A stream in Solstice Canyon
PHOTO: SARAH WOODARD

IMPACT OF DEVELOPMENT ON AQUATIC BENTHIC MACROINVERTEBRATE COMMUNITIES IN THE SANTA MONICA MOUNTAINS OF SOUTHERN CALIFORNIA

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Abstract

Urban runoff due to development poses one of the greatest threats to the health of riparian and ocean ecosystems today. Past studies of urbanized watersheds have found that increased urbanization leads to impaired biological diversity in streams. This study assesses the impact of urbanization on aquatic benthic macroinvertebrates in the Santa Monica Mountains watersheds. We calculated the percent of developed area and percent of impervious area at monitoring sites based on geographic information system (GIS) mapping to quantify development in the region. We assessed the relationship between development and benthic macroinvertebrate communities, using the multi-metric Index of Biological Integrity (IBI) score given out of 0–100. At our fifteen sites, the average IBI scores ranged from 13 to 76, percent developed area ranged from 0.2% to 33.1%, and percent impervious area ranged from 2.1% to 21.2%. We found significant negative relationships between percent developed and impervious area and IBI score. Taking into account year and season sampled, as well as field protocol used, both percent developed area and percent impervious area explained a large amount of the variation in IBI scores (62% and 64%, respectively). We identified levels of 8.8% developed area and 6.6% impervious area, where sites with development over these levels showed biological impairments based on the regulatory threshold (IBI score of 39). This research shows that even low levels of urbanization and development impact biological health in streams, indicating a need to reduce impervious surface impacts through low-impact development (LID) and curb further development in the Santa Monica Mountains and Malibu Creek Watershed.

Introduction

The world's rapidly growing population and economy has led to the extensive urbanization of once natural watersheds. Urbanization and development have been shown to cause negative impacts to both water quality and the biota of streams, through loss or alteration of habitat, as well as through urban runoff and pollution (Jones and Clark 1987; Lenat and Crawford 1994; Weaver and Garman 1994; Basnyat et al. 1999; Paul and Meyer 2001; Brabec et al. 2002; Hatt et al. 2004; Miltner et al. 2004; Walsh et al. 2005). Developed areas often have significant impervious surface area, including roads, parking lots, and commercial and residential buildings, which impede water from infiltrating directly into the ground and lead to higher and faster runoff volumes, and subsequently affect the hydrology, chemistry, channel morphology, and biological health of aquatic ecosystems (Paul and Meyer 2001; Center for Watershed Protection 2003). Urban runoff also often contains trash and debris, bacteria, sediments, nutrients, metals, toxic chemicals, and other pollutants, which can adversely affect the quality of the receiving waters, associated biota, and public health. Previous studies have documented negative ecological impacts at levels of 10% or more impervious cover (Schueler 1994); biological impacts to aquatic vertebrate communities were seen at 8% or greater urbanization in the Santa Monica Mountains of Southern California (Riley et al. 2005). Other studies have found impacts to streams at even lower levels of development and imperviousness (Walsh et al. 2007; King et al. 2011).

Direct measurements of biological communities such as plants, invertebrates, fish, and microbial organisms are well accepted as effective indicators of stream health (Harrington and Born 2000). Combined with measurements of watershed characteristics such as land use practices, physical features of in-stream habitat, and water chemistry, biological assessment (bioassessment) provides information about the health status of a waterbody through the presence and abundance of different organisms and can be an effective tool for long-term trend monitoring of watershed condition (Davis and Simon 1995; Karr 1998; Karr and Yoder 2004). The results of the assessment can also be compared to a biological standard to quantify the health of the waterbody in question (US EPA 2012). Benthic macroinvertebrate (BMI) monitoring is a widely used method of stream bioassessment. BMIs are critical to the health of stream systems, as they are a significant food source for other aquatic and terrestrial animals. They are ubiquitous, relatively stationary, and their high species diversity allows for a spectrum of responses to environmental stresses (Rosenberg and Resh 1993; Merritt and Cummins 1996). Individual BMI species vary in sensitivity to environmental stressors, such as low dissolved oxygen, temperatures elevated above natural background, sedimentation, scouring, invasive species, nutrient loading, and chemical pollution (Resh and Jackson 1993), making BMIs very useful in identifying the cause of stream habitat impairment. Previous studies have also found that BMIs are sensitive to development and imperviousness in a drainage basin. In watersheds of high impervious surface area, the BMI community tends to be dominated by pollution tolerant species (Paul and Meyer 2001). BMI diversity and abundance has also been shown to decline with increases in urbanization and impervious surface cover at levels of 5–15% (May et al. 1997; Paul and Meyer 2001; Morse et al. 2003). Declines in stream macroinvertebrates were also found at impervious cover as low as 0.5–2% (King et al. 2011) and sensitive benthic macroinvertebrates were rare at sites with greater than 4% imperviousness (Walsh et al. 2007).

The Santa Monica Mountains of Southern California are located in close proximity to highly urbanized Los Angeles. Despite this proximity to one of the largest urban areas in the world, much of the study area remains undeveloped, offering the opportunity to study the impacts of urbanization on relatively natural stream ecosystems. At 109 square miles, the Malibu Creek Watershed is the second largest watershed draining to the Santa Monica Bay. Over 75% of the Malibu Creek Watershed is undeveloped, with several small cities and rural residential communities located within its reaches. The highly visited, world-famous Surfrider Beach is located at the terminus of the watershed. Protecting water quality and biological resources in the Malibu Creek Watershed is paramount for preserving the treasured natural resources and allowing safe recreational use of the Santa Monica Bay.

The purpose of this study was to assess the impact of urbanization on the condition of aquatic benthic macroinvertebrate communities in the Malibu Creek Watershed. We measured urbanization as both amount of area developed and amount of impervious area and looked for a relationship between urbanization and BMI assemblages using the common metric, Index of Biological Integrity (IBI) score. As previously described, benthic macroinvertebrates are known to be sensitive to urbanization and we sought to confirm this pattern on a local watershed-scale level. Although similar impacts have been shown elsewhere, documenting it for a specific area and on a local scale is important and useful for land use planners and management agencies in the Santa Monica Mountains. The study further examined the level of urbanization or imperviousness that corresponds to the established regulatory limits (IBI score of 39). Determining levels of urbanization and imperviousness that cause ecological impacts will help guide the development and implementation of new management policies and practices. For instance, the impact level could serve as a cap for future development, as well as an impervious surface reduction goal for redevelopment projects through the implementation of low impact development (LID).

Methods

Site Description

The Malibu Creek watershed is located in Southern California's Santa Monica Mountains, just north of the City of Malibu, Los Angeles County. It contains both urban/residential development and undeveloped parklands within the Santa Monica Mountain National Recreation Area. The drainage network includes Malibu Creek and its tributaries, Cold, Las Virgenes, Medea, Cheeseboro, Stokes, and Triunfo Creeks. Other nearby, less-developed watersheds in the Santa Monica Mountains include Arroyo Sequit, Lachusa,

Sample Location	Site[a]	Number of Samples	Average IBI Score	SD IBI Score	Average IBI Category	Percent Developed Area	Percent Impervious Area
Upper Cold Creek	H3	14	76	8.8	Good	1.46	2.47
Cheeseboro Creek	H6	7	51	10.3	Fair	0.23	2.07
Upper Las Virgenes Creek	H9	9	41	10.3	Fair	1.16	2.36
Solstice Creek	H14	11	67	10.7	Good	2.32	2.76
Lachusa Creek	H18	10	56	18.6	Fair	5.29	4.07
Arroyo Sequit Creek	H19	11	66	6.9	Good	3.06	2.89
Mid-Cold Creek	M11	10	51	8.3	Fair	10.50	5.36
Mid-Malibu Creek, upstream	M12	13	22	9.1	Poor	26.87	14.06
Mid-Las Virgenes Creek	M13	10	19	7.2	Very Poor	12.92	8.64
Mid-Malibu Creek, downstream	M15	12	25	10.9	Poor	22.38	12.07
Outlet Malibu Creek	O1	13	23	7.8	Poor	21.61	11.72
Outlet Cold Creek	02	11	39	16.3	Poor	11.89	6.13
Outlet Las Virgenes Creek	O5	12	26	8.6	Poor	14.72	9.24
Medea Creek	O7	11	19	7.8	Very Poor	33.09	21.24
Triunfo Creek	017	9	13	8.3	Very Poor	29.94	13.20

[a] H= high-quality site, M = middle site, O= outlet site

TABLE 1. Monitoring locations, numbers of samples, average Index of Biological Integrity (IBI) score, standard deviation of IBI scores, category of average IBI score, and percent developed area and percent impervious area upstream of monitoring sites in the Santa Monica Mountains.

and Solstice Creeks. Flow is naturally intermittent in some stream reaches due to the prevailing Mediterranean-type climate, with hot dry summers and winter rainfall. However, import of water into the basin for urban uses over many years has shifted the flow regime in some streams from intermittent to perennial, primarily caused by dry-weather runoff, wastewater treatment plant discharges, and regulatory flow requirements. Other hydrological alterations within the watershed include roadway stream crossings, horse ranches, field spraying of treated wastewater effluent in the Las Virgenes Creek sub-basin, and the construction of Rindge Dam in lower Malibu Creek.

Field Sampling

The field sampling was conducted by Heal the Bay's Stream Team. The Stream Team program was initiated in 1998 and uses field crews comprising skilled professional staff and trained volunteers to conduct watershed monitoring. We conducted benthic macroinvertebrate assessments at fifteen sites between 2000 and 2011 (Table 1). All sites are within the Santa Monica Bay Watershed; twelve sites are within in the Malibu Creek subwatershed and three sites are outside the Malibu Creek watershed (see Figure 1 for sampling locations). Sites were grouped into categories of high-quality sites, middle watershed sites, and outlet sites (Table 1). These sites were selected to provide a gradient of urbanization so that we could test the relationship between urbanization or imperviousness and the condition of biological communities. High-quality sites were selected at minimally developed areas in the watershed; waters at these sites are just downstream from protected open space with some hiking uses and minimal paved areas. Our criteria for high-quality sites are not based on the same criteria and are less stringent than those used in the State's Reference Condition Management Program (RCMP), as our sites were selected prior to the development of the RCMP and the Surface Water Ambient Monitoring Program (SWAMP) protocols. Middle sites are located in the mid-watershed and were selected to detect where stream degradation may occur in each tributary, as well as the gradient of impacts that might occur between the upper and lower stretches of individual streams. Outlet sites were selected at the outlets of tributaries and most are directly downstream of residential or commercial development and/or stream alterations such as culverts and concrete banks.

Bi-annual samples were collected between 2000 and 2004 during spring and fall. In 2005, sites were sampled once in the winter and between 2006 and 2011, sites were sampled once a year in the spring. In 2004 and 2007, bioassessment monitoring was not performed.

Between 2000 and 2003, BMI samples were collected using the California Stream Bioassessment Procedure (CSBPs) for non-point source assessments (Harrington 1996). With this method, three riffles in each monitoring reach were randomly chosen and one sample was collected in the top third of each. Starting with the lowermost riffle, the benthos within a 1 ft^2 area was disturbed upstream of a 1 ft wide, 0.5 mm mesh D-frame kick-net. Three locations along the transect representing the richest habitats were

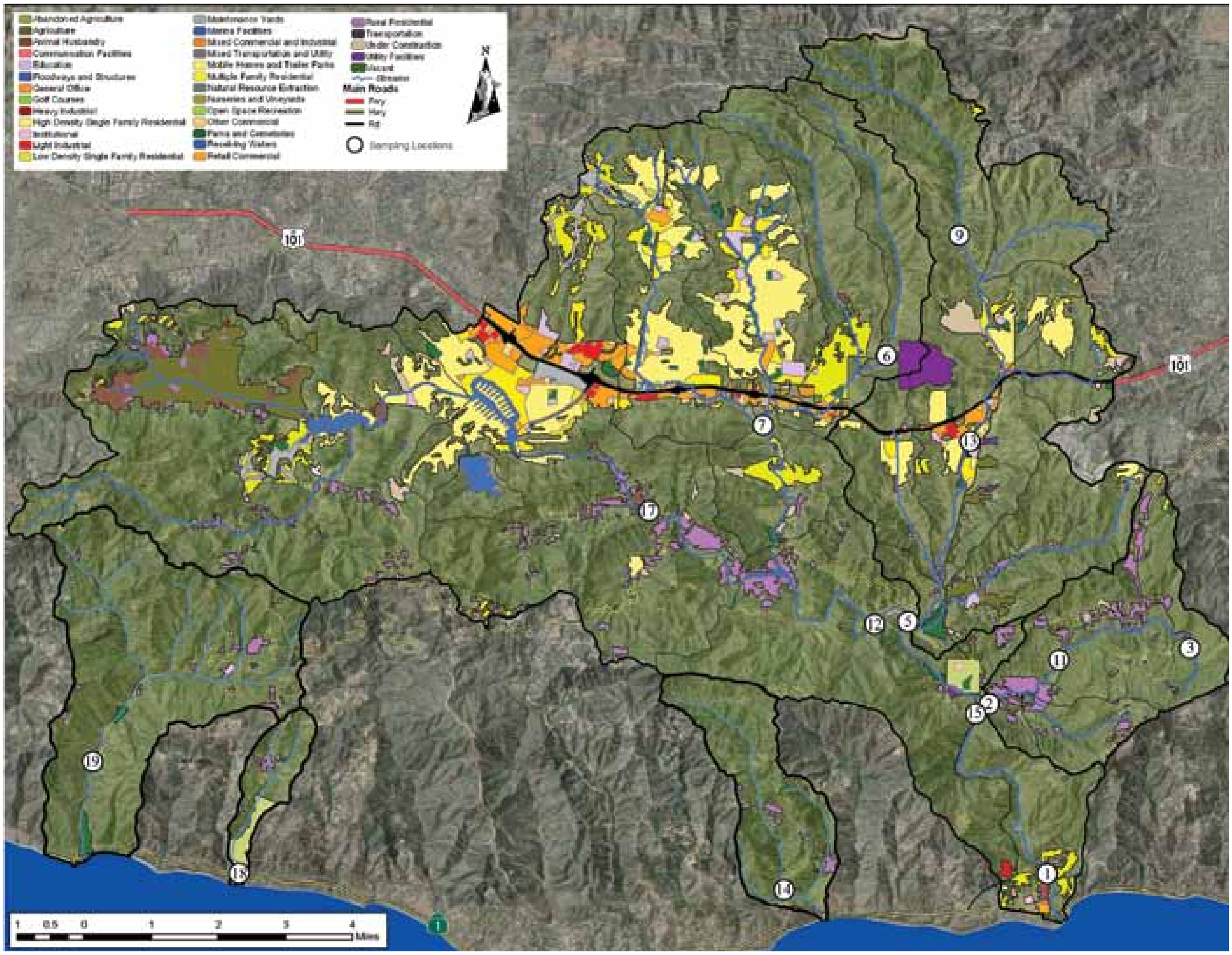

FIG. 1. Land use in the Malibu Creek Watershed and surrounding watersheds. Land uses in the Malibu Creek Watershed and adjacent watersheds based on SCAG (2001) data and aerial photos. Heal the Bay monitoring locations are designated by white circles with numbered site locations.

sampled and combined into a composite sample (representing a 3 ft^2 area). Sampling of the benthos was performed manually by rubbing cobble and boulder substrates in front of the net followed by "kicking" the upper layers of substrate to dislodge any invertebrates remaining in the substrates. The duration of sampling ranged from 60 to 120 seconds, depending on the amount of boulder and cobble-sized substrates that required rubbing by hand; more and larger substrates required more time to process. This procedure was repeated for the three riffles and maintained as three separate samples for the reach. The three samples were transferred into a 500 ml wide-mouth plastic jar containing approximately 200 ml of 95% ethanol.

In 2005 through 2007, sampling was conducted using the US EPA targeted riffle composite (TRC) procedure (Peck et al. 2004), which was adapted by the SWAMP and described in Ode (2007). With this procedure, a 1 ft2 of riffle area of the benthos was disturbed using the method previously described for the CSBP. Eight samples were taken from eight different riffles if available or by collecting more than one sample per reach if fewer than eight riffles were available. The locations in the riffles were randomly chosen using a number from 1 to 10 representing 10% increments upstream from the bottom of the riffle and from the right wetted bank. The eight collections from the riffles were composited and transferred into a 500 ml wide-mouth plastic jar containing approximately 200 ml of 95% ethanol.

Starting in 2008, sampling was conducted by using the Reach Wide Benthos (RWB) procedure also described in Ode (2007). With this procedure, 11 transects are established equidistant (15 m) along a 150 foot reach. Starting with lowermost transect and on the right side (25% distance from right bank), a 1 ft^2 area of the benthos

Land Use Category	Impervious Factor (IF)
Abandoned Agriculture	0.060
Agriculture	0.060
Animal Husbandry	0.060
Communication Facilities	0.750
Education	0.750
Floodways and Structures	0.000
General Office	0.850
Golf Courses	0.060
Heavy Industrial	0.800
High-Density Single Family Residential	0.600
Institutional	0.750
Light Industrial	0.750
Low-Density Single Family Residential	0.400
Maintenance Yards	0.750
Marina Facilities	0.750
Mixed Commercial and Industrial	0.800
Mixed Transportation and Utility	0.750
Mobile Homes and Trailer Parks	0.417
Multiple Family Residential	0.600
Natural Resource Extraction	0.750
Nurseries and Vineyards	0.060
Open Space Recreation	0.030
Other Commercial	0.850
Parks and Cemeteries	0.100
Receiving Waters	0.000
Retail Commercial	0.850
Rural Residential	0.350
Transportation	0.750
Under Construction	0.060
Utility Facilities	0.750
Vacant	0.019

TABLE 2. Impervious factors (IF) for land use categories in the Malibu Creek Watershed used to calculate percent impervious area.

was disturbed using the method previously describe for the CSBP. After securing the BMIs in the net or sample jar, the next transect upstream was sampled in the center (50% distance for the right bank) in the same manner and then the next transect was sampled on the left (75% distance from the right bank). This pattern was continued until all 11 transects were sampled (representing 11 ft^2). The 11 collections from the transects were composited and transferred into a 500 ml wide-mouth plastic jar containing approximately 200 ml of 95% ethanol. To compare different field protocols, duplicate samples using both techniques were collected at a site in 2008 when we switched from riffle-based BMI collection (CSBP and TRC) to a multi-habitat method (RWB).

Laboratory Analysis

The BMI samples were processed by Sustainable Land Stewardship International Institute (SLSII) in Sacramento or Chico, California. Each sample was rinsed through a No. 35 standard testing sieve (0.5 mm brass mesh) and transferred into a tray marked with twenty 25 cm2 grids. All sample material was removed from one randomly selected grid at a time and placed in a petri dish for inspection under a stereomicroscope. All invertebrates from the grid were separated from the surrounding detritus and transferred to vials containing 70% ethanol and 5% glycerol.

In 2000 through 2006, this process was continued until 300 organisms were removed from each sample and starting in 2008, this process was continued until 500 organisms were removed from one composite sample per site. The material left from the processed grids was transferred into a jar with 70% ethanol and labeled as "remnant" material. Any remaining unprocessed sample from the tray was transferred back to the original sample container with 70% ethanol and archived. BMIs were then identified to the Southwest Association of Freshwater Invertebrate Taxonomists (SAFIT) Standard Taxonomic Effort (STE) Level 1 (Richards and Rogers 2006). A taxonomic list of all BMIs identified from the samples was used to calculate and summarize the aquatic macroinvertebrate community–based metric values.

Data Analysis

The IBI score for each site was calculated based on the methods in Ode et al. (2005). Briefly, the southern California IBI assigns an overall site score from 0 to 100 through a multi-metric, multivariate technique based on seven metrics: EPT taxa richness (Ephemeroptera [mayflies], Plecoptera [stoneflies], and Trichoptera [caddisflies]), Coleoptera (beetle) richness, predator richness, percent of individuals in specific feeding groups (collector-filterers + collector-gatherers), percent pollution intolerant individuals, percent non-insect taxa, and percent pollution-tolerant taxa. Within the southern California (SoCal) IBI, scores are divided into the following five categories to assess biotic condition: "excellent" (81–100), "good" (61–80), "fair" (41–60), "poor" (21–40), and "very poor" (0–20). Values of 39 or lower depict a biologically impaired waterbody with poor or very poor biotic condition (Ode et al. 2005). The State Water Resources Control Board uses this score to designate waterbodies as impaired for macroinvertebrate communities in the 303(d) List of Impaired Waters. The SoCal IBI has different scoring methods for different ecoregions in southern coastal California; our sites all fall within Omernik Ecoregion 6 and were scored accordingly (Ode et al. 2005).

BMI Sample Calibration and Re-verification

To use the SoCal IBI, specific biological metrics had to be calculated based on 500 organisms. Since the version of the CSBP used in 2000 through 2003 required the collection of three samples from which a subsample of 300 organisms per sample were counted, there were 900 organisms in total identified for each site (according

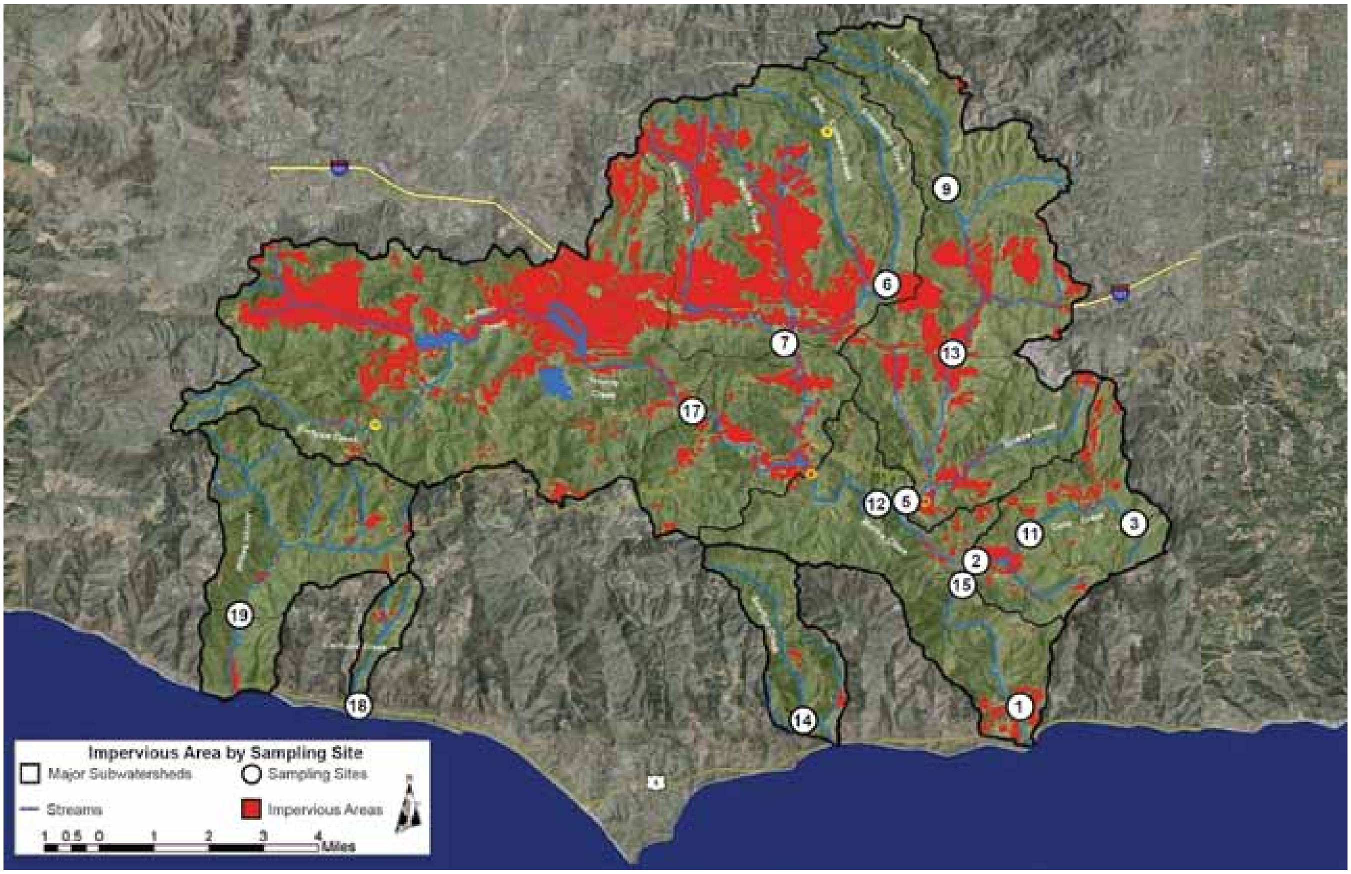

FIG. 2. Impervious area in the Malibu Creek Watershed and surrounding watersheds. Impervious area (shown in red) in the Malibu Creek Watershed and adjacent watersheds based on SCAG (2001) data and impervious factors (Table 2). Heal the Bay monitoring locations are designated by white circles with numbered site locations.

to the CSBP laboratory processing). A Monte Carlo simulation model developed by DFG was used by SLSII staff to reduce the 900 identified organism count from the 2000 through the 2003 samples to 500. The 2005 through 2010 BMI samples were collected using the SWAMP Bioassessment Procedure (Ode 2007), and therefore no conversion or use of the Monte-Carlo procedure was necessary.

Land Use: Development and Imperviousness

We analyzed land use maps to determine the extent of urbanization as measured by the percent developed area and percent impervious area. Land use data was obtained from the 2001 Southern California Association of Governments (SCAG) and aerial photographs for Los Angeles County (2002) and Ventura County (2003). We reclassified the SCAG data using the Anderson classification system (Anderson et al. 1976) and created two additional land use categories: Parks and Cemeteries and Abandoned Agriculture. Abandoned Agriculture is generally placed into the Vacant Land use category; however, our analysis of aerial photographs indicated that runoff from Abandoned Agriculture will act more like runoff from existing Agriculture than Vacant Land. The Parks and Cemeteries category included the following SCAG land use categories: Cemeteries, Other Open Space and Recreation, Undeveloped Local Parks and Recreation, Developed Local Parks and Recreation, and Developed Regional Parks and Recreation.

After reclassification, we calculated the amount of development upstream of monitoring sites. We calculated percent developed area as the amount of land that was not classified as Vacant or Open Space Recreation divided by the total amount of land upstream of a given site. Further, the SCAG land use data were evaluated to determine how much of a given land use category would result in runoff. Each land use category was assigned an impervious factor (IF) or a number representing what percentage of the land use results in runoff (Table 2). The IFs were derived from the Los Angeles County Department of Public Works (2006) and Ackerman et al. (2003). Animal Husbandry has no specific documentation by Los Angeles County Department of Public Works (2006) or Ackerman et al. (2003). We assigned an impervious factor of 6% to it, which is the same designation used by Ackerman et al. (2003) for Agriculture, Nurseries, and Vineyards. The Golf Course and Under Construction land uses were also considered to have 6% impervious cover, as they are more similar to irrigated agriculture than to unmanaged open space. The IF was multiplied by the acres of each specific land use, these values were totaled for all land-uses upstream of each site, and divided by the total amount of land to determine the percent impervious area that drains into each monitoring location. This calculation may not provide a complete picture of runoff in the watershed because it does not distinguish between those surfaces that are directly connected to the storm drain network versus those surfaces that drain into pervious areas. Further, percent developed area and impervious area for each site were assumed to be constant over time because land use data is only available approximately every five years. On the other hand, there has been relatively little new development over the time period of our study.

Statistical Analyses

To examine the relationship between development and biological community, we performed multiple regression analyses in R (R Development Core Team 2011). We assessed the statistical relationship between percent development (developed area and percent impervious area) and IBI score. Percent developed area and percent impervious area were log transformed for normality. We included possible confounding factors of year, season, and field protocol through multiple regression analyses. We also examined bivariate plots of just IBI score and percent developed area and IBI score and percent impervious area to determine the level of development that corresponds to the regulatory impaired IBI score of 39. We determined the best fit trendlines for the bivariate relationships through simple regression analyses.

Results

Upstream percent development ranged from less than 1% to over 33% at the monitoring sites, while percent impervious area ranged from approximately 2% to over 21% (Table 1). High-quality sites had the lowest percent developed and impervious area; all high-quality sites had less than 6% development upstream and less than 5% impervious area (Table 1). In contrast, middle and outlet sites all had over 10% developed area upstream and over 5% impervious area (Table 1). Development and imperviousness in general occur in the upper watershed, along the 101 Ventura Freeway corridor (Fig. 1 and 2). Land uses in developed areas are primarily high-density single family residential, multiple-family residential, and mixed commercial and industrial (Figure 1). In the middle watershed, there is less development and impervious area overall, with the primary developed land use in that area being rural residential (Fig. 1 and 2). However, middle watershed sites still had moderate levels of development and imperviousness as upstream of these sites includes the more developed areas in the upper watershed. At the terminus of the Malibu Creek Watershed, development and imperviousness also increase somewhat as the Creek flows through the city of Malibu right before reaching Malibu Lagoon and Santa Monica Bay (Fig. 1 and 2).

To assess whether the results would vary due to the use of different field sampling protocols, we qualitatively compared the IBI scores as well as the individual metrics that comprise the IBI score for one site that was sampled in 2008 using both the riffle based method (CSBP and TRC) and the multi-habitat method (RWB). We found no major difference in IBI score obtained using the two types of SWAMP sampling procedure (RWB vs. TRC) and no notable differences at the individual metric level. The duplicate samples collected using the two sampling procedures produced IBI scores with a difference of 3 points, which is lower than the average difference found for all duplicate samples in other years.

On average, high-quality sites had much higher IBI scores than middle and outlet sites (Table 1). The average IBI score at high-quality sites was 60, in the "fair" range, while average IBI scores at middle and outlet sites fell in the "poor" range, with scores of 29 and 24 respectively (Table 1). Moreover, we found that both percent developed area and percent impervious area were significant predictors of IBI score, taking year, protocol, and season into account (Table 3). The confounding variables (year, protocol, and season), on their own, were not significant predictors of IBI score. Percent impervious area (log transformed), year, protocol, and season explained 71% of the variation in IBI scores. Percent developed area (log transformed), year, protocol, and season explained 68% of the variation in IBI scores.

When we examined the bivariate relationship between IBI score and percent developed area, we found that percent developed area was a significant predictor of IBI score ($p<0.0001$) and explained 61.9% of the variation in IBI score (Figure 3a). A logarithmic trendline was the best fit for the relationship between percent developed area and IBI score (Figure 3a). The trendline had an IBI score of 39 (impairment) when percent developed area was equal to 8.8%. No sites with greater than 4% developed area had average IBI scores above 60, in the good range and above (Table 1).

IBI scores decreased dramatically as the impervious area above each site increased (Fig. 3b). We found that a logarithmic trendline was the best fit line for the bivariate relationship between percent impervious area and IBI score. Percent impervious area was a significant predictor of IBI score ($p<0.0001$) and explained 64.1% of the variation in IBI scores. The trendline had an IBI score of 39 (impairment) when percent impervious area was equal to 6.6%. No sites with greater than 3% impervious area had average IBI scores above 60, in the good range and above (Table 1).

Discussion

We found a clear and significant negative relationship between development and biological communities of benthic macroinvertebrates in the waterways of the Santa Monica Mountains. IBI scores decreased dramatically with increasing percent developed area and impervious area. Based on the regression lines, sites with over 8.8% developed upstream area or over 6.6% impervious upstream area would be classified as impaired based on having an IBI score of 39 or lower. These results are somewhat surprising, as previous studies have identified ecological impacts at higher levels of impermeability—habitat degradation in areas with 10% or more

Independent Variable	Coefficient	Std. Error	t-value	p-value
Model 1				
Log(Impervious area)	-25.54	1.35	-18.94	<0.001
Year	-2.03	1.06	-1.91	0.06
Protocol – reach wide benthos	7.26	8.75	0.83	0.41
Protocol – targeted riffle composite	-2.90	5.76	-0.50	0.61
Season – spring	-3.12	2.71	-1.15	0.25
Season – winter	-4.91	5.46	-0.90	0.37
R^2 adjusted = 0.71				
Model 2				
Log(Developed area)	-15.92	0.90	-17.71	<0.001
Year	-1.87	1.11	-1.69	0.09
Protocol – reach wide benthos	6.05	9.16	0.66	0.51
Protocol – targeted riffle composite	-3.44	6.03	-0.57	0.57
Season – spring	-2.41	2.84	-0.85	0.40
Season – winter	-4.54	5.72	-0.79	0.43
R^2 adjusted = 0.68				

TABLE 3. Multiple regression analysis of percent development (percent impervious area and developed area) and IBI score. Confounding factors include year, field protocol, and season.

impervious cover (Schueler 1994), and biological impacts to aquatic vertebrate communities in areas of 8% or greater urbanization in the Santa Monica Mountains (Riley et al. 2005). Studies in Washington and Maryland have demonstrated measurable decreases in BMI diversity and abundance in response to an increase in urbanization, correlated with impervious surface areas of 10–20% (Klein 1979; Paul and Meyer 2001). On the other hand, the identification of impacts at low levels of urbanization is not without precedence. A study in Maine found that impairment occurs at a similar level to our observation; they found degradation of the insect community-structure with a percent total impervious area greater that 6% (Morse et al. 2003). Other studies have documented even lower levels at which negative impacts occur (Walsh et al. 2007; King et al. 2011), including one study that found impacts at levels of impervious cover under 1% (King et al. 2011). Nevertheless, additional analysis, especially one that incorporates additional local data, would be a useful way to test the robustness of our findings. One readily available source of the data is from bioassessment monitoring conducted by the Stormwater Monitoring Coalition (SMC), a group of Southern California stormwater regulators and management agencies. It would be valuable to add or compare their data on BMI and urbanization to our data including testing whether a logarithmic regression continues to be the best fit for the bivariate relationships and to assess whether an IBI score of 39 (impaired) still corresponds to an impervious level of 6.6%.

Percent developed and impervious area account for 68% and 71% of the variation in IBI scores, respectively, taking year, protocol, and season into account. Consequently, it is critical that the amount of development and impervious cover throughout the watershed be reduced and modified to improve the biotic condition of streams. Though the Malibu Creek Watershed is nearly 80% open space, the density of impermeable area throughout the watershed has a profound effect on biological integrity. Low impact development (LID) is a means to decrease runoff and increase permeability in developed areas. We recommend that local municipalities in the Malibu Creek Watershed incorporate LID measures into new development and redevelopment to reduce impervious cover and the impacts associated with it in their planning with a subwatershed target of less than 3% effective impervious area. Widespread implementation of LID systems in developed areas of the Malibu Creek Watershed would help increase water to soil infiltration and reduce impacts of impervious area, thus improving habitat and water quality throughout the watershed. Additionally, implementation and enforcement of new and existing water quality regulations would help improve biotic condition. These and other improvements should be seriously considered to benefit aquatic life and the overall biological health of the Malibu Creek Watershed. Progress is already being made towards these LID goals with the adoption of the recent Los Angeles County municipal stormwater permit and other local ordinances; however additional attention is needed on redevelopement.

In order to better understand how impervious area impacts the benthic macroinvertebrate community, we suggest conducting more site-specific research to examine density of impermeable

FIG 3.a

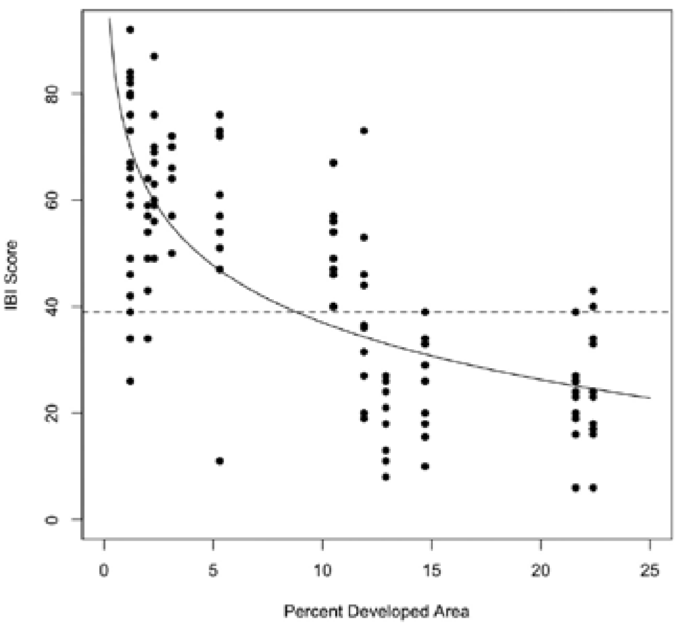

FIG 3.b

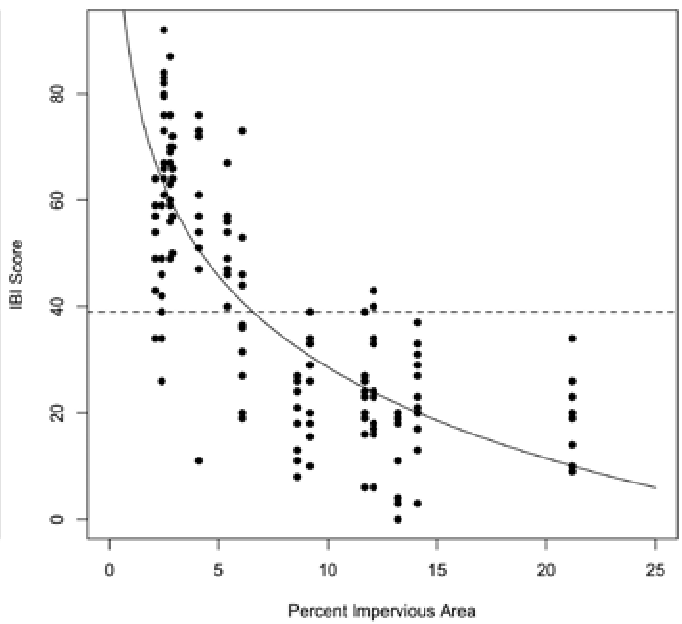

FIG. 3. Bivariate relationship between development and average IBI score. Bivariate relationship between percent developed area and average IBI score (a) and percent impervious area and average IBI score (b). The solid lines are the best fit trendlines and the dashed lines show the IBI score, which indicates impairment (39). A score of 39 or lower indicates biological impairment. IBI score decreased with increasing developed and impervious area. When examined in a simple regression, percent developed area was a significant predictor of IBI score ($p<0.0001$, R2=0.619). Percent impervious area was also a significant predictor of IBI score ($p<0.0001$, R2=0.641). The best fit trendlines crossed the regulatory threshold of biological impairment (IBI score of 39) at 8.8% developed area (a) and 6.6% impervious area (b).

area in specific places and its impact on IBI scores. Looking at impacts on a smaller scale may help to determine which component of urbanization has the greatest effect on a certain region. In addition, effective impervious area (EIA), which considers only the impervious surface that is directly connected from the drainage catchment to the streambed (US EPA 2012) is considered a better way to quantify impervious surface area and should be used as indicator of the effects of urbanization. Hatt et al. (2004) found that increased EIA has a more dramatic effect on water chemistry and stream morphology. Further, examining impervious cover at different scales would be useful to determine at which scale (local, catchment, or watershed) impervious cover is most important.

In addition to better quantifying impervious area and investigating how specific development patterns affect stream biota, it is important to examine the causal factors that negatively impact biota. From the results of this study, it is clear that urbanization and development negatively impact aquatic macroinvertebrates in the Malibu Creek Watershed. However, we do not know which stressor and the proportional impacts of each stressor causing degradation. It is reasonable to assume that increased runoff from development is the main culprit, as it both alters the flow regime of, adds pollution loading to, and alters the physical and chemical habitat of streams. However, there may be other factors that are also important to the physical, chemical, and biological health of streams. Previous studies have found that physical habitat is an important predictor of stream biota and benthic macroinvertebrate health (Maddock 1999; Nerbonne and Vondracek 2001). For example, studies have shown that benthic macroinvertebrates are negatively affected by the percent of fines (stream substrate) and embeddedness of stream substrate (Nerbonne and Vondracek 2001; Kaller and Hartman 2004). Examining additional landscape factors beyond impervious area would be beneficial; for example, road density and vegetation condition in the riparian zone may also be important. To tease out relative impacts of these parameters, further causal assessment needs to be performed and more water quality and habitat parameters should be included in the analyses. Heal the Bay's Stream Team currently collect water quality and physical habitat data in the watershed. A logical next step is to incorporate the data collected from this effort into the analysis to determine which parameters also exhibit strong correlations with IBI scores in addition to development.

Identifying the specific factors of urbanization that are negatively impacting stream biota will allow managers and policy makers to target their recommendations and actions to improve biological health streams in the watershed. Consequently, it is critical that the amount of development and impervious cover throughout the watershed be limited and reduced through the incorporation of LID measures into new development and redevelopment by local municipalities in the Malibu Creek Watershed, and they should do so with a subwatershed target of less than 3% effective impervious area.

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