{-6}$	$p = 0.19$	$p < 2 \times 10^{-16}$
ASCI-D	$p = 0.55$	$p = 0.003$	$p < 2 \times 10^{-16}$
IPI	$p = 0.15$	$p = 0.008$	$p = 0.002$

Conditions of modified channels

At a subset of sites in Santa Clara County with channel type information, most were in the "natural" category (63%), followed by "soft" (28%) and "hard" (9%) (Table 11, Figure 9 to Figure 17). Overall, the mean values for all indices were higher in natural channel types compared to soft and hard channel types. The percentage of sites that were considered likely intact were also higher in natural channel types for all indices. (Figure 9). Median ASCI-D scores were below the 10th percentile reference threshold for all channel type categories (Figure 10). In contrast, median IPI scores were above the threshold for all channel types (Figure 11).

Table 11. Summary of index condition by channel type in Santa Clara County.

Index	Channel type	N	Likely intact	Possibly altered	Likely altered	Very likely altered	Mean	SD
CSCI	Natural	150	37%	13%	27%	23%	0.74	0.23
CSCI	Soft	67	4%	7%	19%	69%	0.53	0.17
CSCI	Hard	22	0%	9%	9%	82%	0.48	0.13
ASCI-D	Natural	86	19%	9%	22%	50%	0.77	0.17
ASCI-D	Soft	42	2%	7%	12%	79%	0.64	0.15
ASCI-D	Hard	14	7%	7%	21%	64%	0.71	0.18
IPI	Natural	46	83%	13%	4%	0%	1.01	0.09
IPI	Soft	23	57%	22%	4%	17%	0.93	0.24
IPI	Hard	8	50%	13%	0%	38%	0.78	0.33

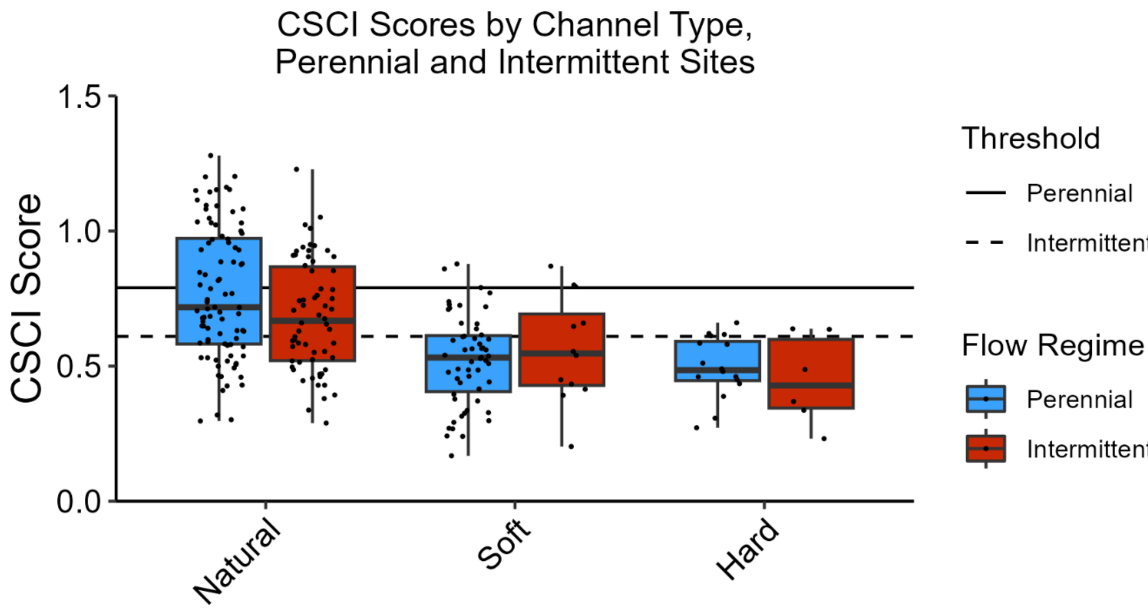


Figure 9. CSCI scores by channel type in Santa Clara County. Each point represents the score at a sampling location. The horizontal lines are the 10th percentile reference thresholds (perennial: 079; intermittent: 0.61).

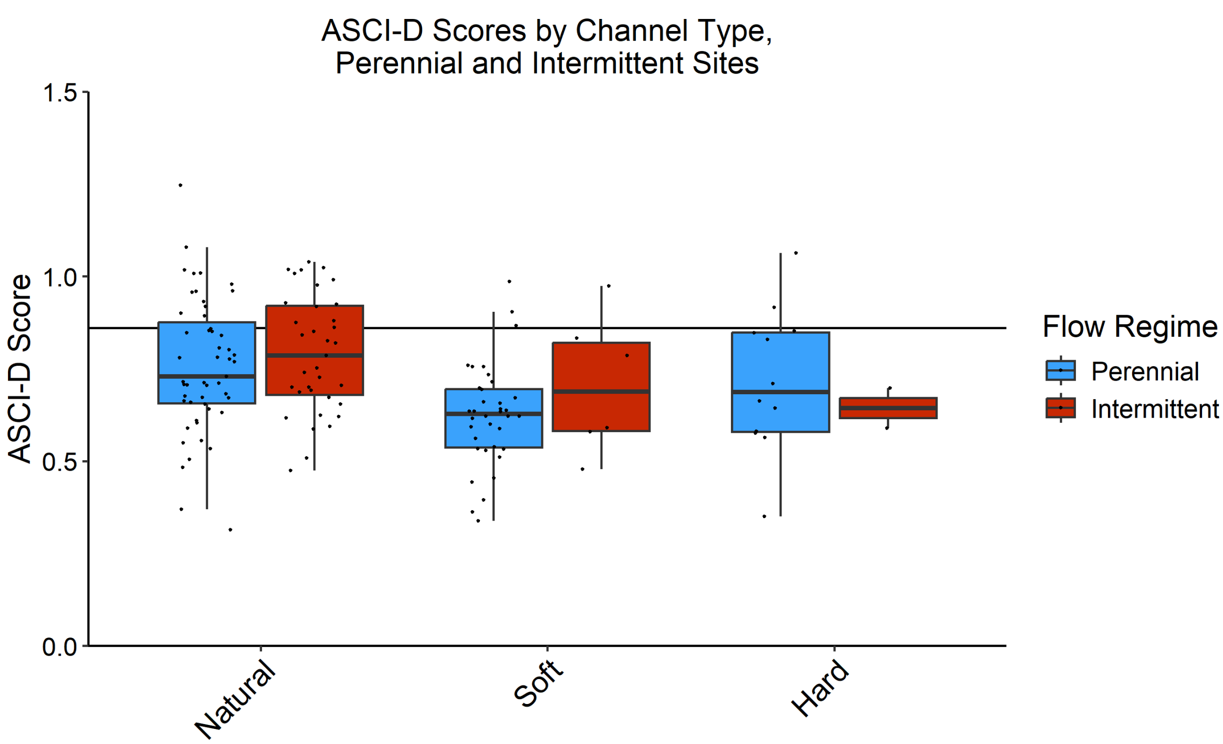


Figure 10. ASCI-D scores by channel type in Santa Clara County. Each point represents the score at a sampling location. The dashed horizontal line is the 10th percentile reference threshold (0.86).

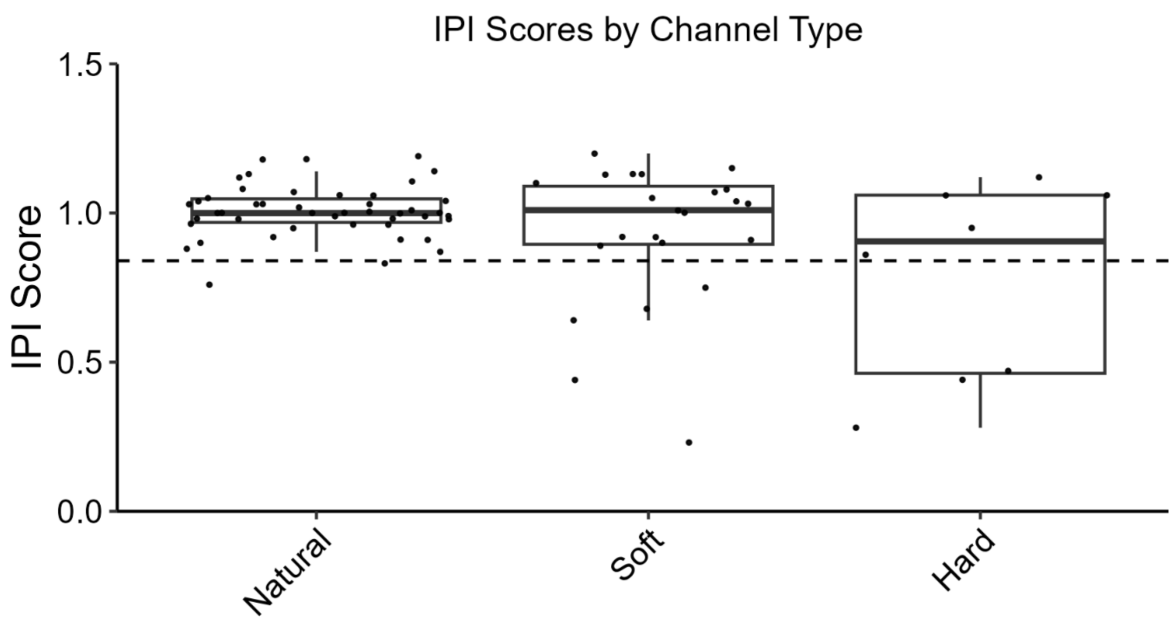


Figure 11. IPI scores by channel type in Santa Clara County. Each point represents the score at a sampling location. The dashed horizontal line is the 10th percentile reference threshold (0.84).

Table 12. Summary of data distribution of CSCI and ASCI by channel type and flow regime. C.I. = confidence interval; Q = quantile (normalized).

Index	Channel type, flow regime	Mean	Std Dev	Upper 95% C.I.	Lower 95% C.I.	Q01	Q10	Q30
CSCI	Natural, Perennial	0.77	0.24	0.82	0.72	0.20	0.46	0.64
CSCI	Natural, Intermittent	0.69	0.21	0.74	0.63	0.21	0.42	0.58
CSCI	Soft, Perennial	0.52	0.17	0.57	0.48	0.14	0.31	0.43
CSCI	Soft, Intermittent	0.56	0.20	0.68	0.45	0.10	0.31	0.46
CSCI	Hard, Perennial	0.50	0.11	0.55	0.44	0.23	0.35	0.44
CSCI	Hard, Intermittent	0.45	0.17	0.58	0.32	0.06	0.24	0.36
ASCI-D	Natural, Perennial	0.76	0.18	0.81	0.71	0.34	0.53	0.66
ASCI-D	Natural, Intermittent	0.79	0.16	0.84	0.74	0.42	0.59	0.71

Index	Channel type, flow regime	Mean	Std Dev	Upper 95% C.I.	Lower 95% C.I.	Q01	Q10	Q30
ASCI-D	Soft, Perennial	0.62	0.14	0.67	0.58	0.30	0.45	0.55
ASCI-D	Soft, Intermittent	0.71	0.19	0.86	0.56	0.27	0.47	0.61
ASCI-D	Hard, Perennial	0.72	0.19	0.83	0.61	0.27	0.47	0.61
ASCI-D	Hard, Intermittent	0.64	0.08	0.75	0.54	0.47	0.55	0.60

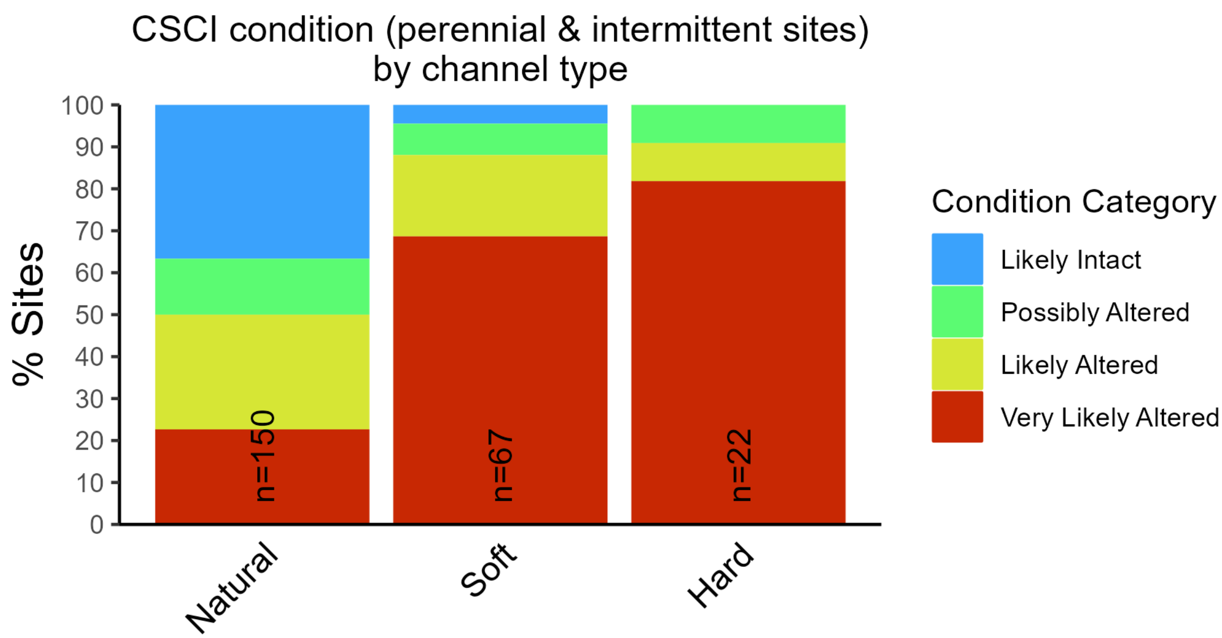


Figure 12. CSCI condition by channel type in Santa Clara County. The numbers in the plot indicate the total number of sites per channel type.

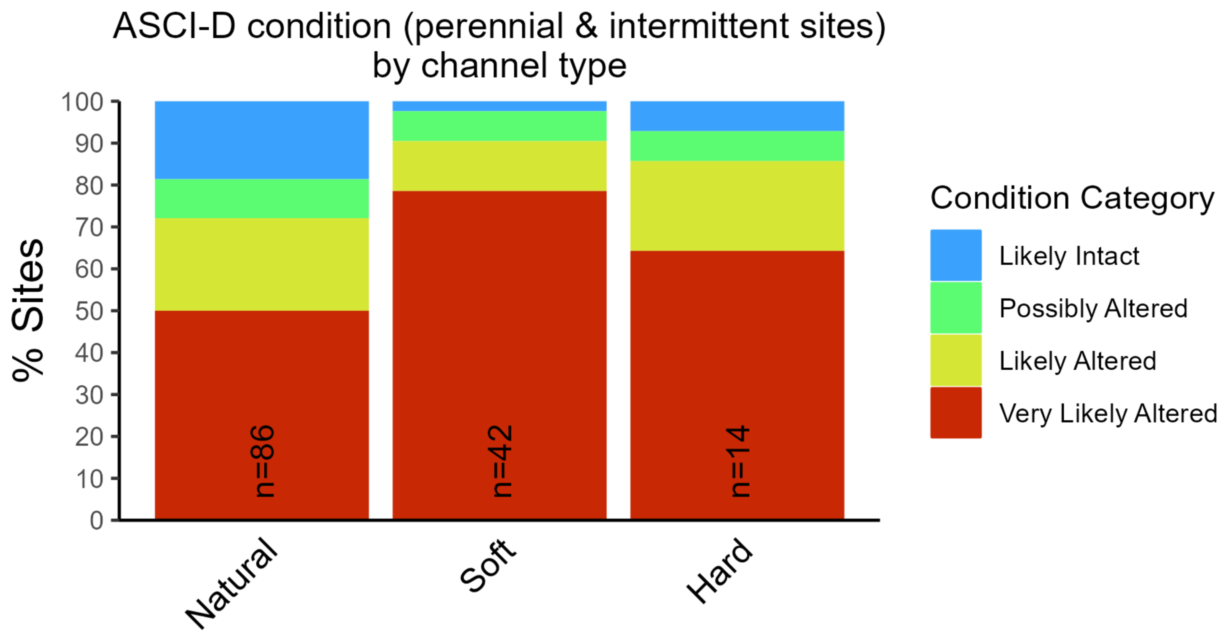


Figure 13. ASCI-D condition by channel type in Santa Clara County. The numbers in the plot indicate the total number of sites per channel type.

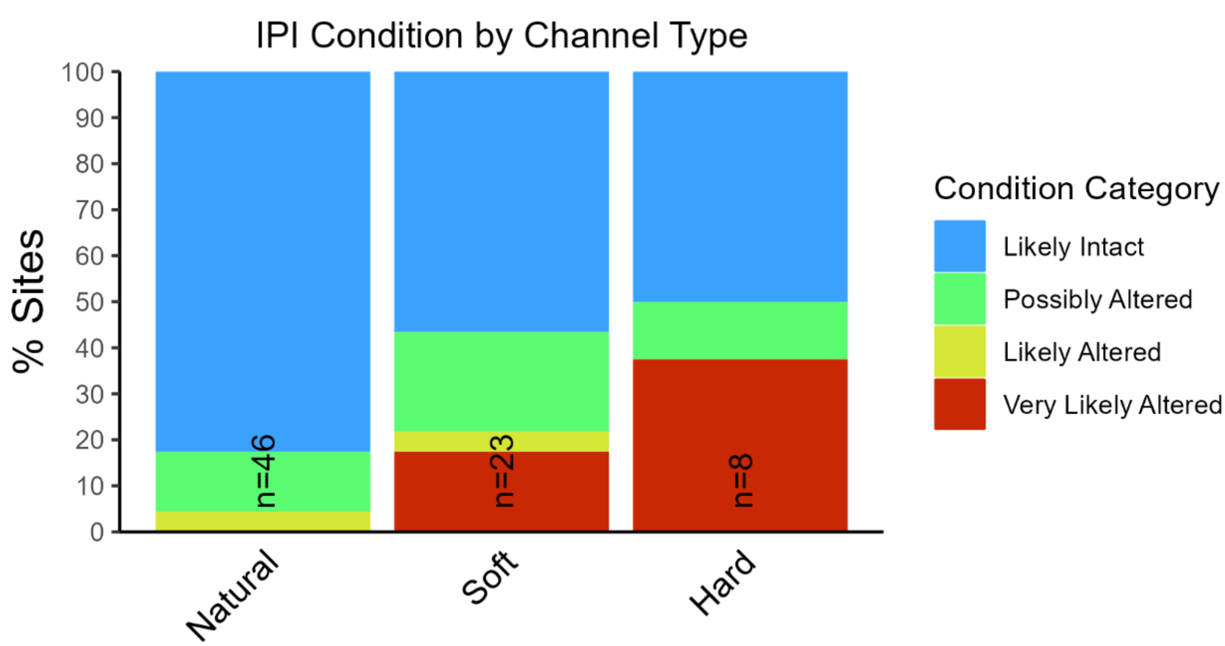


Figure 14. IPI condition by channel type in Santa Clara County. The numbers in the plot indicate the total number of sites per channel type.

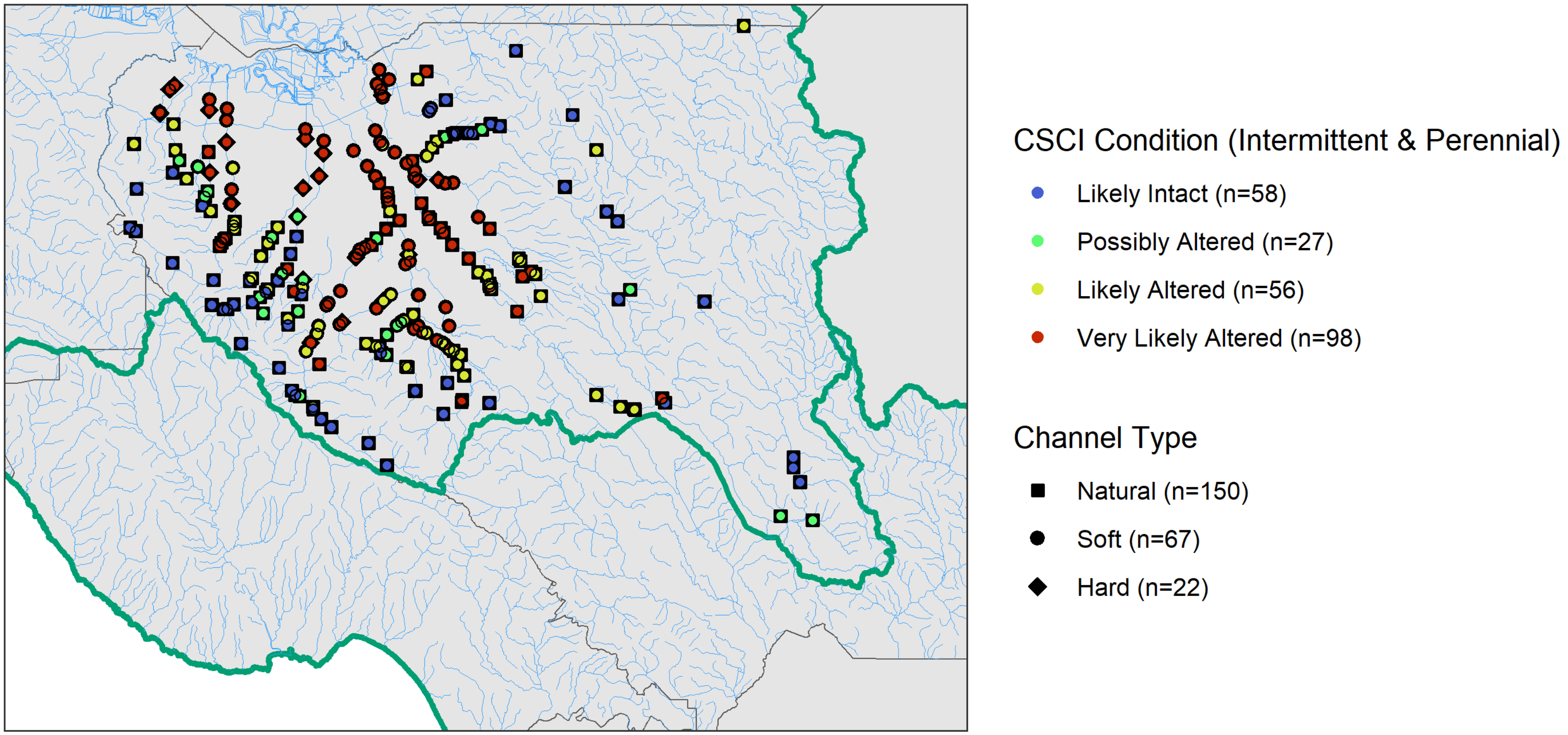


Figure 15. Map of CSCI condition by channel type in Santa Clara County. The green lines indicate Regional Water Board boundaries while grey lines are county boundaries.

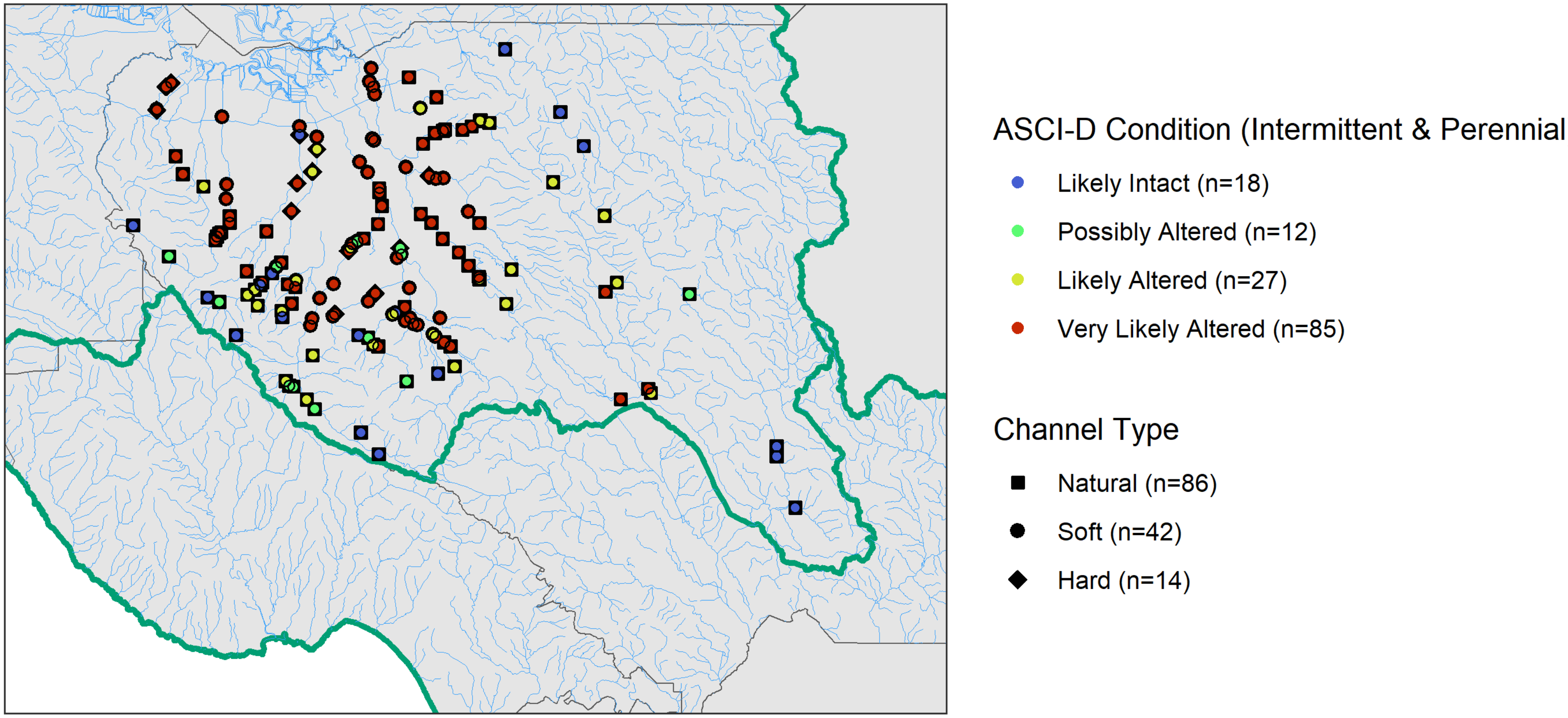


Figure 16. Map of ASCI-D condition by channel type in Santa Clara County. The green lines indicate Regional Water Board boundaries while grey lines are county boundaries.

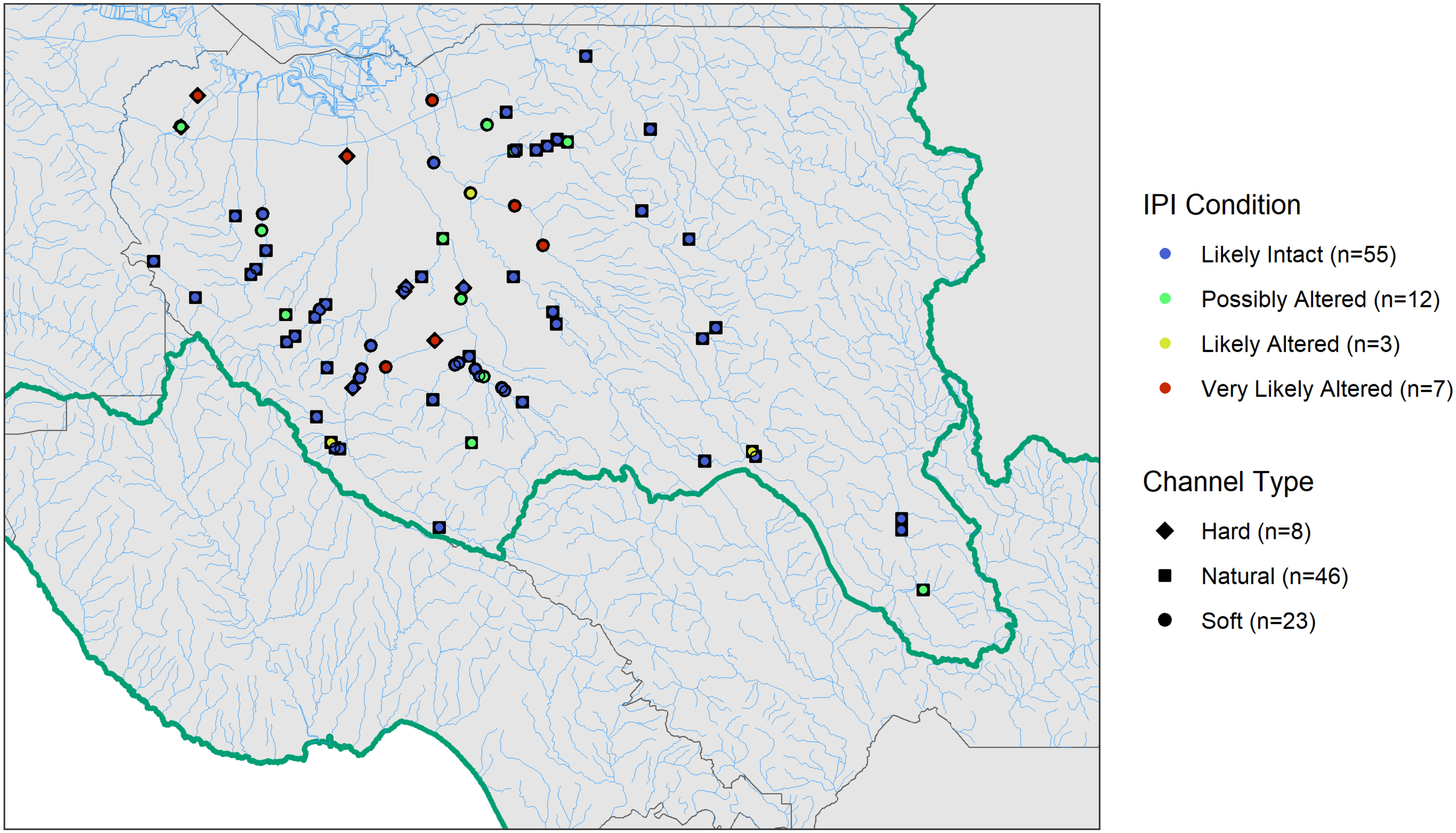


Figure 17. Map of IPI condition by channel type in Santa Clara County. The green lines indicate Regional Water Board boundaries while grey lines are county boundaries.

Table 13. Potential biointegrity index thresholds for different classes of streams calculated from statewide data. SB0: Soft-bottom modified channels with no hardened sides. SB1: Soft-bottom modified channels with one hardened side. SB2: Soft-bottom modified channels with two hardened sides. Reproduced from Mazor et al. (2024)

Stream class	Index	N	99th percentile	90th percentile	70th percentile
SB0	ASCI_D	51	1.01	0.77	0.68
SB0	CSCI	78	0.99	0.78	0.66
SB1	ASCI_D	36	1.01	0.85	0.68
SB1	CSCI	52	1.10	1.00	0.81
SB2	ASCI_D	57	0.93	0.77	0.64
SB2	CSCI	67	0.96	0.75	0.64
HB	ASCI_D	152	1.05	0.88	0.74
HB	CSCI	203	0.74	0.67	0.55

Evaluation of landscape constraints

SCAPE analysis relies on condition predictions based on land use gradient information at individual stream segments. There were 6,722 stream km in Water Board Region 2 that had SCAPE data available (representing 4,383 stream segments with SCAPE data out of 6,685 NHD stream segments total). More than half of the total stream length in Water Board Region 2 (62%) had predicted SCAPE values in the "possibly-", "likely -", or "very likely unconstrained" categories (Figures 18 and 19, Table 14).

About half of the measured CSCI scores in Water Board Region 2 (47%) compared favorably with the predicted SCAPE categories, and thus were classified as "expected" (Figures 20 to 21, Table 15). The proportion of sites that were "better", "expected" and "worse" were similar between the perennial and intermittent sites. However, there was a greater proportion of "substantially better" sites among perennial streams, and a greater proportion of "substantially worse" sites among intermittent streams.

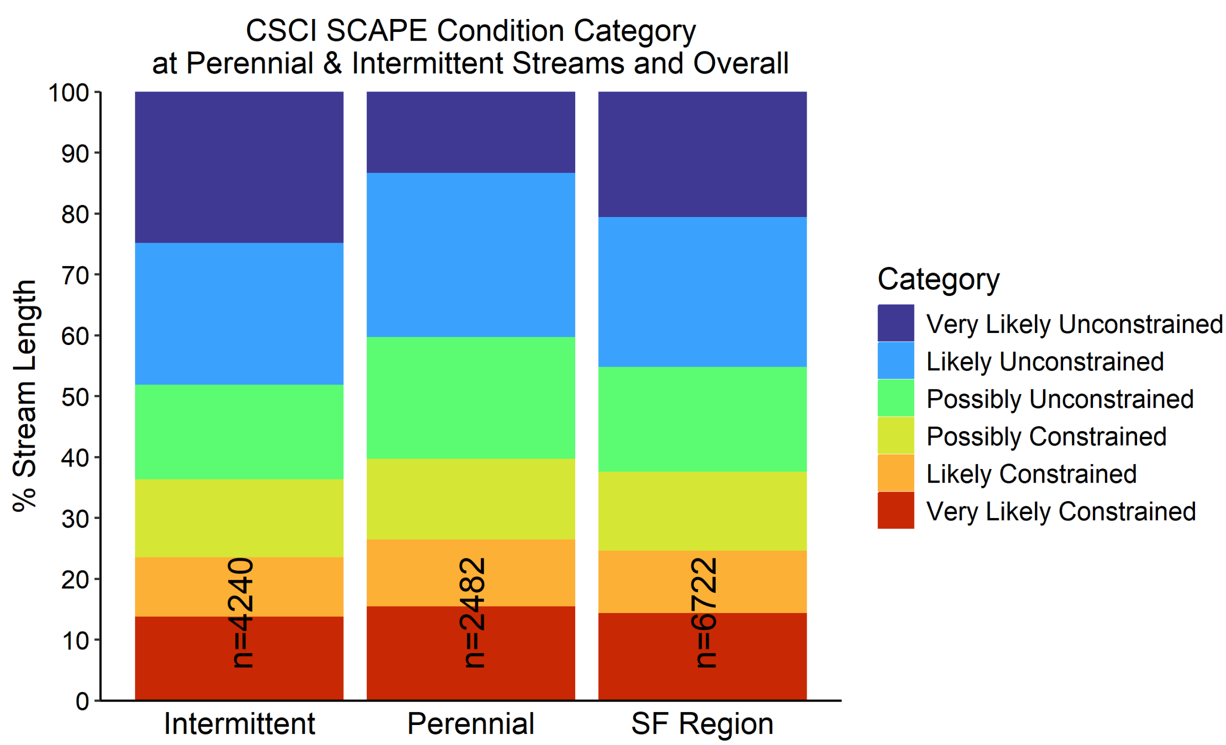


Figure 18. Proportion of stream segment length predicted in each Stream Classification and Priority Explorer (SCAPE) category, by flow regime and all of Water Board Region 2. The numbers in the plot indicate the total stream length (km) per flow regime category.

Table 14. Percentage of stream kilometers predicted in each Stream Classification and Priority Explorer (SCAPE) category, by flow regime and Water Board Region 2. qtN: Nth percentile of predicted CSCI scores from the SCAPE model. Flow duration status was inferred from sites with classifications provided by Regional Board staff; for reaches without such information, flow duration designations from NHD attribute tables were used. For perennial stream segments, a value of 0.79 was used as a target threshold for comparison; for intermittent stream segments, a value of 0.61 was used as a target threshold for comparison. Flowlines without any information about streamflow duration were excluded from this analysis.

Subpopulation	Very Likely Unconstrained (q10 ≥ target)	Likely Unconstrained (q10 < target but q25 ≥ target)	Possibly Unconstrained (q25 < target but q50 ≥ target)	Possibly Constrained (q50 < target but q75 ≥ target)	Likely Constrained (qt75 < target but qt90 ≥ target)	Very Likely Constrained (qt90 < target)
Perennial (2482 km)	13.4%	26.9%	20.0%	13.3%	11.0%	15.4%
Intermittent (4240 km)	24.8%	23.3%	15.6%	12.8%	9.8%	13.8%
Water Board Region 2 (6722 km)	20.6%	24.6%	17.2%	13.0%	10.2%	14.4%

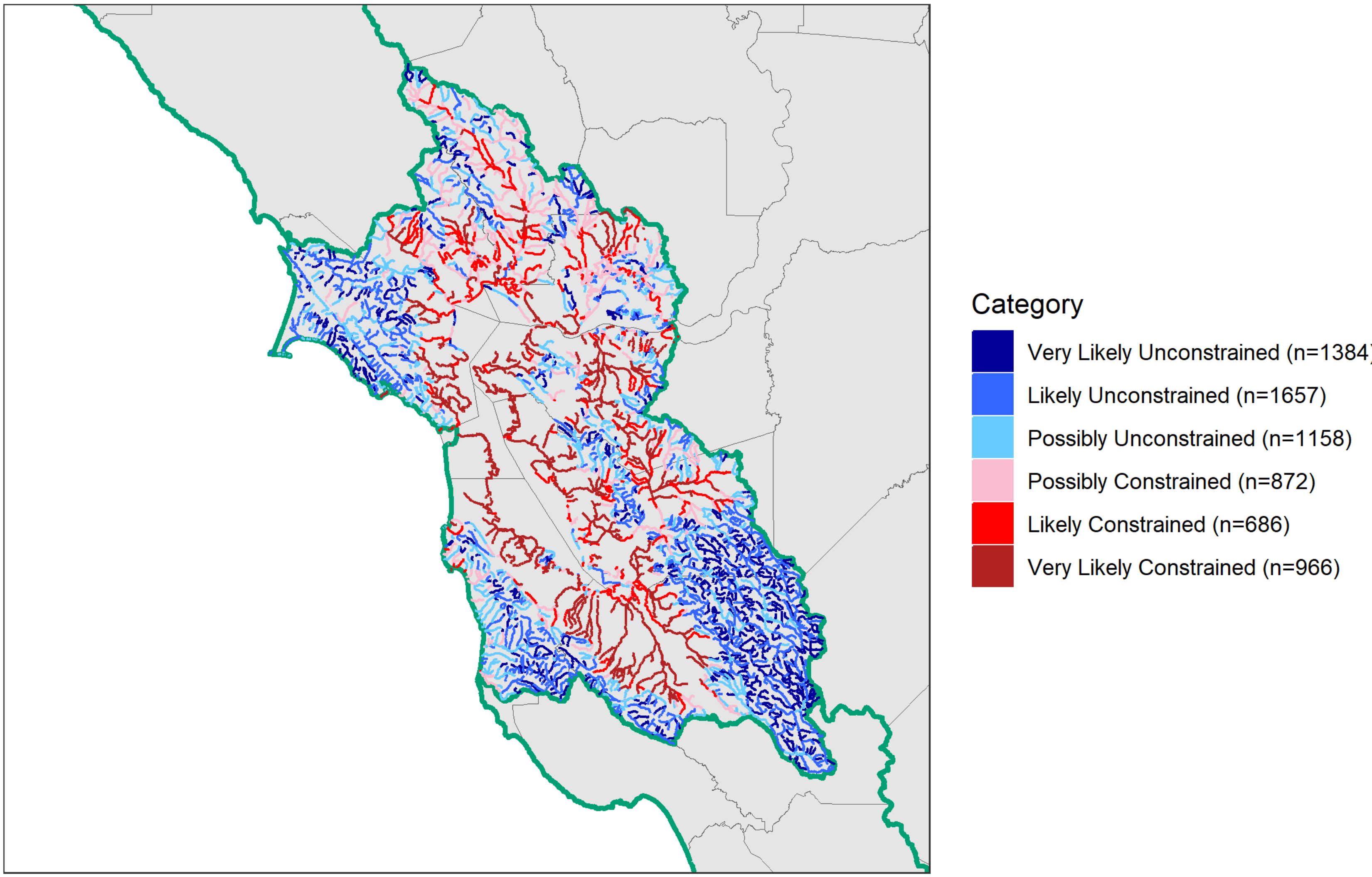


Figure 19. Map of CSCI Stream Classification and Priority Explorer (SCAPE) constrained/unconstrained stream segment length (km).

Table 15. Performance of measured CSCI scores relative to predictions in Stream Classification and Priority Explorer (SCAPE), by county and all of Water Board Region 2.

Subpopulation	Substantially Better %	Better %	Expected %	Worse %	Substantially Worse %
Perennial	8.5%	17.0%	53.1%	14.0%	7.4%
Intermittent	8.3%	10.0%	39.6%	23.5%	18.7%
Water Board Region 2	8.4%	13.8%	46.9%	18.4%	12.6%

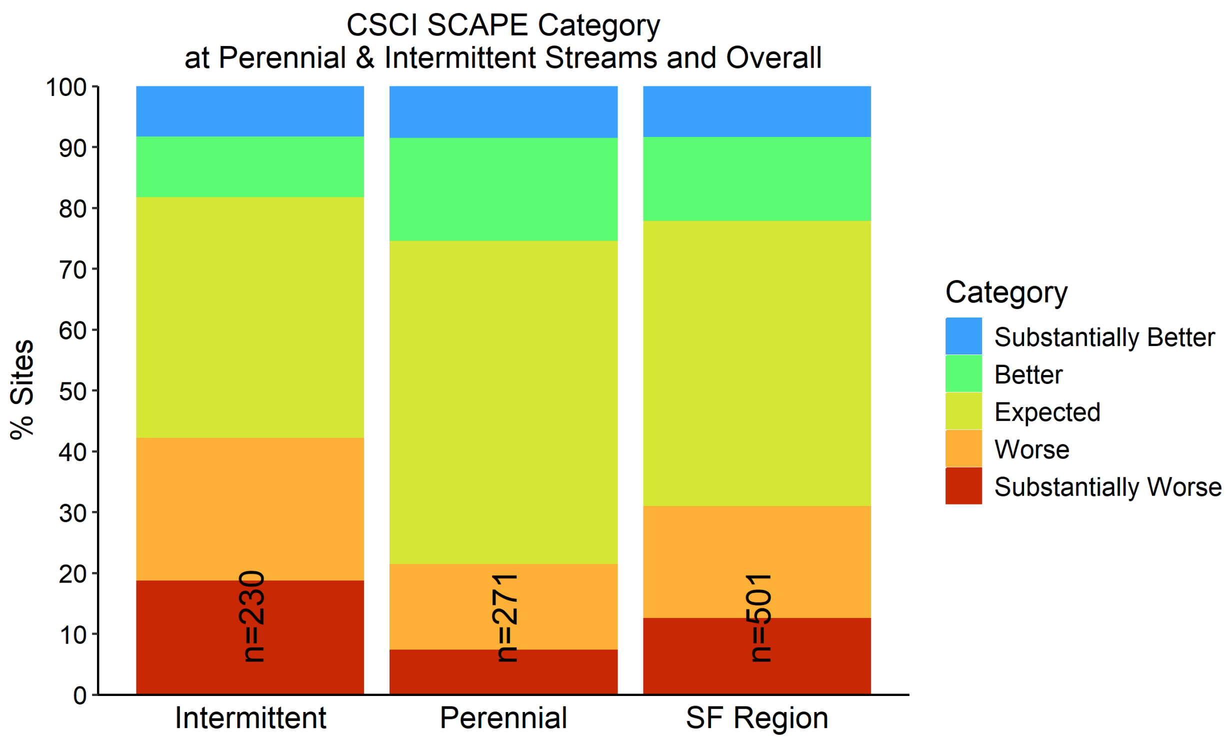


Figure 20. Measured CSCI score performance relative to predictions in Stream Classification and Priority Explorer (SCAPE), by flow regime and all of Water Board Region 2. The numbers in the plot indicate the total number of sites in a flow regime that have both CSCI index scores and SCAPE data.

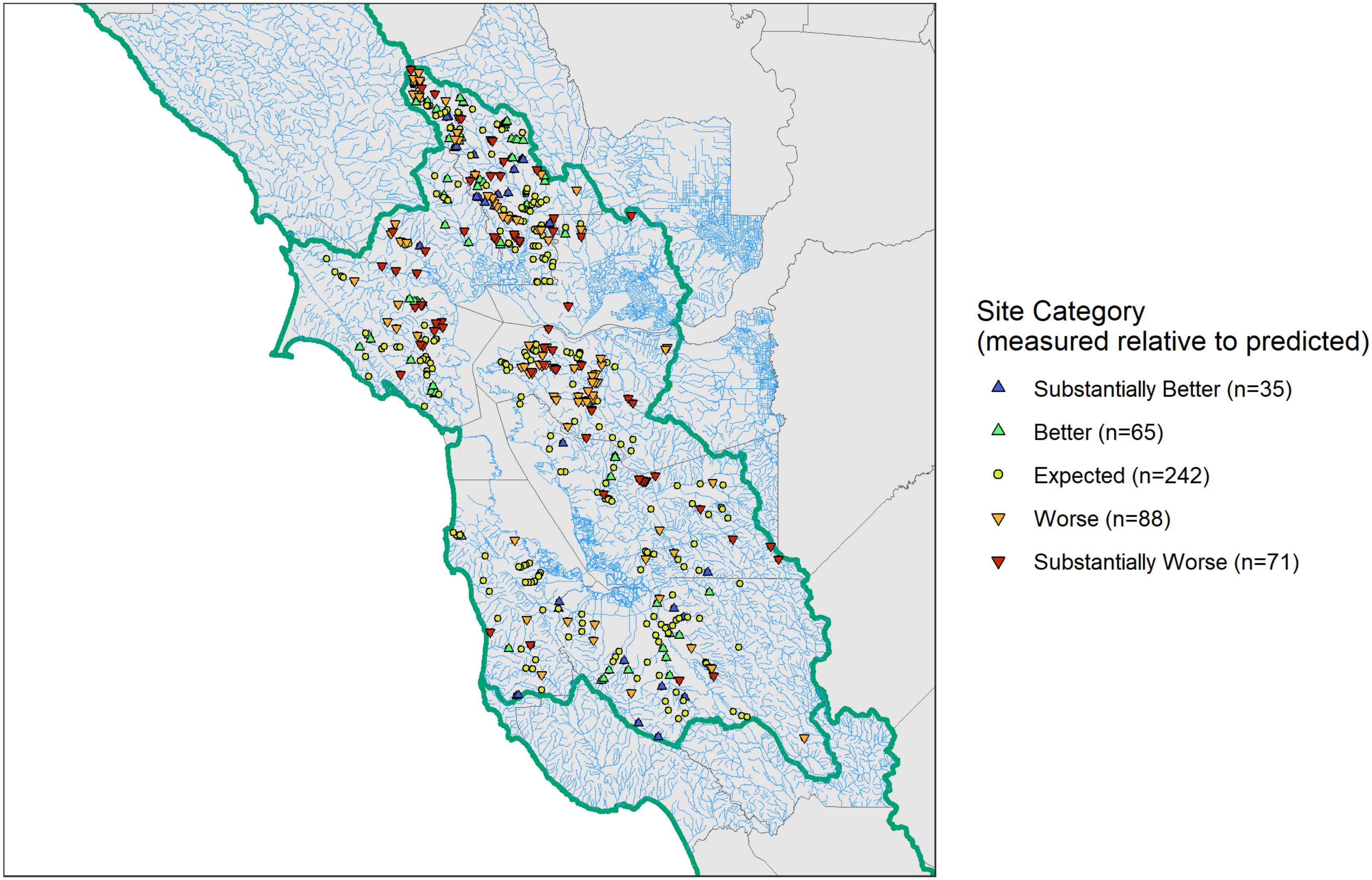


Figure 21. Maps of measured CSCI score performance relative to predictions in SCAPE.

Aggregating sites to stream segments

The number of CSCI sampling stations associated with each stream segment varied, from a minimum of one station to a maximum of eight, with an average of 1.6 sites per stream segment. The number of sites per km of stream varied from 0.09 to 9.08 sites/km, with a mean of 0.91 sites/km. Over half (56%) of the stream segment kilometers in the San Francisco Region were consistently degraded (i.e., segments with >50% of sites had CSCI scores in poor or very poor condition). Consistently degraded stream segments were common in the interior of Contra Costa county and the lower elevations of Santa Clara county. One quarter of the total stream segment length was high quality (all sites in good or excellent condition) and 19% of the total stream length was intermediate (Table 16, Figure 22).

Table 16. Summary of condition categories by stream segment length.

Condition	Total length (km)
High Quality	295
Intermediate	228
Degraded	659

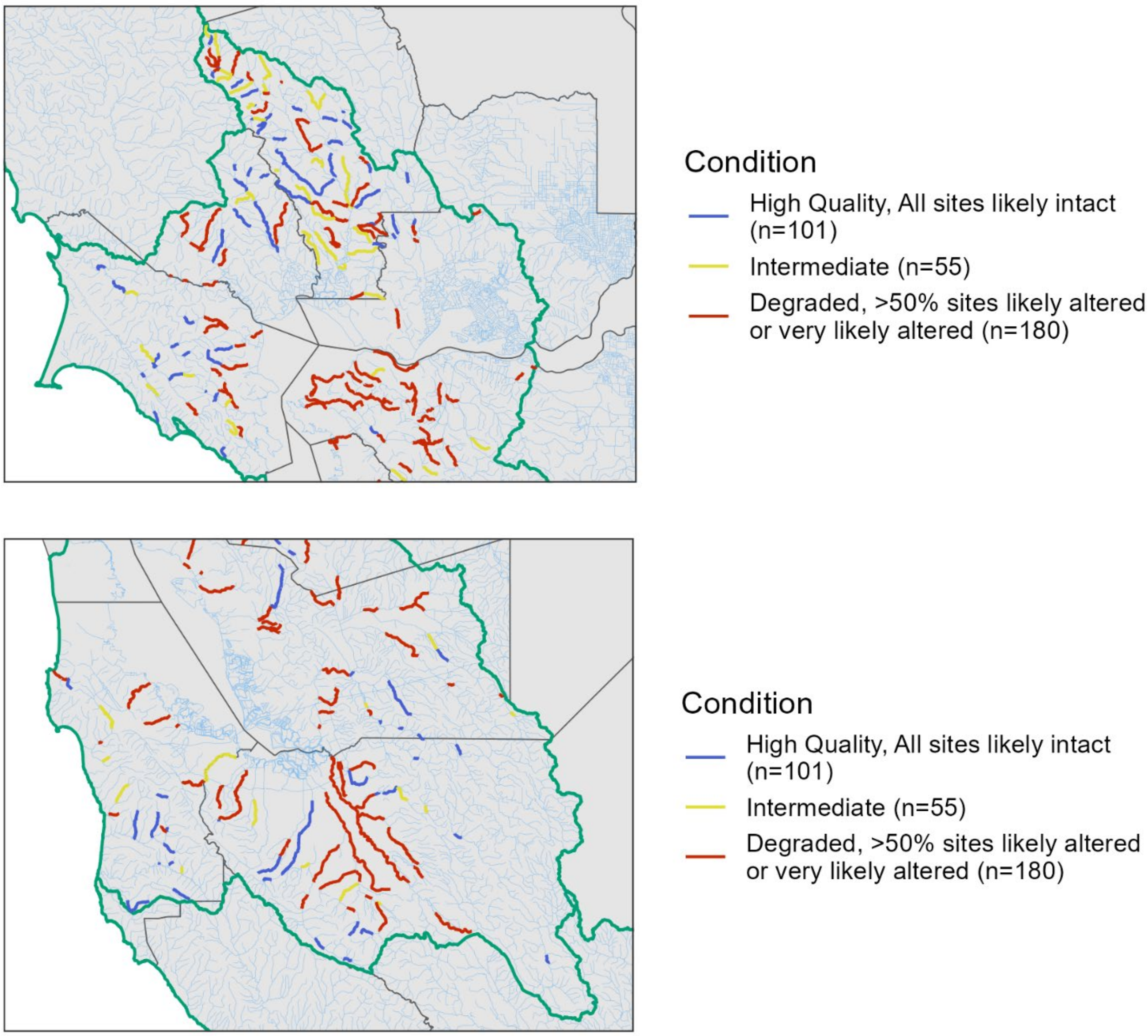


Figure 22. Stream segment condition based on consistency of CSCI scores among sites within NHD reach.

Within site variability of CSCI scores

The variability of CSCI scores for sites sampled more than once was greatest among non-reference sites (Figure 23). The mean coefficients of variation for non-reference perennial sites were 15.8%, and 15.7% for non-reference intermittent sites, with maximum values of 73.9% and 65.8%, respectively. For reference sites with repeated sampling, the mean CVs among CSCI scores were 9.4% for perennial stream sites and 12.3% for intermittent sites, with maximum CVs of 24.9% and 24.7%, respectively (Table 17, Table 18).

Table 17. The number of sites, number of samples, and mean coefficients of variability of CSCI scores for sites with repeat sampling.

Site Status	Flow Regime	Number of sites	Number of samples	Mean % CV
Reference	Perennial	19	58	9.4%
Reference	Intermittent	11	42	12.3%
Non-reference	Perennial	257	813	15.8%
Non-reference	Intermittent	135	353	15.7%

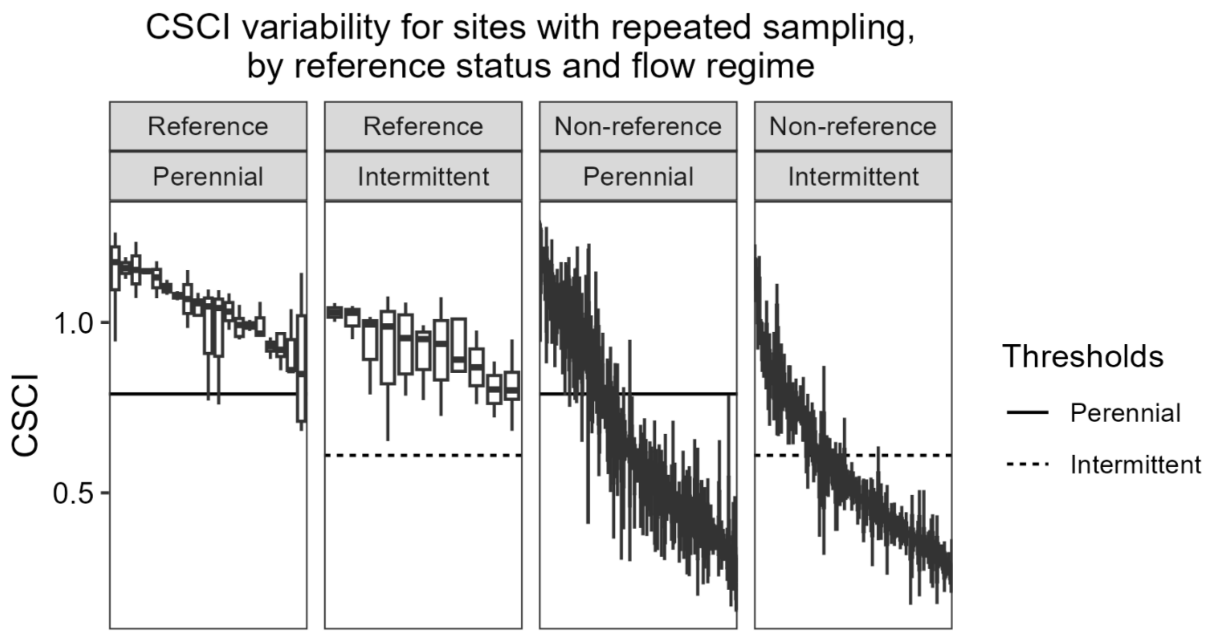


Figure 23. Variability in CSCI scores for sites sampled more than once. Each boxplot shows scores for individual sites, arranged in order of decreasing median score.

Table 18. Maximum difference in CSCI scores from sites with repeated sampling. The minimum and maximum scores are from the same station.

Number of Samples	Minimum CSCI Score	Maximum CSCI Score	Year of Minimum Score	Year of Maximum Score	Difference in Scores	Difference in Years
2	0.30	0.95	2006	2000	0.65	6
3	0.22	0.79	2009	2000	0.57	9
4	0.36	0.90	2007	2006	0.54	1
5	0.41	1.22	2000	2000	0.80	0
6	0.33	0.86	2011	2006	0.53	5
7	0.65	1.09	2021	2002	0.44	19
8	0.42	0.91	2021	2020	0.50	1
9	0.61	0.93	2015	2021	0.32	6
10	0.70	1.04	2014	2021	0.34	7
11	0.35	0.67	2004	1998	0.32	6
12	0.83	1.13	2014	2021	0.30	7

Question 2: How do indices correspond to each other?

There was a significant relationship between index scores for all indices ($p<0.05$) with relatively strong relationships identified for most index pairs (Figure 24 and Table 19). In general, the algal indices were somewhat more sensitive than the CSCI. For example, 19% had healthy scores (i.e., in the top two condition classes) for the CSCI and unhealthy scores for ASCI-D, compared with only 6% showing the reverse (Table 20). The greatest concordance among condition categories for each index pair was for the “very likely altered” category, with at least 39% of the data for both indices in this category (Table 19,Table 20). The other condition category pairs had no more than 10% of the data. This is not surprising, given that most sites were in the “very likely altered” category for CSCI and ASCI-D scores. There was a greater concordance among CSCI and ASCI-D for sites where both indicators were poor or very poor condition, compared to good or excellent condition. Specifically, of the 754 sites that had CSCI and ASCI-D scores, 446 sites were in poor or very poor condition according to both indicators, compared with 120 sites where all three indicators (i.e., CSCI, ASCI-D, and IPI) were good or excellent condition.

There was good agreement between IPI and ASCI-D for both likely intact and very likely altered conditions (Table 19,Table 22). However, the highest proportion of sites for these indices was when IPI condition was likely intact and ASCI-D was very likely altered (22% of sites), suggesting that the algal indices may be responding to water quality impacts in sites with good habitat.

CSCI also had good agreement with IPI among both likely intact (26% of sites) and very likely altered (15%) condition sites, and less agreement at sites IPI was likely intact and CSCI was very likely altered (12%).

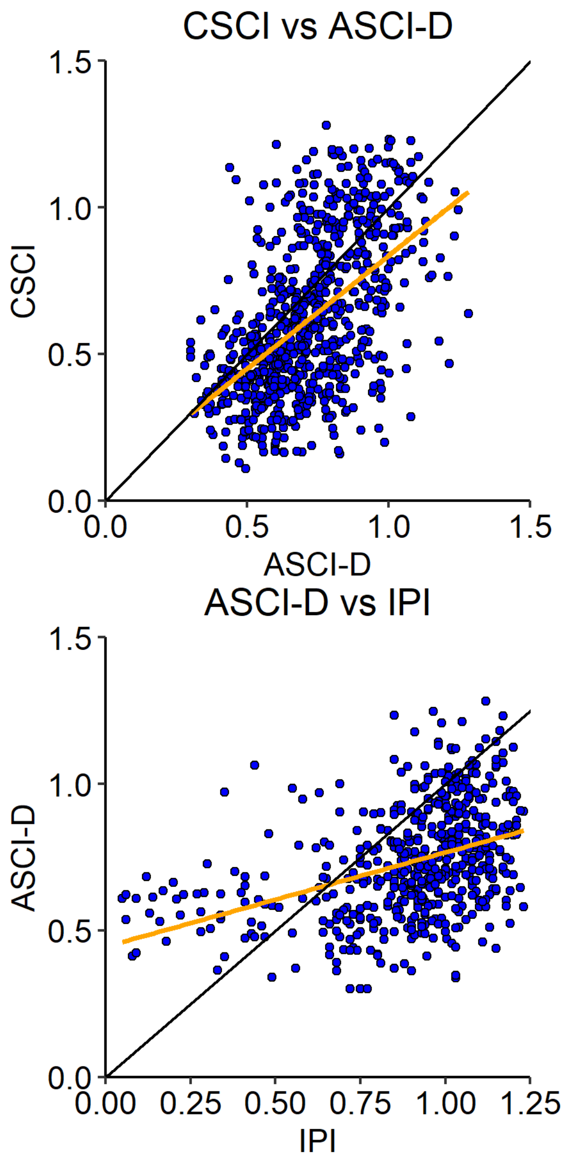


Figure 24. Concordance among CSCI, ASCI-D and IPI. The black line indicates the 1:1 relationship, while the orange line indicates the linear regression line.

Table 19. Concordance among indices using Spearman rank correlation.

Indices	Number of Sites	Spearman p-value	Spearman rho
CSCI vs ASCI-D	754	<0.001	0.55
CSCI vs IPI	600	<0.001	0.64
ASCI-D vs IPI	519	<0.001	0.44

Table 20. Concordance among CSCI and ASCI-D condition categories.

	CSCI Likely intact	CSCI Possibly altered	CSCI Likely altered	CSCI Very likely altered
ASCI-D Likely intact	59 (8%)	14 (2%)	12 (2%)	11 (1%)
ASCI-D Possibly altered	32 (4%)	15 (2%)	11 (1%)	10 (1%)
ASCI-D Likely altered	42 (6%)	21 (3%)	22 (3%)	46 (6%)
ASCI-D Very likely altered	45 (6%)	36 (5%)	78 (10%)	300 (39%)

Table 21. Concordance among CSCI and IPI condition categories.

	IPI Likely intact	IPI Possibly altered	IPI Likely altered	IPI Very likely altered
CSCI Likely intact	153 (26%)	14 (2%)	4 (1%)	0 (0%)
CSCI Possibly altered	45 (8%)	17 (3%)	8 (1%)	0 (0%)
CSCI Likely altered	64 (11%)	27 (4%)	4 (1%)	9 (2%)
CSCI Very likely altered	72 (12%)	45 (8%)	48 (8%)	90 (15%)

Table 22. Concordance among ASCI-D and IPI condition categories.

	IPI Likely intact	IPI Possibly altered	IPI Likely altered	IPI Very likely altered
ASCI-D Likely intact	66 (13%)	7 (1%)	0 (0%)	5 (1%)
ASCI-D Possibly altered	40 (8%)	8 (2%)	3 (0.6%)	2 (0.4%)
ASCI-D Likely altered	62 (12%)	19 (4%)	8 (2%)	5 (1%)
ASCI-D Very likely altered	116 (22%)	61 (12%)	48 (9%)	69 (13%)

Question 3: What stressors are associated with variability in index scores?

Correlation analysis

Water quality stressors

Index scores decreased with increasing levels of TN, TP, AFDM, specific conductivity, temperature and chlorophyll a, and increased with increasing levels of dissolved oxygen (Table 23; scatterplots are presented in Appendix B). Each of the correlations were statistically significant ($p \leq 0.01$), and for specific conductivity the relationship was relatively strong (rho < -0.50). AFDM was strongly associated with CSCI (rho = -0.56). Dissolved oxygen was positively correlated with CSCI and ASCI scores. However, the relationships between DO and biointegrity indices were unimodal (peaking at around 10 mg/L), rather than linear; therefore, the correlation coefficients do not adequately capture the strength of these relationships.

Table 23. Spearman rank correlation analysis of index scores and water quality parameters.

Index	Parameter	N	Spearman p	Spearman rho	Rho squared
CSCI	AFDM	667	<0.001	-0.56	0.32
CSCI	Specific Conductance	846	<0.001	-0.53	0.28
CSCI	TN	649	<0.001	-0.50	0.25
CSCI	Temperature	989	<0.001	-0.45	0.20
CSCI	Chlorophyll a	662	<0.001	-0.41	0.17
CSCI	Dissolved Oxygen	923	<0.001	0.28	0.08
CSCI	TP	763	<0.001	-0.26	0.07
ASCI-D	Specific Conductance	733	<0.001	-0.51	0.26
ASCI-D	Temperature	734	<0.001	-0.46	0.22
ASCI-D	AFDM	656	<0.001	-0.45	0.21
ASCI-D	TN	573	<0.001	-0.44	0.19
ASCI-D	Chlorophyll a	651	<0.001	-0.39	0.15
ASCI-D	TP	672	<0.001	-0.24	0.06
ASCI-D	Dissolved Oxygen	717	0.01	0.09	0.01

Geospatial stressors

Index scores decreased with increasing levels of land use disturbances (agriculture, urbanization, Code21, road & railroad density) and increased with increasing levels of open space (Table 23; scatterplots are presented in Appendix B). The relationship was significant ($p<0.001$) at all three landscape scales tested (1 km, 5 km, watershed). The land use attributes with the strongest relationship to CSCI and ASCI-D was urbanization ($rho \leq -0.54$) and open space ($rho \geq 0.55$).

When sites were divided by percent urban at 1 km, sites with greater urbanization tended to have a larger range of chemical stressor levels (nutrients, specific conductivity, temperature) and lower CSCI and ASCI-D (Table 25; figures are presented in Appendix B). This trend was observed for both perennial and intermittent stream sites. The results also showed that most chemical stressors were still an important factor for CSCI and ASCI-D scores at both low and high levels of urbanization.

Table 24. Spearman rank correlation of index scores vs landscape attributes. WS = watershed.

Index	Stressor	Scale	N	Spearman p	Spearman rho
CSCI	Agriculture	1 km	1,431	<0.001	-0.15
CSCI	Agriculture	5 km	1,431	<0.001	-0.28
CSCI	Agriculture	WS	1,431	<0.001	-0.29
CSCI	Urban	1 km	1,431	<0.001	-0.68
CSCI	Urban	5 km	1,431	<0.001	-0.70
CSCI	Urban	WS	1,431	<0.001	-0.73
CSCI	Open	1 km	1,431	<0.001	0.67
CSCI	Open	5 km	1,431	<0.001	0.70
CSCI	Open	WS	1,431	<0.001	0.73
CSCI	Code 21	1 km	1,431	<0.001	-0.30
CSCI	Code 21	5 km	1,431	<0.001	-0.47
CSCI	Code 21	WS	1,431	<0.001	-0.47
CSCI	Road & railroad density	1 km	1,431	<0.001	-0.60
CSCI	Road & railroad density	5 km	1,431	<0.001	-0.58
CSCI	Road & railroad density	WS	1,431	<0.001	-0.54
ASCI-D	Agriculture	1 km	753	<0.001	-0.27
ASCI-D	Agriculture	5 km	753	<0.001	-0.41
ASCI-D	Agriculture	WS	753	<0.001	-0.42
ASCI-D	Urban	1 km	753	<0.001	-0.54
ASCI-D	Urban	5 km	753	<0.001	-0.57
ASCI-D	Urban	WS	753	<0.001	-0.54
ASCI-D	Open	1 km	753	<0.001	0.55
ASCI-D	Open	5 km	753	<0.001	0.58
ASCI-D	Open	WS	753	<0.001	0.55

Index	Stressor	Scale	N	Spearman p	Spearman rho
ASCI-D	Code 21	1 km	753	<0.001	-0.30
ASCI-D	Code 21	5 km	753	<0.001	-0.41
ASCI-D	Code 21	WS	753	<0.001	-0.38
ASCI-D	Road & railroad density	1 km	753	<0.001	-0.46
ASCI-D	Road & railroad density	5 km	753	<0.001	-0.48
ASCI-D	Road & railroad density	WS	753	<0.001	-0.39

Table 25. Spearman rank correlation analysis of index scores and water quality parameters, by level of urbanization within 1km. Low = 0 – 5%, Medium = 5 – 10%, High = >10%.

Index	Parameter	Urbanization	N	Spearman p	Spearman rho	Rho squared
CSCI	TN	Low	178	<0.001	-0.30	0.09
CSCI	TN	Medium	33	0.20	-0.23	0.05
CSCI	TN	High	444	<0.001	-0.29	0.08
CSCI	TP	Low	237	0.005	-0.18	0.03
CSCI	TP	Medium	45	0.68	-0.06	0.00
CSCI	TP	High	494	<0.001	-0.21	0.04
CSCI	AFDM	Low	219	<0.001	-0.33	0.11
CSCI	AFDM	Medium	35	0.09	-0.30	0.09
CSCI	AFDM	High	424	<0.001	-0.42	0.18
CSCI	Specific Conductance	Low	283	<0.001	-0.24	0.06
CSCI	Specific Conductance	Medium	49	0.11	-0.24	0.06
CSCI	Specific Conductance	High	530	<0.001	-0.41	0.16
CSCI	Temperature	Low	392	<0.001	-0.23	0.05
CSCI	Temperature	Medium	58	0.14	-0.20	0.04
CSCI	Temperature	High	555	<0.001	-0.26	0.07
CSCI	Dissolved Oxygen	Low	366	<0.001	0.27	0.07
CSCI	Dissolved Oxygen	Medium	52	0.001	0.45	0.20
CSCI	Dissolved Oxygen	High	518	<0.001	0.24	0.06
CSCI	Chlorophyll	Low	208	0.06	-0.13	0.02
CSCI	Chlorophyll	Medium	34	0.16	-0.25	0.06
CSCI	Chlorophyll	High	423	<0.001	-0.21	0.04
ASCI-D	TN	Low	155	<0.001	-0.36	0.13
ASCI-D	TN	Medium	26	0.03	-0.42	0.18
ASCI-D	TN	High	394	<0.001	-0.23	0.05
ASCI-D	TP	Low	205	<0.001	-0.26	0.07
ASCI-D	TP	Medium	33	0.41	-0.15	0.02
ASCI-D	TP	High	436	0.003	-0.14	0.02

Index	Parameter	Urbanization	N	Spearman p	Spearman rho	Rho squared
ASCI-D	AFDM	Low	210	0.001	-0.23	0.05
ASCI-D	AFDM	Medium	31	0.44	-0.14	0.02
ASCI-D	AFDM	High	417	<0.001	-0.29	0.09
ASCI-D	Specific Conductance	Low	238	<0.001	-0.31	0.09
ASCI-D	Specific Conductance	Medium	36	0.07	0.30	0.09
ASCI-D	Specific Conductance	High	461	<0.001	-0.41	0.17
ASCI-D	Temperature	Low	240	0.29	-0.07	0.00
ASCI-D	Temperature	Medium	36	0.27	-0.19	0.04
ASCI-D	Temperature	High	460	<0.001	-0.34	0.12
ASCI-D	Dissolved Oxygen	Low	237	0.39	-0.06	0.00
ASCI-D	Dissolved Oxygen	Medium	36	0.85	0.03	0.00
ASCI-D	Dissolved Oxygen	High	446	0.11	0.08	0.01
ASCI-D	Chlorophyll	Low	204	0.001	-0.23	0.06
ASCI-D	Chlorophyll	Medium	30	0.09	-0.31	0.10
ASCI-D	Chlorophyll	High	419	<0.001	-0.21	0.04

Relative risk of water quality contaminants

Relative risks of elevated stress levels were greater for CSCI scores than for ASCI, but all indices showed similar patterns (Figure 25, Table 26). Channel modification status and poor IPI scores were particularly high risks for low CSCI scores, as were indicators of eutrophication (e.g., benthic ash-free dry mass). The risk from sulfate was particularly high for ASCI scores, but was not significantly elevated for CSCI scores. Several contaminants (alkalinity, As, Cd, Cr, Pb, Zn, ammonia) did not exceed the thresholds in Table 7, and therefore we could not evaluate the risk from these stressors.

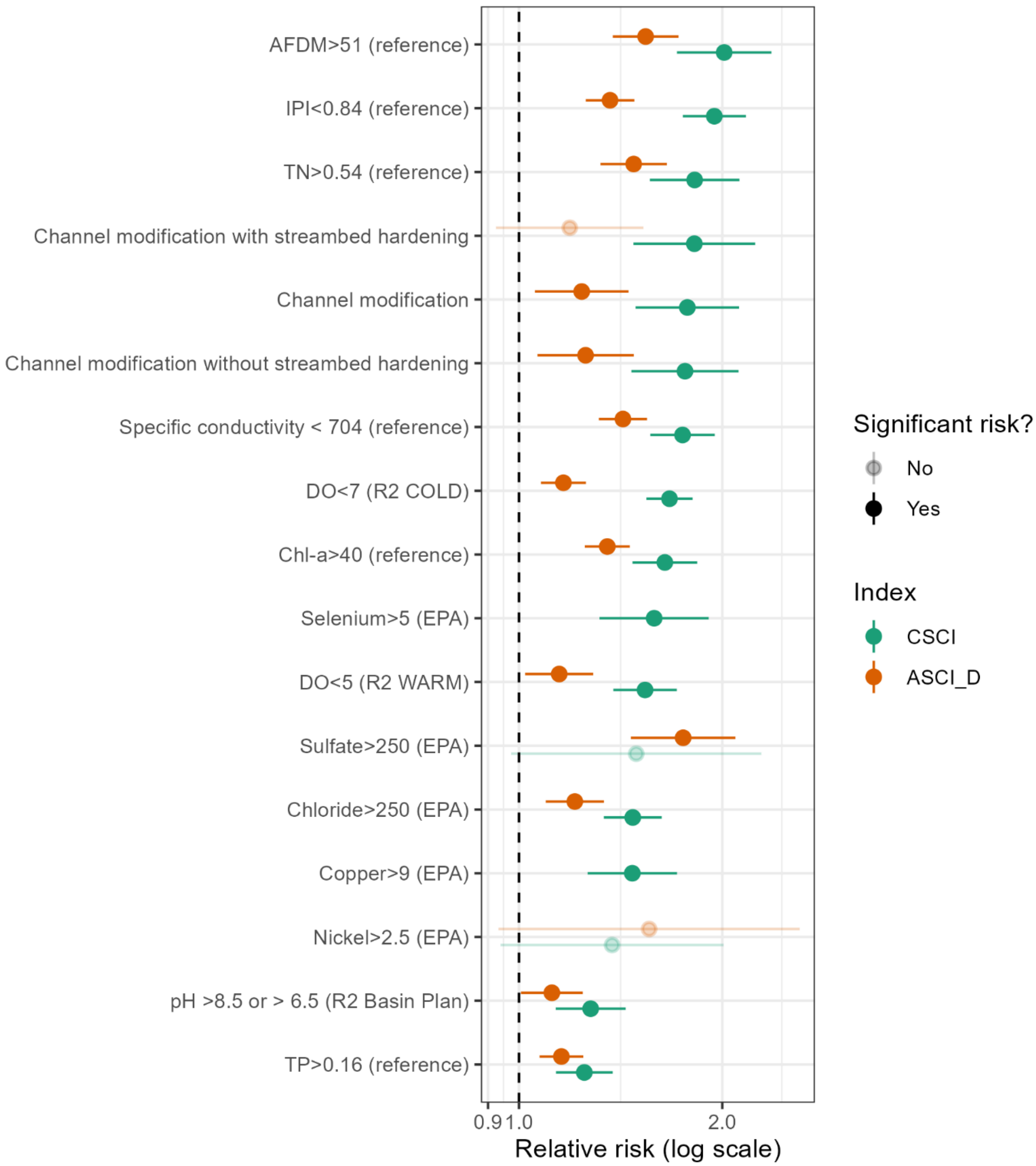


Figure 25. Relative risk of site being degraded when contaminant exceeds a threshold. Horizontal lines represent the 95% confidence interval around the estimated risk. The vertical dashed line indicates a relative risk of 1 (that is, no increased risk). If the confidence interval includes 1, the relative risk is not considered statistically significant based on the available data.

Table 26. Relative risks for major water quality and habitat stressors. NA: Not applicable, or relative risk not assessed due to insufficient data. Risk = relative risk of site being degraded when contaminant exceeds a threshold; L95 = lower 95% confidence interval; U95 = upper 95% confidence interval.

Stressor	Threshold	Threshold source	Index	Stressed and degraded (n)	Stressed and healthy (n)	Unstressed and degraded (n)	Unstressed and healthy (n)	Risk	L95	U95
Ash-free dry mass	51	Reference	ASCI_D	389	43	138	98	1.54	1.38	1.72
Ash-free dry mass	51	Reference	CSCI	345	87	98	149	2.01	1.71	2.36
Alkalinity as CaCO3	20000	EPA	ASCI_D	0	0	275	75	NA	NA	NA
Alkalinity as CaCO3	20000	EPA	CSCI	0	0	325	153	NA	NA	NA
Ammonia as N	1.71	EPA	ASCI_D	0	0	522	126	NA	NA	NA
Ammonia as N	1.71	EPA	CSCI	0	0	493	231	NA	NA	NA
Arsenic	150	EPA	ASCI_D	0	0	17	6	NA	NA	NA
Arsenic	150	EPA	CSCI	0	0	44	25	NA	NA	NA
Cadmium	2.2	EPA	ASCI_D	0	0	16	6	NA	NA	NA
Cadmium	2.2	EPA	CSCI	0	0	40	19	NA	NA	NA
Channel modification	Modified vs. natural	NA	ASCI_D	21	1	531	142	1.21	1.10	1.34
Channel modification	Modified vs. natural	NA	CSCI	23	1	487	262	1.47	1.34	1.63
Channel modification	Hard-bottom vs. natural	NA	ASCI_D	273	22	252	116	1.35	1.25	1.46
Channel modification	Hard-bottom vs. natural	NA	CSCI	250	47	193	184	1.64	1.47	1.84
Channel modification	Soft-bottom vs. natural	NA	ASCI_D	12	2	62	24	1.19	0.92	1.53
Channel modification	Soft-bottom vs. natural	NA	CSCI	20	2	75	75	1.82	1.48	2.24
Chlorophyll-a	40	Reference	ASCI_D	38	4	62	24	1.25	1.07	1.48
Chlorophyll-a	40	Reference	CSCI	59	8	75	75	1.76	1.47	2.11
Chloride	250	EPA	ASCI_D	50	6	62	24	1.24	1.06	1.45

Stressor	Threshold	Threshold source	Index	Stressed and degraded (n)	Stressed and healthy (n)	Unstressed and degraded (n)	Unstressed and healthy (n)	Risk	L95	U95
Chloride	250	EPA	CSCI	79	10	75	75	1.78	1.49	2.12
Chromium	180	EPA	ASCI_D	0	0	16	6	NA	NA	NA
Chromium	180	EPA	CSCI	0	0	43	24	NA	NA	NA
Copper	9	EPA	ASCI_D	0	0	24	7	NA	NA	NA
Copper	9	EPA	CSCI	1	0	53	25	1.47	1.26	1.71
Dissolved oxygen	5	R2 Basin Plan (WARM)	ASCI_D	106	13	467	143	1.16	1.08	1.26
Dissolved oxygen	5	R2 Basin Plan (WARM)	CSCI	123	10	444	358	1.67	1.54	1.81
Dissolved oxygen	7	R2 Basin Plan (COLD)	ASCI_D	34	4	539	152	1.15	1.02	1.29
Dissolved oxygen	7	R2 Basin Plan (COLD)	CSCI	40	4	527	364	1.54	1.38	1.71
IPI	0.84	Reference	ASCI_D	130	10	258	121	1.36	1.26	1.48
IPI	0.84	Reference	CSCI	151	12	208	229	1.95	1.75	2.17
Lead	52	EPA	ASCI_D	0	0	15	6	NA	NA	NA
Lead	52	EPA	CSCI	0	0	39	21	NA	NA	NA
Nickel	2.5	EPA	ASCI_D	10	1	7	5	1.56	0.93	2.60
Nickel	2.5	EPA	CSCI	27	10	17	15	1.37	0.94	2.01
Selenium	5	EPA	ASCI_D	0	0	16	6	NA	NA	NA
Selenium	5	EPA	CSCI	3	0	41	24	1.59	1.32	1.91
Specific conductivity	704	Reference	ASCI_D	351	31	234	129	1.43	1.31	1.55
Specific conductivity	704	Reference	CSCI	348	77	203	230	1.75	1.56	1.95
Sulfate	250	EPA	ASCI_D	3	0	52	39	1.75	1.46	2.09
Sulfate	250	EPA	CSCI	6	2	88	87	1.49	0.97	2.28
Total nitrogen	0.54	Reference	ASCI_D	363	29	119	71	1.48	1.32	1.66
Total nitrogen	0.54	Reference	CSCI	365	77	98	118	1.82	1.56	2.12
Total phosphorus	0.16	Reference	ASCI_D	127	16	415	125	1.16	1.07	1.24
Total phosphorus	0.16	Reference	CSCI	146	39	372	217	1.25	1.13	1.38

Stressor	Threshold	Threshold source	Index	Stressed and degraded (n)	Stressed and healthy (n)	Unstressed and degraded (n)	Unstressed and healthy (n)	Risk	L95	U95
Zinc	120	EPA	ASCI_D	0	0	15	6	NA	NA	NA
Zinc	120	EPA	CSCI	0	0	41	24	NA	NA	NA
pH	6.5 to 8.5	R2 Basin Plan	ASCI_D	53	8	532	153	1.12	1.01	1.24
pH	6.5 to 8.5	R2 Basin Plan	CSCI	62	14	499	282	1.28	1.13	1.44

CONCLUSIONS

Condition of streams in the Bay Area

This study looked at biological condition from a very large and comprehensive dataset in the San Francisco Bay Area. The samples were collected from across a range of spatial, temporal and stressor gradients, including a total of 95 reference sites. Within the Bay Area, 64% sampled sites appear to be in poor or very poor biological condition, underscoring a need to develop strategies to protect conditions in the remaining healthy streams and improve conditions where biological conditions are poor.

The use of a provisional CSCI threshold for intermittent streams demonstrates one approach to successfully integrate intermittent and perennial streams in comprehensive regional stream assessments. This approach was possible because the Water Board collected flow observation data in summer from all 1,489 bioassessment sites, classifying these stream reaches as either perennial or intermittent. The coding and analysis approach to evaluate CSCI thresholds with an alternative threshold is available. In the San Francisco Bay Area, the ASCI-D and IPI scores for reference sites were equivalent for perennial and intermittent streams. Therefore, there is no justification for using an alternative threshold for ASCI-D and IPI in intermittent San Franciso Bay Area streams.

The alternative CSCI threshold for northern California intermittent streams should be viewed as provisional, and the numeric value is likely to change as new data become available. Although this report used a single value calculated for all of northern California, it is possible that a different approach (e.g., different thresholds applied to intermittent streams in different regions or different environmental settings) may be appropriate. SWAMP's bioassessment program is advised to continue to collect and evaluate data from intermittent reference sites throughout the state to support these investigations.

Concordance among bioassessment indices

This study underscores the value of using multiple indicators to assess stream condition. The CSCI and ASCI indices provide complementary information about stream condition, as indicated by their high levels of concordance. The fact that the ASCI has a somewhat weaker relationship with the IPI and channel modification status underscores its value in tracking the impacts of water quality in streams where habitat is heavily degraded. It is also important to use multiple indicators as they respond differently to various water quality and habitat stressors.

For habitat assessments, we recommend the continued collection of physical habitat using the SWAMP protocol (Ode et al. 2016a). However, the IPI may not be the best tool for interpreting physical habitat data as it can yield very high scores for reaches widely viewed as having degraded habitat (A.C. Rehn, personal communication). The SWAMP bioassessment workgroup has plans to recalibrate the index due to its relatively poor sensitivity. The inability of this index to differentiate between reference and non-reference sites suggests that a new IPI may be useful in the Bay Area as well.

Stressors associated with poor biological conditions

This study used multiple approaches to identify key stressors impacting aquatic communities. At a broad scale, urbanization in the watershed had a strong influence on both aquatic macroinvertebrates and algae, as well as the impacts of chemical stressors on these indicators. Both the correlation and risk analyses identified AFDM and TN (eutrophic indicators) as important stressors of aquatic communities. The risk analysis further showed that poor benthic macroinvertebrate communities were impacted by habitat degradation (channel modification and the IPI index) and chloride, whereas poor algal communities were also associated with sulfate and specific conductivity. These results highlight the complexity of assessing the impacts of aquatic communities, and also implementing effective watershed management plans to protect them.

Many of the chemical and habitat stressors identified in this analysis are directly related to urbanization, the dominant land use in the region. Although aquatic communities may benefit from localized restoration, watershed-scale approaches that ameliorate the impacts of land use are also needed.

Opportunities and potential for protection or restoration doubtlessly vary across sites. For example, degraded streams in modified channels or draining highly developed watersheds may have less potential for improvement than degraded streams in natural channels and in watersheds with low levels of development. The comparison to predicted ranges of CSCI scores for different levels of landscape alteration (that is, the SCAPE analyses presented in this study) provide a first-cut approach to support stream restoration prioritization. However, priorities may also consider potential stressors (e.g., through causal assessments; Norton et al. 2014, U.S. Environmental Protection Agency 2017, Gillett et al. 2023) and likely success of strategies to control sources of stressors. Furthermore, a prioritization framework should not only consider the ecological benefits of restoration or protection, but the social benefits and environmental justice implications of how these priorities are set.

This study points towards steps that California’s Surface Water Ambient Monitoring Program can take to improve the capacity to assess streams. The approach of using different thresholds to assess intermittent versus perennial streams requires knowledge of the flow conditions in streams which is not a component of the current bioassessment protocol (Ode et al. 2016a). Developing a method to assess and document a stream’s flow duration would facilitate the assessment of these streams. Likewise, documenting the type of channel engineering at sites where bioassessment is conducted would provide context to interpreting index scores.

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Appendix A: County-level results

Table 5, reproduced in part below, shows the number of sites and samples in each county with bioassessment data.

Table 5. Sample distribution among subpopulations for CSCI. Flow duration and reference status were not available for every site. Channel modification status was only available for a subset of sites in Santa Clara county.

Classification	Subpopulation	Number of sites	Number of samples
Entire region	Bay Area	1432	2276
County	Alameda	320	475
County	Contra Costa	245	504
County	Marin	124	248
County	Napa	188	246
County	San Francisco	2	2
County	San Mateo	177	289
County	Santa Clara	310	409
County	Santa Cruz	2	3
County	Solano	36	37
County	Sonoma	28	63

Conditions of streams in the region and in each county

Alameda, Contra Costa, Santa Clara and Solana Counties had the highest proportion of degraded sites for these indicators (Table 27, Figure 26 to Figure 32). ASCI-D scores were also low in Sonoma County, while CSCI scores were marginal in this county. ASCI-D scores tended to be relatively high in Napa County, and CSCI scores tended to be high in Marin County. CSCI and ASCI-D scores indicated intact conditions in Santa Cruz County, although the results represent only two sampling locations for CSCI and one site for ASCI.

In contrast to the CSCI and ASCI scores, IPI scores were above the 10th percentile reference threshold at the majority of sites in Water Board Region 2 (73%), indicating that intact physical habitat conditions were widespread. The highest overall IPI scores were in Marin, Napa, San Mateo, Santa Clara and Santa Cruz Counties, each with >80% intact sites. Overall CRAM scores indicated degraded habitat conditions in Water Board Region 2 (63% of sites), although the number of sites evaluated using CRAM was relatively low (41 sites total). The highest proportion of intact CRAM scores were identified in Napa County (75% sites), while the lowest CRAM scores were in Alameda, Contra Costa, Solano and Sonoma Counties (0% intact sites, although $\leq$4 sites were assessed in each of these counties).

Table 27. Summary of index scores by county and all of Water Board Region 2.

Index	County	N	Likely intact (%)	Possibly altered (%)	Likely altered (%)	Very likely altered (%)	Mean	SD
CSCI	Water Board Region 2	1,432	26	10	18	46	0.63	0.26
CSCI	Alameda	320	14	8	15	63	0.51	0.23
CSCI	Contra Costa	245	8	6	14	72	0.48	0.16
CSCI	Marin	124	48	13	15	24	0.78	0.26
CSCI	Napa	188	46	16	28	10	0.76	0.24
CSCI	San Francisco	2	0	0	0	100	0.32	0.02
CSCI	San Mateo	177	36	12	14	38	0.74	0.29
CSCI	Santa Clara County	310	25	12	23	40	0.66	0.24
CSCI	Santa Cruz	2	100	0	0	0	1.02	0.09
CSCI	Solano	36	14	8	14	64	0.52	0.21
CSCI	Sonoma	28	43	11	7	39	0.67	0.32
ASCI-D	Water Board Region 2	753	13	9	17	61	0.72	0.18
ASCI-D	Alameda	205	6	6	15	73	0.66	0.18
ASCI-D	Contra Costa	92	10	3	12	75	0.66	0.16
ASCI-D	Marin	43	26	21	23	30	0.83	0.15
ASCI-D	Napa	41	46	12	17	24	0.90	0.21
ASCI-D	San Mateo	124	15	15	26	44	0.78	0.15
ASCI-D	Santa Clara	203	12	8	18	62	0.72	0.18
ASCI-D	Santa Cruz	1	100	0	0	0	1.14	0.00
ASCI-D	Solano	31	3	6	13	77	0.66	0.17
ASCI-D	Sonoma	13	0	8	0	92	0.63	0.12

Index	County	N	Likely intact (%)	Possibly altered (%)	Likely altered (%)	Very likely altered (%)	Mean	SD
IPI	Water Board Region 2	607	56	17	11	16	0.90	0.24
IPI	Alameda	163	34	20	13	33	0.77	0.29
IPI	Contra Costa	72	43	22	17	18	0.86	0.20
IPI	Marin	51	88	6	4	2	1.01	0.14
IPI	Napa	44	86	9	2	2	1.06	0.13
IPI	San Mateo	95	65	18	6	11	0.96	0.22
IPI	Santa Clara	144	67	14	9	10	0.95	0.20
IPI	Santa Cruz	1	100	0	0	0	0.98	NA
IPI	Solano	21	19	24	33	24	0.79	0.21
IPI	Sonoma	16	25	44	25	6	0.87	0.10

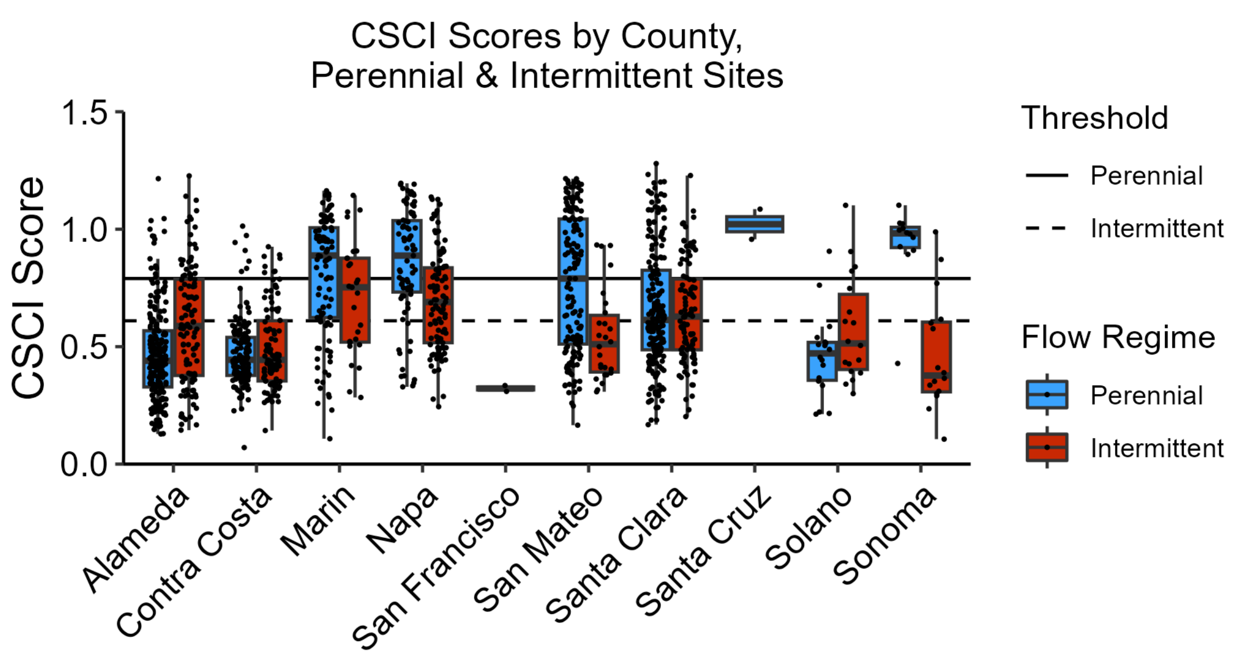

Figure 26. CSCI scores by county. Each point represents the average score at a sampling location, with circles representing possible outliers. The horizontal lines are the 10th percentile reference thresholds (perennial: 0.79; intermittent: 0.61).

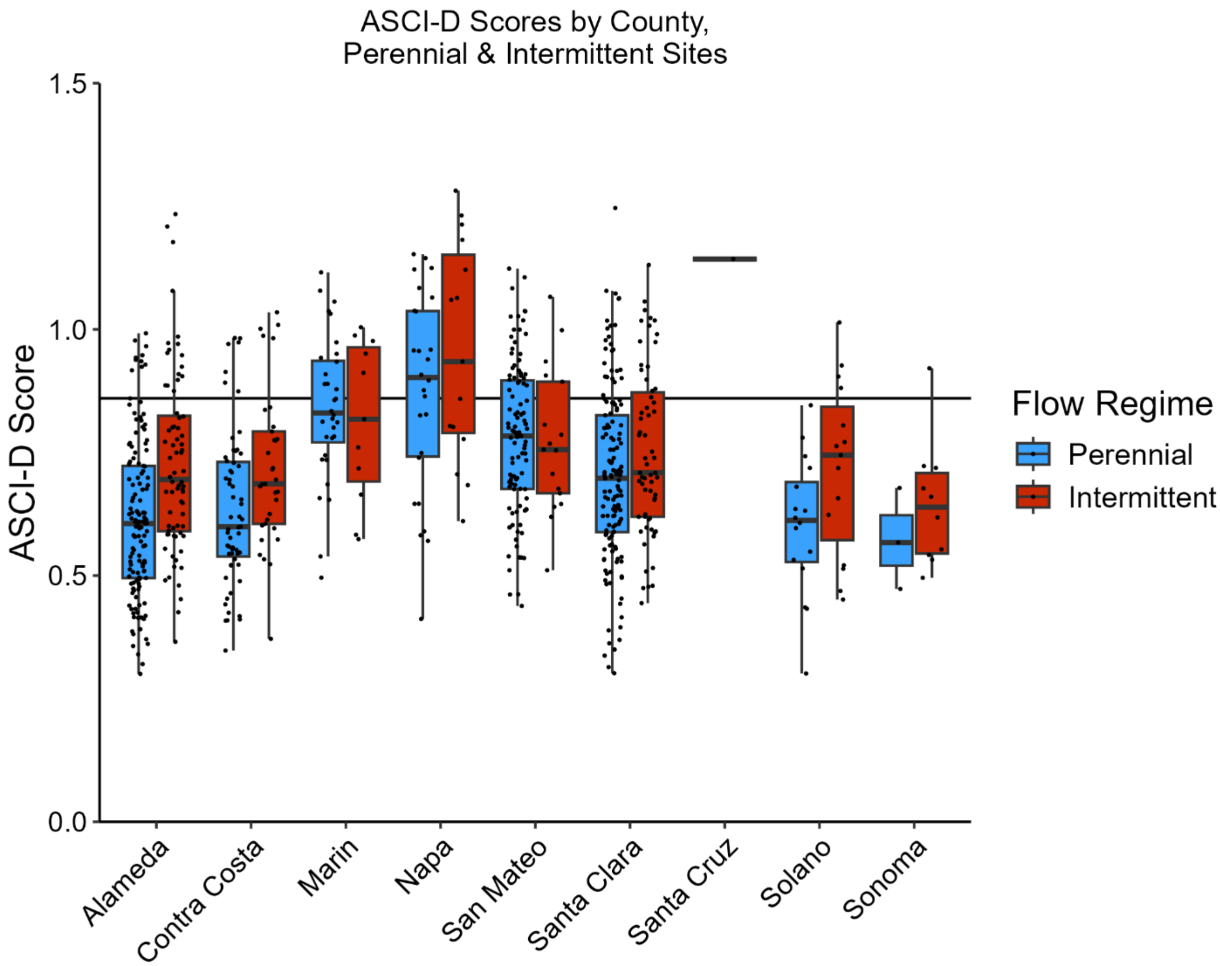

Figure 27. ASCI-D scores by county. Each point represents the score at a sampling location, with circles representing possible outliers. The horizontal line is the 10th percentile reference threshold (0.86).

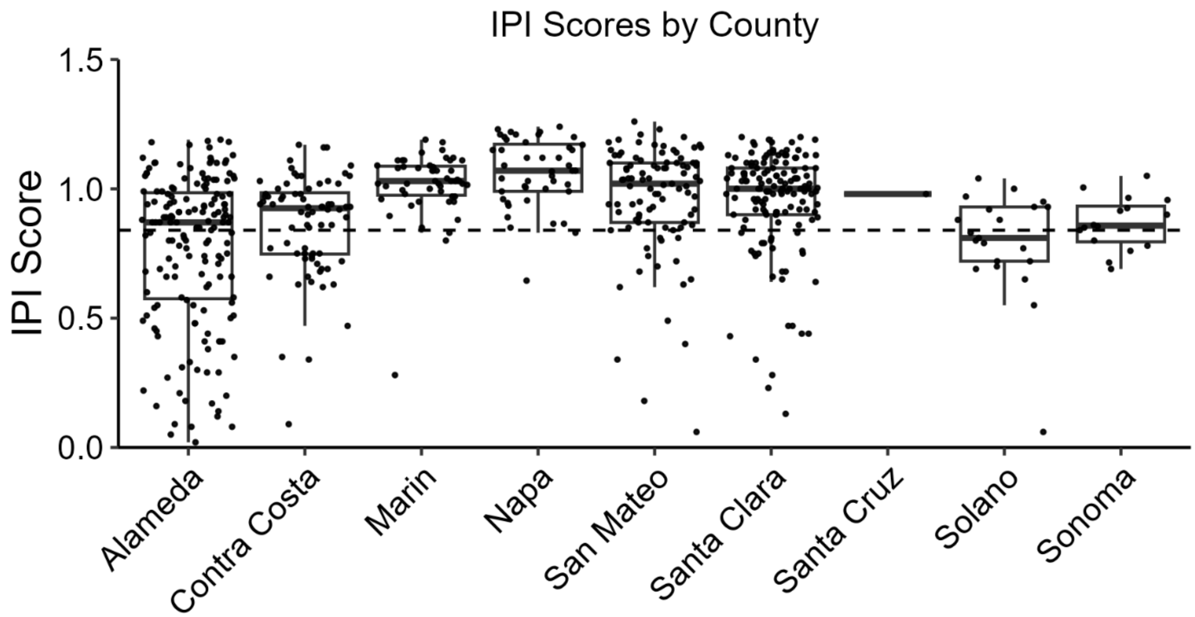

Figure 28. IPI scores by county. Each point represents the score at a sampling location, with circles representing possible outliers. The dashed horizontal line is the 10th percentile reference threshold (0.84).

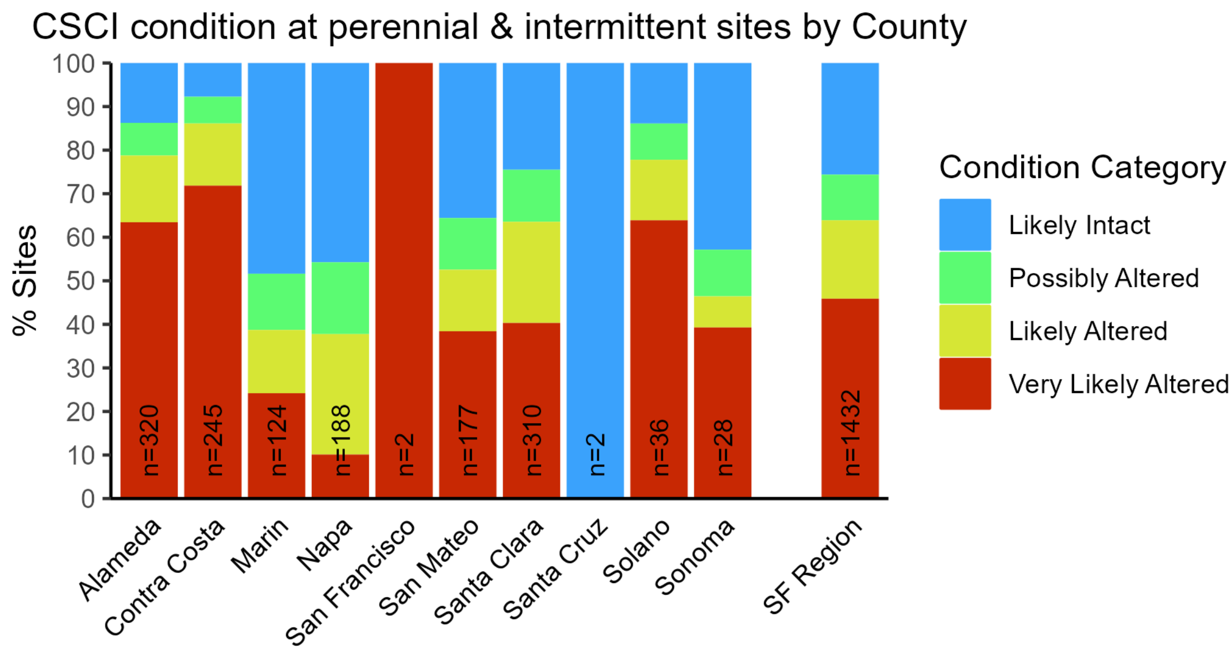

Figure 29. CSCI condition by county and total Water Board Region 2. The numbers in the plot indicate the total number of sites per county.

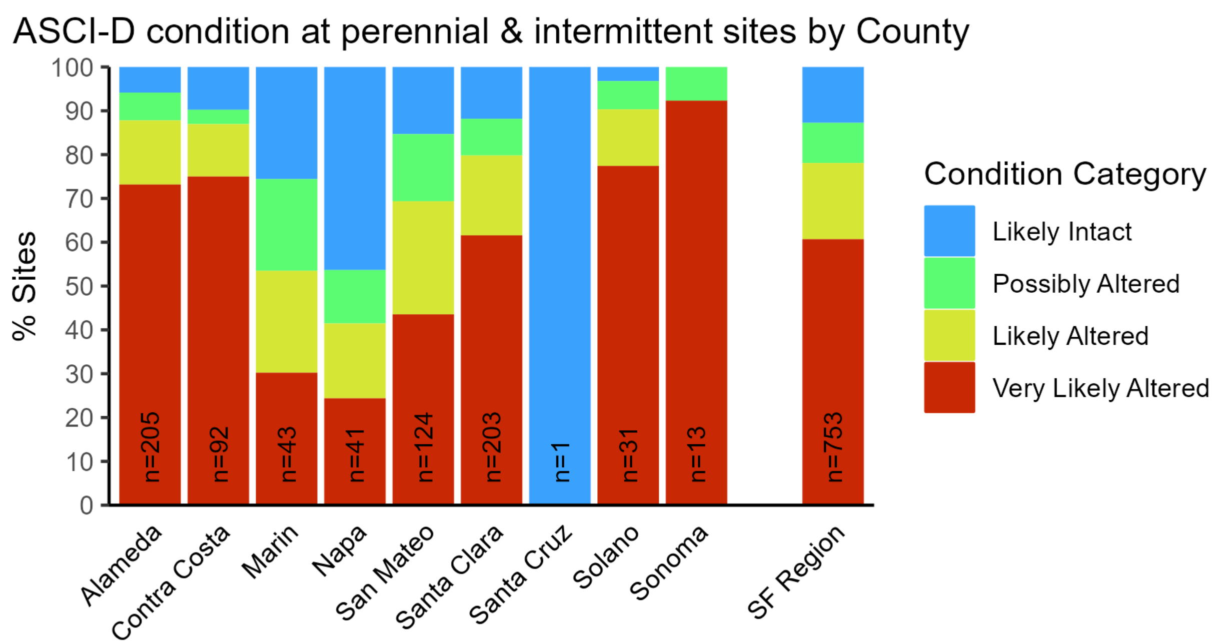

Figure 30. ASCI-D condition by county and total Water Board Region 2. The numbers in the plot indicate the total number of sites per county.

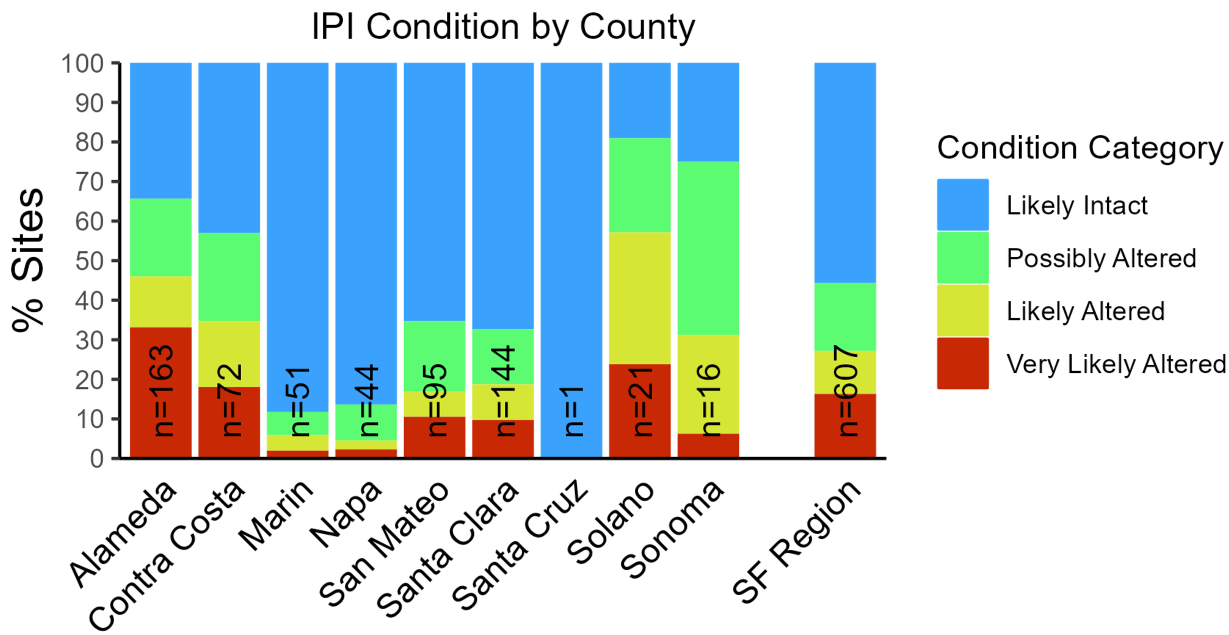

Figure 31. IPI condition by county and total Water Board Region 2. The numbers in the plot indicate the total number of sites per county.

Evaluation of Landscape Constraints

Alameda, Contra Costa, Napa, San Francisco, Solano and Sonoma Counties exceeded the regional rate of constrained stream length, while Marin, San Mateo, Santa Clara and Santa Cruz Counties had the highest rate of “possibly-”, “likely-” or “very likely unconstrained” stream length (Table 28, Figure 32). Santa Cruz only had four km of stream in Water Board Region 2.

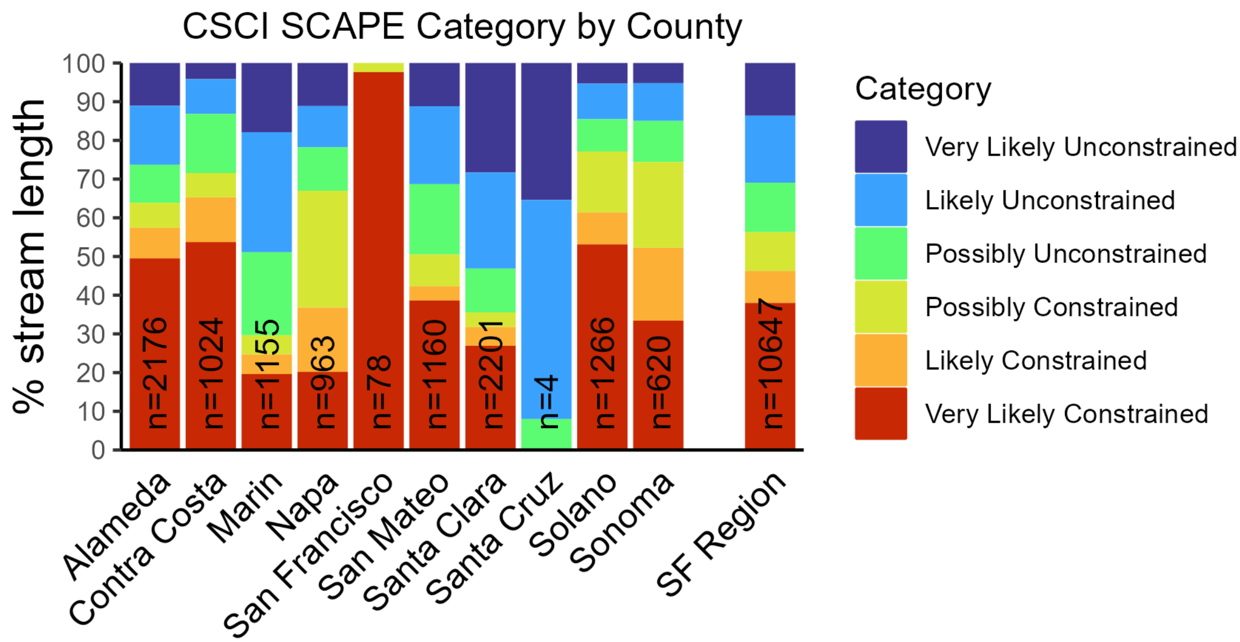

Figure 32. Proportion of stream segment length predicted in each Stream Classification and Priority Explorer (SCAPE) category, by county and all of Water Board Region 2. The numbers in the plot indicate the total number of sites per county.

Table 28. Percentage of stream kilometers predicted in each Stream Classification and Priority Explorer (SCAPE) category, by county and Water Board Region 2.

Subpopulation	Very Likely Unconstrained	Likely Unconstrained	Possibly Unconstrained	Possibly Constrained	Likely Constrained	Very Likely Constrained
Water Board Region 2	13.6%	17.3%	12.8%	10.1%	8.3%	38.0%
Alameda	11.1%	15.2%	9.8%	6.5%	7.9%	49.5%
Contra Costa	4.2%	9.0%	15.3%	6.3%	11.6%	53.7%
Marin	17.9%	31.0%	21.5%	4.9%	5.1%	19.6%
Napa	11.1%	10.6%	11.3%	30.2%	16.6%	20.2%
San Francisco	0.0%	0.0%	0.0%	2.3%	0.0%	97.7%
San Mateo	11.2%	20.1%	18.2%	8.3%	3.6%	38.6%
Santa Clara	28.3%	24.8%	11.3%	3.8%	4.8%	26.9%
Santa Cruz	35.4%	56.6%	8.0%	0.0%	0.0%	0.0%
Solano	5.3%	9.2%	8.3%	15.8%	8.3%	53.1%
Sonoma	5.2%	9.8%	10.6%	22.2%	18.8%	33.4%

Appendix B: Correlational analysis of stressor relationships with bioassessment index scores

Water quality stressors

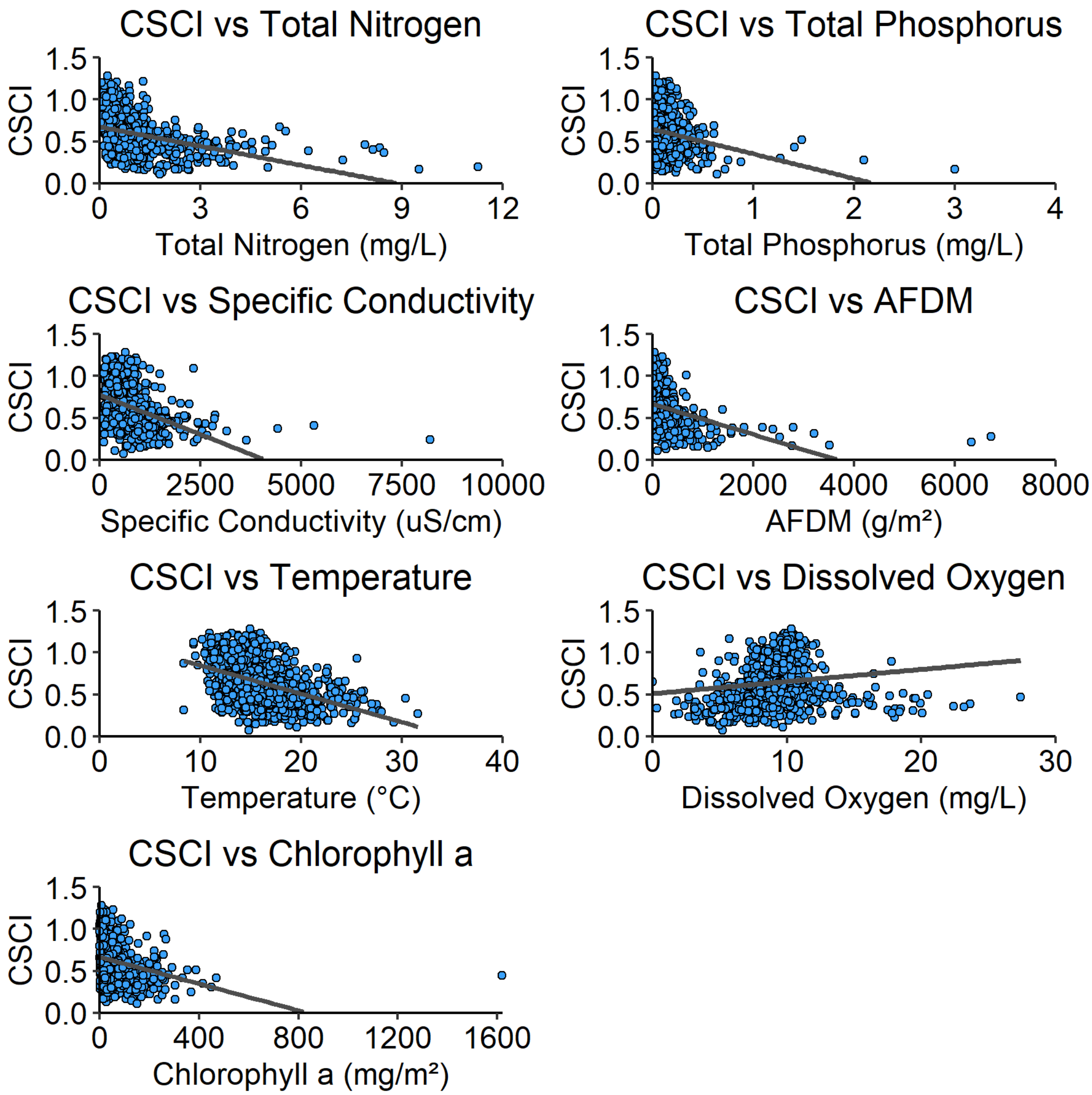

Figure 33. CSCI vs chemistry stressors. The grey line indicates the linear regression line.

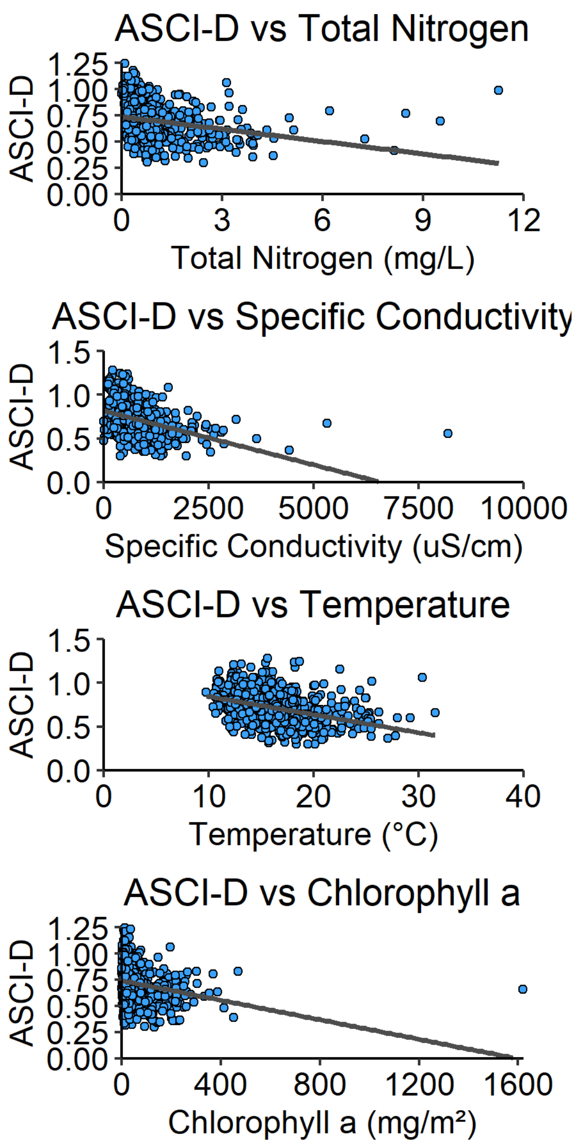

Figure 34. ASCI-D vs chemistry stressors. The grey line indicates the linear regression line.

Geospatial stressors

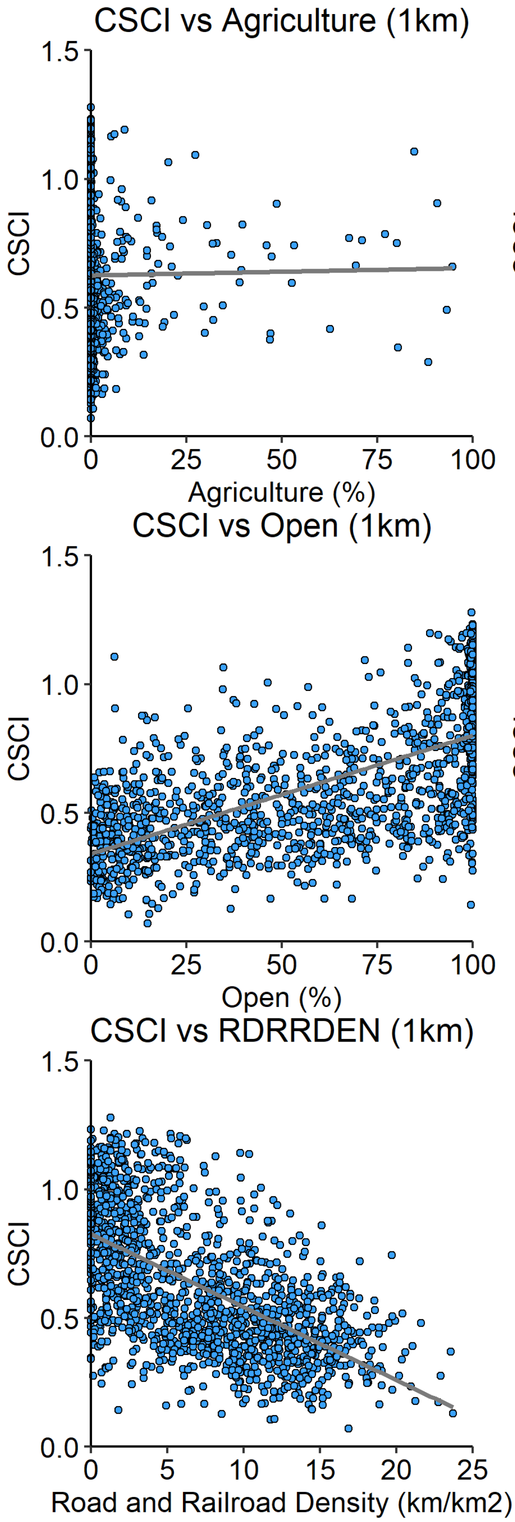

Figure 35. CSCI by landscape attributes at 1km upstream of sampling location. The grey line is the linear regression line.

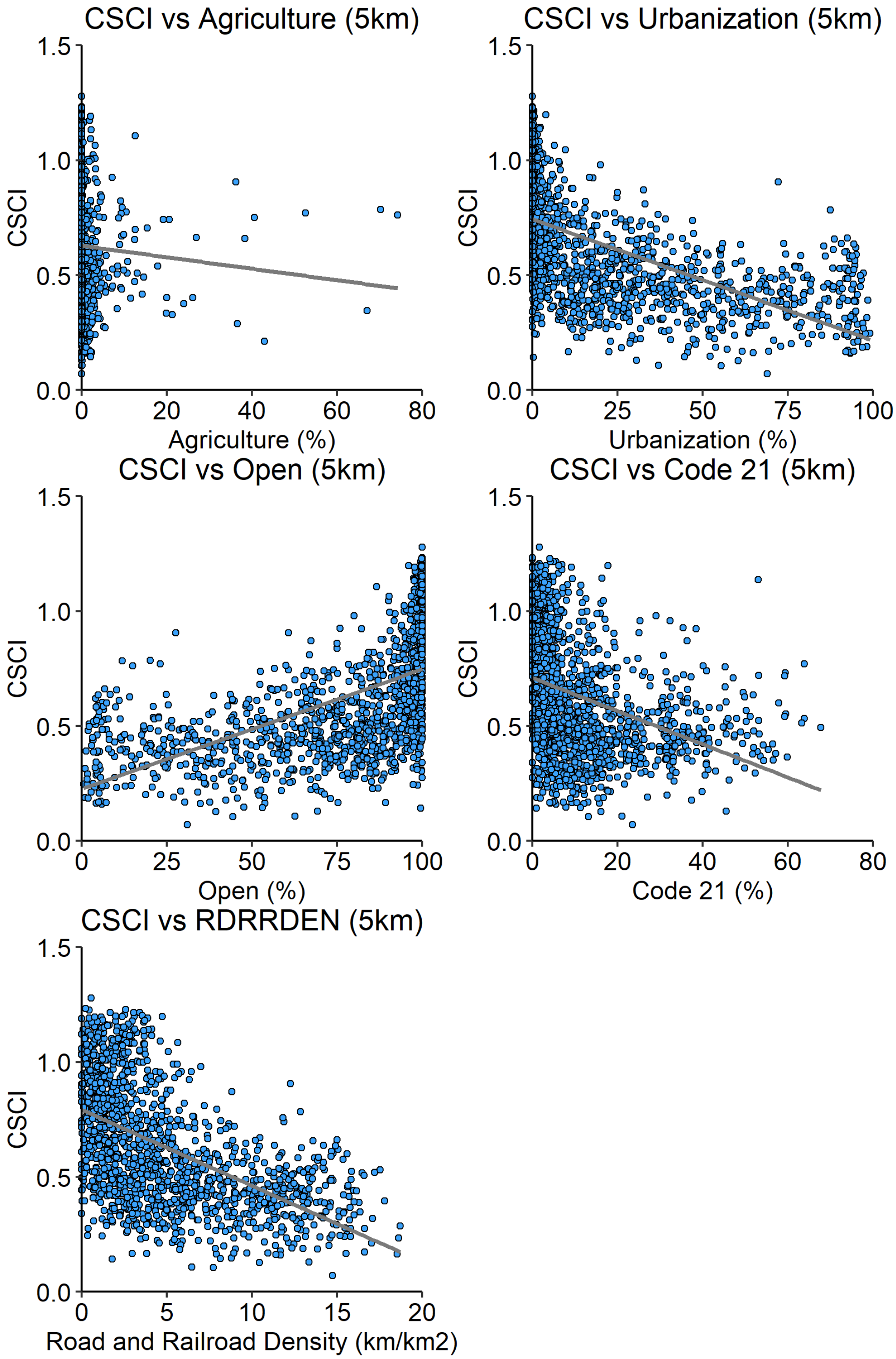

Figure 36. CSCI by landscape attributes at 5km upstream of sampling location. The grey line is the linear regression line.

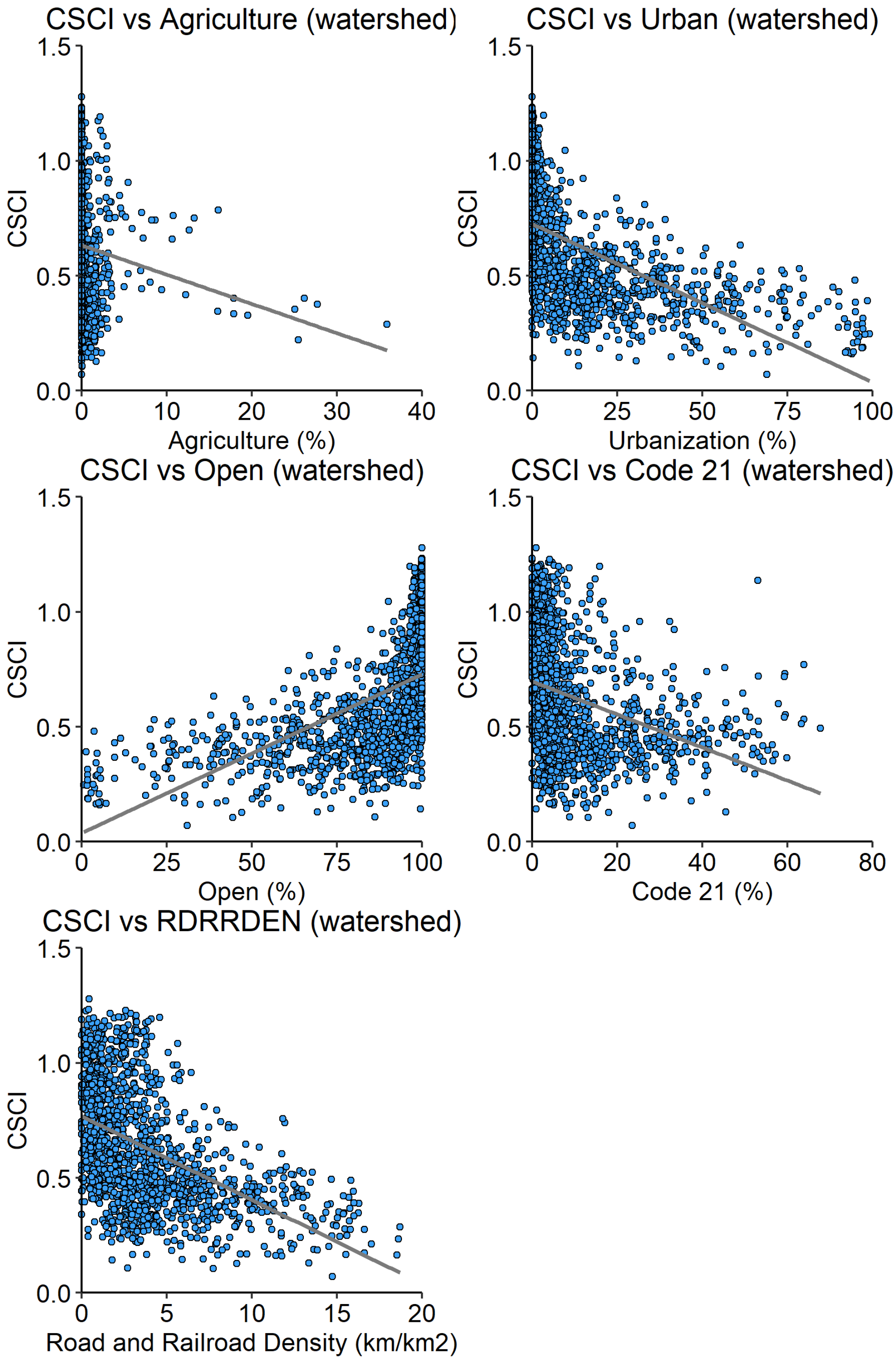

Figure 37. CSCI by landscape attributes for the watershed upstream of sampling location. The grey line is the linear regression line.

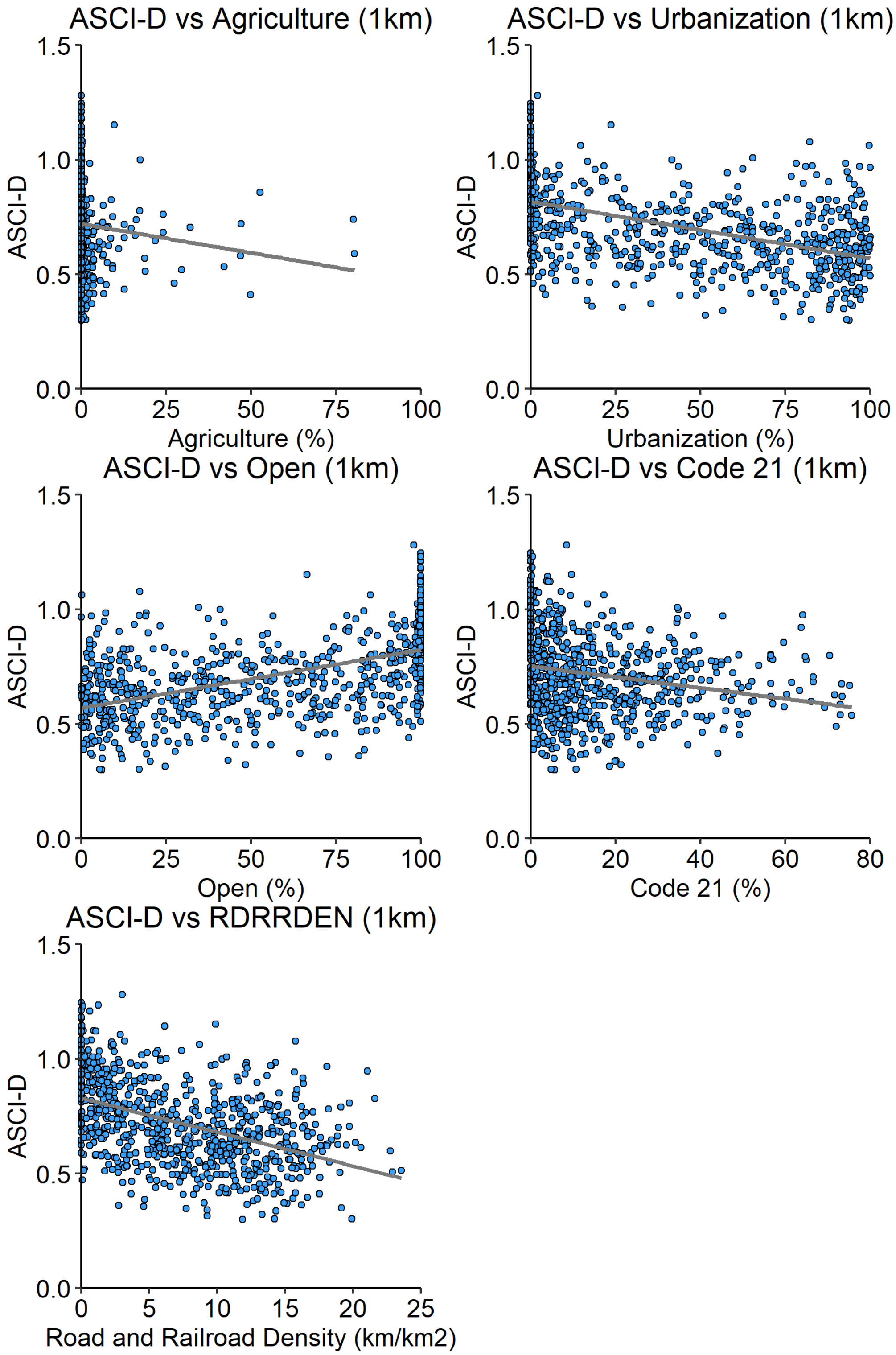

Figure 38. ASCI-D by landscape attributes at 1 km upstream of sampling location. The grey line is the linear regression line.

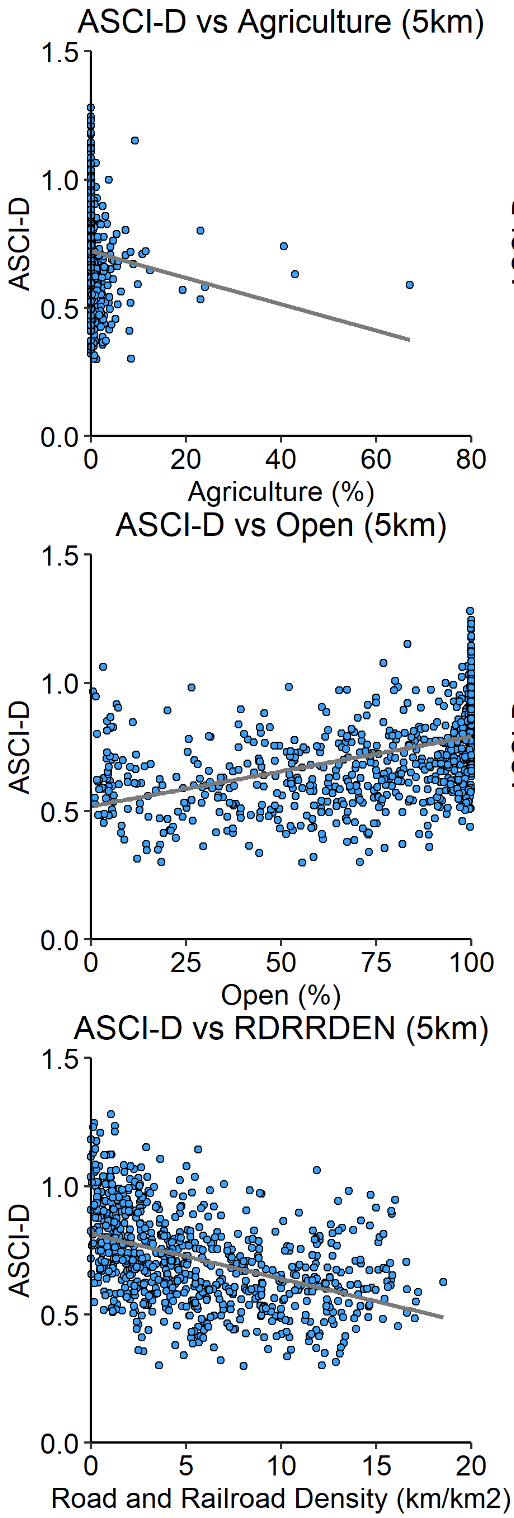

Figure 39. ASCI-D by landscape attributes at 5 km upstream of sampling location. The grey line is the linear regression line.

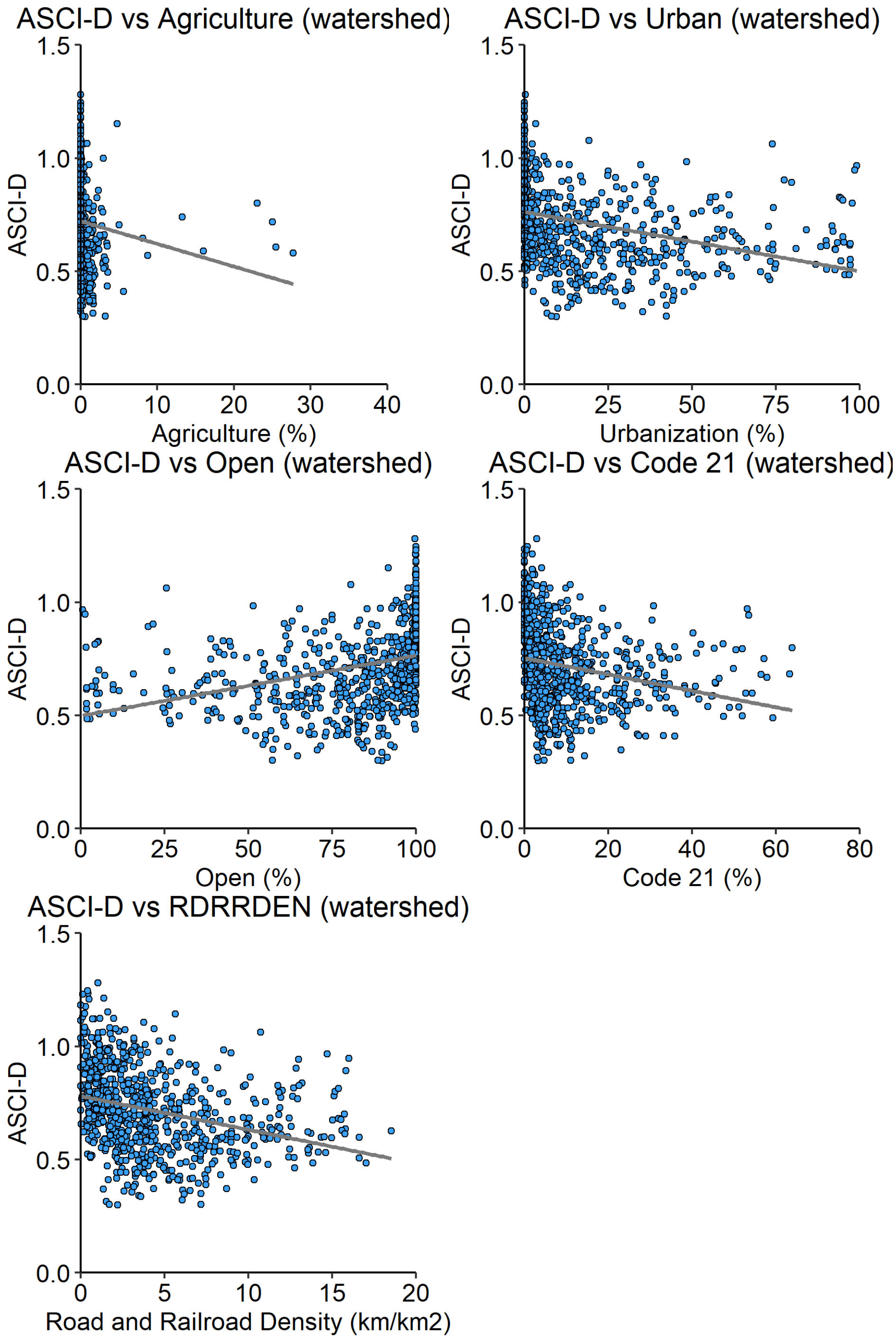

Figure 40. ASCI-D by landscape attributes for the watershed upstream of sampling location. The grey line is the linear regression line.

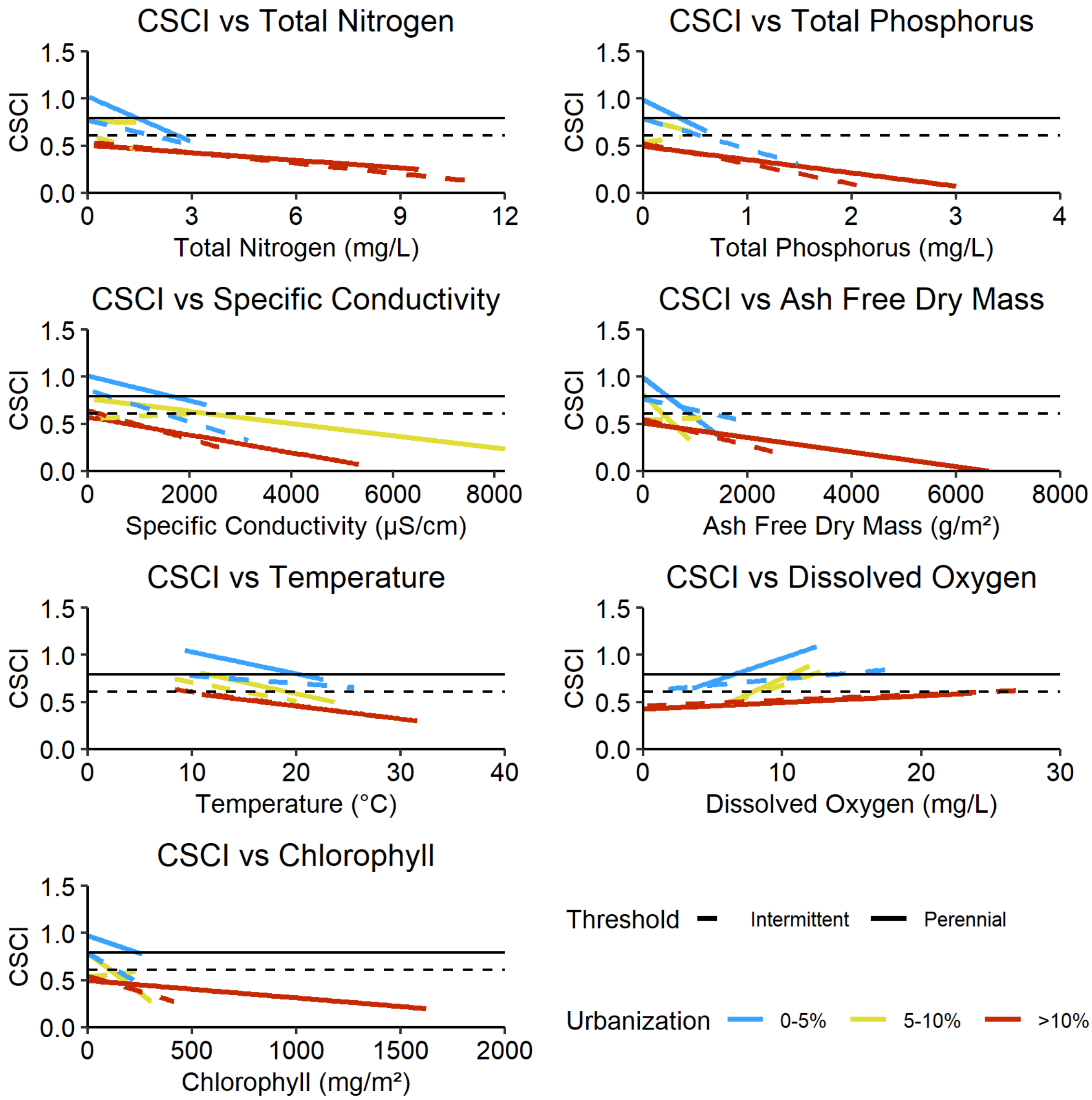

Figure 41. CSCI vs chemistry stressors, by level of urbanization within 1 km. The horizontal lines are the 10th percentile reference thresholds, and the other lines indicate the linear regression lines.

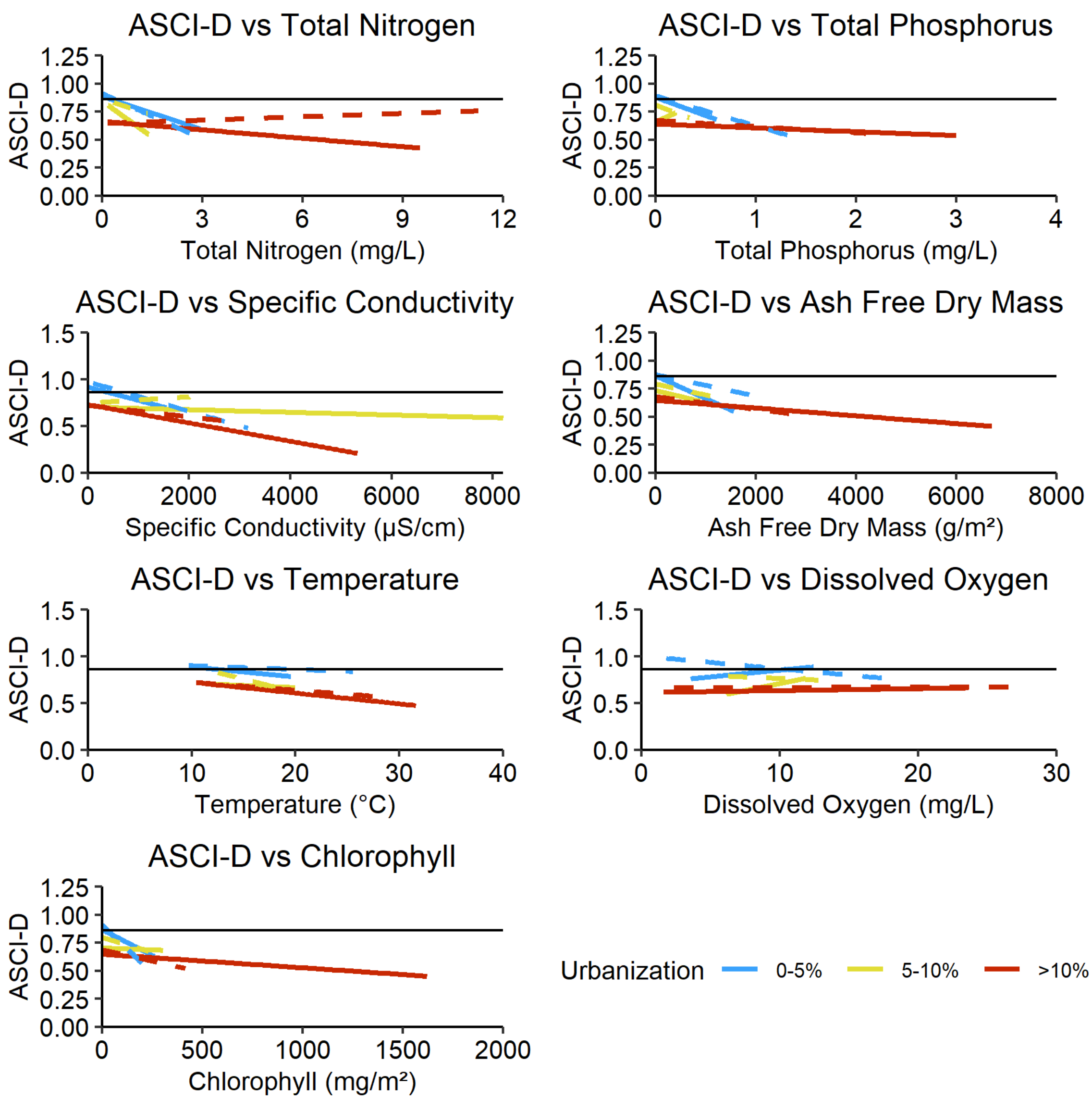

Figure 42. ASCI-D vs chemistry stressors, by level of urbanization within 1 km. The horizontal lines are the 10th percentile reference thresholds, and the other lines indicate the linear regression lines.