Marin County Bioassessment Data Evaluation and Recommendations for Future Monitoring

Summary Report

Prepared for:

Marin County Stormwater Pollution Prevention Program

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1.0 INTRODUCTION AND BACKGROUND

The Marin County Stormwater Pollution Prevention Program (MCSTOPPP[1]) began conducting benthic macroinvertebrate[2] (BMI) bioassessments in 1999 because of their utility as indicators of the ecological health of creeks and associated water quality. Based on information provided by MCSTOPPP staff, the bioassessment program was originally implemented to meet the following primary objectives:

1. Measure the ecological health of creeks and watersheds in Marin County and detect changes that occur over time;
2. Evaluate potential land use and other stressor-related impacts to the ecological health of creeks and watersheds; and
3. To inform and educate the public about the ecological condition of creeks and watersheds.

In 2004, all Marin County municipalities obtained coverage under the statewide National Pollutant Discharge Elimination System permit (NPDES), issued by the State Water Resources Control Board for coverage of stormwater discharges from small municipal separate storm sewer systems (i.e., Water Quality Order No. 2003-00005-DWQ), commonly referred to as the Phase II General Permit (Phase II Permit). As required by the Phase II Permit, MCSTOPPP updated the countywide Stormwater Management Plan in 2005 (Action Plan 2010), which includes a commitment by MCSTOPPP to coordinate watershed assessments and reporting. Bioassessments conducted since 2005, as well as this report, fulfill this commitment.

This report summarizes monitoring data collected by MCSTOPPP from 1999 to 2009 through the implementation of their BMI bioassessment and monitoring program. Additionally, monitoring data collected in the Novato Creek Watershed by Friends of Novato Creek and in west Marin watersheds by the Regional Water Quality Control Board's (Region 2) Surface Water Ambient Monitoring Program (SWAMP) are also discussed. The report is intended to provide a comprehensive review of data collected in Marin County with the goal of developing recommendations on future BMI bioassessment data collection if MCSTOPPP, other agencies or citizen monitoring groups continue their monitoring programs. Specifically, the report addresses the management questions:

1. What is the ecological condition of selected creek sites in Marin County?
2. What is the intra-annual and inter-annual variability in ecological condition of Marin County creek sites?

[1] MCSTOPPP is a joint effort of Marin's municipalities (i.e., County of Marin, Cities of Belvedere, Larkspur, Mill Valley, Novato, San Rafeal, and Sausalito, and the Towns of Corte Madera, Fairfax, Ross, San Anselmo and Tiburon) that is focused on the development and implementation of stormwater pollution prevention activities designed to reduce the discharge of pollutants in stormwater to the maximum extent practicable.

[2] Freshwater benthic macroinvertebrates (BMI or benthos) are animals without backbones that are larger than 0.5 millimeter. Benthos include crustaceans, mollusks, aquatic worms and the immature forms of aquatic insects such as stonefly and mayfly nymphs.

3. What natural (e.g., flow regime) and anthropogenic (e.g., land use) factors explain patterns in BMI taxonomic composition at creek sites?
4. How can the MCSTOPPP BMI bioassessment program be adapted to allow more efficient data collection that answers priority monitoring/management questions?

1.1 Marin County Creeks and Watersheds

Marin County watersheds drain into either Northern San Francisco Bay (North Bay), Tomales Bay, or the Pacific Ocean. The largest of Marin County watersheds, Lagunitas Creek (107 mi^2) and Walker Creek (74 mi^2), drain into Tomales Bay. Watersheds that drain into the Pacific Ocean (Redwood Creek, Rodeo Creek, Pine Gulch Creek, Easkoot Creek, Webb Creek, Tennessee Valley Creek, Morses Gulch and Audubon Canyon) are relatively small in size, ranging from approximately 1 to 9 mi^2. The remaining watersheds fully in Marin County[3] drain into the North Bay. The east Marin watersheds addressed in this report include Novato Creek, Miller Creek, Corte Madera Creek and Arroyo Corte Madera del Presidio. These watersheds ranged in size from 39 mi^2 (Novato Creek) to 5.8 mi^2 (Arroyo Corte Madero del Presidio).

1.2 Benthic Macroinvertebrates as Indicators of Ecological Condition

The MCSTOPPP identified freshwater benthic macroinvertebrate (BMI) communities as useful indicators of ecological health and water quality at creek sites and subsequently established a bioassessment monitoring program in 1999.

BMIs include insect larvae, mollusks and worms. They are part of the aquatic food web as they provide food for fish and they consume algae and aquatic vegetation (Karr and Chu, 1999). In streams, BMIs have been shown to vary in distribution at geographic locations based on elevation, stream gradient, and substrate (Barbour et al. 1999).

Because some BMIs have been shown to be sensitive to site-specific stressors to physical habitat and water column and sediment chemistry, both along the riparian zone and in the stream channel, and because of their relatively long life cycles (approximately 1 year) and limited migration, benthic macroinvertebrates are considered to be useful as indicators of in-stream biotic health (Barbour et al. 1999).

[3] The northern part of Marin County is part of the Petaluma River watershed (San Antonio Creek), which flows primarily through Sonoma County, eventually emptying into the North Bay.

1.3 Existing BMI Bioassessment Data for Marin County

Between fall 1999 and spring 2007[4], the MCSTOPPP[5], Friends of Novato Creek (FNC)[6], and the Region 2 SWAMP conducted BMI bioassessments and physical habitat assessments (PHAB) in Marin County creeks (Table 1). The MCSTOPPP conducted BMI bioassessments during the fall season (September) of 1999 and 2000 and the remaining BMI bioassessments were conducted during the spring season (April – May).

Table 1. Bioassessments conducted in Marin County by MCSTOPPP, FNC and SWAMP between 1999 and 2007.

Sample Period	Agency/Program	Index Period	Methodology[a]	# Watersheds	# Sites
1999	MCSTOPPP	Fall	1	4	17
2000	MCSTOPPP	Fall	1	4	23
2000	MCSTOPPP	Spring	1	4	30
2001	MCSTOPPP	Spring	1	4	28
2001	SWAMP	Spring	1	2	30
2002	MCSTOPPP	Spring	1	3	7
2004	MCSTOPPP	Spring	1	3	11
2005	MCSTOPPP	Spring	2	2	10
2005	SWAMP	Spring	2	8	14
2006	MCSTOPPP	Spring	2	2	12
2006	FNC/MCSTOPPP	Spring	2	1	4
2007	FNC/MCSTOPPP	Spring	2	2	6

[a] Methodologies: (1) California Stream Bioassessment Protocol (Harrington 1996, 1999, 2004); (2) SWAMP Bioassessment Procedure (Ode 2007)

Over the eight-year period (1999 through 2007), the MCSTOPPP and FNC (FNC conducted sampling in Novato Creek in 2006 and 2007 only) conducted BMI bioassessments at a total of 44 sites in the watersheds that drain into the North Bay (Novato Creek, Corte Madera Creek, Arroyo Corte Madera Creek and Miller Creek). The SWAMP conducted bioassessments at 45 sites in watersheds that drain into Tomales Bay (Lagunitas Creek and Walker Creek) or the Pacific Ocean (Redwood Creek, Rodeo Creek, Tennessee Valley Creek, Pine Gulch Creek, Audubon Creek, Morses Gulch, Easkoot Creek and Webb Creek). The number of watersheds and sites assessed during each year are shown in Table 1. Sites assessed by MCSTOPPP/FNC were sampled 2 to 7 times over the 1999 to 2007 timeframe, while sites sampled by SWAMP were assessed only once. Sites and watersheds in Marin County where BMI bioassessments have been conducted are shown in Figure 1[7] and

[4] BMI bioassessments were not conducted in Marin County in 2003

[5] MCSTOPPP contracted with the Sustainable Land Stewardship International Institute (SLSII) to conduct the bioassessments during this timeframe.

[6] Friends of Novato Creek received Proposition 13 grant funds, through a partnership with the North Bay Watershed Association, to conduct bioassessments within the Novato Creek Watershed in 2006 and 2007. MCSTOPPP assisted the citizen monitoring group and sampling occurred at established MCSTOPPP monitoring sites.

[7] Figure 1 includes new MCSTOPPP sites sampled in 2009 (i.e., nine sites within the east Marin watersheds and three sites in the San Geronimo watershed in west Marin.

sampling site locations are described in Table 2. Sampling frequency for each site is listed in Appendix A.

The non-profit Mill Valley StreamKeepers (MVSK) conducted BMI sampling at MCSTOPPP sites in Arroyo Corte Madera Creek in 2005 with grant funds from the San Francisco Estuary Project. These data were not included in this analysis. Results from this sampling effort are discussed in a report that was prepared for MVSK by Gary Reedy (Reedy 2005).[8]

1.4 Bioassessment Methodologies Used in Marin County

The California Stream Bioassessment Protocol (CSBP) as described in Harrington (1996, 1999) was used by MCSTOPPP and SWAMP for all BMI bioassessments conducted in Marin County between 1999 and 2004. During this timeframe, the CSBP was recognized by the California Department of Fish and Game's Aquatic Bioassessment Laboratory (ABL) and stormwater programs in the San Francisco Bay Area as the standard protocol that should be used for conducting BMI bioassessments. In concert with the CSBP, a USEPA protocol (Plafkin et al. 1989, Barbour et al. 1999) was also used to qualitatively assess physical habitat quality (PHAB) of sampling reaches where BMI bioassessments were conducted.

The CSBP consists of sampling three randomly selected riffles within a study reach. A transect was established perpendicular to stream flow along the upstream third of each riffle. Starting at the downstream riffle, the benthos within a 2 ft^2 area were sampled upstream of a 1 ft wide, 0.5 mm mesh D-frame kick-net. Sampling of the benthos was performed manually by rubbing cobble and boulder substrates in front of the net. Three locations representing a diversity of habitat types along each transect were sampled and combined into a composite sample. The total sample area was 6 ft^2 for each transect and 18 ft^2 for the entire reach. Each composite sample was transferred into a 500 ml wide-mouth plastic jar containing approximately 200 ml of 95% ethanol. This technique was repeated for each of three riffles at each site.

[8] MCSTOPPP will include the MVSK 2005 data if future reports are prepared. The MVSK data will be shared with Bay Area municipal stormwater programs currently developing a San Francisco Bay Benthic Index of Biotic Integrity (Bay Area B-IBI) through a project currently coordinated through the Bay Area Macroinvertebrate Bioassessment Information (BAMBI) Network.

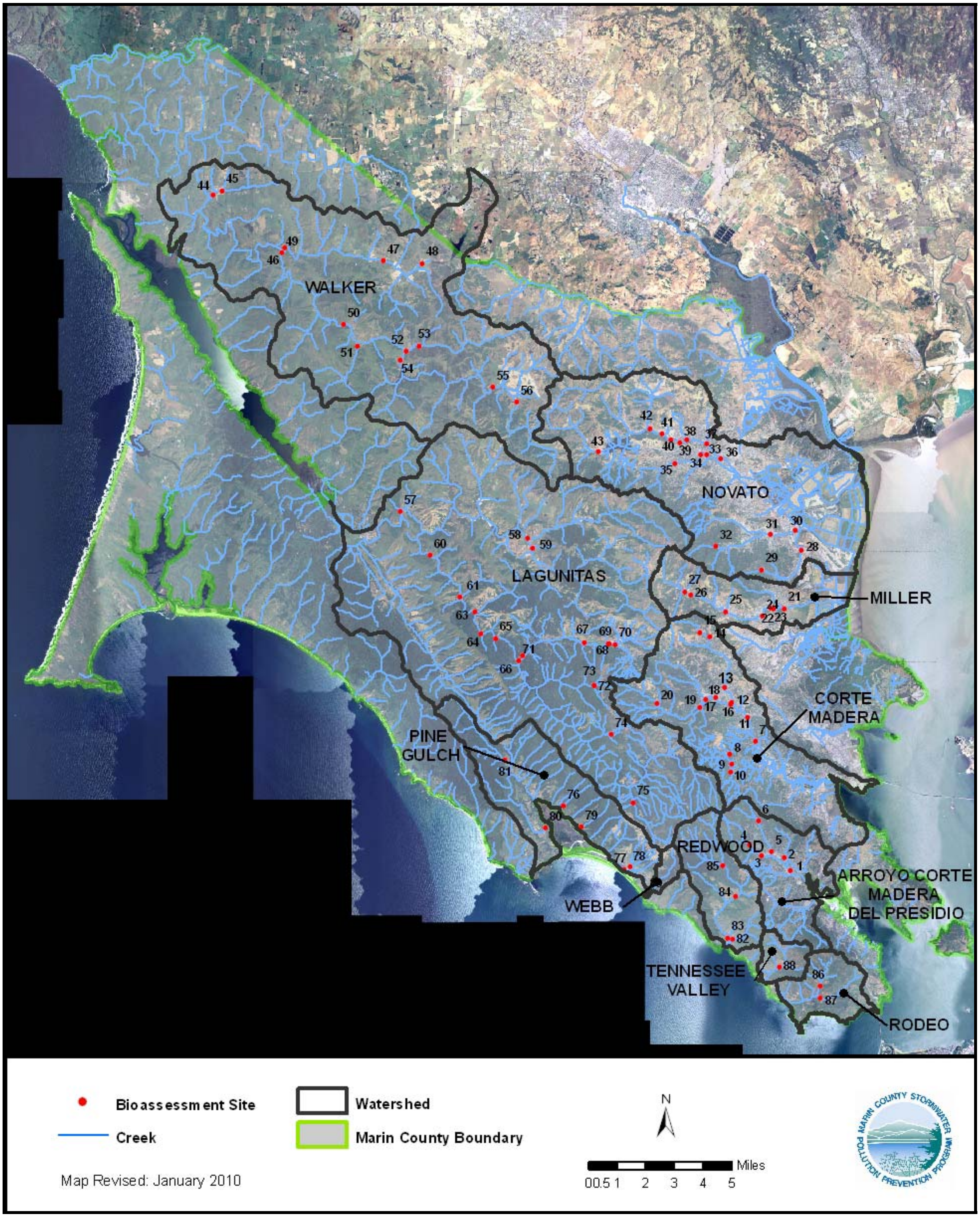

Figure 1. Marin County watersheds and bioassessment sites sampled by MCSTOPPP (includes site sampled by Friends of Novato Creek) and/or SWAMP between 1999 and 2009.

Table 2. Bioassessment sites sampled by MCSTOPPP, Friends of Novato Creek, and SWAMP between 1999 and 2009.

Map ID	Station ID[a]	Station Name	Latitude	Longitude
Arroyo Corte Madera Del Presidio Watershed				
1	203ACM070	Arroyo Corte Madera Del Presidio at Goma Bridge	37.89764	-122.53502
2	203ACM080	Warner Creek at Boyle Park	37.90404	-122.53903
3	203ACM100	Old Mill Creek at Cascade Road Bridge	37.90538	-122.55328
4	203ACM110	Old Mill Creek at Three Wells Park	37.91075	-122.56094
5	203ACM120	Arroyo Corte Madera Del Presidio at MV City Hall	37.90722	-122.54694
6	203ACM140	Arroyo Corte Madera Del Presidio at Blithedale Park Sign	37.92285	-122.55542
Corte Madera Creek Watershed				
7	203COR060	Corte Madera Creek at Lagunitas Rd Bridge	37.96321	-122.55710
8	203COR080	Ross Creek at Natalie Coffin Greene Park	37.95696	-122.57352
9	203COR090	Bill Williams Cr at Phoenix Lake	37.95181	-122.57230
10	203COR091	Bill Williams Cr above Water Main Crossing	37.94784	-122.57324
11	203COR120	Corte Madera Creek at Creek Park	37.97537	-122.56216
12	203COR140	Sleepy Hollow Creek at Drake HS	37.98307	-122.57186
13	203COR150	Sleepy Hollow Creek at Brookside School	37.99051	-122.57658
14	203COR170	Sleepy Hollow Creek above VanWinkle Rd.	38.01635	-122.58571
15	203COR171	Sleepy Hollow Creek upstream San Domenico High School	38.01868	-122.59232
16	203COR200	Corte Madera Creek at Drake High School	37.98214	-122.57251
17	203COR210	San Anselmo Creek At Pacheco; upstream of Fairfax Creek	37.98445	-122.58876
18	203COR211	San Anselmo Creek downstream of Fairfax Creek	37.98571	-122.58241
19	203COR260	San Anselmo Creek at Bolinas Rd Bridge	37.98080	-122.59263
20	203COR290	Cascade Creek at Elliott Preserve	37.98256	-122.61973
Miller Creek Watershed				
21	206MIL020	Miller Creek at Marinwood Dr.	38.03067	-122.53821
22	206MIL040	Miller Creek Middle School	38.03043	-122.54525
23	206MIL041	Miller Creek above MCMS Footbridge	38.03102	-122.54723
24	206MIL050	Miller Creek at Canyon Oak Drive	38.02689	-122.55227
25	206MIL060	Miller Creek at Mt Shasta Dr	38.02927	-122.57596
26	206MIL080	Miller Creek at Westgate Dr Bridge	38.03779	-122.59779
27	206MIL090	Miller Creek at Grady Fire Road Bridge	38.03944	-122.60194
Novato Creek Watershed				
28	206NOV030	Pacheco Creek at Hamilton Field	38.06020	-122.52693
29	206NOV050	Pacheco Creek at Open Space near Pacheco Creek Dr.	38.05038	-122.55235
30	206NOV060	Arroyo San Jose at Digital Drive	38.07015	-122.53065
31	206NOV070	Arroyo San Jose at Ignacio	38.06809	-122.54676
32	206NOV080	Arroyo San Jose at Open Space above Fairway Dr.	38.06242	-122.58207
33	206NOV120	Warner Creek Below McClay Bridge	38.10889	-122.58755
34	206NOV130	Vineyard Creek at Wilmac at Center Rd Bridge	38.10902	-122.59140
35	206NOV140	Vineyard Creek at Mill Rd.	38.10445	-122.60812
36	206NOV160	Novato Creek at Lee Gerner Park	38.10700	-122.57863
37	206NOV170	Novato Creek at Pioneer Park	38.11423	-122.58742
38	206NOV178	Novato Creek at Miwok Park Upstream Pedestrian Bridge	38.11647	-122.60041
39	206NOV180	Novato Creek upstream Novato Blvd at Miwok Park	38.11486	-122.60462

Table 2. Continued.

Map ID	Station ID[a]	Station Name	Latitude	Longitude
40	206NOV190	Novato Creek O'Hair Park - downstream	38.11653	-122.61019
41	206NOV195	Novato Creek O'Hair Park - upstream	38.11944	-122.61639
42	206NOV210	Novato Creek below Bowman Canyon	38.12218	-122.62384
43	206NOV240	Novato Creek at Stafford Park Footbridge	38.11040	-122.65731
Walker Creek Watershed				
44	201WLK030	Keyes Creek at Tomales	38.24111	-122.90431
45	201WLK050	Keyes Creek @ Irvin Road	38.24353	-122.89806
46	201WLK100	Chileno Creek - Chileno Canyon	38.21425	-122.85794
47	201WLK120	Chileno Creek - Chileno Valley	38.20764	-122.79456
48	201WLK130	Chileno Creek - Laguna Lake	38.20639	-122.76975
49	201WLK140	Walker Creek - Walker Canyon	38.21192	-122.86006
50	201WLK160	Walker Creek Ranch	38.17544	-122.82044
51	201WLK170	Verde Canyon Creek	38.16444	-122.81136
52	201WLK180	Salmon Creek at Gambonini Mine	38.16175	-122.78033
53	201WLK190	Salmon Creek	38.16458	-122.77194
54	201WLK200	Arroyo Sausal Creek at Soulejule	38.15758	-122.78408
55	201WLK230	Arroyo Sausal Creek	38.14342	-122.72472
56	201WLK240	Arroyo Sausal Creek at Cheese Factory	38.13589	-122.70914
Lagunitas Creek Watershed				
57	201LAG130	Lagunitas Creek at Gallagher's Ranch	38.08064	-122.78450
58	201LAG150	Halleck Creek	38.06669	-122.70264
59	201LAG160	Nicasio Creek	38.06156	-122.69958
60	201LAG165	Lagunitas Creek below Tocaloma	38.05839	-122.76522
61	201LAG180	Lagunitas Creek - Cheda	38.03722	-122.74611
62	201LAG18X	Lagunitas Creek at swimming hole @ S.P. Taylor Park	38.06485	-122.80336
63	201LAG190	Devils Gulch	38.02964	-122.73636
64	201LAG210	Lagunitas Creek at Samuel P. Taylor Park	38.01861	-122.73306
65	201LAG220	Lagunitas Creek at Irving Bridge	38.01611	-122.72297
66	201LAG240	San Geronimo Creek at White Horse Bridge	38.00703	-122.70569
67	201LAG270	San Geronimo Creek at Creamery Gulch	38.01356	-122.66664
68	201LAG289	San Geronimo Creek below Bridge to Water Treatment Plant	38.01327	-122.65103
69	201LAG290	San Geronimo Creek above Bridge to Water Treatment Plant	38.01306	-122.65056
70	201LAG300	San Geronimo Creek - Woodacre Creek	38.01275	-122.64689
71	201LAG320	Lagunitas Creek at Shafter Bridge	38.00453	-122.70878
72	201LAG330	Big Carson Creek - 1	37.99206	-122.66022
73	201LAG335	Big Carson Creek - 2	37.99206	-122.66022
74	201LAG380	Little Carson Creek	37.96722	-122.64944
75	201LAG390	Cataract Creek	37.93250	-122.63556
Pacific Ocean Draining Watersheds				
76	201AUD020	Audubon Canyon	37.93081	-122.68037
77	201EAS020	Easkoot	37.89844	-122.64174
78	201EAS050	Fitzhenry	37.90023	-122.63733
79	201MRS020	Morses Gulch	37.92010	-122.66887
80	201PNG010	Pine Gulch - Lower	37.91971	-122.69181

Table 2. Continued.

Map ID	Station ID[a]	Station Name	Latitude	Longitude
81	201PNG050	Pine Gulch at Teixeira Ranch	37.95451	-122.71800
82	201RDW040	Green Gulch	37.86306	-122.57202
83	201RDW060	Redwood Creek - Lower	37.86369	-122.57514
84	201RDW100	Redwood Creek at Miwok Bridge	37.88444	-122.57005
85	201RDW120	Redwood Creek at Muir Woods	37.90023	-122.57811
86	201ROD040	Gerbode Creek	37.83904	-122.51644
87	201ROD050	Rodeo Creek - Lower	37.83291	-122.51613
88	201TVY030	Tennessee Valley	37.84857	-122.54224
89	201WBB010	Webb Creek at Steep Ravine	37.88671	-122.62655

[a] Station ID represents site identification number developed by Water Board for the SWAMP Program to create unique identification codes for all monitoring sites in San Francisco Bay watersheds. The first three numbers represent the hydrological unit, the middle three letters represent the major watershed site is located within and the last three numbers represent site location, with numbers increasing in an upstream direction.

In 2005, the ABL moved away from the CSBP and adopted the nationally standardized Wadeable Stream Assessment procedures, established by USEPA, as the standard BMI bioassessment protocol for California (US EPA 2006). The USEPA procedure provides more quantitative methods for assessing physical habitat and two separate methods for conducting BMI bioassessments: 1) targeted riffle composite (TRC); and, 2) reachwide benthos (RWB). Bioassessments conducted between 2005 and 2007 by MCSTOPPP, Friends of Novato Creek, and SWAMP utilized the targeted riffle method. In 2007, the ABL incorporated some modifications to the USEPA procedures into SWAMP's *Standard Operating Procedures for Collecting Benthic Macroinvertebrate Samples and Associated Physical and Chemical Data for Ambient Bioassessments in California* (Ode 2007). This SWAMP Standard Operating Procedure (SOP) currently serves as the standard BMI bioassessment procedure for the State of California.

There are many notable differences between the CSBP and the SWAMP procedure (Table 3). One of the most important relates to the number of organisms that are identified in each sample. The CSBP requires the identification of 300 organisms for each of three randomly selected riffles within a sequence of five riffles in a creek reach, for a total of 900 organisms. The SWAMP procedure requires the identification of at least 500 organisms that are collected and composited from eight riffles systematically selected across a creek reach. Another important difference in the two procedures relates to the types of PHAB data now required under the SWAMP procedure. Prior to 2005, PHAB assessments consisted of ranking physical habitat conditions at each site using ten qualitative assessment parameters. Additional quantitative physical habitat measurements, including channel dimensions, percent canopy cover, percent habitat types and percent substrate composition were added in 2005.

As described above, all BMIs sampled by SWAMP, MCSTOPPP and Friends of Novato Creek from 1999 through 2007 were collected within targeted riffles in Marin County creeks. However, in 2008, the SWAMP identified the reachwide benthos (RWB) method described in Ode (2007) as the standardized approach for bioassessments conducted for ambient monitoring in wadeable streams in California. The RWB method involves the collection of BMIs at evenly spaced transects across a range of habitat types (i.e., does not target riffle habitats). The RWB method was subsequently utilized in bioassessments conducted by MCSTOPPP in 2009 (see Section 2.1.2).

Table 3. Comparison of BMI bioassessment and PHAB assessment procedures used by the State of California and MCSTOPPP

BMI Bioassessment Protocol	Years Applied	Habitat	BMI Sample Size	Physical Habitat
CSBP (3 samples per reach)	1999-2004	Target Riffle	900	Qualitative PHAB
USEPA/SWAMP (composite)	2005-2007	Target Riffle	500	Qualitative & Quantitative PHAB
SWAMP (composite)	2009	Reachwide	500	Qualitative & Quantitative PHAB

1.5 Previous Bioassessment Data Evaluations and Benthic Indices of Biotic Integrity (B-IBIs)

1.5.1 Summary of Marin County Bioassesment Data (SLSII 2008)

On behalf of the MCSTOPPP, the Sustainable Land Stewardship International Institute (SLSII) developed draft report in 2008 that provides a summary and evaluation of the BMI bioassessment and PHAB data collected by MCSTOPPP between fall 1999 and spring 2007. The summary report evaluates the ecological condition of 44 sampling sites using the Northern California Benthic Index for Biological Integrity (NorCal B-IBI). The report also provides recommendations for conducting bioassessments at selected sites in the future.

1.5.2 Bay Area Bioassessment Data Evaluation (SWAMP 2007, 2008)

The goal of the Surface Water Ambient Monitoring Program (SWAMP) is to develop data that could be used to evaluate watersheds for Clean Water Act section 305(b) reporting and 303(d) listing. Specific objectives of the monitoring program include: develop data to support beneficial use protection; 2) evaluate spatial and temporal trends of water quality indicators; 3) determine relations between indicators, specific stressors and land use; 4) identify reference sites and 5) evaluate monitoring tools. The San Francisco Bay Regional Water Quality Control Board's SWAMP program produced two reports summarizing the results of BMI bioassessment and water quality monitoring conducted by SWAMP in Marin County during 2001 (SFBRWQCB 2007) and 2005 (SFBRWQCB 2008).

1.5.3 Draft Northern California Index of Biotic Integrity (Rehn and Ode 2007)

An Index of Biotic Integrity (IBI) is a data interpretation tool that reduces complex information about biological community structure into a simple numerical value based on metric scores. Typically, metrics are tested and validated for a particular region of interest and combined into a multi-metric index (e.g., IBI) to assess the biological condition in creeks. More specifically, Barbour *et al.* (1999) identify six general steps involved in the development of an IBI:

1. Classify stream types into classes and select reference sites
2. Select potential metrics
3. Evaluate metrics to select most robust ones
4. Score metrics and combine scores into IBI
5. Assign rating categories to IBI score ranges
6. Evaluate IBI and refine

Benthic macroinvertebrate IBIs (B-IBIs) have previously been developed for Northern and Southern California wadable streams. The Northern California B-IBI (NorCal B-IBI) includes an area ranging from Coastal Oregon border to Marin County, and the Southern California B-IBI (SoCal B-IBI) was developed for the area between Coastal Mexico Border to Monterey County. Descriptions of the metrics and application of NorCal B-IBI for analyses conducted in this report is described in Section 2.0.

There is also currently an effort to develop a San Francisco Bay B-IBI (Bay Area B-IBI) through a project currently managed by Bay Area municipal stormwater programs and coordinated through the Bay Area Macroinvertebrate Bioassessment Information (BAMBI) Network. The Bay Area B-IBI is schedule to be completed in 2010 and will fill a geographic gap existing between watershed areas represented by the NorCal and SoCal B-IBIs.

2.0 FIELD, LABORATORY AND DATA ANALYSIS METHODS

2.1 Sampling Locations

To supplement data collection efforts described in Section 1.2, BMI bioassessments and physical habitat (PHAB) assessments were conducted during April and May in 2009 at 12 creek sites in five Marin County watersheds (Corte Madera Creek, Arroyo Corte Madera Del Presidio, San Geronimo Creek (a subwatershed of the Lagunitas Creek Watershed), Novato Creek and Miller Creek). Sampling locations are shown in Figure 1 and information on site description, location and date of sampling are shown in Table 4. All 2009 BMI bioassessments and PHAB assessments were conducted by EOA, Inc. (Oakland, CA), with assistance at selected sites from MCSTOPPP staff. All BMI taxonomic identification on 2009 samples was performed by Bioassessment Services, Inc. (Folsom, CA).

Table 4. Sampling locations for BMI bioassessments in Marin County during spring 2009.

Site Code	New Site	Description	Sample Date	Latitude	Longitude	Elevation
Arroyo Corte Madero Del Presidio Watershed						
ACM080	X	Warner Creek at Boyle Park	5/4/2009	37.90404	-122.53903	40
ACM100		Old Mill Creek at Cascade Road Bridge	5/1/2009	37.90538	-122.55328	95
ACM140		Arroyo Corte Madero Del Presidio at Blithedale Park sign	5/1/2009	37.92285	-122.55542	380
Corte Madera Creek Watershed						
COR091	X	Bill Williams Creek above Watermain crossing	4/29/2009	37.94784	-122.57324	260
COR140		Sleepy Hollow Creek at Drake High School	4/29/2009	37.98307	-122.57186	65
COR210		San Anselmo Creek at Pacheco; Upstream of Fairfax Creek	5/7/2009	37.98528	-122.58730	100
Lagunitas Creek Watershed						
LAG240		San Geronimo Creek at Whitehorse Bridge	5/6/2009	38.00677	-122.70523	210
LAG270		San Geronimo Creek above Creamery Gulch	5/7/2009	37.01276	-122.66633	290
LAG289	X	San Geronimo Creek below MMWD Treatment Plant Bridge	5/6/2009	38.01327	-122.65103	320
Novato Creek Watershed						
NOV070		Arroyo San Jose at Ignacio Boulevard	5/8/2009	38.06808	-122.54670	35
NOV140		Vineyard Creek at Mill Road	5/8/2009	38.10445	-122.60812	100
Miller Creek Watershed						
MIL041	X	Miller Creek above footbridge, Miller Middle School	5/4/2009	38.03102	-122.54723	50

2.2 Field and Laboratory Methods

2.2.1 Bioassessment Sampling and Processing

The SWAMP's RWB method described in Ode (2007) was used to conduct BMI bioassessments in Marin County creeks in 2009. Each bioassessment sampling site consisted of an approximately 100 to 150 m reach[9] of creek that was divided into 11 equidistant "main transects" aligned perpendicular to the direction of water flow. Using a 500-um mesh D-frame net to collect BMIs, the benthos from a 1ft^2 area located at approximately 1m downstream of the main transect at alternating positions of 25%, 50% and 75% of the distance of the wetted width of the stream at each main transect was disturbed by manually rubbing the coarse substrate and disturbing the upper layers of substrate to dislodge any remaining invertebrates. Slack water habitat procedures were used at transects with deep and/or slow moving water (Ode 2007). Substrate material collected from all eleven 1ft^2 areas was then transferred into 500-ml wide-mouth jar(s) and preserved in the field with 95% ethanol.

Based on Harrington (1999) each sample was rinsed in a standard no. 35 sieve (0.5 mm) and transferred to a tray with twenty, 4 in.^{2} (26 cm^2) grids for subsampling. Benthic material in the subsampling tray was transferred from randomly selected grids (or half grids if BMI densities were high) to petri dishes where the BMIs were removed systematically with the aid of a stereomicroscope and placed in vials containing 70% ethanol solution. For samples exceeding 500 organisms, a total of 500 (± 5%) BMIs were subsampled from a minimum of three grids. If there were more BMIs remaining in the last grid after 500 were archived, then the remaining BMIs were tallied and archived in a separate vial. This was done to assure a reasonably accurate estimate of BMI abundance based on the portion of benthos in the tray that was subsampled. These "extra" BMIs were not included in the taxonomic lists and metric calculations.

Subsampled BMIs were identified using taxonomic keys (Kathman and Brinkhurst 1998, Merritt and Cummins 1996, Stewart and Stark 1993, Thorp and Covich 2001, Wiggins 1996) and unpublished references. A standard taxonomic level of effort was used as specified in the Southwest Association of Freshwater Invertebrate Taxonomists (SAFIT) master taxa list[10]. California tolerance values and functional feeding group designations were obtained from the California Aquatic Macroinvertebrate Laboratory Network (CAMLnet) list of taxonomic effort (27 January, 2003 revision). One exception to the level 1 standard taxonomic effort included identifying chironomids (midges) to subfamily/tribe instead of family (Chironomidae). Minor exceptions included lower resolution identification of some immature organisms and pupae. The subsampled BMIs identified from each sample were archived in labeled vials with a mixture of 70% ethanol solution.

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[9] Ode (2007) identifies minimum reach length as 150 meters in length, except when site conditions require shorter reach lengths. MCSTOPPP monitoring locations typically had features (e.g., road crossings, deep water habitat) that precluded standard reach lengths. As a result, shorter reach length was applied at some sites.
[10] http://www.waterboards.ca.gov/ swamp/docs/safit/ste_list.pdf.

2.2.3 Physical Habitat Assessment and Water Quality

Quantitative and qualitative PHAB assessments were also conducted at each BMI bioassessment sampling site using protocols described in Ode (2007). Quantitative physical habitat data were collected at each main transect and "inter-transect" located between main transects. The SWAMP "basic" level of effort was used for PHAB, with the following additional measurements: water depth and pebble counts, cobble embeddedness, flow habitat delineation, and instream habitat complexity. In addition, bankfull width and heights were measured at 3 transect locations (where possible) and water velocities were measured at one transect (where possible) using protocols described in Ode (2007). The quality of physical habitat was also assessed qualitatively using three physical habitat sub-categories (epifaunal substrate/cover, sediment deposition, and channel alteration). Combined qualitative PHAB scores range from 0 to 60 (20 possible points per sub-category), with higher scores reflecting higher quality habitat. Appendix B includes example PHAB field data sheets.

Conventional water quality parameters of temperature, pH, conductivity, and dissolved oxygen (D.O.) were also measured at each site with portable field instruments. Water quality was measured during the BMI bioassessments using a multi-parameter probe YSI model 556MPS. Stream velocity was measured at each sample riffle using a Global Water FP201 flow meter.

2.3 Data Quality Assessment

Quality Assurance/Quality Control (QA/QC) activities associated with the field data collection and laboratory analyses are described in more detail in the SWAMP Bioassessment Quality Assurance Project Plan (SCCWRP 2009) The major goal of these QA/QC procedures is to have representative, comparable, accurate and precise data, to the extent possible under the given limitations. Accepted QA/QC activities associated with water quality field sampling included the following:

- Adherence to documented procedures, USEPA methods and written SOPs;
- Calibration of analytical instruments;
- Use of quality control samples (i.e., duplicates and validation datasets)
- Complete documentation of sample tracking and analysis.

Duplicate samples were collected at 10% of sites (1 site) sampled to evaluate precision of BMI field sampling methods. In addition to duplicate samples, 10% of the total number of BMI samples collected were submitted to ABL for independent assessment of taxonomic accuracy, enumeration of organisms and conformance to standard taxonomic level. Results from duplicate sample analysis are included in Appendix C.

2.4 Data Analysis and Interpretation (1999 through 2009)

Bioassessment data collected in Marin County from 1999 through 2009 were uploaded, complied and stored in a Microsoft Access database (i.e., CalEDAS[11]). Datasets collected from 1999 through 2004 using the CSBP (i.e., 900 BMIs) were randomly subsampled using a Monte Carlo method to produce a dataset of 500 BMIs for each applicable sampling event. Standardized datasets (i.e., the subsampled BMI datasets collected using the CSBP and the datasets collected using the SWAMP protocol) were then used to generate BMI metrics used in the NorCal B-IBI.

2.4.1 Northern California Benthic Index Biological Integrity (B-IBI)

The NorCal B-IBI was used to evaluate all compiled Marin County bioassessment data. The NorCal B-IBI was developed by ABL using a bioassessment dataset from 91 reference sites and 164 non-reference sites located in Marin County and counties north of Marin County (Rehn and Ode 2007). The NorCal B-IBI consists of eight BMI metrics that showed the greatest discrimination (dose-response) from a field of 77 biological metrics (SLSII 2008). The eight metrics, representing taxonomic richness, composition, tolerance and functional feeding group categories include:

1. # EPT Taxa
2. % Non-Gastropoda Scrapers
3. # Coleoptera Taxa
4. % Predators
5. # Diptera Taxa
6. % Shredder Taxa
7. % Intolerant Organisms
8. % Non-insect Taxa

Based on metric ranges, each NorCal B-IBI metric was portioned into metric scores from one to ten, with higher scores representing better ecological condition. The scoring range for each of the eight metrics is shown in Table 5. The total B-IBI score is the sum of the individual metric scores multiplied by 1.25, to adjust the scoring range to a 100 point scale. Categories for total IBI scoring ranges are as follows: very good (100-81), good (80-61), fair (60-41), poor (40-21), and very poor (20-0).

Seasonal differences in ecological condition were evaluated by comparing B-IBI scores at sites sampled during both fall and spring seasons (i.e., 1999 through 2001 datasets). Inter-annual variation in ecological condition was evaluated by comparing B-IBI scores for all spring sampling events at bioassessment sites that were sampled three or more times.

2.4.2 Nonmetric Multidimensional Scaling (NMS) Ordination

Nonmetric multidimensional scaling (NMS) ordination was used to evaluate the relative similarity of samples based on BMI taxonomic composition. NMS ordination is based on ranking distances of taxonomic dissimilarity, which make it suitable for ecological data that are often not normally distributed nor measured on continuous scales (McCune and Grace 2002). The output of NMS is a graph, which shows sites (sample units) oriented in relative space where the distance between the sites increases with increasing taxonomic dissimilarity. In addition, quantitative environmental variables can be included as an overlay of lines (joint

[11] The CalEDAS database was developed by ABL to store and maintain bioassessment data collected throughout the State of California.

plot) radiating from the center of the graph, with each line indicating both the direction and strength of correlation with the graph axes.

Table 5. Scoring ranges for BMI metrics used in Northern California B-IBI (Ode and Rehn 2007).

Metric Score	# EPT Taxa	# Coleoptera Taxa	# Diptera Taxa	% Intolerant Organisms	% non-Gastropoda Scrapers	% Predators	% Shredder Taxa	% Non-Insect Taxa
10	>20	≥8	≥10	≥28	≥18	≥16	≥16	0-7
9	19-20	7	9	24-27	17	14-15	14-15	8-13
8	17-18	6	8	21-23	15-16	12-13	12-13	14-18
7	15-16	-	7	17-20	13-14	11	11	19-24
6	13-14	5	6	14-16	11-12	9-10	9-10	25-29
5	11-12	4	5	10-13	9-10	8	8	30-35
4	9-10	3	4	7-9	7-8	6-7	6-7	36-40
3	7-8	-	3	3-6	5-6	5	5	41-46
2	5-6	2	2	0-2	3-4	3-4	3-4	47-51
1	3-4	1	1	-4 - -1	1-2	2	2	52-56
0	0-2	0	0	≤ -5	0	0-1	0-1	≥57

The taxonomic composition of each sample was generated by querying CalEDAS and exporting data into spreadsheets. Due to high number of BMI taxa for all Marin County sites, several taxa were grouped into higher taxonomic levels to reduce the "noise" for ordination.

In addition to examining distributions of BMI taxonomic composition between sites, categorical and quantitative variables were incorporated in NMS to explore factors that could influence taxonomic composition. Categorical environmental variables included:

- Watershed Drainage: San Francisco Bay (east Marin watersheds) or Pacific Ocean (west Marin watersheds)
- Land use: urban, mixed, rural residential, grazing/agriculture, and open space. Land use designations were based on assessment of the land use adjacent to the sample site.
- Flow Regime: Perennial and intermittent flow[12].

[12] Flow status was recorded by either MCSTOPPP or SWAMP. Flow categories for SWAMP bioassessment sites were based on best professional judgment and have not been validated by MCSTOPPP.

Quantitative environmental variables included elevation, substrate size, qualitative physical habitat assessment (PHAB) score, weighted mean habitat type and canopy cover. Qualitative PHAB scores consisted of a sum of three variables: epifuanal substrate, sediment deposition and channel alteration. The weighted mean habitat type was calculated by multiplying the percent habitat type (pools, glide, run and riffle) with a weighted factor (1-4), with pools getting lowest score (1) and riffles receiving the highest score (4).

PC-ORD version 5 software (McCune and Mefford 2006) was used to perform NMS in "autopilot mode", utilizing the "medium" setting (200 iterations) and the Sorensen (Bray-Curtis) distance measure. Plots of stress versus iteration (scree plots) were evaluated to assure that improvement in fit was achieved with added dimensions and exceeded a cumulative coefficient of determination of 0.6.

3.0 RESULTS

3.1 Bioassessments

3.1.1 Benthic Macroinvertebrates

A total of 6,531 benthic macro-inveretbrates (BMIs) comprised of 91 taxa were identified in the twelve bioassessment samples collected during spring 2009. Individual BMI metric values and metric scores used to calculate NorCal B-IBI are shown in Table 6. The total B-IBI score and ecological condition category for each site are also presented. Individual BMI metric values and metric scores used to calculate NorCal B-IBI for 89 sites assessed between 1999 and 2009 are shown in Appendix D. The biological conditions of these sites are discussed in Section 4.0 of this report.

Taxonomic richness metrics measure the number of different BMI taxa within a sample or a particular grouping of organisms (e.g., Ephemeroptera). Generally, greater the taxa richness indicates better the ecological condition at a particular assessment site. Three taxonomic richness metrics (i.e., EPT[13] Taxa, Coleoptera Taxa and Diptera Taxa) are incorporated into the NorCal B-IBI. The highest values for EPT Taxa, 18 and 16, occurred at sites LAG240 and COR091, respectively. Coleoptera Taxa Richness ranged from 0 to 5 for all the sites, with the highest (5) occurring at sites LAG240 and ACM140. Diptera Taxa Richness ranged from 2 to 7, with the greatest richness occurring at sites LAG240 and COR 210. There were five sites, had two or less taxa for both EPT and Coleoptera Richness metrics. All five sites received a "very poor" B-IBI score.

Percent Intolerant Organisms is another metric used in the NorCal B-IBI. Tolerance values indicate the degree to which specific BMI taxa are sensitive to chemicals (i.e., organic material) in water bodies. Tolerance values range from 0 for organisms very intolerant of organic wastes, to 10 for organisms that are very tolerant. Those taxa considered intolerant to organic pollution have tolerance values less than three and tolerant taxa have tolerance values greater than seven. The percentage of intolerant organisms in samples collected in 2009 ranged from 0 to 30%, with the highest value occurring at site COR091, and the lowest value occurring at all five sites receiving a "very poor" condition-IBI score.

The feeding mechanisms of BMIs or functional feeding groups (FFGs) provide information on the balance of feeding strategies (food acquisition and morphology) in BMI communities. Without relatively stable food dynamics, an imbalance in FFGs will occur and result in stressed conditions in a water body. Examples of FFGs include scrapers, shredders, collector-gatherers, collector-filterers, and predators. There were three function feeding groups metrics used in NorCal B-IBI: 1) % non-Gastropod scrapers, 2) % predators and 3) % shredder taxa. The highest values for % non-Gastropod scrapers, 37 and 32, occurred at sites ACM100 and ACM140, respectively. The highest values for % predators, 11 and 10, occurred at sites COR210 and COR091, respectively. The highest values for % shredder taxa, 17 and 14, occurred at sites COR091 and ACM100, respectively.

[13] BMIs from the Orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) are generally intolerant of pollution, and are therefore may be useful indicators of ecological condition.

Table 6. BMI metric score, NorCal B-IBI score and condition categories for 12 bioassessment sites sampled in 2009.

Site ID	EPT Taxa	Score	Coleoptera Taxa	Score	Diptera Taxa	IBI Score	% Intolerant	Score	% non-Gastropod Scrapers	Score	% Predators	Score	% Shredder Taxa	Score	% Non-Insect Taxa	Score	Total B-IBI	Adjusted Total B-IBI[a]	Category
203COR091	16	7	3	4	5	5	30	10	13	7	10	6	17	10	17	8	57	71	Good
203LAG240	18	8	5	6	7	7	8	4	7	4	8	5	11	7	14	8	49	61	Good
203ACM140	13	6	5	6	4	4	11	5	32	10	4	2	10	6	20	7	46	58	Fair
203ACM100	12	5	2	2	2	2	8	4	37	10	5	3	14	9	32	5	40	50	Fair
203COR210	10	4	3	4	7	7	10	5	1	1	11	7	10	6	35	5	39	48	Fair
203LAG289	15	7	4	5	6	6	6	3	4	2	3	2	6	4	24	7	36	45	Fair
203LAG270	10	4	4	5	6	6	7	4	2	1	6	4	8	5	20	7	36	44	Fair
203ACM080	2	0	2	2	4	4	0	2	1	1	1	0	0	0	25	6	15	18	Very Poor
203MIL041	2	0	2	2	3	3	0	2	0	0	4	2	0	0	50	2	11	14	Very Poor
203COR140	1	0	0	0	4	4	0	2	0	0	0	0	0	0	38	4	10	13	Very Poor
203NOV140	1	0	1	1	3	3	0	2	0	0	1	0	0	0	50	2	8	10	Very Poor
203NOV070	1	0	0	0	2	2	0	2	0	0	1	0	0	0	56	1	5	6	Very Poor

[a] The Adjusted Total B-IBI score is the sum of the individual metric scores multiplied by 1.25, to adjust the scoring range to a 100 point scale.

Community composition and structure metrics can be used as another indicator for habitat and water quality. Percent non-insect taxa is one type of metric that is included in the NorCal B-IBI and is inversely correlated with good condition (i.e., the higher the value, the lower the metric score). The lowest values for % non-insect taxa, 17 and 14, occurred at sites LAG240 and COR091.

NorCal B-IBI scores (0-100 possible) for sites sampled in 2009 ranged from 6 to 71. Arroyo Corte Madera sites ranged from 18 to 58, Corte Madera Creek sites from 13 to 71, San Geronimo Creek sites from 44 to 61, and Novato Creek sites from 6 to 10. The B-IBI score was 14 for the single site on Miller Creek (Figure 3). The approximate elevation for each monitoring location is also illustrated in Figure 3.

Of all sites sampled in 2009, the highest B-IBI scores occurred in Bill Williams Creek (COR091) and San Geronimo Creek (LAG240), both falling into the "good" ecological condition category (Figure 3). Two sites in Novato Creek, one site in Miller Creek, and lowest elevation sites in Arroyo Corte Madera and Corte Madera Creek watersheds received scores in the "very poor" category. The remaining five sites received "fair" B-IBI scores.

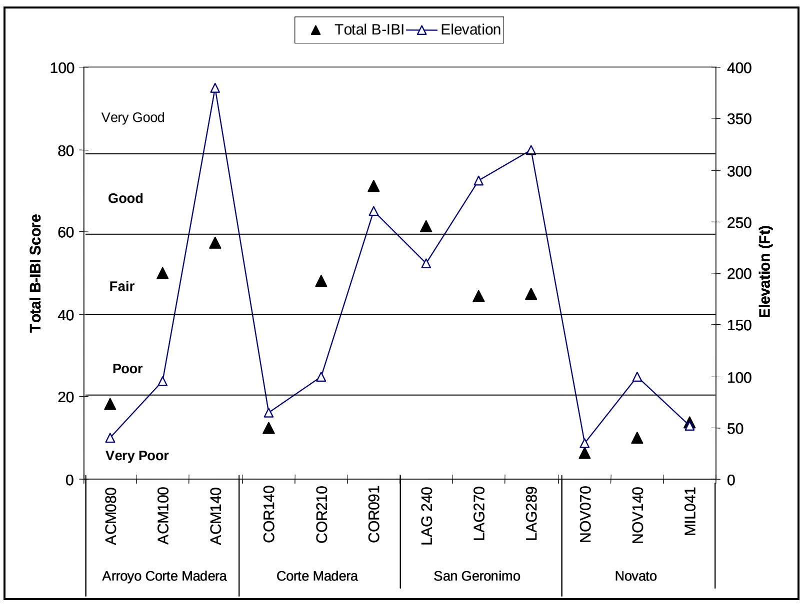

Figure 3. Northern California Benthic Index of Biotic Integrity (IBI) scores for sites in Marin County watersheds sampled during spring 2009 with associated site elevations.

The NorCal B-IBI provides a useful tool to evaluate ecological health of a stream reach and to assess if aquatic life uses are supported. Due to the wide range of confounding factors potentially affecting BMI assemblages, the B-IBI alone does not provide clear linkages to specific sources or stressors potentially impacting the biological condition. Additional information, such as water quality and physical habitat data, as well as additional biological indicators (e.g., benthic algae, riparian assessments) would assist managers to identify key causal factors that may be impacting the biological condition. There appears to be positive relationship between elevation and B-IBI scores (Figure 3).

3.1.2 Physical Habitat

Qualitative physical habitat assessment (PHAB) scores can range from 0 to 60 (score of 60 = most optimal habitat conditions). The PHAB scores are shown with total B-IBI scores in Table 7. Scores for all 2009 sampling sites ranged from 12-58, with the highest score occurring at site COR091. Total B-IBI score was relatively well correlated with Total PHAB score ($r^2 = 0.56$, $p<0.005$) (Figure 4). Epifaunal Substrate score, Sediment Deposition score and elevation were also well correlated with B-IBI scores. Channel Alteration score was poorly correlated with B-IBI score and elevation was poorly correlated with Total PHAB scores. These results suggest that management actions to improve habitat diversity and quality may in turn, improve the biological condition.

Table 7. Physical habitat assessment scores for the 12 BMI assessment sites.

Site Code	Total B-IBI Score	PHAB			
		Epifaunal Substrate (0-20)	Sediment Deposition (0-20)	Channel Alteration (0-20)	Total Score (0-60)
COR091	71	19	19	20	58
ACM140	58	17	12	10	39
LAG240	61	12	13	12	37
ACM100	50	12	9	15	36
COR210	48	11	8	10	29
MIL041	14	9	6	13	28
LAG270	44	10	6	11	27
NOV070	6	7	5	15	27
NOV140	10	7	5	12	24
LAG289	45	5	2	14	21
ACM080	18	4	5	7	16
COR140	13	6	4	2	12

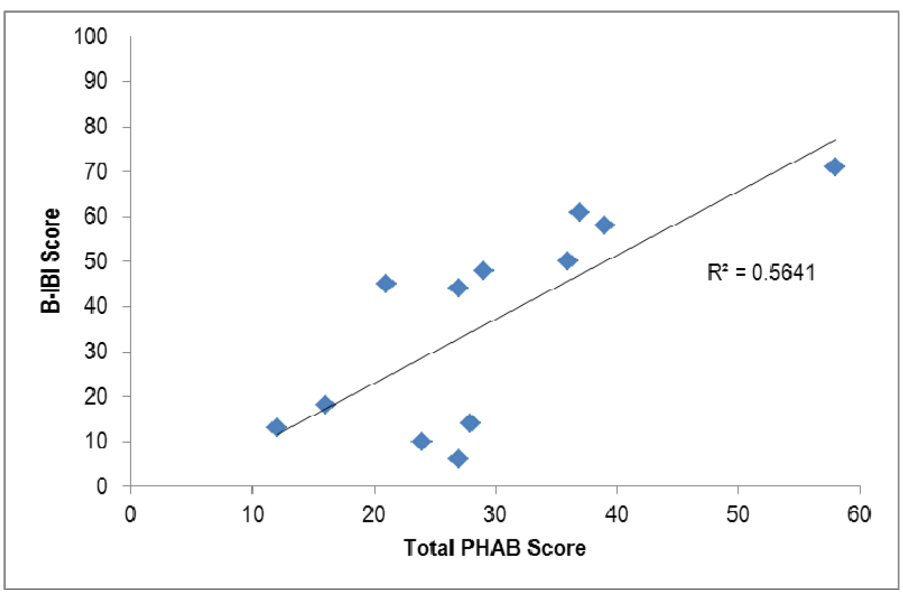

Figure 4. Correlation between Total PHAB Score and B-IBI Score.

The three points clustered below the trend line in Figure 4 all have low B-IBI scores with moderate PHAB scores. Two of these sites (NOV140 - Vineyard Creek and NOV070 - Arroyo San Jose) are located in the Novato Creek Watershed and site MIL041 is located in Miller Creek. Although the dataset is limited, these data suggest that factors other than physical habitat (e.g., poor water quality) may be influencing the biological condition at these sites.

3.1.3 Water Quality

Water temperature measured during BMI sampling at 2009 sites ranged from 10.4 °C (site ACM100) to 15.6 °C (site NOV140). Measurements of pH taken during BMI bioassessments were between 6.5 to 8.5. Dissolved oxygen (DO) concentrations at all sites were above 7.0 mg/L (i.e., the Water Quality Objective for DO in fresh coldwater creeks that drain to the Bay and Pacific Ocean). Conductivity measurements ranged 145 to 489 across all sites. Water quality data are provided in Appendix E.

4.0 DISCUSSION

Bioassessment data collected between September 1999 and April/May 2009 were evaluated to answer the questions described in this report and to determine if MCSTOPPP monitoring objectives for the bioassessment and water quality monitoring program are being achieved. Bioassessment data was evaluated using B-IBI scores and/or NMS Ordination analyses to answer the following questions:

1. What is the ecological condition of selected creek sites in Marin County?
2. What is the intra-annual and inter-annual variability in ecological condition of Marin County creek sites?
3. What natural (e.g., flow regime) and anthropogenic (e.g., land use) factors explain patterns in BMI taxonomic composition at creek sites?
4. How can the MCSTOPPP BMI bioassessment program be adapted to allow more efficient data collection that answers priority monitoring/management questions?

The following sections discuss the results of data analyses conducted to evaluate each management question.

4.1 What is the Ecological Condition of Selected Creek Sites in Marin County?

The NorCal B-IBI was used to evaluate ecological condition for Marin County creek sites sampled during the spring season from 1999 through 2009. The ranges of B-IBI scores for bioassessment sites located in watersheds draining to the North San Francisco Bay are shown in Figure 5. Scores for sites draining to Tomales Bay and the Pacific Ocean are presented in Figure 6. In both figures, sites are grouped by watershed and organized by elevation, which generally increases from left to right in each figure. Average B-IBI scores for each site sampled from 1999 through 2009 are presented by watershed in Appendix F.

Based on this evaluation, the ecological condition of sites in Marin County creeks draining to the North Bay is highly variable. Mean B-IBI scores for bioassessment sites in the Arroyo Corte Madera Del Presidio watershed ranged from 13 to 65, in Corte Madera Creek watershed from 11 to 82, Miller Creek watershed from 14 to 60, and in Novato Creek watershed from 7 to 58. The mean B-IBI score for all sites in each watershed was highest in Arroyo Corte Madera Del Presidio watershed (41) and lowest in Novato Creek watershed (27).

With the exception of the Walker Creek watershed, the ecological condition at bioassessment sites in watersheds draining to Tomales Bay or the Pacific Ocean was less variable compared to those draining to the North Bay. Mean B-IBI scores for bioassessment sites in the Lagunitas Creek watershed, (excluding one site LAG160) [14] and sites within the smaller Pacific Ocean watersheds ranged from 45 to 85. Mean B-IBI scores for bioassessment sites in Walker Creek watershed, however, ranged from 8 to 79. Furthermore, for Pacific Ocean draining watersheds, the mean B-IBI scores for all sites combined was highest in Lagunitas Creek (66) and lowest in the Walker Creek watershed (41).

The number of Marin County bioassessment sites with mean B-IBI scores in each ecological condition category is shown in Table 8. The percent of total sites in each condition category is also shown for each watershed. Only 9% of sites in creeks that drain into the North San Francisco Bay had B-IBI scores that were in the "very good" or "good" condition category, compared to 51% of all sites in creeks that drain to the Pacific Ocean.

It is important to note that the locations of BMI bioassessment sites were targeted for a number of purposes, including evaluation of water quality from stormwater runoff, land use impacts, evaluation of the effectiveness of restoration projects[15], and identification of least impacted sites. Although targeting sites for monitoring can provide useful information for answering specific management questions, there is an inherent bias in selecting sites based on a targeted approach. This bias is coupled with the potential uncertainty that targeted sites are not representative of other unsampled creek sites in the watershed. For these reasons, the B-IBI score at any given site is only a measure of ecological condition at that site and should not be extrapolated to sites that have not been monitored/assessed. A probabilistic monitoring design is more applicable for evaluating ecological condition at the waterbody and/or watershed scale.

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[14] Site LAG160 was sampled in 2001 and received a B-IBI score of 26. In SFBRWQCB 2007, a discussion of the BMI results at LAG160 states "When compared to conditions at minimally disturbed intermittent streams the benthic assemblage of Nicasio Creek appears significantly degraded. The sample was numerically dominated by chironomid midges (80 percent of individuals), and only 8 EPT taxa were present. The benthic assemblage at this site, although better than conditions found in heavily urbanized areas, was very different from other sites in the watershed and indicative or poor water quality."

[15] SWAMP site WLK120 is located in a section of creek that had undergone physical habitat restoration by the landowners several years before the sampling occurred in 2001. In addition, an existing MCSTOPPP site, COR120, was sampled by Friends of Corte Madera Creek Watershed and Marin County Department of Public Works staff in 2006 after a riprap removal and biotechnical bank stabilization project at the San Anselmo Creek Park. Final Report - http://www.nbwatershed.org/projectPDF/FinalProjectReport_04-155-552-2.pdf

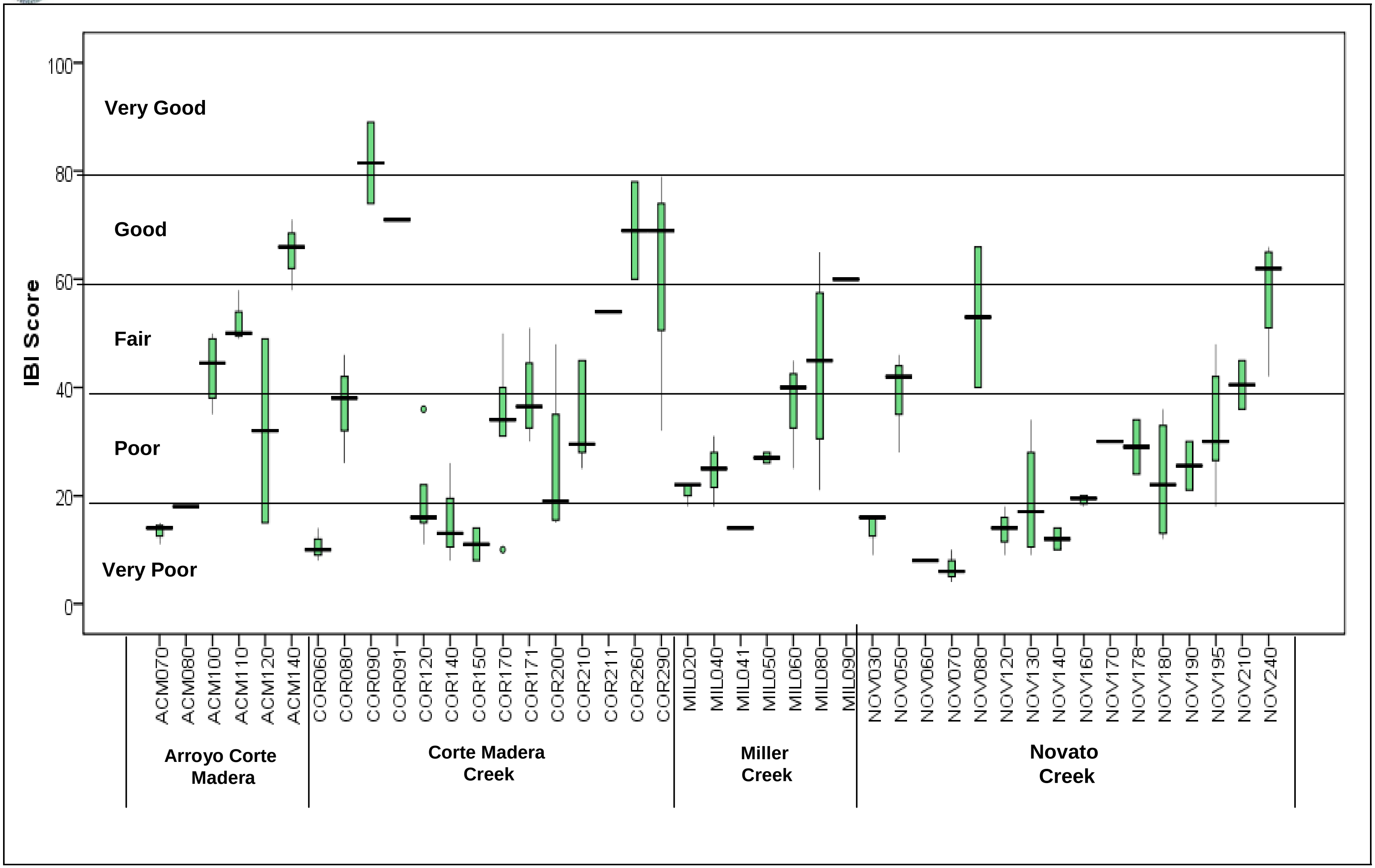

Figure 5. Box-whisker plots of B-IBI scores for bioassessment sampling sites in Marin County watersheds that drain into North San Francisco Bay. Box whisker plots illustrate the median as horizontal line at roughly the midpoint of the box, interquartiles (25th and 75th percentiles) as the length of the box, and the range of non-outlier data (those within 1.5 times the interquartiles) as the whiskers. Those sites with only one sampling event are illustrated as horizontal lines.

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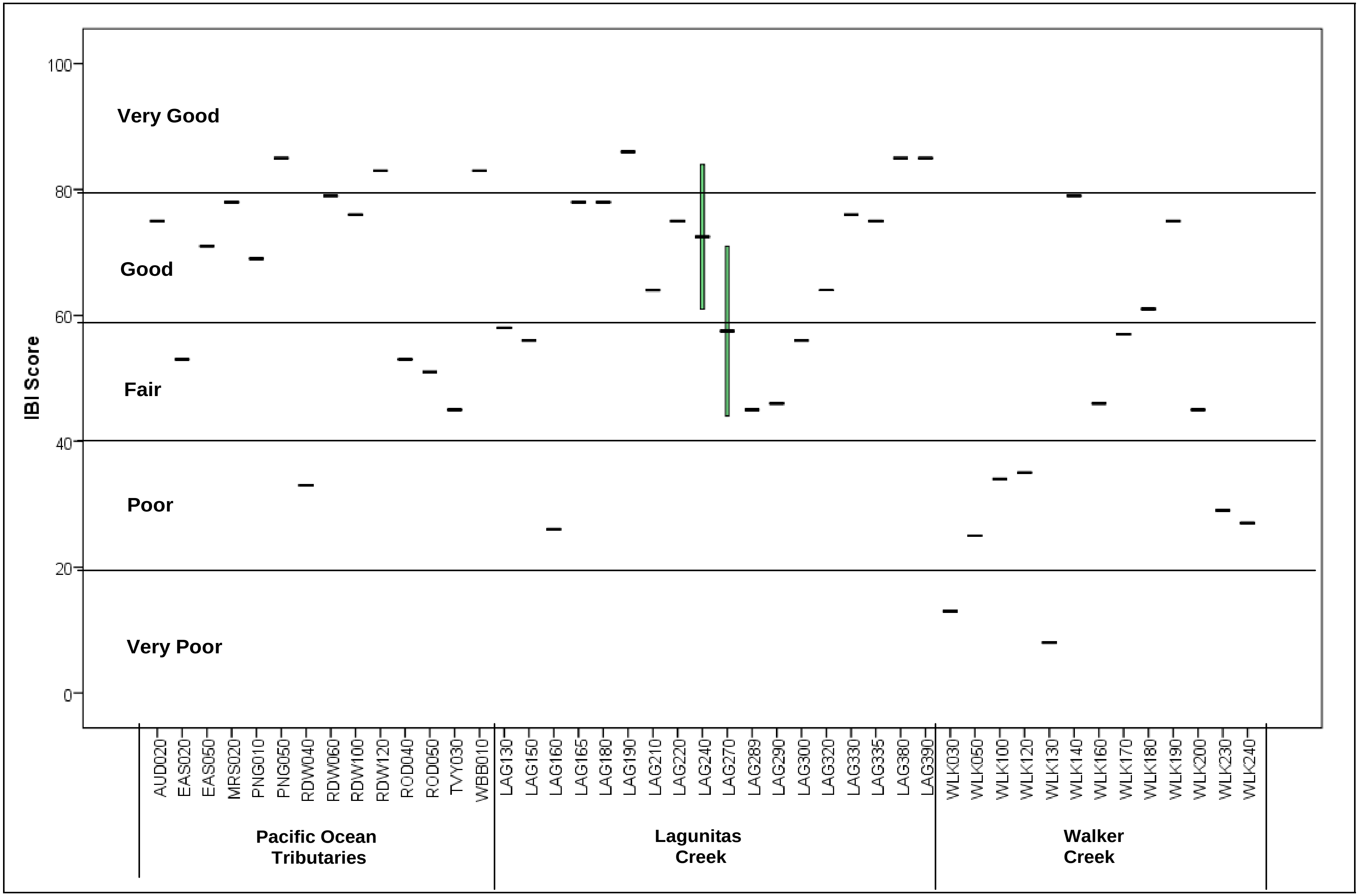

Figure 6. Box-whisker plots of B-IBI scores for bioassessment sampling sites in Marin County watersheds that drain into the Pacific Ocean or Tomales Bay. Box whisker plots illustrate the median as horizontal line at roughly the midpoint of the box, interquartiles (25th and 75th percentiles) as the length of the box, and the range of non-outlier data (those within 1.5 times the interquartiles) as the whiskers. Those sites with only one sampling event are illustrated as horizontal lines.

Table 8. Number and percentage Marin County sites in each watershed with mean B-IBI scores in each condition category.

Watershed	Very Good (100-81)	Good (80-61)	Fair (60-41)	Poor (40-21)	Very Poor (20-0)	Total Sites
Draining into North San Francisco Bay						
Arroyo Corte Madera	0	1	2	1	2	6
Corte Madera	1	2	2	5	4	14
Miller	0	0	2	4	1	7
Novato	0	0	3	6	7	16
% of All Sites	*2%*	*7%*	*21%*	*37%*	*33%*	-
Draining into Pacific Ocean (Including Tomales Bay)						
Walker	0	3	3	5	2	13
Lagunitas	3	8	6	1	0	18
Redwood	1	2	0	1	0	4
Pine Gulch	1	1	0	0	0	2
Seven Tributaries	1	3	4	0	0	8
% of All Sites	*13%*	*38%*	*30%*	*15%*	*4%*	-

4.2 What is the seasonal and inter-annual variability in ecological condition of Marin County creek sites?

4.2.1 Seasonal Variability in Ecological Condition

Benthic communities in creek/riverine systems typically have an inherent level of variability between seasons in Mediterranean climates such as those in the San Francisco Bay Area (Linke 1999; Beche et al. 2006). This variability can create difficulties in interpreting BMI bioassessment data that are only collected during a single season. For example, BMI data collected during a season that inherently exhibits a significantly lower number and diversity of pollutant-sensitive BMI taxa may under-predict ecological condition, compared to data collected during a more ecological robust season. Therefore, the selection of a season to base ecological condition assessments is likely an important factor.

In the San Francisco Bay Area (Bay Area), many creeks exhibit intermittent flow regimes and large fall/winter storm events that create unsafe sampling conditions, making the spring season the most practical sampling timeframe. Additionally, bioassessments in the Bay Area have been historically conducted during the spring season under to the assumption that BMI richness and diversity in creeks are greatest at this time of year. Therefore, it is assumed that sampling in the spring season in Bay Area creeks reduces the chance of under-predicting ecological condition via BMI bioassessments. Although from a practical standpoint, sampling in the spring season is ideal, little information is currently available to test the assumption that BMI community composition in the spring season and associated B-IBI scores are representative of ecological condition in the Bay Area.

To begin assessing seasonal differences BMI community composition and B-IBI scores, bioassessment data collected during two consecutive spring and fall seasons (September 1999 through April 2001) from 13 sites were compared[16]. First, differences between seasons in BMI community composition were evaluated using NMS ordination. As illustrated in Figure 7, ordination results appear to indicate that BMI taxonomic composition in creek sites sampled in the fall season differs from the spring season. These results are consistent with previous published studies (Linke 1999; Beche et al. 2006).

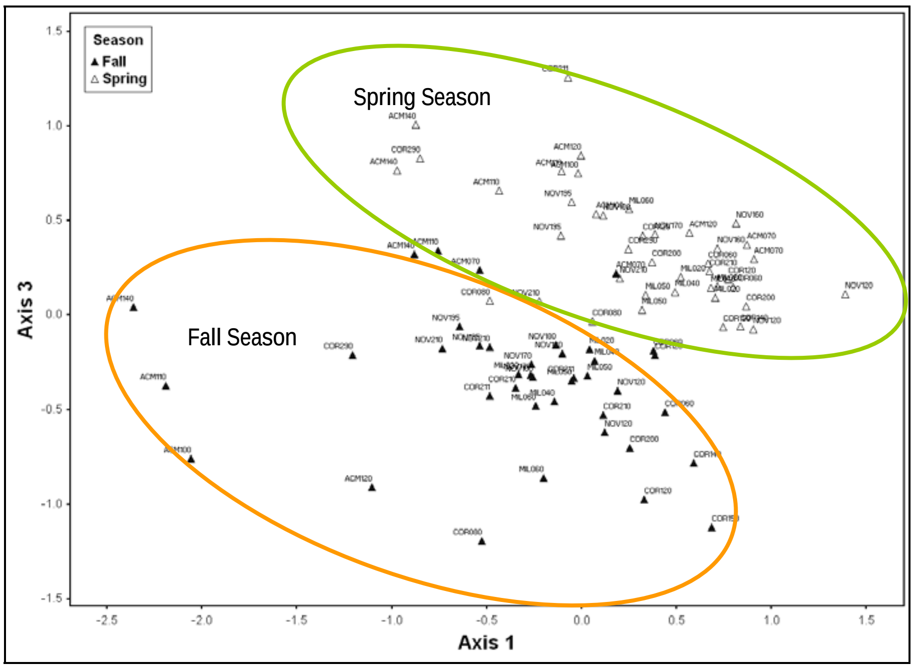

Figure 7. Seasonal differences in BMI community composition at 13 Marin County creeks sampled during two consecutive spring and fall seasons from 1999 to 2001.

Although BMI community composition in Marin County creeks appears to differ between seasons, B-IBI scores (as opposed to BMI community composition) are typically used to assess ecological condition. Therefore, seasonal differences in B-IBI scores for 13 Marin County creek monitoring sites were also evaluated. Figure 8 presents total B-IBI scores for BMI bioassessments conducted at the 13 sites. Furthermore, differences between average (mean) fall and spring season B-IBI scores for these sites are shown in Table 9.

[16] There are a total of 24 sites with data from both seasons, but bioassessments were conducted during two consecutive fall and spring events at only 13 of the 24 sites.

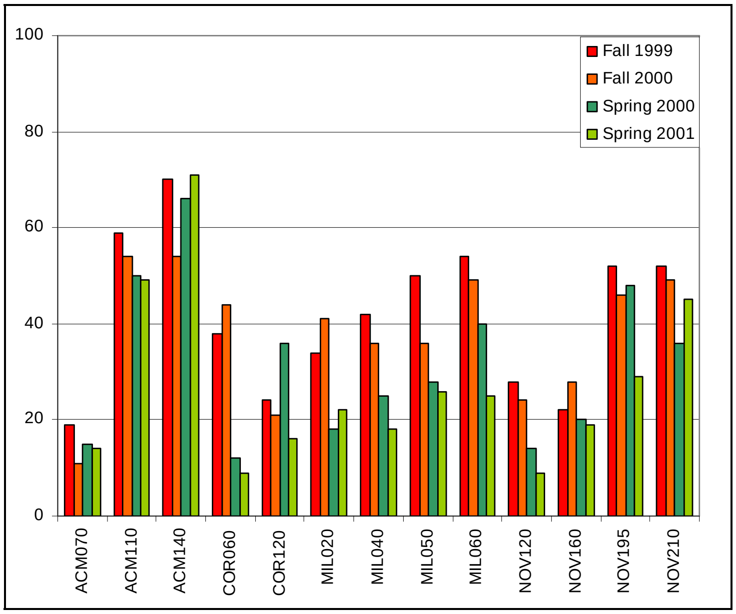

Figure 8. Total B-IBI scores for 13 Marin County sites where bioassessments were conducted during both fall and spring seasons between 1999 and 2001.

Table 9. Differences between average (mean) B-IBI scores for fall and spring season sampling events at 13 Marin County bioassessment sites.

Site Code	Average B-IBI Score		Difference between Fall & Spring Average B-IBI Scores	Land Use	Elevation
	Fall Season	Spring Season			
COR060	41	10.5	30.5	Urban	30
MIL060	51.5	32.5	19	Urban	130
MIL020	37.5	20	17.5	Urban	35
MIL040	39	21.5	17.5	Urban	50
MIL050	43	27	16	Urban	85
NOV120	26	11.5	14.5	Urban	30
NOV195	49	38.5	10.5	Ag/Grazing	90
NOV210	50.5	40.5	10	Ag/Grazing	120
ACM110	56.5	49.5	7	Mixed	195
NOV160	25	19.5	5.5	Urban	30
ACM070	15	14.5	0.5	Urban	10
COR120	22.5	26	-3.5	Urban	45
ACM140	62	68.5	-6.5	Mixed	380

Mean seasonal B-IBI scores at 11 of the 13 sites were higher in the fall season. Furthermore, fall season scores were at least 10 B-IBI points higher at 8 of the 13 sites evaluated, suggesting that the ecological condition category for a given site could differ based on sampling season. One explanation for differences in BMI community composition and seasonal B-IBI scores could be that relatively high creek flows during the late-winter or early spring scoured BMI communities from the creek bed prior to spring sampling events in 2000 and 2001. It is plausible that high flows during the spring season could have the greatest impact to BMI communities at urban sites that have incised channels with limited habitat complexity that provides refugia during high flows. Further analysis of seasonal differences in B-IBI scores at a larger number of sites (especially at minimally disturbed sites), would provide useful data to inform the selection of a sampling timeframe that is both practical and adequately predicts the ecological condition of creek sites. This analysis may occur through the implementation of the statewide SWAMP's (implemented by State Water Resources Control Board) Reference Condition Management Program (RCMP) that began in spring 2009. In Marin County, however, fall sampling would be limited to perennial sites.

4.2.2 Inter-Annual Variability in Ecological Condition

Bioassessments conducted over multiple years can provide data that are useful for understanding the range and central tendency of ecological condition at a given site. Longer-term monitoring can provide data to evaluate temporal trends associated with chronic impacts (e.g., urbanization, changes in land use practices) or more acute impacts associated with episodic events (e.g., fire), as well as improvements associated with stream/watershed restoration projects.

Evaluating ecological condition at minimally disturbed or reference sites are thought to be especially valuable for understanding natural variability, such as annual precipitation or temperature. Variability at minimally disturbed sites can also provide a frame-of-reference for understanding variability at non-reference sites. However, confounding factors related to natural variability and human disturbances can make evaluation of temporal trends at non-reference sites challenging and inconclusive (Mazor et al. 2009).

A number of sites in the MCSTOPPP/FNC bioassessment dataset were sampled during multiple spring seasons between 2000 and 2009. Inter-annual variability in ecological condition was evaluated at those Marin County bioassessment sites that were sampled three or more years during the spring season (n=27). Table 10 presents annual and average (mean) B-IBI scores for each of the 27 sites. Standard deviations and coefficients of variation[17] of B-IBI scores are also presented to assess the magnitude of inter-annual variability for each site. Sites in bold were identified as potential reference sites during the initial development of the Bay Area B-IBI (Kevin Lundy, University of California, Berkeley, personal communication).[18]

[17] The coefficient of variation (CV) is a normalized measure of dispersion of a probability distribution. It is defined as the ratio of the standard deviation to the mean.
[18] Eleven reference sites were identified via the Bay Area B-IBI, but only three of these sites were sampled three or more years.

Table 10. Annual and average (mean) B-IBI scores, standard deviations and coefficients of variation for Marin County bioassessment sites sampled during three or more spring seasons between 2000 and 2009. (note: reference sites are **bolded and sites are listed in order of their B-IBI score, from high to low).**

Site Code	Annual B-IBI Scores								Mean	Standard Deviation	Coefficient of Variation
	2000	2001	2002	2004	2005	2006	2007	2009			
ACM140	66	71	-	-	-	-	-	58	65	6.6	0.10
COR290	79	32	-	-	-	69	-	-	60	24.8	0.41
NOV240	66	64	-	-	-	60	42	-	58	11.0	0.19
ACM110	50	49	58	-	-	-	-	-	52	4.9	0.09
MIL080	40	50	21	65	-	-	-	-	44	18.5	0.42
ACM100	48	41	35	-	-	-	-	50	44	6.9	0.16
NOV050	-	42	-	46	28	-	-	-	39	9.5	0.24
COR171	51	30	35	-	38	-	-	-	39	9.0	0.23
MIL060	40	25	-	45	-	-	-	-	37	10.4	0.28
COR080	38	46	-	-	-	26	-	-	37	10.1	0.27
COR210	-	25	30	29	45	28	-	48	34	9.7	0.29
COR170	40	-	31	50	10	34	-	-	33	14.8	0.45
NOV195	48	29	18	36	24	48	30	-	33	11.5	0.34
COR200	48	16	15	-	-	22	-	-	25	15.5	0.61
MIL040	25	18	-	31	-	-	-	-	25	6.5	0.26
NOV180	36	-	12	30	14	-	-	-	23	11.8	0.51
MIL020	18	22	22	-	-	-	-	-	21	2.3	0.11
COR120	36	16	15	-	-	11	22	-	20	9.8	0.49
NOV130	22	34	12	-	-	9	-	-	19	11.3	0.59
NOV160	20	19	-	-	-	20	18	-	19	1.0	0.05
COR140	26	-	-	-	-	8	-	13	16	9.3	0.59
NOV120	14	9	-	-	-	18	-	-	14	4.5	0.33
NOV030	-	16	-	16	9	-	-	-	14	4.0	0.30
ACM070	15	14	11	-	-	-	-	-	13	2.1	0.16
COR060	12	9	14	-	8	10	-	-	11	2.4	0.23
NOV070	-	-	-	4	10	-	-	6	7	3.1	0.46

As indicated by standard deviations and coefficients of variation presented in Table 10, B-IBI score variability does not appear to have a discernable pattern between those sites with relatively high and low average B-IBI scores. For example, B-IBI scores for MIL080, a reference site identified through the development of the Bay Area B-IBI, exhibited a high level of variability (21 to 65) during the 2000 to 2009 timeframe. Many other non-reference sites also exhibited a similar level of variability.

These findings are in contrast to those discussed in a State Water Resources Control Board Technical Report (SWRCB 2008). Researchers found that variability in IBI scores at perennial stream sampling sites in California's Central Valley were shown to increase as the mean IBI score decreased at sites with at least 3 repeat visits (sites with higher IBI scores showed less inter-annual variability).

A Contra Costa Monitoring and Assessment Program (CCCWP 2007) report noted that inter-annual variability of B-IBI scores made it difficult to detect changes (improvements or degradation) in the ecological condition over time and suggested that a longer time frame is needed to detect temporal trends from variable data. The Contra Costa report identified potential explanations for inter-annual variability such as changes in annual incident winter rainfall and changes in the data collection protocol. The report showed a correlation between lower B-IBI scores for samples collected in spring 2006 and high 2005-2006 rainfall. The higher creek flows (resulting from higher rainfall) may have flushed creek sediment downstream and prevented the establishment of diverse and populous benthic assemblages. The hypothesis in the CCCWP (2007) report is supported by findings described in Mazor et al. (2009), where precipitation patterns, including droughts and El Nino events, are likely important factors in determining the variability in BMI indices. The difficulty is in trying to establish temporal trends, even with long-term rainfall datasets.

4.3 What natural and anthropogenic factors best explain patterns in BMI community composition and B-IBI scores at Marin County creek sites?

4.3.1 Natural Factors

Natural (e.g., flow regime and elevation) and anthropogenic (e.g.., land uses, pollutants and physical habitat impacts) factors are important to consider when interpreting BMI bioassessment data and subsequently recommending watershed management actions. With regard to natural variability due to flow regime and associated precipitation patterns, initial evaluations of bioassessment data from reference sites established through the development of the Bay Area B-IBI suggests that BMI community composition in sites within watersheds draining to the Pacific Ocean differ from those in sites draining to the San Francisco Bay (Kevin Lundy, University of California, Berkeley, personal communication). Additionally, although not entirely unrelated, flow regime also appears to be an important factor in BMI community composition at Bay Area reference sites.

To examine differences in BMI communities due to natural factors, two analyses (i.e., B-IBI evaluation and NMS ordination) were conducted. First, relative similarities between BMI communities at sites sampled during 2000 -2009 in the spring season were evaluated using NMS ordination. Sites were grouped by watershed drainage type (i.e., North San Francisco Bay or Pacific Ocean) and plotted (Figure 9). Results suggest that BMI community composition at sites within watersheds draining to the Northern San Francisco Bay and those draining to the Pacific Ocean are generally clustered in groups at opposite ends of Axis 1. As described later in this section, partitioning of sites can be explained by a combination of land use patterns and elevation.

Average (mean) B-IBI scores for sites initially identified as reference (i.e., least disturbed) through the development of the Bay Area B-IBI were also compared based on considerations of flow regime and the watershed drainage type (i.e., Pacific Ocean or North San Francisco Bay). Although data from a limited number of sites are available, results presented in Table 11 suggest that B-IBI scores at reference sites draining to the North Bay are substantially lower than those draining to the Pacific Ocean Additionally, analyzing scores at reference sites according to with intermittent flow regimes do not show lower B-IBI scores relative to sites with perennial flow. These results provide additional information supporting the notion that least impacted (i.e., reference) sites in coastal watersheds may inherently score higher on BMI indices, compared to more inland sites. Therefore, scaling within regional B-IBIs or separate B-IBIs based on natural variations in BMI communities associated with ecoregion types or flow regimes should be further explored.

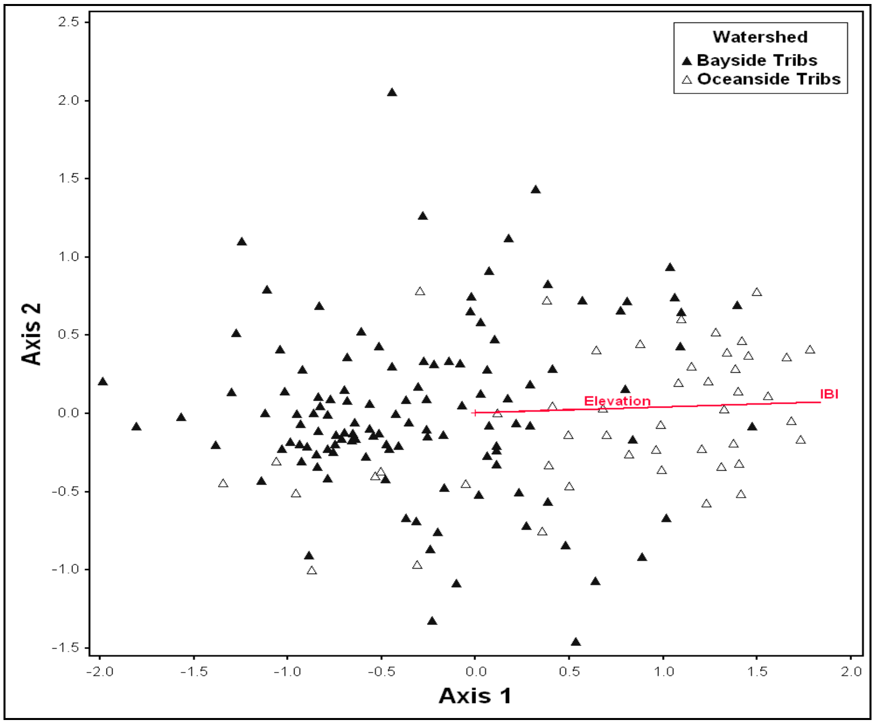

Figure 9. Relative differences in BMI community composition in Marin County creeks sampled between 1999 and 2009 (presented by watershed drainage type).

Table 11. Comparisons between average (mean) B-IBI scores, flow regime (perennial or intermittent) and receiving water body (North Bay or Pacific Ocean).

		Average Site-Specific B-IBI Score		Countywide Average B-IBI Score
Flow Regime	Site Code	North Bay Draining Watersheds	Pacific Ocean Draining Watersheds	
Perennial	RDW100	-	76	
	MIL090	60	-	
	MIL080	44		
	LAG380	-	85	
	LAG335	-	75	
	LAG190	-	86	
	LAG180	-	78	
Perennial Average		52	80	72
Intermittent	NOV240	58	-	
	NOV080	53	-	
	MRS020	-	78	
	COR290	60	-	
Intermittent Average		57	78	62
Average B-IBI Score		55	80	67

4.3.2 Anthropogenic Factors

In addition to exploring natural factors that play a part in BMI bioassessment data interpretation, biological monitoring programs typically conduct evaluations of relationships between BMI community composition and anthropogenic factors. These evaluations are conducted in attempts to identify watershed- and reach-scale variables that explain ecological conditions at creek sites. Anthropogenic factors that have been shown to play important roles in BMI composition and B-IBI scores in Bay Area creeks include physical habitat conditions and land uses (EOA 2007, SCVURPPP 2007).

Information on five major land use classes (see section 2.3.2) was available for all bioassessment sites sampled between 1999 and 2009. NMS ordination was used to evaluate BMI community composition for all Marin County reference and non-reference sites and plotted by land use class in Figure 10. As illustrated in Figure 10, results indicate that BMI communities at the vast majority of sites with adjacent "urban" land uses are distinctively different than those at sites with open space land uses. A number of sites, however, do not cluster within land use class. This is likely because classifications based solely on adjacent land uses may not accurately depict upstream land uses, or consider larger watershed-scale disturbances that may affect BMI community composition. For example, sites ACM100 and COR260 were originally classified as urbanized sites, but based on ordination results, appear to exhibit BMI community composition similar to open space sites. Upon further evaluation, these sites are located at the edge of the urban boundary just downstream of protected lands, suggesting that land use should be considered at multiple spatial scales.

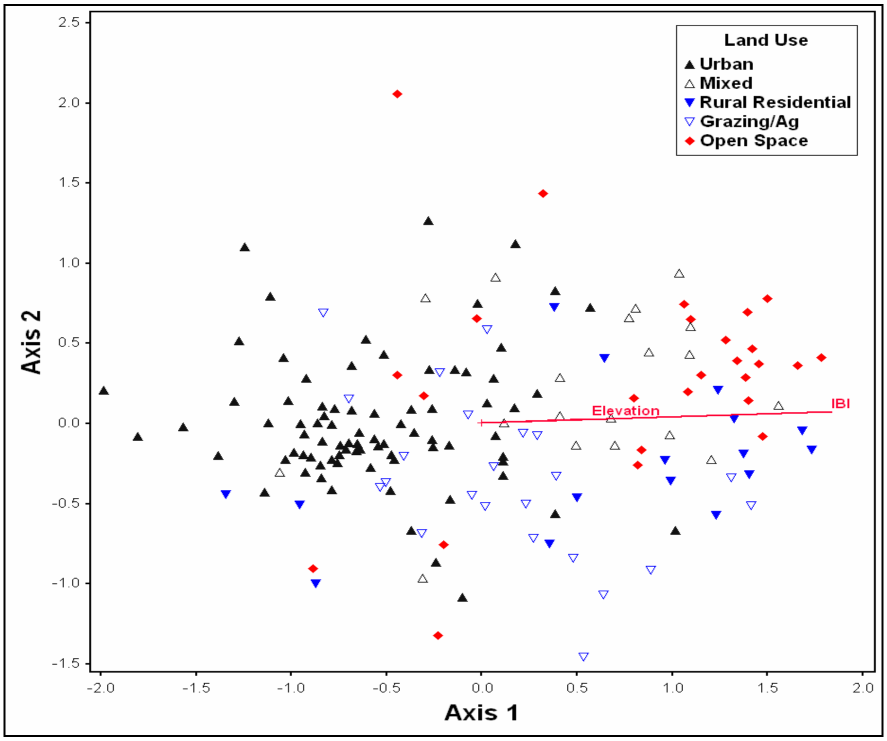

Figure 10. Relative differences in BMI community composition in Marin County creeks sampled between 1999 and 2009 (presented by adjacent land use type).

In addition to evaluating the relationships between BMI communities and land use types, comparisons to physical habitat variables were also conducted using NMS ordination. Begining in 2005, additional quantitative physical habitat variables[19] were measured during bioassessments. Figure 11 presents the relative site similarity as a function of BMI composition showing all sites sampled between 2005 and 2009 grouped by adjacent land use type. BMI community composition at bioassessment sites correlate well with changes in environmental metrics that are typically measured during bioassessments (i.e., habitat type and qualitative PHAB scores), and biological metrics used in the NorCal B-IBI (i.e., EPT taxa and % Predators). These results suggest that along with land use, BMI community composition in Marin County sites is partially explained by habitat quality and structure (i.e., type).

[19] Quantitative variable include: habitat type (pool, glide, riffle, run), substrate embeddedness, % canopy cover.

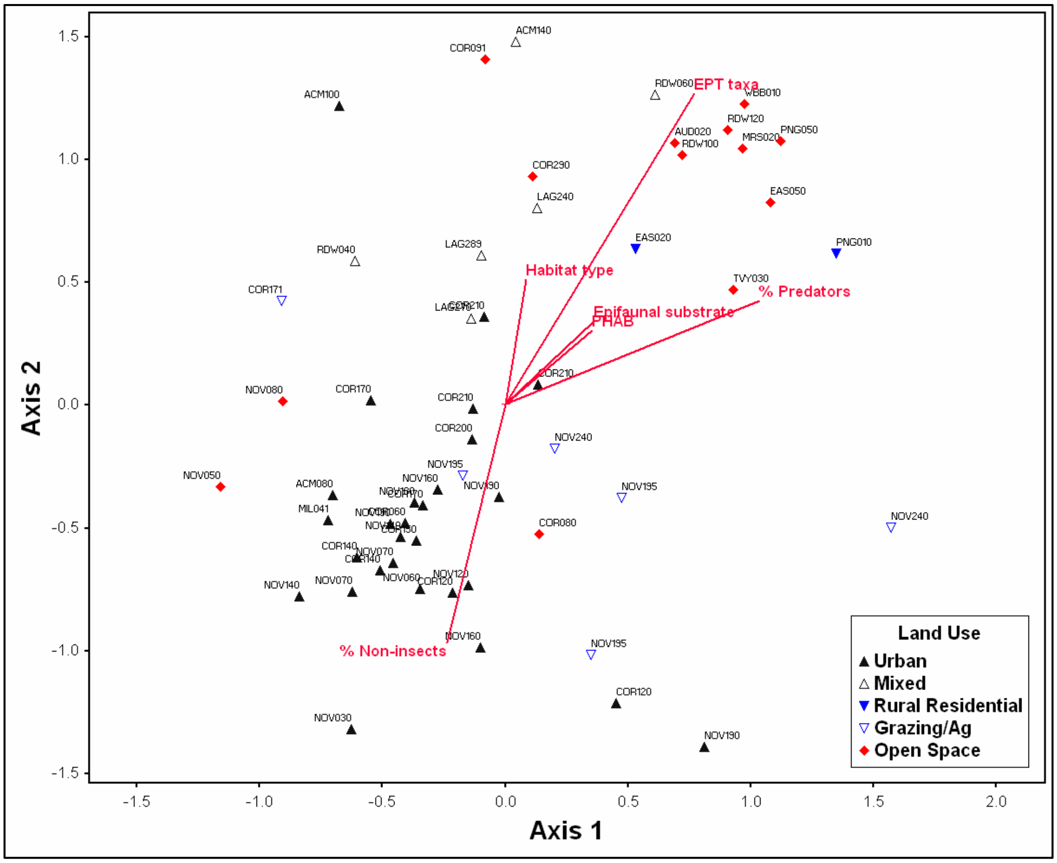

Figure 11. Relative differences in BMI community composition in Marin County creeks sampled between 2005 and 2009 presented by adjacent land use type and compared to physical habitat variables and selected B-IBI metrics.

4.4 How can the MCSTOPPP BMI bioassessment program be adapted to allow more efficient data collection that answers priority monitoring/management questions?

Between 1999 and 2009, the MCSTOPPP and SWAMP bioassessment programs collected BMI data from 89 creek sites in Marin County. Although SWAMP collected only one year of data, MCSTOPP has conducted bioassessments for two or more years at a majority of their sites, which provide data to compare BMI community composition among sites within specific watersheds. Comparisons allow sites providing redundant information to be identified based on correlation analyses (Pearson's Correlation Coefficients), which can be used to inform decisions on targeted site selection in the future.

Matrices containing correlation coefficients for logged BMI data collected from the four Marin County watersheds draining to the North San Francisco Bay are presented in Appendix G. Table 12 presents (by watershed) adjacent sites where BMI communities are well correlated ($r^2 \geq 0.8$) and associated average (mean) B-IBI scores. These comparisons suggest that bioassessments conducted at these sites are providing redundant information. Depending on the extent and magnitude of anticipated changes in factors that may impact ecological condition (e.g., land use) or potential management actions in watershed areas upstream of these sites, MCSTOPPP may choose to temporarily eliminate one site from each set of well correlated sites presented in Table 12.

Table 12. MCSOTPPP bioassessment sites with significantly ($r^2 > 0.8$) correlated BMI communities and associated average (mean) B-IBI scores.

Watershed	Site #1	# Sample Events	Mean B-IBI Score	Site #2	# Sample Events	Mean B-IBI Score
Corte Madera Creek	COR060	3	11	COR120	4	20
	COR140	3	16	COR150	2	11
	COR170	3	33	COR171	3	39
	COR200	2	25	COR210	5	34
Novato Creek	NOV060	1	8	NOV070	2	7
	NOV120	2	14	NOV130	1	19
	NOV140	3	12	NOV160	4	19
	NOV178	2	29	NOV180	3	23
Miller Creek	MIL020	2	21	MIL040	4	25
				MIL041	1	14
	MIL050	3	27	MIL060	3	37
	MIL080	3	44	MIL090	1	60
Arroyo Corte Madera	ACM070	2	13	ACM080	?	18

5.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the information presented in this summary evaluation, the following conclusions were developed:

1. Ecological condition, as defined by NorCal Benthic –Index of Biotic Integrity (B-IBI) scores, in Marin County bioassessment sites ranges from "very poor" to "very good", with sites scoring in the "very good" category located at higher elevations. Sites scoring in the "very good" category are generally consistent with those initially identified as reference (i.e., least disturbed) during the development of the Draft B-IBI for Bay Area creeks.
2. Ecological condition was generally lower and more spatially variable at sites in watersheds draining the North San Francisco Bay, compared to those in watersheds draining to the Pacific Ocean. Additionally, although limited information is currently available, it appears that reference sites identified as having an intermittent flow regime inherently score lower on the NorCal B-IBI, than sites that have perennial flow.
3. Seasonal variability was observed in both BMI community composition and B-IBI scores. Fall sampling events had distinctly different BMI communities and higher B-IBI scores compared to spring samples collected in 1999 through 2001. Further analysis of seasonal differences in B-IBI scores at a larger number of sites (especially at minimally disturbed sites), would provide useful data to inform the selection of a sampling timeframe that is both practical and adequately predicts the ecological condition of creek sites. However, if a fall sampling timeframe were used, sites with an intermittent flow regime would be eliminated from the monitoring program.
4. Inter-annual variability in B-IBI scores does not appear to have a discernable pattern between reference (i.e., least impacted) and non-reference sites. In some cases, reference sites exhibited higher inter-annual variability than non-reference sites. This variability at reference sites provides a challenging scenario of accounting for natural variability in non-reference sites.
5. Benthic Macroinvertebrate communities at the vast majority of sites with adjacent "urban" land uses were distinctively different than those at sites with open space land uses in most cases. Sites within the remaining land use classes (i.e., rural residential, agricultural/grazing and mixed) were evenly distributed in between open space and urban sites. A few sites on the urban boundary did not exhibit this pattern (i.e., sites identified as urban were more similar to open space sites), suggesting that land use classification should be considered at multiple spatial scales (e.g., adjacent- and watershed-scales).
6. BMI community composition at bioassessment sites correlate well with changes in environmental metrics that are typically measured during bioassessments (i.e., habitat type and qualitative Physical Habitat assessment (PHAB) scores), and biological metrics used in the NorCal B-IBI (i.e., EPT taxa and % Predators). These results suggest that along with land use, BMI community composition in Marin County sites is partially explained by habitat quality and structure (i.e., type).

7. BMI communities in adjacent bioassessment sites in Marin County watersheds are well correlated, suggesting that bioassessments conducted at these sites are providing redundant information.

Based on the conclusions described above and previous evaluations of MCSTOPPP bioassessment data (SLSII 2008), recommendations are provided below on future bioassessment activities in Marin County. Brief recommendations are provided in the context of the three original bioassessment program objectives stated in Section 1.0, with consideration of SWAMP activities currently underway and the initial development of the Bay Area Stormwater Management Agencies Association's (BASMAA) Regional Monitoring Coalition (RMC).

Prior to implementing recommendations presented below or continuing to implement its current bioassessment program, however, it is strongly suggested that MCSTOPPP review existing monitoring objectives and create succinct and well defined questions it wishes to answer over the next decade.

Objective #1: Measure the ecological health of creeks and watersheds in Marin County and detect changes that occur over time.

Ecological health of creek systems is typically measured using one or a combination of biological, chemical, physical and toxicological indicators. Each type of indicator provides information to watershed managers to assist with answering different types of management questions. For example, BMIs are believed to be good indicators of ecological condition at points in time and over the long-term (i.e., decadal). However, BMI communities are inherently insensitive to short-term moderate stress, such as moderate changes in land use in upstream watersheds. This is especially true because bioassessment sampling typically occurs only once per year (maximum), which does not allow short-term (i.e. <5 years) impacts or improvements to be identified unless directly associated with the bioassessment site (e.g., bank and bed restoration project). Therefore, BMI bioassessments may be appropriate to answer a question, such as: "What is the ecological condition of Marin County Creeks"?

To answer this question for <u>all</u> Marin County creeks using bioassessments would, however, require MCSTOPPP to either sample all reaches of creeks in Marin County, or develop a probability-based sampling design that allows for extrapolation of information to unsampled reaches with a known level of statistical confidence. Targeted sampling, as conducted by MCSTOPPP since 1999, would not be appropriate for extrapolation to all creeks in the County because this type of sampling design introduces an unknown level of bias that could skew ecological condition assessments. Targeted sampling may be appropriate, however, for specific questions regarding the effectiveness of an upstream riparian restoration project or impacts to a specific creek reach/site. It is important to note, however, that inter-annual variability confounds attempts to detect temporal trends (improvements or degradation) at specific sites. Other assessment methods, such as bird, vegetation or geomorphic surveys may yield more useful information on the effectiveness of riparian restoration or bank stabilization projects.

Currently, the State of California's statewide ambient monitoring program (SWAMP) uses BMIs, attached algae (i.e., periphyton), quantitative PHAB, California Rapid Assessment Method (CRAM) and limited chemical parameters to assess the condition of aquatic life uses (i.e., ecological condition) in California perennial creeks. To allow for extrapolation of data to all creeks in California, a probabilistic sampling design was created. Similar efforts have occurred through the Southern California Stormwater Monitoring Coalition (SMC) (SCCWRP 2008) and are currently being discussed in the Bay Area through the BASMAA Regional Monitoring Coalition (RMC).

Recommendation: Review existing management questions developed through SWAMP, the SMC and the BASMAA RMC, and develop a small set of well defined management questions specific to MCSTOPPP's needs to assess ecological condition of creeks in Marin County. Once priority questions have been established, MCSTOPPP may choose to evaluate whether those questions can be efficiently answered through the following options: 1) review additional watershed health indicators and monitoring methods in order to design a program specific to Marin County, 2) participate in the design of a regional bioassessment monitoring program via the BASMAA RMC, or; 3) or maintain its current targeted design with variations in sampling frequency.

Objective #2: Evaluate potential land use and other stressor-related impacts to the ecological health of creeks and watersheds.

The observed ecological condition of creeks can be affected by stressors that occur at the watershed, reach, or site scale. The most documented watershed-scale stressors that have been shown to change BMI community composition include unmitigated changes in land uses, construction of large-scale water impoundments (i.e., dams), and associated modifications to the creek hydrology. Stressors that occur at the "reach-scale" may include changes or encroachments to the riparian corridor. Sampling site-specific impacts may include degraded water quality or physical habitat structure.

Although stressors at each spatial scale may likely be interrelated, measuring the relationship between a specific stressor and an indicator of ecological condition requires a specific monitoring approach. For example, if a watershed manager is interested in understanding how changes in land use at a watershed or sub-watershed scale are impacting the ecological condition of a specific stream reach, then periodically conducting BMI bioassessments along with other physical habitat measurements may be an appropriate approach to identifying changes in ecological condition due to land use, over time. Alternatively, if existing land use information and physical habitat data suggest that a site-specific stressor such as water quality may be impacting ecological condition, then sampling BMIs at a finer spatial scale may not be the best approach, as BMIs do not typically provide information necessary to identify impacts associated with specific water quality parameters. Rather, the implementation of a water quality (or bedded sediment) based monitoring approach that is informed through a review of existing water quality data, evaluation of adjacent or upstream land uses and associated pollutants, and field reconnaissance would likely be more successful.

Recommendation: Based on the development of management questions by MCSTOPPP (see Objective #1 above), if watershed managers are interested in better understanding impacts to ecological condition due to watershed-scale changes/stressors, consider including upstream land use as a site selection variable (i.e., strata) if the MCSTOPPP bioassessment program continues to be implemented. Additionally, if managers are interested in identifying the site/reach specific stressor impacting ecological condition at a specific site or set of sites, it is recommended that a more refined and site/reach specific management question(s) and conceptual model be developed. Refined questions and conceptual models will assist managers in designing monitoring approaches that are focused on identifying stressors or causes of impacts at a specific creek reach/site and associated sources. An example stressor identification process (including conceptual models) titled the Causal Analysis/Diagnosis Decision Information System (CADDIS) has been develop by the USEPA and may be useful. A guidance document and online step-by-step guide is available via the USEPA website (http://cfpub.epa.gov/caddis/index.cfm).

Objective #3: Inform and educate the public about the ecological condition of creeks and watersheds using an easily understandable monitoring tool.

Bioassessments have been successfully used throughout the U.S. and the world to inform the general public on the ecological condition and importance of water bodies. Simple graphs and figures explaining ecological condition can provide watershed managers with valuable information to forward to the public. However, watershed managers must be mindful that results and conclusions based on specific monitoring programs are not overstated. For example, using the BMI example discussed in Objective #1 above, extrapolating targeted bioassessment data to larger geographical areas is not recommended, as it may over- or under-predict ecological condition to an unknown degree.

Recommendation: Use reliable measurement tools of ecological condition and develop simple factsheets illustrating the objectives and results of the MCSTOPPP bioassessment program. Use factsheets and information developed (i.e., graphs and figures) to educate the general public on the condition of Marin County creeks through the MCSTOPPP website and public information and participation activities.

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APPENDICES

APPENDIX A
BIOASSESSMENT MONITORING
FREQUENCY 1999-2009

Table A-1. Frequency for bioassessment sites sampled between 1999 and 2009.

Site Code	Fall 1999	Spring 2000	Fall 2000	Spring 2001	Spring 2002	Spring 2004	Spring 2005	Spring 2006	Spring 2007	Spring 2009
Arroyo Corte Madera Del Presidio Watershed										
ACM070	x	x	x	x	x					
ACM080										x
ACM100		x	x	x	x					x
ACM110	x	x	x	x	x					
ACM120		x	x	x						
ACM140	x	x	x	x						x
Corte Madera Creek Watershed										
COR060	x	x	x	x	x		x	x		
COR080		x	x	x				x		
COR090		x		x						
COR091										x
COR120	x	x	x	x	x			x	x	
COR140		x	x					x		x
COR150		x	x					x		
COR170		x			x	x	x	x		
COR171		x		x	x		x			
COR200		x	x	x	x			x		
COR210	x		x	x	x	x	x	x		x
COR211	x		x	x						
COR260		x		x						
COR290	x	x		x				x		
Miller Creek Watershed										
MIL020	x	x	x	x	x					
MIL040	x	x	x	x		x				
MIL041										x
MIL050	x	x	x	x						
MIL060	x	x	x	x		x				
MIL080		x		x	x	x				
MIL090		x								
Novato Creek Watershed										
NOV030				x		x	x			
NOV050				x		x	x			
NOV060							x			
NOV070						x	x			x
NOV080						x	x			
NOV120	x	x	x	x				x		
NOV130		x		x	x			x		
NOV140								x		x
NOV160	x	x	x	x				x	x	
NOV170	x	x	x							
NOV178								x	x	
NOV180		x	x		x	x	x			
NOV190								x	x	
NOV195	x	x	x	x	x	x	x	x	x	
NOV210	x	x	x	x						
NOV240		x		x				x	x	
Lagunitas Creek Watershed										
LAG240										x
LAG270										x
LAG289										x

APPENDIX B
2009 BIOASSESSMENT AND PHYSICAL HABITAT ASSESSMENTS FIELD DATA SHEETS - Available on CD-ROM

APPENDIX C
QA/QC RESULTS

STATE OF CALIFORNIA - THE RESOURCES AGENCY Arnold Schwarzenegger

DEPARTMENT OF FISH AND GAME
AQUATIC BIOASSESSMENT LABORATORY-CHICO
CALIFORNIA STATE UNIVERSITY, CHICO
CHICO, CA 95929-0555
530-898-4792

July 10, 2009

Tom King
Bioassessment Services
24988 Blue Ravine Road, Suite 108
Folsom, CA 95630

Dear Tom,

Attached are the results of my QC analysis of 2 samples submitted from the Bay Area Urban Streams 2009 project. The results are presented in five summary tables. This QC analysis was performed in accordance to the Southwest Association of Freshwater Invertebrate Taxonomists (SAFIT)'s Standard Taxonomic Effort Document (STE) 28 November 2006 version (Richards and Rogers, 2006).

There were three instances of "tagalong" organisms. These are defined as specimens accidentally included in a vial of organisms of another taxon and are marked as "Probable sorting error" in the attached Listing of Taxonomic Discrepancies file.

In the submitted data file, *Neophylax* was listed twice for sample BAS-2901. Only one vial of *Neophylax* was present, although there was a vial labeled *Neoplasta* which wasn't in the submitted data file. This was most likely a transcription error in the data file as the identifications correctly matched the vial labels.

A *Zaitzevia* larva was found in the *Cleptelmis addenda* (Fall) vial. *Zaitzevia* larvae were correctly identified in the sample, so this was likely a sorting error rather than a misidentification.

The snail specimens originally identified as *Planorbella* are more properly referred to *Helisoma* instead as referred to in the mollusc section of the STE (Richards and Rogers, 2006). These specimens will key to *Planorbella* in Burch (1982) so if this project is still following the previous version of the STE, the identification to *Planorbella* would be correct.

I welcome any questions or comments you may have concerning this report.

Sincerely,

Austin Brady Richards
Aquatic Bioassessment Laboratory–Chico
California State University, Chico
Chico, CA 95929-0555
arichards@csuchico.edu
(530) 898-4792

Literature Cited

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Comparative Taxonomic Listing of all Submitted Samples

Samples submitted by BioAssessment Services for Project: Bay Area Urban Streams 2009

Report prepared by Brady Richards, CDFG ABL-Chico, 7/10/2009

Taxonomist	Sample no.	Vial no.	Original ID	Original Count	Stage	ABL Count	ABL ID
	BAS-2891						
		1	Baetis	106	L	1	Tanytarsini
		1	Baetis	106		108	Baetis
		2	Chironomini	22	L&P	22	Chironomini
		3	Corbicula	1		1	Corbicula
		4	Crangonyx	1		1	Crangonyx
		5	Fallceon quilleri	3		3	Fallceon quilleri
		6	Gyraulus	17		17	Gyraulus
		7	Helobdella	1		1	Helobdella
		8	Hyalella	20		20	Hyalella
		8	Hyalella	20	L	1	Orthocladiinae
		9	Hydropsyche	2	L	2	Hydropsyche
		10	Lebertia	1		1	Lebertia
		11	Menetus	1		1	Menetus
		12	Oligochaeta	32		32	Oligochaeta
		13	Orthocladiinae	16	L&P	16	Orthocladiinae
		14	Ostracoda	22		21	Ostracoda
		15	Oxyethira	5	L	5	Oxyethira
		16	Physa	5		5	Physa
		17	Planorbella	1		1	Helisoma
		18	Polychaeta	3		3	Polychaeta
		19	Simulium	4	L&P	4	Simulium
		20	Sperchon	2		2	Sperchon
		21	Tanypodinae	1	L	1	Tanypodinae
		21	Tanypodinae	1	L	1	Elmidae
		22	Tanytarsini	234	L	233	Tanytarsini
		23	Turbellaria	3		3	Turbellaria

Taxonomist	Sample no.	Vial no.	Original ID	Original Count	Stage	ABL Count	ABL ID
	BAS-2901						
				0	x	0	
		1	Agapetus	17	L	17	Agapetus
		2	Ameletus	1		1	Ameletus
		3	Amiocentrus aspilus	35	L	36	Amiocentrus aspilus
		4	Antocha	13	L&P	13	Antocha
		5	Baetis	42		42	Baetis
		6	Cleptelmis addenda	19	L	1	Zaitzevia
		6	Cleptelmis addenda	19	L&A	18	Cleptelmis addenda
		7	Clinocera	1	L	1	Clinocera
		8	Diphetor hageni	1		1	Diphetor hageni
		9	Drunella	2		2	Drunella
		10	Ephemerellidae	4		4	Ephemerellidae
		11	Glossosoma	2	L	2	Glossosoma
		12	Hemerodromia	5	L	5	Hemerodromia
		13	Hydropsyche	9	L	9	Hydropsyche
		14	Hydroptila	2	L	2	Hydroptila
		15	Isoperla	1		1	Isoperla
		16	Lebertia	4		4	Lebertia
		17	Lepidostoma	9	L	9	Lepidostoma
		18	Micrasema	14	L	14	Micrasema
		19	Narpus	1	L	1	Narpus
		20	Neophylax	1	L	1	Neoplasta
		21	Neophylax	4	L	4	Neophylax
		22	Oligochaeta	2		2	Oligochaeta
		23	Optioservus	25	L&A	25	Optioservus
		24	Orthocladiinae	152	L&P	152	Orthocladiinae
		25	Paraleptophlebia	2		2	Paraleptophlebia
		26	Pisidium	1		1	Pisidium
		27	Rhyacophila	10	L	10	Rhyacophila
		28	Sialis	2	L	2	Sialis

Taxonomist	Sample no.	Vial no.	Original ID	Original Count	Stage	ABL Count	ABL ID
	BAS-2901						
		29	Simulium	83	L	83	Simulium
		30	Sperchon	6		6	Sperchon
		31	Tanypodinae	5	L&P	5	Tanypodinae
		32	Tanytarsini	27	L	27	Tanytarsini
		33	Torrenticola	5		5	Torrenticola
		34	Zaitzevia	5	L&A	5	Zaitzevia

Listing of Enumeration Discrepancies

Samples submitted by BioAssessment Services for Project: Bay Area Urban Streams 2009

Report prepared by Brady Richards, CDFG ABL-Chico, 7/10/2009

	Sample #	Vial #	Original ID	# Counted Original	# Counted QC	Difference (Original - QC)
Minor Counting Discrepancies						
	BAS-2891	1	Baetis	106	109	-3
		8	Hyalella	20	21	-1
		14	Ostracoda	22	21	1
		21	Tanypodinae	1	2	-1
		22	Tanytarsini	234	233	1
	BAS-2901	3	Amiocentrus aspilus	35	36	-1

Listing of Taxonomic Discrepancies

Samples submitted by BioAssessment Services for Project: Bay Area Urban Streams 2009

Report prepared by Brady Richards, CDFG ABL-Chico, 7/10/2009

Sample #	Vial #	Final ID Original ID	QC Final ID	Taxonomic level of dispute	# Organisms	Comments
BAS-2891						
Disputed ID						
	17	Planorbella	Helisoma	Genus	1	
Probable sorting error						
	1	Baetis	Tanytarsini	Order	1	This disputed ID also represents a difference in taxonomic precision.
	8	Hyalella	Orthocladiinae	Subphylum	1	This disputed ID also represents a difference in taxonomic precision.
	21	Tanypodinae	Elmidae	Order	1	This disputed ID also represents a difference in taxonomic precision.
BAS-2901						
Disputed ID						
	6	Cleptelmis addenda	Zaitzevia	Genus	1	This disputed ID also represents a difference in taxonomic precision.
	20	Neophylax	Neoplasta	Order	1	

Summary of Taxonomic and Enumeration Discrepancies

Samples submitted by BioAssessment Services for Project: Bay Area Urban Streams 2009

Report prepared by Brady Richards, CDFG ABL-Chico, 7/10/2009

		Taxonomic Discrepancies						Counting Discrepancies			
				Taxonomic Precision Relative to QC							
Sample #	**Total Taxa**	**Disputed ID**		**More precise**		**Less Precise**		Major		Minor	
		*f**	*n***	*f*	*n*	*f*	*n*	*f*	*d****	*f*	*d*
BAS-2891	24	1	1	-	-	-	-	-	-	5	7
BAS-2901	34	2	2	-	-	-	-	-	-	1	1

* = the frequency of occurence of the discrepancy, in number of samples *f*
** = the number of organisms affected (by QC Lab counts) *n*
*** = the sum total of (absolute value of) differences in counts *d*

QC Report - Disputed ID's only

Samples submitted by BioAssessment Services for Project: Bay Area Urban Streams 2009

Report prepared by Brady Richards, CDFG ABL-Chico, 7/10/2009

Sample #	***Vial #.***	***Original ID***	***QC ID***	***comments***
BAS-2891	17	Planorbella	Helisoma	
BAS-2901	6	Cleptelmis addenda	Zaitzevia	This disputed ID also represents a difference in taxonomic precision.
	20	Neophylax	Neoplasta	

APPENDIX D
SITE METRIC AND B-IBI SCORES
BY SAMPLING EVENT

Table D-1. Metric and IBI scores listed by site and sampling event

Site Code	Date	EPT Taxa		Coleoptera Taxa		Diptera Taxa		% Intolerant		% Non-Gast. Scrapers		% Predators		% Shred Taxa		% Non-Insect Taxa		IBI Score[1]
		metric	IBI	metric	IBI	metric	IBI	metric	IBI	metric	IBI	metric	IBI	metric	IBI	metric	IBI	
203ACM070	FALL 1999	3	1	1	1	3	3	5	3	2	1	2	1	7	4	53	1	19
203ACM070	SPRING 2000	2	0	1	1	3	3	0	2	0	0	0	0	0	0	25	6	15
203ACM070	FALL 2000	2	0	0	0	0	0	0	2	0	0	1	0	11	7	78	0	11
203ACM070	SPRING 2001	3	1	0	0	1	1	0	2	0	0	2	1	9	6	64	0	14
203ACM080	SPRING 2009	2	0	2	2	4	4	0	2	1	1	1	0	0	0	25	6	18
203ACM100	SPRING 2000	12	5	3	4	3	3	16	6	12	5	1	1	9	6	18	8	48
203ACM100	FALL 2000	8	3	0	0	0	0	60	10	0	0	22	10	36	10	27	6	24
203ACM100	SPRING 2001	5	2	2	2	1	1	2	2	27	10	8	5	12	8	44	3	41
203ACM100	SPRING 2009	12	5	2	2	2	2	8	4	37	10	5	3	14	9	32	5	50
203ACM110	FALL 1999	12	5	2	2	6	6	16	6	17	9	5	3	12	8	15	8	59
203ACM110	SPRING 2000	14	6	3	4	6	6	11	5	13	5	5	3	7	4	20	7	50
203ACM110	FALL 2000	9	4	0	0	0	0	50	10	2	1	29	10	33	10	17	8	54
203ACM110	SPRING 2001	13	6	2	2	3	3	10	5	29	10	9	4	7	4	30	5	49
203ACM120	SPRING 2000	12	5	1	1	7	7	26	9	7	4	1	0	8	5	16	8	49
203ACM120	FALL 2000	4	1	0	0	0	0	14	6	0	0	16	10	10	6	40	4	34
203ACM120	SPRING 2001	3	1	1	1	2	2	1	2	3	2	2	1	0	0	46	3	15
203ACM140	FALL 1999	18	8	4	5	5	5	17	7	19	10	7	4	15	9	18	8	70
203ACM140	SPRING 2000	19	9	4	5	2	2	38	10	41	10	4	2	9	6	12	9	66
203ACM140	FALL 2000	12	5	0	0	0	0	33	10	1	1	13	8	33	10	13	9	54
203ACM140	SPRING 2001	21	10	4	5	5	5	29	10	32	10	4	2	11	7	14	8	71
203ACM140	SPRING 2009	13	6	5	6	4	4	11	5	32	10	4	2	10	6	20	7	58
203COR060	FALL 1999	5	2	0	0	6	8	0	2	0	2	31	10	5	3	45	3	38
203COR060	SPRING 2000	2	0	1	1	3	3	1	2	0	0	1	0	0	0	36	4	12
203COR060	FALL 2000	6	2	1	1	7	7	1	2	0	0	26	10	13	8	30	5	44
203COR060	SPRING 2001	2	0	1	1	3	3	0	2	0	0	1	0	0	0	54	1	9
203COR060	SPRING 2006	2	0	1	1	2	2	0	2	0	0	0	0	0	0	44	3	10
203COR080	SPRING 2000	7	3	1	1	7	7	3	3	1	2	2	1	10	6	24	7	38
203COR080	FALL 2000	9	4	1	1	5	5	2	2	0	0	29	10	9	6	22	7	44
203COR080	SPRING 2001	12	5	1	1	3	3	8	4	5	3	10	8	12	8	31	5	46
203COR080	SPRING 2006	9	4	0	0	3	3	5	3	0	0	7	4	4	2	32	5	26
203COR090	SPRING 2000	22	9	2	2	7	7	33	10	9	5	16	10	11	7	11	9	74
203COR090	SPRING 2001	23	10	5	6	9	9	32	10	23	10	21	10	11	7	13	9	89
203COR091	SPRING 2009	16	7	3	4	5	5	30	10	13	7	10	6	17	10	17	8	71
203COR120	FALL 1999	4	1	0	0	6	6	1	2	0	0	2	1	10	6	45	3	24
203COR120	SPRING 2000	10	4	1	1	6	6	5	3	1	1	1	0	10	6	15	8	36

Table D-1. Metric and IBI scores listed by site and sampling event

Site Code	Date	EPT Taxa		Coleoptera Taxa		Diptera Taxa		% Intolerant		% Non-Gast. Scrapers		% Predators		% Shred Taxa		% Non-Insect Taxa		IBI Score[1]
		metric	IBI	metric	IBI	metric	IBI	metric	IBI	metric	IBI	metric	IBI	metric	IBI	metric	IBI	
203COR120	FALL 2000	2	0	2	2	4	4	0	2	0	0	3	2	6	4	41	3	21
203COR120	SPRING 2001	4	1	0	0	3	3	1	2	0	0	8	5	0	0	50	2	16
203COR120	SPRING 2006	3	1	0	0	2	2	0	2	0	0	3	2	0	0	50	2	11
203COR120	SPRING 2007	6	2	1	1	3	3	0	2	0	0	14	9	1	0	52	1	22
203COR140	SPRING 2000	2	0	0	0	4	4	0	2	0	2	0	0	10	6	20	7	26
203COR140	FALL 2000	3	1	0	0	6	6	1	2	0	0	32	10	13	8	20	7	42
203COR140	SPRING 2006	1	0	0	0	2	2	0	2	0	0	0	0	0	0	50	2	8
203COR140	SPRING 2009	1	0	0	0	4	4	0	2	0	0	0	0	0	0	38	4	13
203COR150	SPRING 2000	2	0	0	0	3	3	0	2	0	2	1	1	0	0	44	3	14
203COR150	FALL 2000	1	0	0	0	3	3	1	2	0	0	14	9	20	10	40	4	35
203COR150	SPRING 2006	1	0	0	0	2	2	0	2	0	0	1	0	0	0	50	2	8
203COR160	SPRING 2005	2	0	0	0	2	2	0	2	0	0	1	0	0	0	50	2	8
203COR169	SPRING 2005	1	0	0	0	3	3	0	2	0	0	2	1	0	0	50	2	10
203COR170	SPRING 2000	9	4	1	1	3	3	11	5	0	2	8	4	6	4	12	9	40
203COR170	SPRING 2004	6	2	4	5	5	5	28	10	0	0	16	10	0	0	15	8	50
203COR170	SPRING 2006	7	3	2	2	5	5	6	3	1	1	3	2	5	3	13	9	34
203COR171	SPRING 2000	12	5	0	0	3	3	30	10	3	3	8	4	11	7	11	9	51
203COR171	SPRING 2001	9	4	1	1	6	6	6	3	0	0	6	0	0	0	5	10	30
203COR171	SPRING 2005	8	3	2	2	5	5	11	5	1	1	3	2	6	4	17	8	38
203COR200	SPRING 2000	12	5	3	4	3	3	16	6	12	5	1	1	9	6	18	8	48
203COR200	FALL 2000	5	2	2	2	4	2	3	3	2	1	8	5	16	10	32	5	38
203COR200	SPRING 2001	2	0	1	1	3	3	0	2	0	0	1	0	0	0	22	7	16
203COR210	FALL 1999	5	2	2	2	7	7	7	4	2	1	3	2	15	9	20	7	42
203COR210	FALL 2000	9	4	2	2	4	4	3	3	2	1	7	4	10	6	24	7	39
203COR210	SPRING 2001	6	2	1	1	3	3	3	3	0	0	4	4	6	4	14	3	25
203COR210	SPRING 2004	10	4	1	1	4	4	6	3	1	1	7	4	0	0	25	6	29
203COR210	SPRING 2005	10	4	5	6	3	3	6	3	4	2	6	4	13	8	25	6	45
203COR210	SPRING 2006	8	3	1	1	3	3	7	4	2	1	6	4	0	0	29	6	28
203COR210	SPRING 2009	10	4	3	4	7	7	10	5	1	1	11	7	10	6	35	5	48
203COR211	FALL 1999	7	3	3	4	4	4	14	6	2	1	4	2	14	9	19	7	45
203COR211	FALL 2000	10	4	4	5	6	6	10	4	6	3	9	6	15	9	19	7	55
203COR211	SPRING 2001	12	5	0	0	4	4	67	10	1	1	17	7	11	7	11	9	54
203COR260	SPRING 2000	16	7	0	0	4	4	71	10	4	2	36	10	9	6	9	9	60
203COR260	SPRING 2001	23	10	5	6	5	5	32	10	41	10	10	6	10	6	13	9	78
203COR290	FALL 1999	12	5	3	4	5	5	48	10	14	7	8	5	8	5	12	9	62
203COR290	SPRING 2000	18	8	5	6	5	5	50	10	22	10	30	10	7	4	7	10	79
203COR290	SPRING 2001	8	3	2	2	3	3	3	3	1	1	4	2	11	7	32	5	32

Table D-1. Metric and IBI scores listed by site and sampling event

Site Code	Date	EPT Taxa		Coleoptera Taxa		Diptera Taxa		% Intolerant		% Non-Gast. Scrapers		% Predators		% Shred Taxa		% Non-Insect Taxa		IBI Score[1]
		metric	IBI	metric	IBI	metric	IBI	metric	IBI	metric	IBI	metric	IBI	metric	IBI	metric	IBI	
203COR290	SPRING 2006	12	5	6	8	4	4	27	9	4	3	13	8	14	9	4	10	69
203LAG240	SPRING 2009	18	8	5	6	7	7	8	4	7	4	8	5	11	7	14	8	61
203LAG270	SPRING 2009	10	4	4	5	6	6	7	4	2	1	6	4	8	5	20	7	44
203LAG289	SPRING 2009	15	7	4	5	6	6	6	3	4	2	3	2	6	4	24	7	45
203MIL041	SPRING 2009	2	0	2	2	3	3	0	2	0	0	4	2	0	0	50	2	14
203NOV070	SPRING 2009	1	0	0	0	2	2	0	2	0	0	1	0	0	0	56	1	6
203NOV140	SPRING 2009	1	0	1	1	3	3	0	2	0	0	1	0	0	0	50	2	10
206COR200	SPRING 2006	6	2	2	2	4	4	2	2	0	0	4	2	0	0	29	6	22
206MIL020	FALL 1999	6	2	1	1	5	5	14	6	0	0	4	2	10	6	35	5	34
206MIL020	SPRING 2000	4	1	1	1	3	3	0	2	0	0	0	0	0	0	20	7	18
206MIL020	FALL 2000	7	3	3	4	5	5	8	4	2	1	9	6	5	3	23	7	41
206MIL020	SPRING 2001	5	2	0	0	3	3	1	2	0	0	4	2	8	5	38	4	22
206MIL040	FALL 1999	5	2	2	2	5	5	17	7	0	0	8	5	11	7	28	6	42
206MIL040	SPRING 2000	3	1	1	1	4	4	0	2	0	0	1	0	9	6	27	6	25
206MIL040	FALL 2000	4	1	2	2	3	3	22	8	0	0	9	6	6	4	35	5	36
206MIL040	SPRING 2001	2	0	1	1	3	3	0	2	0	0	6	4	0	0	40	4	18
206MIL040	SPRING 2004	4	1	2	2	5	5	4	3	0	0	8	5	6	4	35	5	31
206MIL050	FALL 1999	5	2	2	2	9	9	10	5	0	0	13	8	9	6	18	8	50
206MIL050	SPRING 2000	7	3	1	1	3	3	3	3	0	0	2	1	7	4	20	7	28
206MIL050	FALL 2000	5	2	0	0	5	5	2	2	0	0	16	10	10	6	40	4	36
206MIL050	SPRING 2001	6	2	1	1	3	3	1	2	0	0	5	3	6	4	29	6	26
206MIL060	FALL 1999	11	5	2	2	6	6	7	4	0	0	15	9	15	9	15	8	54
206MIL060	SPRING 2000	14	6	0	0	4	4	18	7	0	0	5	0	10	6	10	9	40
206MIL060	FALL 2000	8	3	1	1	6	6	6	3	0	0	23	10	14	9	19	7	49
206MIL060	SPRING 2001	4	1	0	0	7	7	1	2	0	0	3	2	0	0	15	8	25
206MIL060	SPRING 2004	8	3	2	2	6	6	29	10	1	1	5	3	5	3	16	8	45
206MIL080	SPRING 2000	11	5	1	1	3	3	24	9	1	1	6	0	6	4	11	9	40
206MIL080	SPRING 2001	12	5	0	0	9	9	26	9	0	0	5	3	8	5	8	9	50
206MIL080	SPRING 2004	15	7	5	6	8	8	28	10	0	0	12	8	6	4	12	9	65
206MIL090	SPRING 2000	17	8	0	0	8	8	42	10	3	2	10	2	12	8	4	10	60
206NOV030	SPRING 2001	2	0	0	0	4	4	0	2	0	0	3	0	0	0	22	7	16
206NOV030	SPRING 2004	0	0	0	0	3	3	0	2	0	0	3	2	9	6	64	0	16
206NOV030	SPRING 2005	2	0	0	0	3	3	0	2	0	0	0	0	0	0	50	2	9
206NOV050	SPRING 2001	9	4	4	5	9	9	8	4	0	0	14	2	4	2	15	8	42
206NOV050	SPRING 2004	6	2	6	8	6	6	18	7	1	1	7	4	4	2	22	7	46
206NOV050	SPRING 2005	5	2	1	1	2	2	4	3	0	0	3	2	9	6	27	6	28
206NOV060	SPRING 2005	2	0	0	0	3	3	0	2	0	0	2	1	0	0	58	0	8

Table D-1. Metric and IBI scores listed by site and sampling event

Site Code	Date	EPT Taxa		Coleoptera Taxa		Diptera Taxa		% Intolerant		% Non-Gast. Scrapers		% Predators		% Shred Taxa		% Non-Insect Taxa		IBI Score[1]
		metric	IBI	metric	IBI	metric	IBI	metric	IBI	metric	IBI	metric	IBI	metric	IBI	metric	IBI	
206NOV070	SPRING 2004	0	0	0	0	1	1	0	2	0	0	1	0	0	0	80	0	4
206NOV070	SPRING 2005	1	0	0	0	2	2	0	2	0	0	1	0	0	0	40	4	10
206NOV080	SPRING 2004	14	6	3	4	8	8	46	10	2	1	19	10	9	6	16	8	66
206NOV080	SPRING 2005	9	4	1	1	5	5	16	6	0	0	7	4	5	3	11	9	40
206NOV120	FALL 1999	5	2	1	1	5	5	0	2	0	0	13	8	0	0	37	4	28
206NOV120	SPRING 2000	2	0	0	0	3	3	0	0	0	2	0	0	0	0	29	6	14
206NOV120	FALL 2000	4	1	0	0	3	3	0	2	0	0	32	10	0	0	44	3	24
206NOV120	SPRING 2001	0	0	0	0	3	3	0	2	0	0	0	0	0	0	50	2	9
206NOV120	SPRING 2006	2	0	0	0	4	4	0	2	0	0	7	4	0	0	38	4	18
206NOV130	SPRING 2006	2	0	0	0	2	2	0	2	0	0	0	0	0	0	43	3	9
206NOV140	SPRING 2000	5	2	1	1	2	2	6	3	0	2	2	1	7	4	43	3	22
206NOV140	SPRING 2001	5	2	1	1	6	6	3	3	0	0	2	4	6	4	19	7	34
206NOV140	SPRING 2006	2	0	0	0	3	3	0	2	0	0	1	0	0	0	29	6	14
206NOV160	FALL 1999	6	2	1	1	5	5	1	2	1	1	4	2	4	2	46	3	22
206NOV160	SPRING 2000	5	2	1	1	2	2	2	2	0	2	0	0	0	0	20	7	20
206NOV160	FALL 2000	4	1	1	1	5	5	3	3	1	1	9	6	5	3	50	2	28
206NOV160	SPRING 2001	3	1	1	1	3	3	1	2	1	1	4	2	7	4	53	1	19
206NOV160	SPRING 2006	5	2	0	0	4	4	1	2	0	0	0	0	0	0	18	8	20
206NOV160	SPRING 2007	3	1	0	0	5	5	0	2	0	0	8	5	0	0	53	1	18
206NOV170	FALL 1999	6	2	2	2	4	4	5	3	4	2	5	3	5	3	35	5	30
206NOV170	SPRING 2000	8	3	0	0	3	3	8	4	0	2	4	2	6	4	29	6	30
206NOV170	FALL 2000	3	1	1	1	6	6	0	2	4	2	17	10	8	5	48	2	36
206NOV178	SPRING 2006	5	2	0	0	2	2	1	2	0	0	1	0	17	10	42	3	24
206NOV178	SPRING 2007	7	3	1	1	7	7	5	3	2	1	11	7	2	1	38	4	34
206NOV180	SPRING 2000	12	5	1	1	4	4	14	6	2	2	2	1	5	3	19	7	36
206NOV180	FALL 2000	7	3	1	1	4	4	4	3	5	3	6	4	9	6	36	4	35
206NOV180	SPRING 2004	7	3	1	1	3	3	4	3	1	1	15	9	0	0	39	4	30
206NOV180	SPRING 2005	3	1	0	0	3	3	0	2	0	0	1	0	0	0	33	5	14
206NOV190	SPRING 2006	7	3	0	0	3	3	2	2	0	0	1	0	7	4	33	5	21
206NOV190	SPRING 2007	4	1	1	1	6	6	1	2	0	0	35	10	2	1	50	2	30
206NOV195	FALL 1999	9	4	1	1	6	6	8	4	1	1	12	8	14	9	18	8	52
206NOV195	SPRING 2000	12	5	2	2	6	6	11	5	2	2	4	2	12	8	16	8	48
206NOV195	FALL 2000	7	3	2	2	6	6	15	6	6	3	8	5	9	6	26	6	46
206NOV195	SPRING 2001	10	4	2	2	3	3	12	5	1	1	4	2	0	0	25	6	29
206NOV195	SPRING 2004	10	4	1	1	6	6	4	3	1	1	7	4	7	4	29	6	36
206NOV195	SPRING 2005	5	2	1	1	4	4	1	2	0	0	1	0	8	5	23	7	24
206NOV195	SPRING 2006	7	3	0	0	7	7	5	3	0	0	4	2	11	7	26	6	48

Table D-1. Metric and IBI scores listed by site and sampling event

Site Code	Date	EPT Taxa		Coleoptera Taxa		Diptera Taxa		% Intolerant		% Non-Gast. Scrapers		% Predators		% Shred Taxa		% Non-Insect Taxa		IBI Score[1]
		metric	IBI	metric	IBI	metric	IBI	metric	IBI	metric	IBI	metric	IBI	metric	IBI	metric	IBI	
206NOV195	SPRING 2007	4	1	2	2	5	5	5	3	1	1	13	8	1	0	39	4	30
206NOV210	FALL 1999	12	5	2	2	4	4	11	5	1	1	11	6	12	8	12	9	50
206NOV210	SPRING 2000	11	5	0	0	7	7	6	3	1	2	8	4	4	2	28	6	36
206NOV210	FALL 2000	10	4	2	2	3	3	7	4	1	1	9	6	16	10	11	9	49
206NOV210	SPRING 2001	11	5	1	1	6	6	4	3	1	1	21	10	7	4	29	6	45
206NOV240	SPRING 2000	15	7	0	0	7	7	39	10	6	3	35	10	9	6	4	10	66
206NOV240	SPRING 2001	13	6	1	1	8	8	32	10	4	2	38	10	8	5	12	9	64
206NOV240	SPRING 2006	9	4	3	4	9	9	12	5	1	1	14	9	12	8	16	8	60
206NOV240	SPRING 2007	11	5	4	5	7	7	6	3	3	2	9	6	2	1	30	5	42

[1]The subtotals of IBI values are multiplied by 1.25 to adjust the scoring range to a 100 point scale and then categorized as "very good" (100-81), "good" (80-61), "fair" (60-41), "poor" (40-21) and "very poor" (20-0).

APPENDIX E
2009 WATER QUALITY DATA

Table E-1. General Water Quality Measurements taken at 11 bioassessment locations in 2009.

Site ID	Water Temperature (°C)	pH	Dissolved Oxygen (mg/L)	Conductivity (uS/cm)
ACM080	12.7	7.06	9.97	290
ACM100	10.38	7.09	11.22	164
ACM140	10.91	7.4	11.18	154
COR091	10.45	7.27	11.6	145
COR140	10.79	6.84	9.1	489
COR210	15.29	7.55	9.49	251
LAG240	12.61	7.39	10.02	257
LAG270	12.91	7.45	9.85	344
LAG289	13.64	7.62	10.45	306
MIL041	14.38	7.36	8.07	306
NOV070	15.09	7.13	8.24	394
NOV140	15.61	7.24	9.14	466

APPENDIX F
WATERSHED MAPS DEPICTING AVERAGE B-IBI SCORES FOR SITES SAMPLED FROM 1999 THROUGH 2009

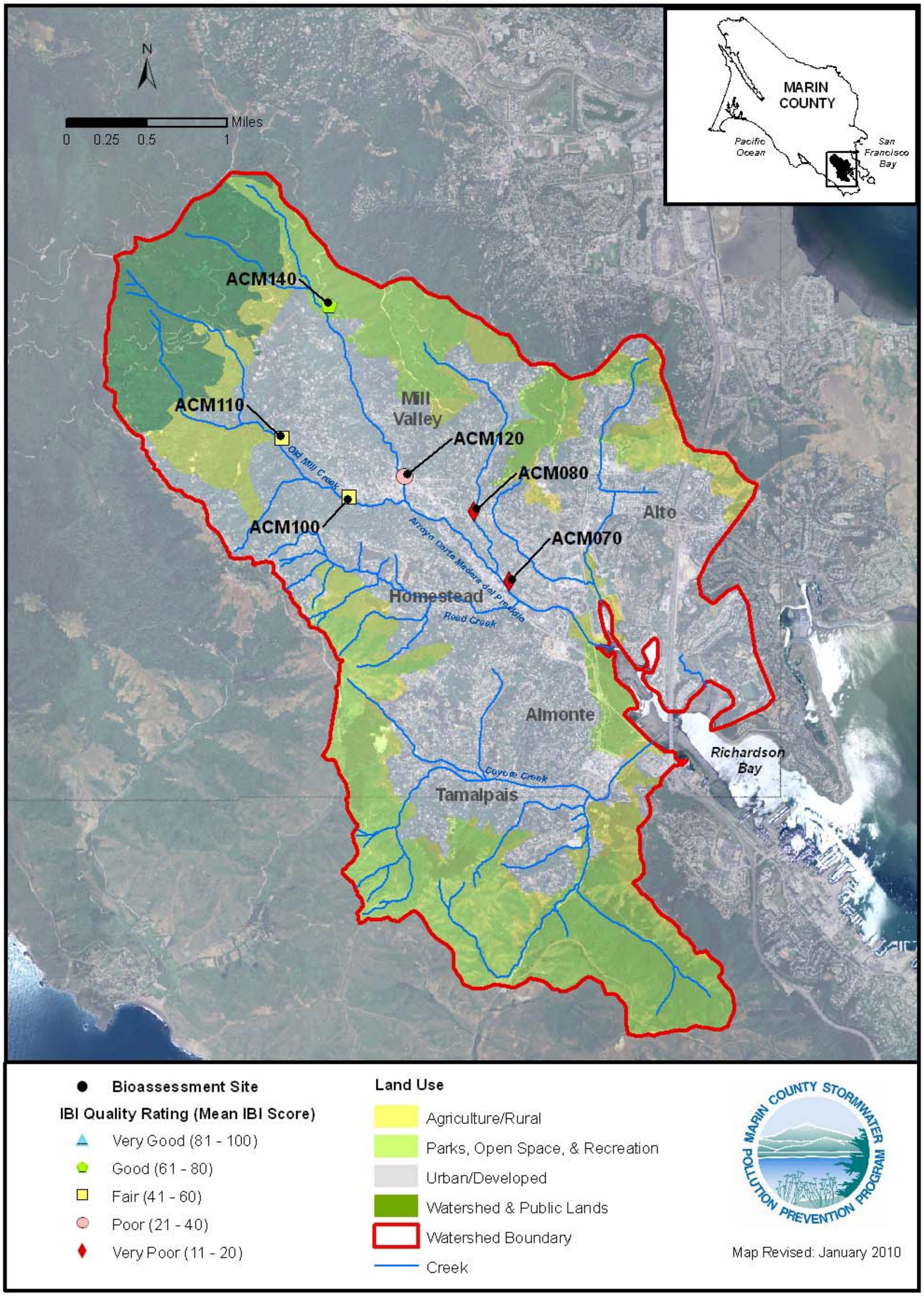

Figure F-1. Mean B-IBI Scores for Sites in the Arroyo Corte Madera Watershed

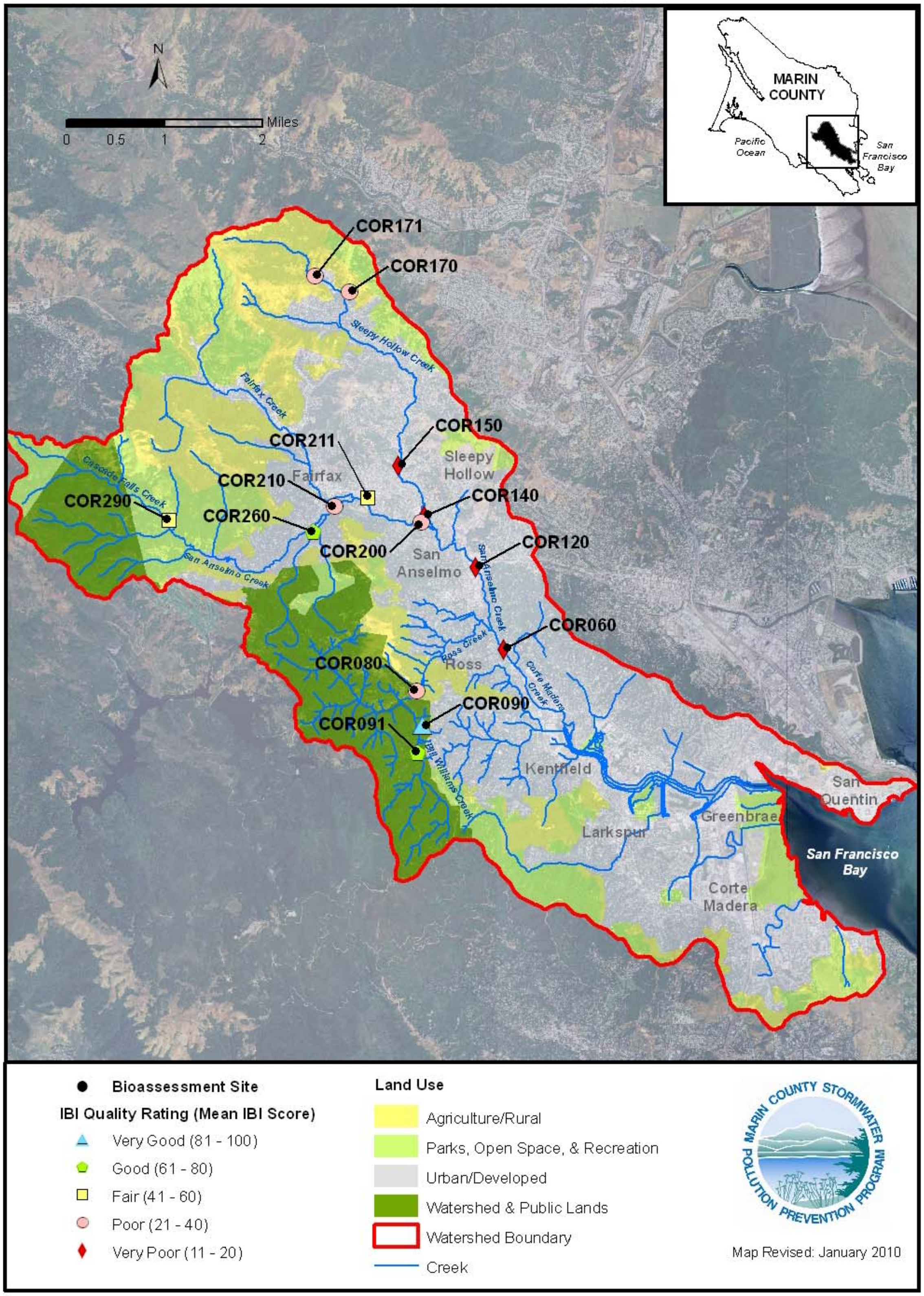

Figure F-2. Mean B-IBI Scores for Sites in the Corte Madera Watershed

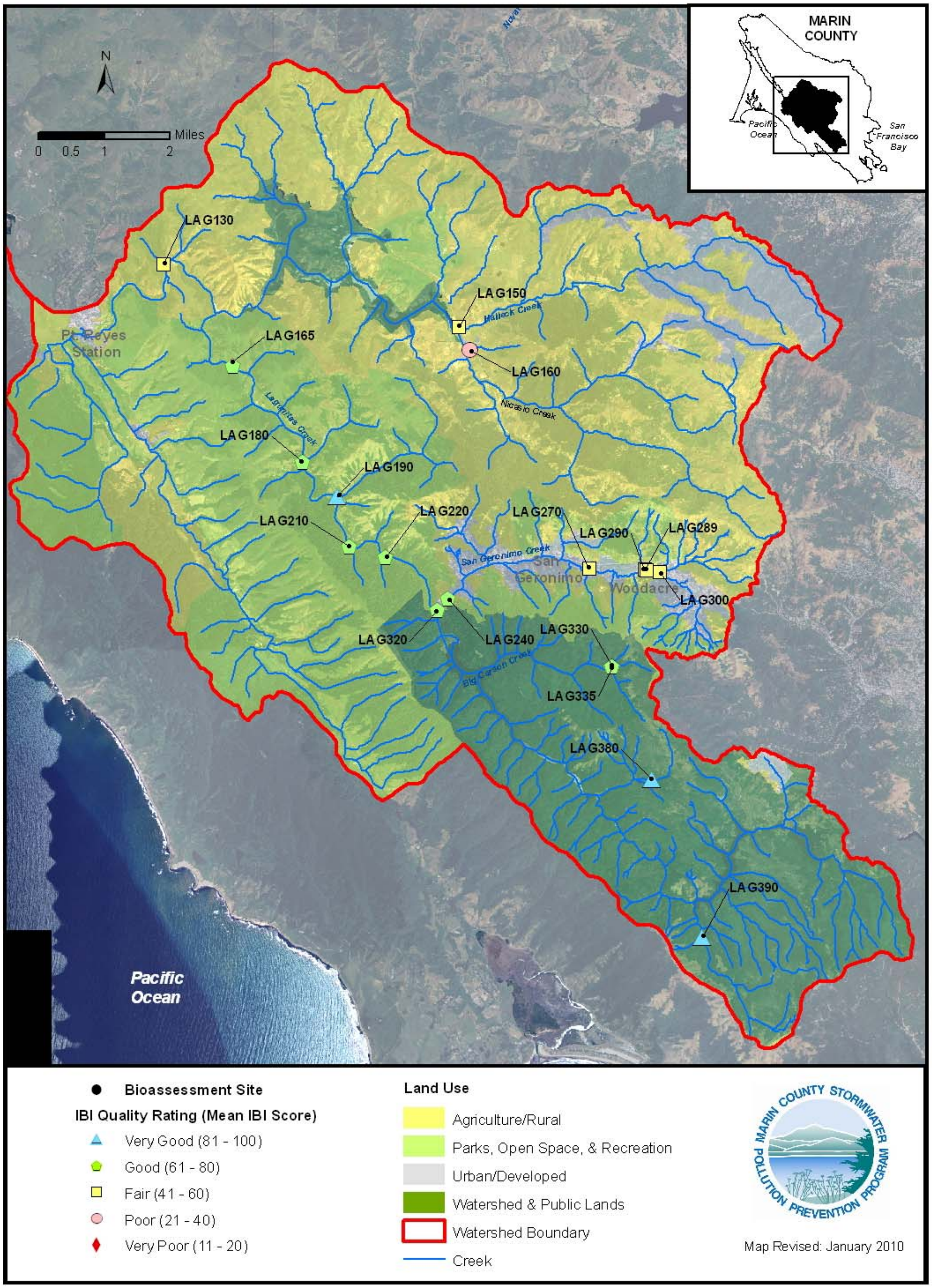

Figure F-3. Mean B-IBI Scores for Sites in the Laginitus Creek Watershed

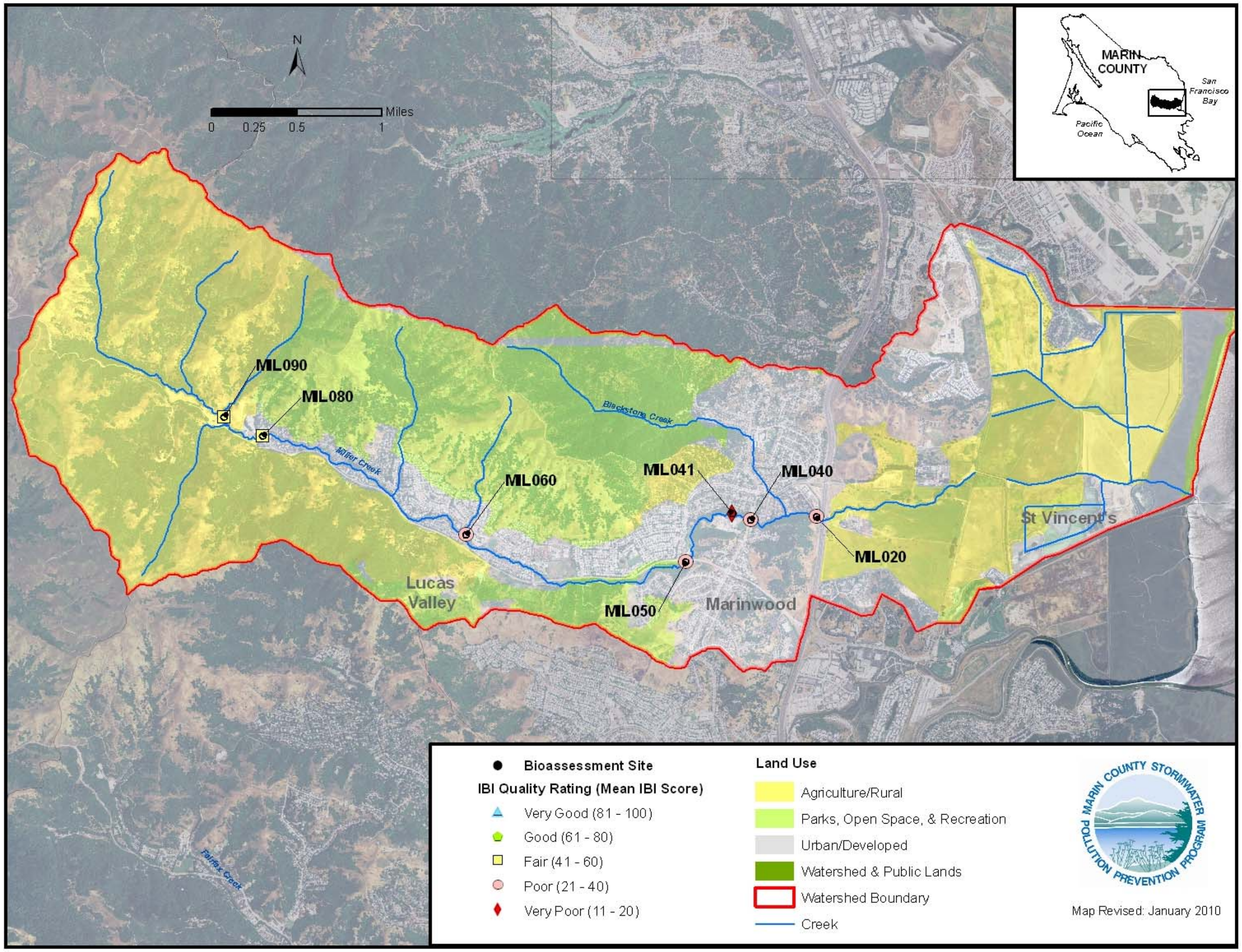

Figure F-4. Mean B-IBI Scores for Sites in the Miller Creek Watershed

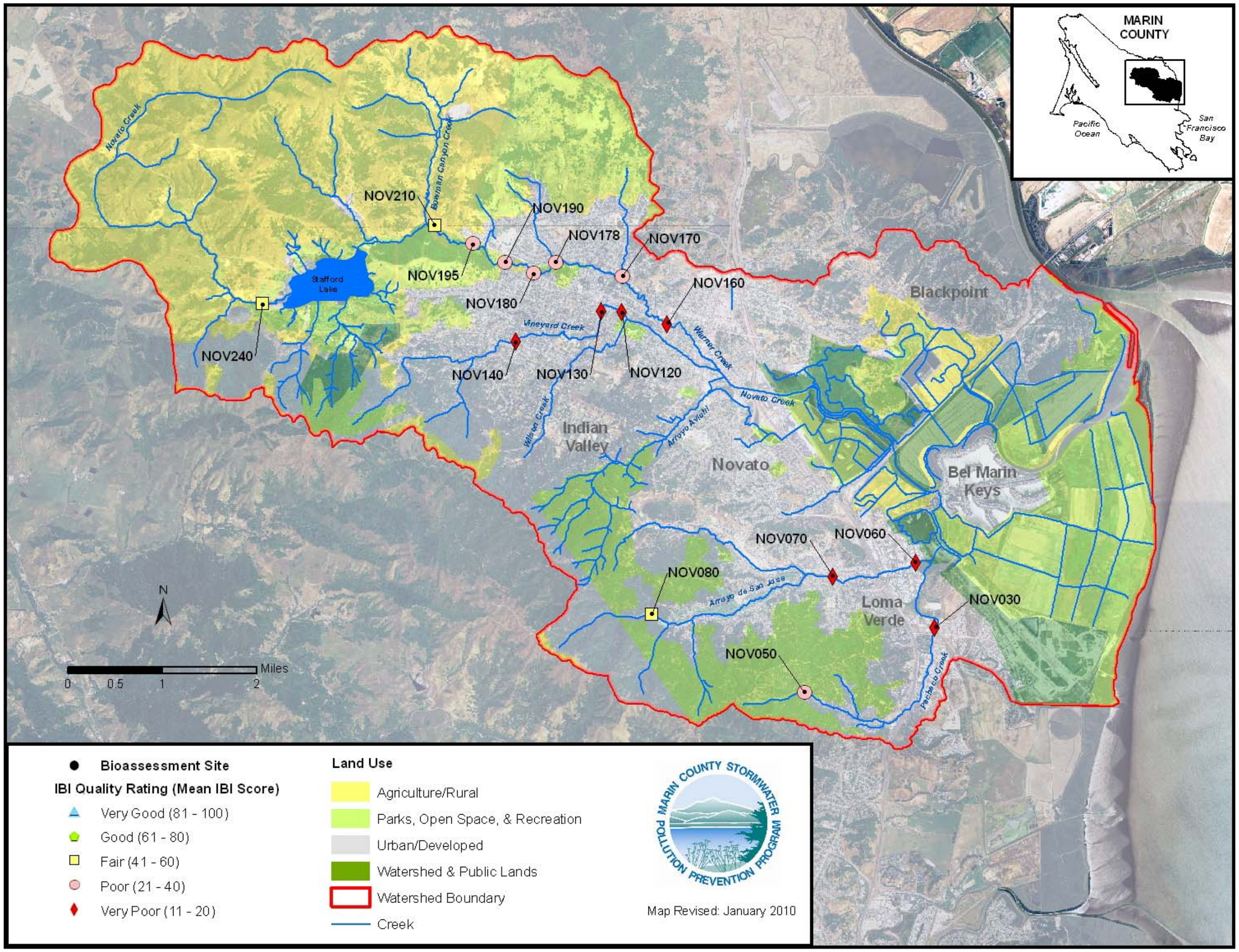

Figure F-5. Mean B-IBI Scores for Sites in the Novato Creek Watershed

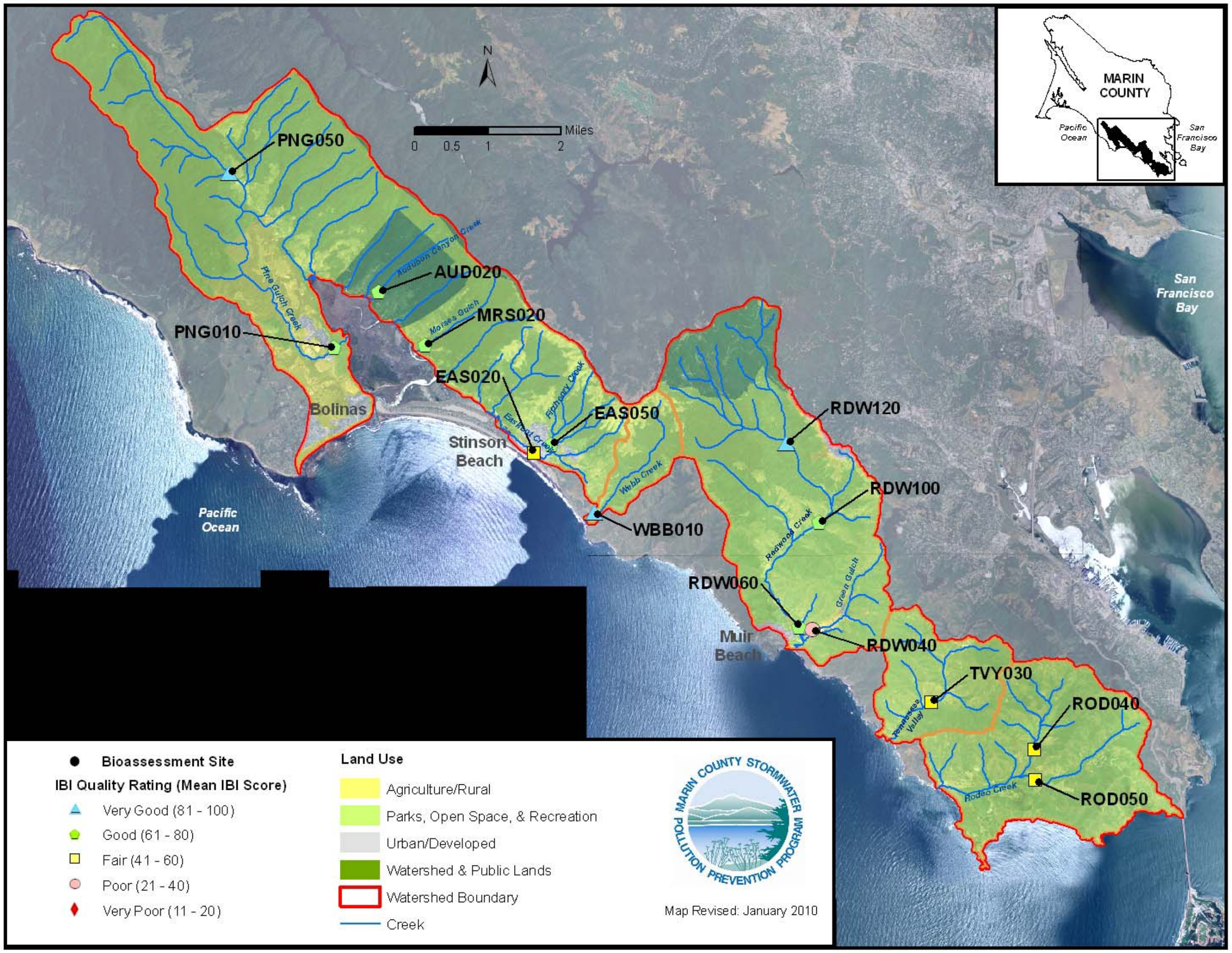

Figure F-6. Mean B-IBI Scores for Sites in Pacific Coast Watersheds

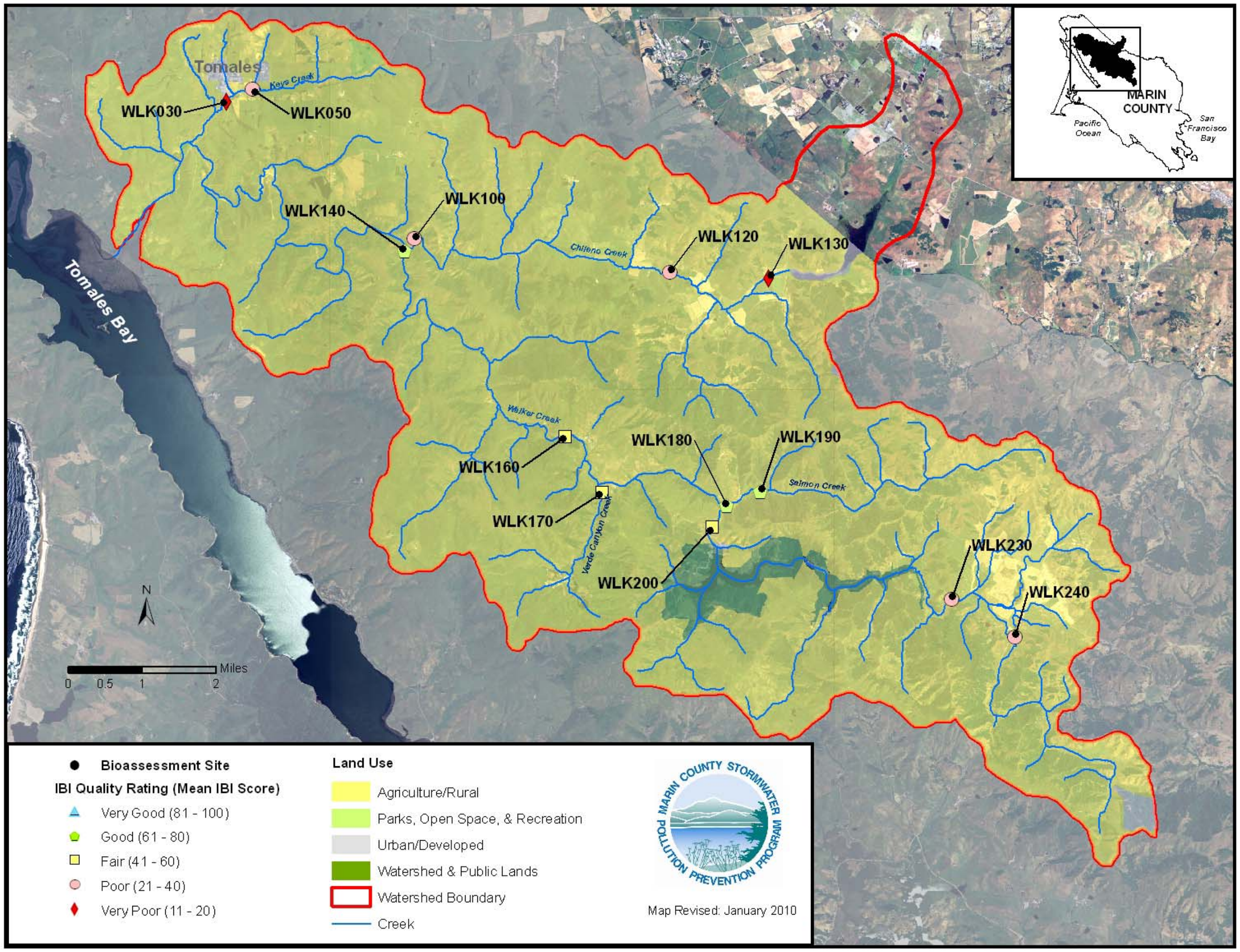

Figure F-7. Mean B-IBI Scores for Sites in Walker Creek Watershed

APPENDIX G
PEARSON'S CORRELATION COEFFICENT MATRICES
FOR SITES IN FOUR MARIN COUNTY WATERSHEDS

Table G-1. Pearson Correlation Coefficents for sites sampled in Corte Madera Watershed (Highlighted Cells = Pearson's Coefficient ≥ 0.8).

	COR060	COR080	COR090	COR091	COR120	COR140	COR150	COR170	COR171	COR200	COR210	COR211	COR260	COR290
COR060														
COR080	0.7													
COR090	0.6	0.6												
COR091	0.4	0.5	0.7											
COR120	0.8	0.7	0.4	0.3										
COR140	0.9	0.7	0.5	0.4	0.7									
COR150	0.8	0.7	0.6	0.5	0.6	0.9								
COR170	0.7	0.7	0.6	0.6	0.6	0.7	0.9							
COR171	0.6	0.7	0.6	0.6	0.5	0.6	0.8	0.9						
COR200	0.9	0.7	0.5	0.4	0.8	0.9	0.8	0.7	0.6					
COR210	0.8	0.7	0.6	0.5	0.7	0.7	0.8	0.8	0.7	0.8				
COR211	0.7	0.6	0.4	0.4	0.6	0.6	0.6	0.6	0.6	0.7	0.7			
COR260	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.8	0.6		
COR290	0.5	0.5	0.7	0.6	0.3	0.4	0.5	0.5	0.6	0.5	0.7	0.5	0.6	

Table G-2. Pearson Correlation Coefficents for sites sampled in Novato Watershed (Highlighted Cells = Pearson's Coefficient ≥ 0.8).

	NOV030	NOV050	NOV060	NOV070	NOV080	NOV120	NOV130	NOV140	NOV160	NOV178	NOV180	NOV190	NOV195	NOV210	NOV240
NOV030															
NOV050	0.6														
NOV060	0.7	0.5													
NOV070	0.7	0.6	0.9												
NOV080	0.3	0.7	0.6	0.6											
NOV120	0.6	0.5	0.8	0.8	0.5										
NOV130	0.6	0.5	0.9	0.9	0.6	0.8									
NOV140	0.7	0.6	0.8	0.9	0.6	0.8	0.9								
NOV160	0.6	0.5	0.9	0.9	0.6	0.9	0.9	0.9							
NOV178	0.4	0.4	0.7	0.7	0.6	0.7	0.8	0.7	0.8						
NOV180	0.5	0.5	0.7	0.7	0.6	0.7	0.8	0.8	0.8	0.8					
NOV190	0.5	0.4	0.7	0.7	0.4	0.7	0.7	0.6	0.7	0.8	0.7				
NOV195	0.5	0.5	0.7	0.7	0.7	0.7	0.8	0.7	0.8	0.9	0.9	0.7			
NOV210	0.5	0.6	0.6	0.6	0.6	0.7	0.6	0.6	0.6	0.6	0.7	0.5	0.7		
NOV240	0.3	0.5	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.6	0.6	0.5	0.7	0.6	

Table G-3. Pearson Correlation Coefficents for sites sampled in Miller Creek Watershed (Highlighted Cells = Pearson's Coefficient ≥ 0.8).

	MIL020	MIL040	MIL041	MIL050	MIL060	MIL080	MIL090
MIL020							
MIL040	0.8						
MIL041	0.8	0.7					
MIL050	0.8	0.9	0.7				
MIL060	0.8	0.8	0.7	0.8			
MIL080	0.7	0.7	0.7	0.8	0.9		
MIL090	0.4	0.5	0.4	0.5	0.7	0.8	

Table G-4. Pearson Correlation Coefficents for sites sampled in Arroyo Corte Madera Watershed (Highlighted Cells = Pearson's Coefficient ≥ 0.8).

	ACM070	ACM080	ACM100	ACM110	ACM120	ACM140
ACM070						
ACM080	0.8					
ACM100	0.8	0.8				
ACM110	0.6	0.7	0.7			
ACM120	0.8	0.8	0.9	0.7		
ACM140	0.6	0.6	0.8	0.7	0.7	