SWAMP
Surface Water Ambient Monitoring Program

TOXICITY IN CALIFORNIA WATERS: SAN DIEGO REGION

Brian Anderson

Bryn Phillips

Dan Markiewicz

Marie Stillway

August 2012

California Water Boards

www.waterboards.ca.gov/swamp

ACKNOWLEDGEMENTS

The authors thank Lillian Busse of the San Diego Regional Board. We are grateful for the services provided by the field crews, laboratory and data management staff who participated in this project. Funding was provided by the Surface Water Ambient Monitoring Program.

TABLE OF CONTENTS TOC

TABLE OF CONTENTS TOC

List of Tables

List of Figures

TABLE OF CONTENTS TOC

TABLE OF CONTENTS TOC

EXECUTIVE SUMMARY E

Toxicity testing has been used to assess effluent and surface water quality in California since the mid-1980s. When combined with chemical analyses and other water quality measures, results of toxicity tests provide information regarding the capacity of water bodies to support aquatic life beneficial uses. This report summarizes the findings of monitoring conducted by the Surface Water Ambient Monitoring Program (SWAMP) and associated programs between 2001 and 2010.

As in Anderson et al. (2011), the majority of data presented in this report were obtained from monitoring studies designed to increase understanding of potential biological impacts from human activities. As such, site locations were generally targeted in lower watershed areas, such as tributary confluences or upstream and downstream of potential pollutant sources. Only a minority of sites was chosen probabilistically (i.e., at random). Therefore, these data only characterize the sites monitored and cannot be used to make assumptions about unmonitored areas.

Toxicity in freshwater, freshwater sediments and marine sediments was common in the San Diego Region. *Moderate* to *high* freshwater toxicity was seen at 17% of sites; while *moderate* to *high* freshwater sediment toxicity was seen at 23% of sites and *high* marine sediment toxicity was observed at 8% of sites.

Ceriodaphnia dubia tests were conducted at the most sites and had the most non-toxic samples (87%). Algal tests were conducted at 37 sites and at least *some* toxicity was observed at over half the sites. Amphipod tests were only conducted at 12 sites, with 75% of the sites being non-toxic.

Stormwater effluent toxicity was examined at 20 permitted National Pollution Discharge Elimination System (NPDES) facilities in the San Diego Region. Ninety percent (90%) of the sites of effluent discharge showed one or more instances of effluent toxicity during the 2001 – 2008 monitoring period. Forty-five percent (45%) of sites showed *moderate* or *high* toxicity. *Hyalella azteca* showed at least *some* toxicity at 80% of sites (16 facilities), the highest portion of the three species tested.

Associations of land use with sediment toxicity were stronger than associations with water toxicity. In *H. azteca* sediment tests, urban sediments showed significantly lower survival than sediments from other less developed sites. Freshwater toxicity to *C. dubia* and algae showed distinctly different patterns relative to land use. For the most part, sites in the San Diego Region were non-toxic to *C. dubia*, but the few toxic sites were located in areas with urban land uses one kilometer upstream. In contrast, algal toxicity was found at *low* to *moderate* levels both in urban and less developed areas.

Data suggest that much of the toxicity to *C. dubia* in urban stormwater was attributed to organophosphate pesticides such as diazinon, and as diazinon concentrations decreased due to EPA residential use restrictions, increasing toxicity to the amphipod *H. azteca* has been observed, mainly due to pyrethroids, including bifenthrin. Sediments significantly toxic to *H. azteca* contained concentrations of pyrethroids, with the most commonly detected pyrethroids being bifenthrin and cypermethrin. Marine water toxicity has been generally attributed to metals (e.g., copper and zinc) in stormwater. Marine sediment toxicity monitoring has pointed to high concentrations of organochlorine pesticides, metals and mixtures of chemicals exceeding sediment quality guideline quotient values.

As discussed in Anderson et al. (2011), the principal approach to determine whether observations of toxicity in laboratory toxicity tests are indicative of ecological impacts in receiving waters has been to conduct field bioassessments of macroinvertebrate communities. These studies have included “triad” assessments of chemistry, toxicity and macroinvertebrate communities, the core components of SWAMP. One recommendation for future SWAMP monitoring is to conduct further investigations on the linkages between surface water toxicity and receiving system impacts on biological communities.

SECTION 1 INTRODUCTION

The California State Water Resources Control Board published a statewide summary of surface water toxicity monitoring data from the Surface Water Ambient Monitoring Program (SWAMP) in 2011 (Anderson et al., 2011; http://www.waterboards.ca.gov/water_issues/programs/swamp/reports.shtml). This report reviewed statewide trends in water and sediment toxicity collected as part of routine SWAMP monitoring activities in the nine California water quality control board regions, as well as data from associated programs reported to the California Environmental Data Exchange Network (CEDEN) database. The report also provided information on likely causes and ecological impacts associated with toxicity and management initiatives that are addressing key contaminants of concern. The current report summarizes a subset of the statewide database that is relevant to the San Diego Region (Region 9). Source programs, test counts and sample date ranges are outlined in Table 1.

Table 1
Source programs, water and sediment toxicity test counts and test dates for San Diego regional toxicity data included in this report.

Toxicity Test Type	Program	Test Count	Sample Date Range
Water Column	SWAMP	228	3/12/02 – 5/14/09
	MS4 (NPDES)	261	11/29/01 – 12/16/08
Sediment	Statewide Urban Pyrethroid Monitoring	12	1/7/07 – 1/8/07
	Stream Pollution Trends (SPoT)	7	5/21/08 – 5/22/08
	Other SWAMP	104	3/12/02 – 4/11/06

The San Diego Region comprises 3,900 square miles, extending 85 miles north from the Mexico border to the El Toro/Lake Elsinore area, and east to the Lagunas Mountains. The Region encompasses San Diego County as well as parts of Riverside and Orange Counties. The Region is comprised of 11 major hydrologic units, including the San Juan, Santa Margarita, San Luis Rey, Carlsbad, San Diequito, Penasquitos, San Diego, Pueblo San Diego, Sweetwater, Otay and Tijuana HUs. The Region also contains coastal areas, bays and harbors including San Diego Harbor and San Diego and Mission Bays, as well as several ecologically important coastal lagoons and estuaries.

SECTION 2
SCOPE AND METHODOLOGY

This study examined all toxicity data included in the SWAMP and CEDEN databases from toxicity tests whose controls showed acceptable performance according to the Measurement Quality Objectives of the 2008 SWAMP Quality Assurance Project Plan (QAPrP)(SWAMP, 2008). The attached maps (Figures 8-19) show locations of sites sampled for toxicity by SWAMP and partner programs and the intensity of toxicity observed in the water and sediment samples collected at those sites. Sites are color-coded using the categorization process described in Anderson et al. (2011), which combines the results of all toxicity tests performed on samples collected at a site to quantify the magnitude and frequency of toxicity observed there. At sites where both water and sediment toxicity data were collected, two toxicity categories were calculated to separately summarize the degree of toxicity in water and in sediment. Toxicity test results reported in the San Diego Region included freshwater exposures of the cladoceran *Ceriodaphnia dubia*, and the alga *Pseudokirchneriella subcapitata* (formerly known as *Selenastrum capricornutum*). The amphipod *Hyalella azteca* was used to test freshwater sediment samples and freshwater samples whose conductivities exceeded the limit for optimal *C. dubia* health (2000 µS/cm). Only survival endpoints and algal growth were considered in the measures of toxicity; therefore all sites identified as toxic showed a significant decrease in test animal survival or algal growth in one or more samples. Some *P. subcapitata* algal growth inhibition tests recorded in the SWAMP/CEDEN databases were performed on water samples that exceeded the upper conductivity limit for optimal growth of this species (1500 uS/cm). These tests were excluded from the data set so as not confuse the effects of high conductivity with the effects of contaminants.

Table 2
Data conditions used to determine toxicity categories for any given sample collection site.

Category	Conditions for Categorization
Non-toxic	No sample is ever toxic to any test species
Some Toxicity	At least one sample is toxic to one or more species, and all of the species' responses fall above their species-specific High Toxicity Threshold
Moderate Toxicity	At least one sample is toxic to one or more species and at least one of the species' responses falls below their respective High Toxicity Threshold
High Toxicity	At least one sample is toxic to one or more species and the mean response of the most sensitive species falls below its respective High Toxicity Threshold

Several steps were followed to determine the toxicity of individual samples, and to categorize the toxicity of individual sites:

1. Standardize the statistical analyses: When data were submitted to the SWAMP/CEDEN databases, reporting laboratories evaluated the potential toxicity of samples using a variety of statistical protocols. In order to standardize the analysis of the entire data set, all control – sample comparisons were re-analyzed using the proposed EPA Test of Significant Toxicity (Anderson et al., 2011; Denton et al., 2011; U.S. EPA, 2010). Individual samples were categorized as not toxic, toxic or *highly* toxic (see 2 below).

2. Calculate the High Toxicity Threshold: The High Toxicity Threshold is determined for each species' endpoint from the entire dataset summarized in the Statewide Report (Anderson et al., 2011). This threshold is the average of two numbers, both expressed as a percentage of the control performance. The first number is the data point for the 99th percentile of the Percent Minimum Significant Difference (PMSD) in the Statewide Report. The second value is the data point for the 75th percentile of Organism Performance Distribution of all toxic samples, representing an organism's response on the more toxic end of the distribution. This average serves as a reasonable threshold for *highly* toxic samples.

3. Determine the Toxicity Category for each site: The magnitude and frequency of toxicity at each sample collection site was categorized (Table 2) according to Anderson et al. (2011) and Bay et al. (2007) as "non-toxic", "some toxicity", "moderately toxic", or "highly toxic". Throughout this document the terms some, moderately and highly will be italicized when in reference to these categories.

Separate categories were created for sediment and for water toxicity, as well as for toxicity to individual species.

Table 3
Species-specific maximum levels of toxicity observed at sites tested with *E. estuarius* and *H. azteca* sediment toxicity tests, and *C. dubia*, and *P. subcapitata* and *H. azteca* water toxicity tests.

Species	Test Type	Number of Sites	Maximum Toxicity Level Observed			
			Non-Toxic	Some Toxicity	Moderately Toxic	Highly Toxic
E. estuarius	Sediment	49	26	19	0	4
H. azteca		61	38	9	5	9
C. dubia	Water Column (Ambient)	60	52	2	3	3
P. subcapitata		37	18	14	4	1
H. azteca		12	9	1	0	2
C. dubia	Water Column (NPDES)	20	12	6	1	1
P. subcapitata		20	10	5	5	0
H. azteca		20	4	11	5	0

SECTION 3
REGIONAL TOXICITY

Toxicity of freshwater, freshwater sediments and marine sediments was common in the San Diego region between 2001 and 2010 (Figure 1). *Moderate* to *high* freshwater toxicity was seen at 17% of sites, while *moderate* to *high* freshwater sediment toxicity was seen at 23% of sites, and *high* marine sediment toxicity was observed at 8% of sites.

AMBIENT WATER COLUMN TOXICITY BY SPECIES

Ambient freshwater toxicity is summarized by individual species in Figure 2. *Moderate* to *high* freshwater toxicity was observed at 10% to 17% of sites, depending on species. *Ceriodaphnia dubia* tests were conducted at the most sites, and had the most non-toxic samples (87%). Algal tests were conducted at 37 sites and at least *some* toxicity was observed at over half of the sites. Amphipod tests were only conducted at 12 of the sites, with 75% of the sites non-toxic.

STORMWATER TOXICITY

Stormwater toxicity was examined at 20 receiving systems that are monitored as part of NPDES stormwater permits in the San Diego Region between 2001 and 2008. Ninety percent (90%) of the sites showed one or more instance of toxicity during the monitoring period (Figure 3). Forty-five percent of sites (45%) showed *moderate* or *high* toxicity. Of all the species tested, *H. azteca* showed at least *some* toxicity at 80% of sites (16 facilities), the highest portion of the three species tested (Figure 4).

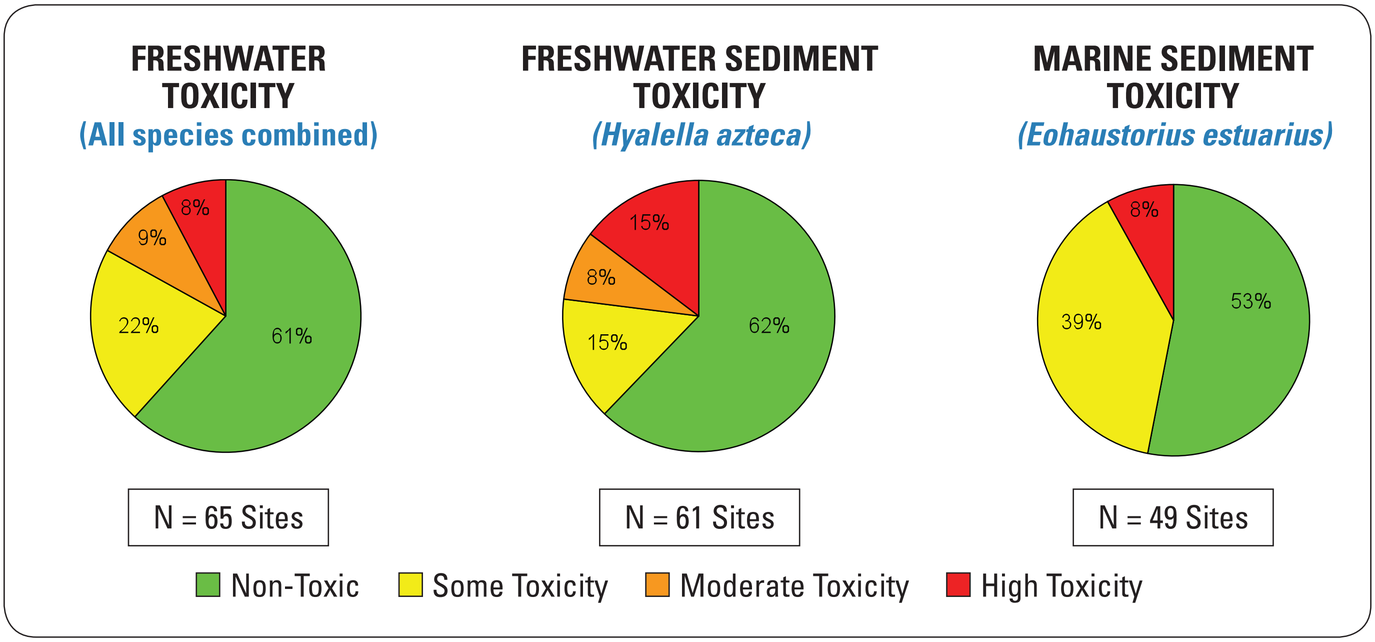


Figure 1. Magnitude of toxicity at sites examined by testing of freshwater, freshwater sediment and marine sediment samples in the San Diego Region of California.

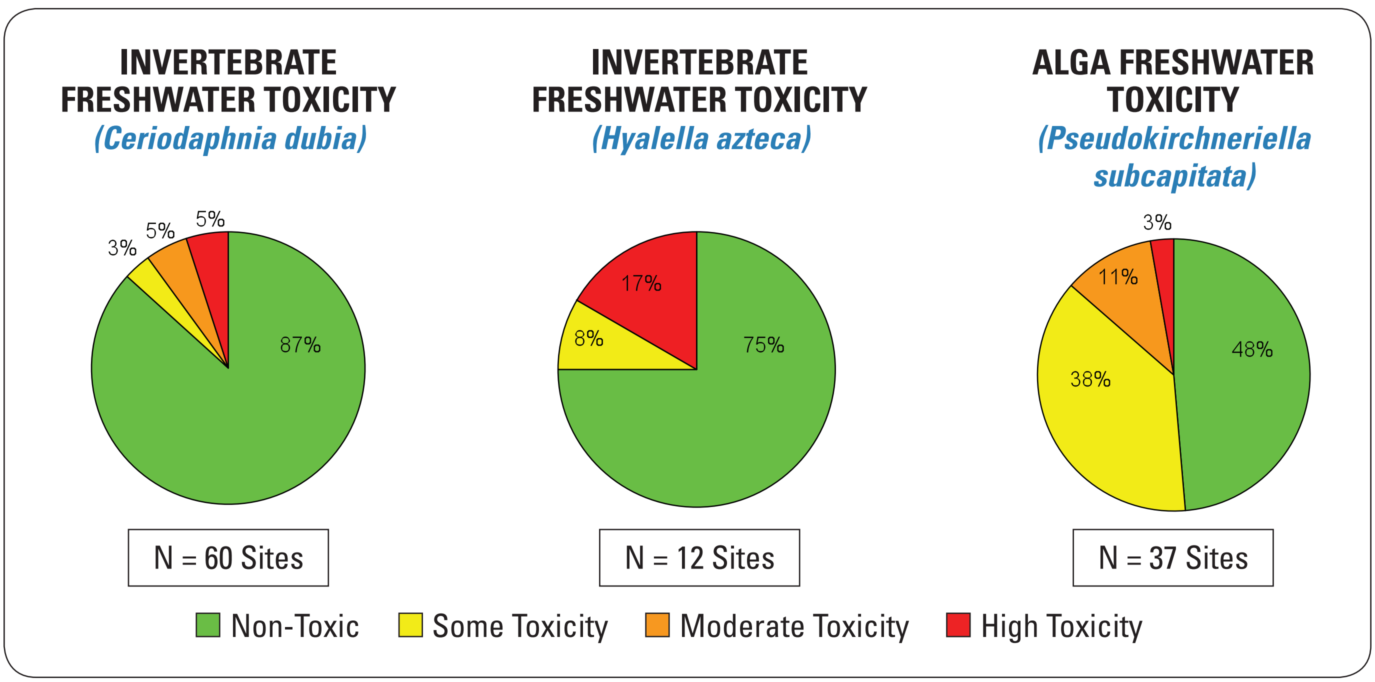


Figure 2. Magnitude of toxicity to individual freshwater species at sites examined by testing of freshwater samples in the San Diego Region of California.

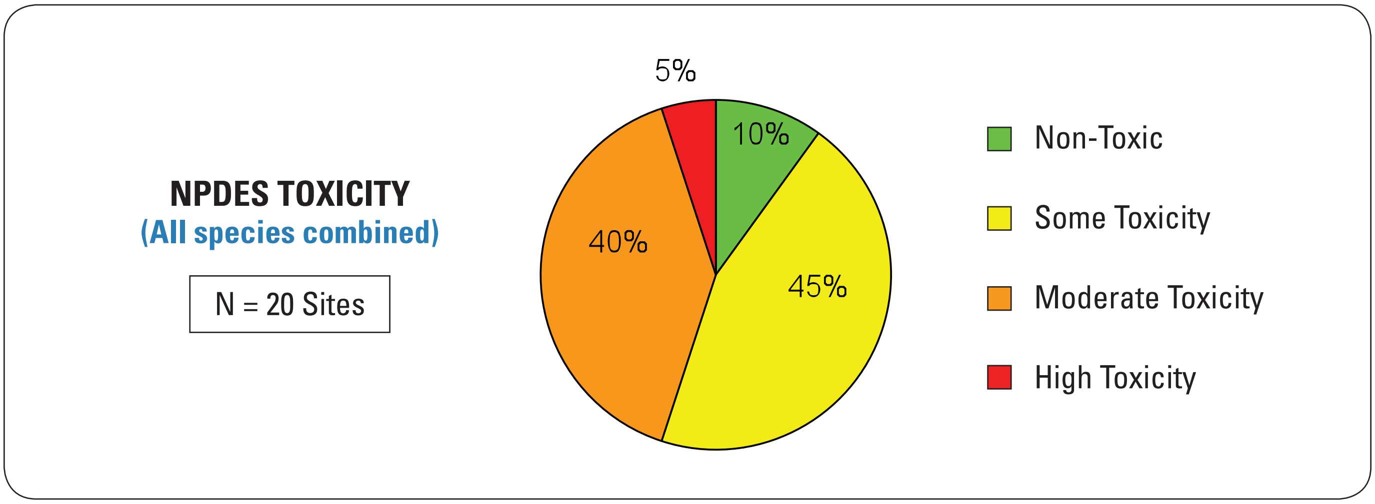


Figure 3. Magnitude of toxicity at sites examined by testing of NPDES freshwater samples in the San Diego Region of California.

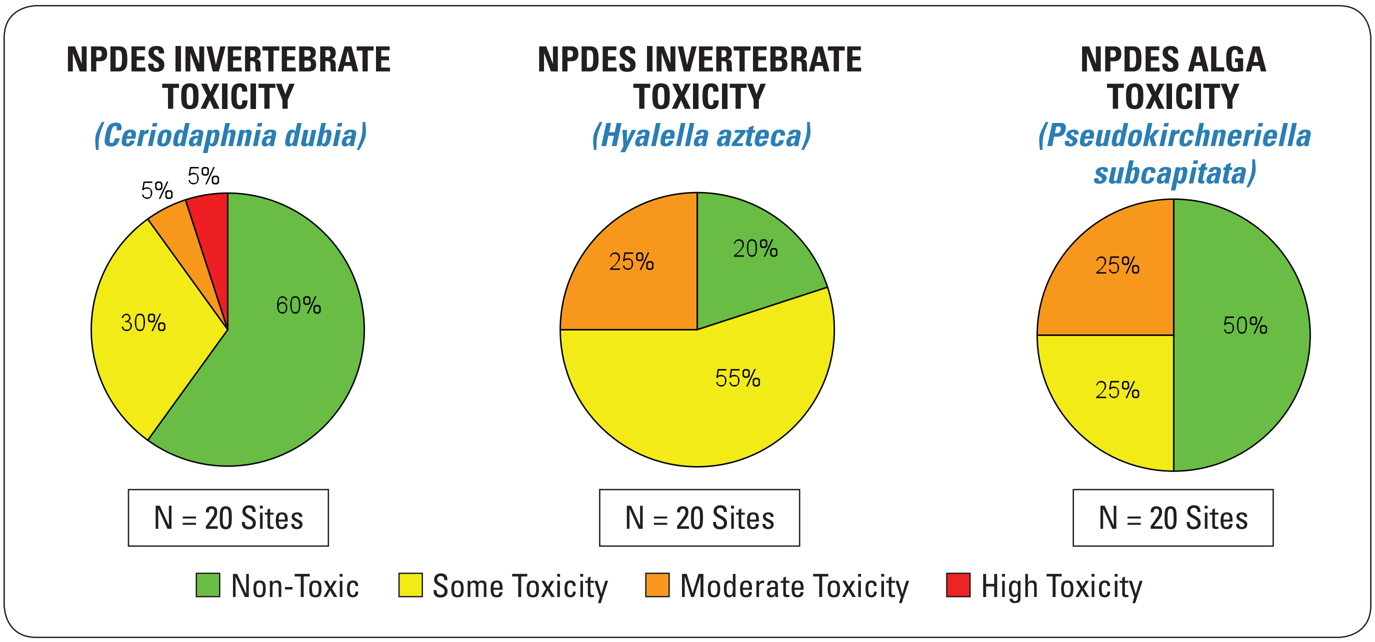


Figure 4. Magnitude of toxicity to individual freshwater species at sites examined by testing of NPDES freshwater samples in the San Diego Region of California.

SECTION 4
RELATIONSHIPS BETWEEN LAND USE AND TOXICITY

Land use was quantified as described in Anderson et al. (2011), around stream, canal and ditch sites at which samples were collected for testing in water column or sediment toxicity tests. Using ArcGIS, polygons were drawn to circumscribe the area within one kilometer of each site that was upstream of the site, in the same catchment, and within 500 meters of a waterway draining to the site. Land use was categorized according to the National Land Cover Database. All "developed" land types in the land cover database were collectively categorized as "urban". "Cultivated crops" and "hay/pasture" were categorized together as "agricultural". All other land types were categorized as "other" for the purpose of this analysis. Percentages of each land use type were quantified in the buffers surrounding the sample collection sites. Urban land category represents sites with nearby upstream land use of greater than 10% urban and less than 25% agricultural areas. Agricultural land category represents sites with nearby upstream land use of greater than 25% agricultural and less than 10% urban areas.

Agricultural land makes up a small part of the area of the San Diego Region, and toxicity information from the San Diego Region was largely limited to data from sites in urban and less-developed areas (Figures 5 and 6).

Associations of land use with sediment toxicity were stronger than associations with water toxicity. In *H. azteca* sediment tests, urban sediments showed significantly lower survival than sediments from less-developed sites (Figure 5: Wilcoxon Rank Sum Test, $p = 0.014$). Severe *H. azteca* sediment toxicity in urban San Diego Region areas has been reported previously (Holmes et al., 2008). Freshwater toxicity to the invertebrate *C. dubia* and freshwater toxicity to the alga *P. subcapitata* showed distinctly different patterns relative to land use. For the most part, sites in the San Diego region were not toxic to *C. dubia*, but the few sites found to be toxic were located in areas with urban land use within one kilometer upstream (Figures 6-A, 7-A). In contrast, algal toxicity was found at *low* to *moderate* levels throughout the San Diego Region, both in urban and in less-developed areas (Figure 6-B, 7-B).

Although it was not possible to use San Diego's regional data set to examine associations between toxicity and agriculture, these associations are well established (de Vlaming et al., 2000; Weston et al., 2004; Holmes et al., 2005; Anderson et al., 2011).

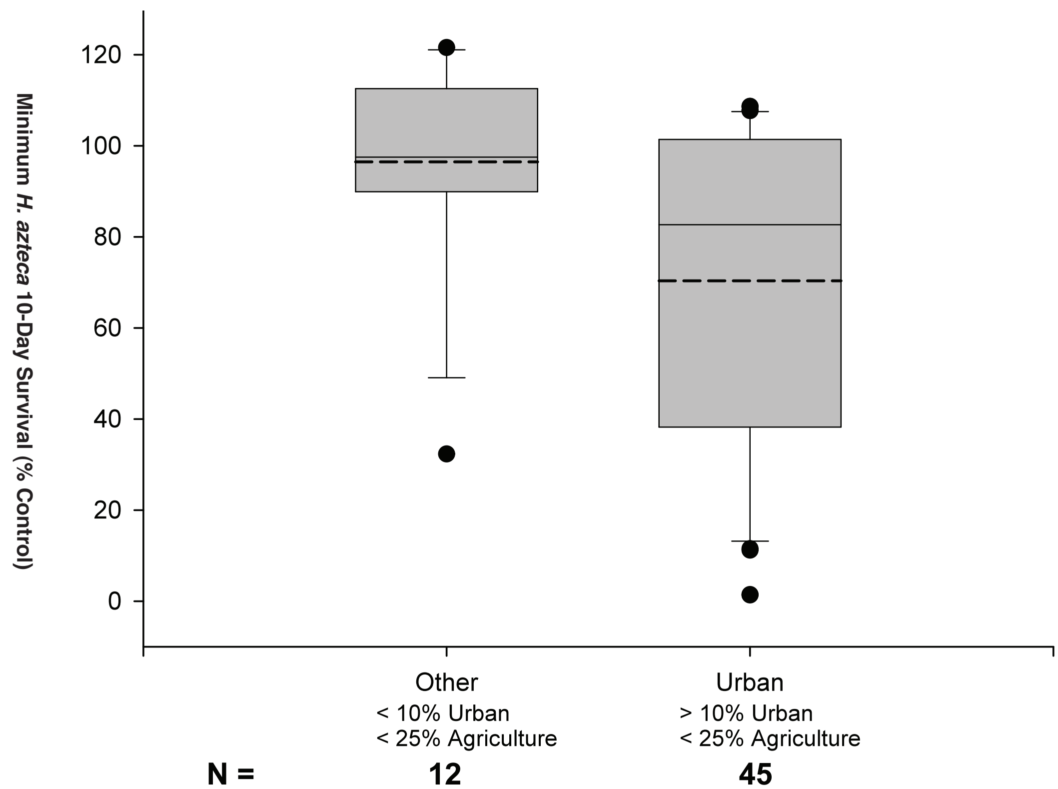
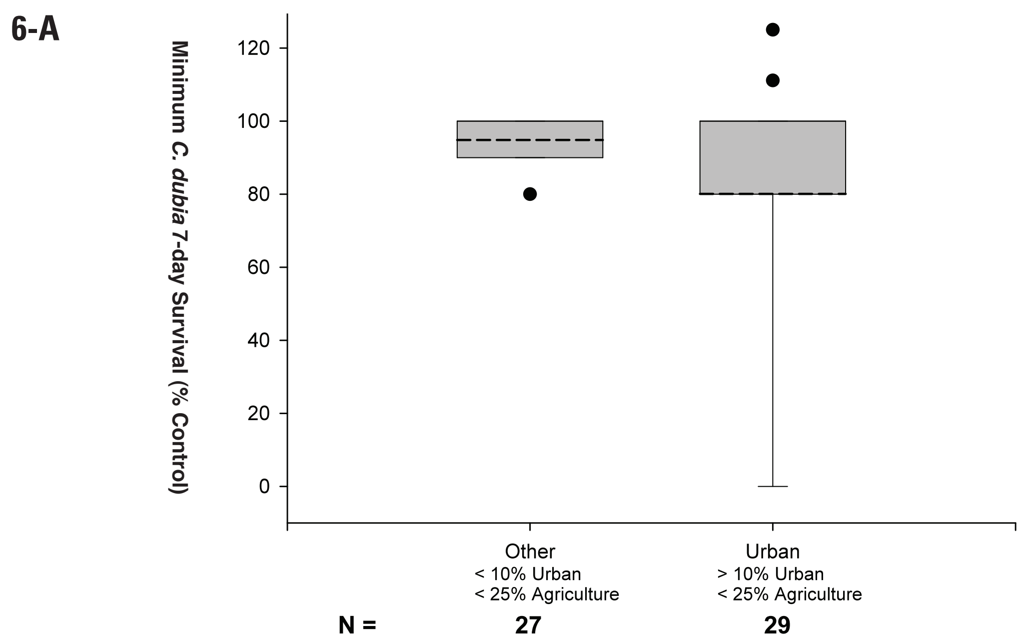


Figure 5. Distribution of freshwater sediment toxicity at urban and less developed sites. Lower values represent lower levels of *H. azteca* survival, and indicate *higher* toxicity. Solid lines, from top to bottom, represent the 90th, 75th, 50th (median), 25th and 10th percentiles of the distribution. Dotted lines are the mean result. Asterisk indicates survival at urban sites was found to be significantly lower than at "other" sites (one-tailed Wilcoxon Rank Sum Tests).



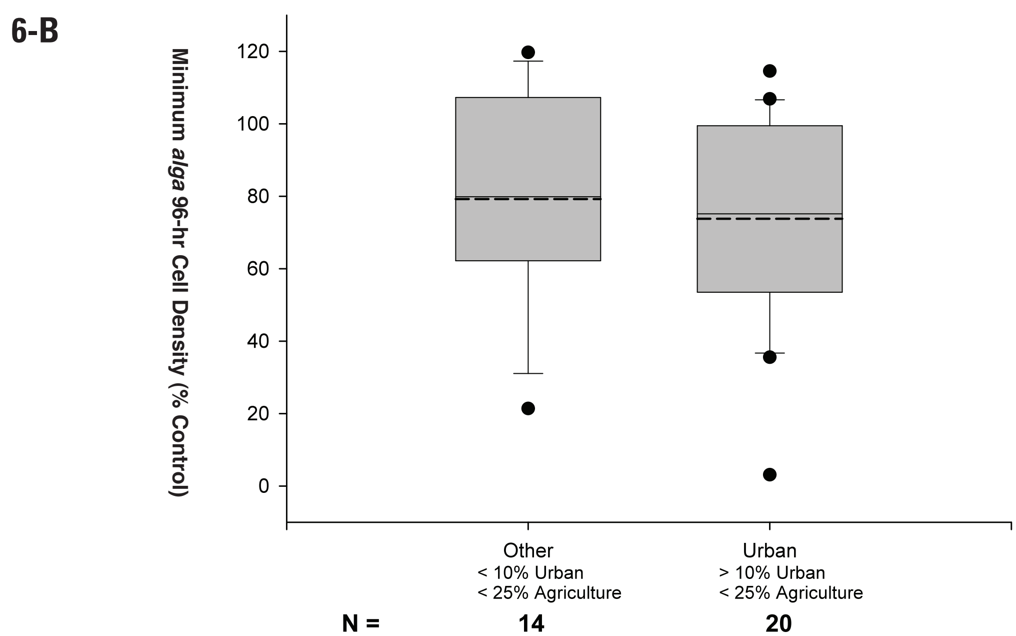
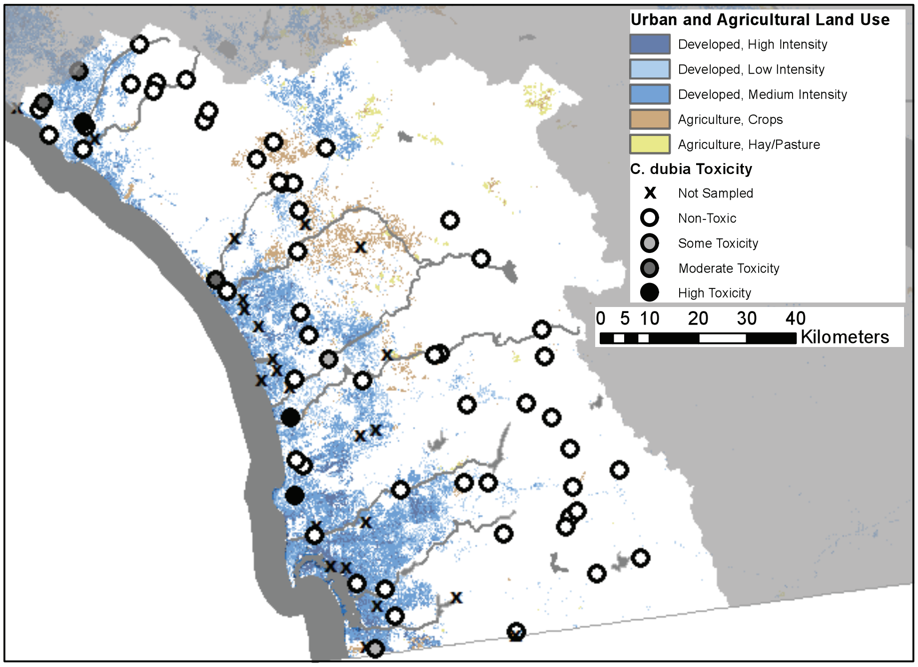


Figure 6. Distribution of freshwater toxicity at urban and less developed sites. Lower values represent lower levels of survival, and indicate *higher* toxicity. Solid lines, from top to bottom, represent the 90th, 75th, 50th (median), 25th and 10th percentiles of the distribution. Dotted lines are the mean result. (A) *C. dubia* toxicity, (B) *P. subcapitata* toxicity.

7-A



7-B

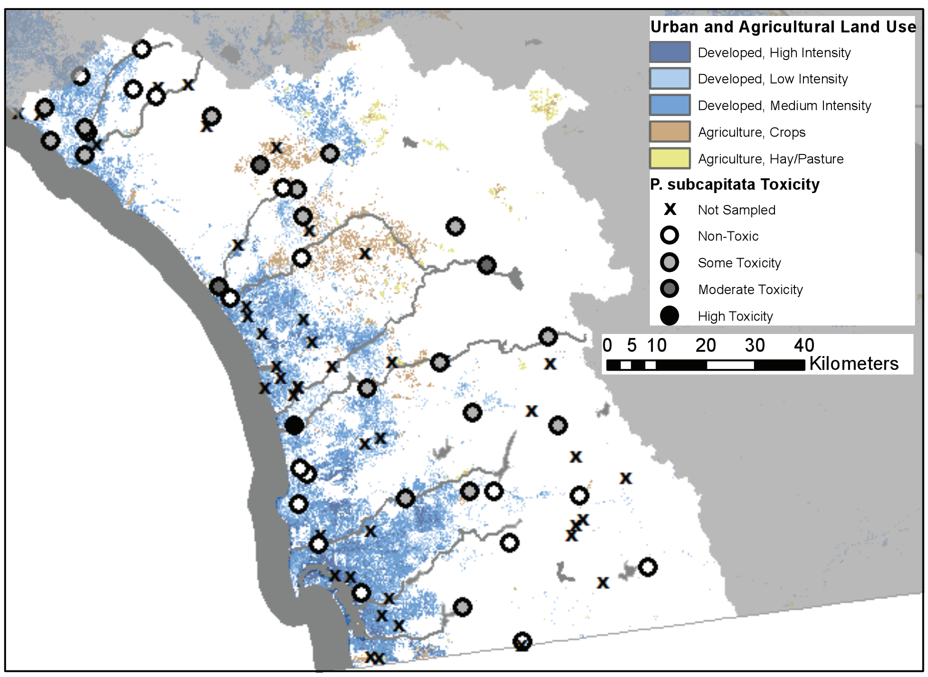


Figure 7. Comparison of the distributions of *C. dubia* (invertebrate) and *P. subcapitata* (alga) toxicity in the San Diego Region. (A) *C. dubia* toxicity, (B) *P. subcapitata* toxicity.

SECTION 5
GEOGRAPHICAL PATTERNS IN TOXICITY

As reflected in the associations between land use and toxicity, most freshwater sediment toxicity was concentrated in the coastal urban areas, while freshwater toxicity was more evenly distributed throughout the Region (Figures 8 and 9). Toxicity to the invertebrates *C. dubia* and *H. azteca* accounted for the majority of the detections of *high* freshwater toxicity in the western urban areas and along the U.S. - Mexico border, while *some* to *moderate* algal (*P. subcapitata*) toxicity accounted for most of the toxicity detections in the less-developed interior of the Region.

Among the marine sediment toxicity data collected in the Southern California Bight in 2003, the *highest* toxicity near the San Diego region was detected on the upper slope stratum of the Orange County Shelf (Site 4201, 3.3 km off of Laguna Beach), and on the coast of the San Diego metropolitan area in Mission Bay and San Diego Bay (Sites 4228 and 4340; Figures 10, 12, 13).

Examination of the geographic patterns in toxicity in receiving systems that are monitored as part of NPDES stormwater permits shows that sites closer to the coast tended to show higher levels of toxicity between 2001 and 2008. Most of the sites closest to the coast showed *moderate* levels of toxicity to one or more test species, while those further inland showed *some* toxicity or, in rare cases, non-toxic conditions. The only site whose receiving water was found to be *highly* toxic was located on the Tijuana River at the southern end of the Region (911TJR-MLS, Figures 11 and 14).

As discussed above, *moderate* to *high* water column toxicity has been observed throughout the San Diego Region, and in samples from the early 2000s this was sometimes associated with organophosphate pesticide detections. Samples from Oso Creek (901SJOS03), English Creek (901SJENG2) and Laguna Canyon Creek (901SJLAG2; Figure 15) in the Mission Viejo area showed low *C. dubia* survival which coincided with detections of diazinon, but the diazinon concentrations were below the LC50 for this species. Sediments from English Creek and San Juan Creek (901SUP068) were toxic to *H. azteca* in 2003.

Water and sediment samples from watersheds monitored between Camp Pendleton and Encinitas also demonstrated *moderate* to *high* water and sediment toxicity during the early 2000s. Water from the Santa Margarita River (902SSMR10; Figure 16) was *highly* toxic to *C. dubia* and *P subcapitata*, in 2003. Sediment samples from Buena Vista Creek (904CBBVR4), Aqua Hedionda Creek (904CBAHC6), San Marcos Creek (904CBSAM3 and 904CBSAM6), and Cottonwood Creek (904CBCWC2; Figure 17) were all *highly* toxic to *H. azteca* in 2002.

Similar trends were observed in water and sediment samples from the San Diego area. Water samples from the San Dieguito Creek (905SDSQ9), Rose Canyon Creek (906LPRSC4), and the Tijuana River (911TTJR05) were all *highly* toxic to *C. dubia* in 2002. All samples had detectable diazinon concentrations but did not exceed the LC50 for *C. dubia*. Sediment samples from Penasquitos Creek (906SUP076; in 2007), Poway Creek (906LPPOW2; in 2002), Forrester Creek (907SDFRC2; in 2004), Switzer Creek (908SUP095; in 2007), Chollas Creek (908SUP096; in 2007), and the Tijuana River (911TTJR05; in 2005; 911TJHRxx; in 2008) were *moderately* to *highly* toxic to *H. azteca*. In the eastern San Diego Region water from Tecate Creek (911TTET02) was *highly* toxic to *C. dubia* in 2005 and 2006, and sediment samples were *highly* toxic to *H. azteca* during this period (Figures 18 and 19). The organophosphate pesticides diazinon and chlorpyrifos were detected in these samples, but both were below known toxicity thresholds for these species.

Marine sediment toxicity monitoring suggests a relatively low level of toxicity to amphipods (*E. estuarius*) in San Diego Region marine waters, but *highly* toxic sediments have been detected at various sites in marinas, bays and harbors. TMDL studies conducted by the San Diego Regional Board showed toxic sediment were often located next to stormwater outfalls, such as at Switzer Creek and the Downtown Anchorage area of San Diego Harbor (Anderson et al., 2004; Anderson et al., 2005), and adjacent to the 7th Street Channel (Chollas/Paleta Creek) (Brown and Bay, 2011). Surveys conducted as part of the Bight 2003 monitoring showed *high* toxicity in Mission Bay, and in San Diego Bay (Bay et al., 2005). Many of these are the same sites identified through Bay Protection Toxic Cleanup Program monitoring in the 1990s (Fairey et al., 1998). Recent monitoring of harbors in the San Diego Region showed very little sediment toxicity to *E. estuarius*, but *moderate* to *high* levels of toxicity to mussel embryo development using *M. galloprovincialis*. Toxicity to mussel embryos was observed in marina and industrialized stations within San Diego Bay: 56% of the marina stations had low embryo development (WestonSolutions, 2010).

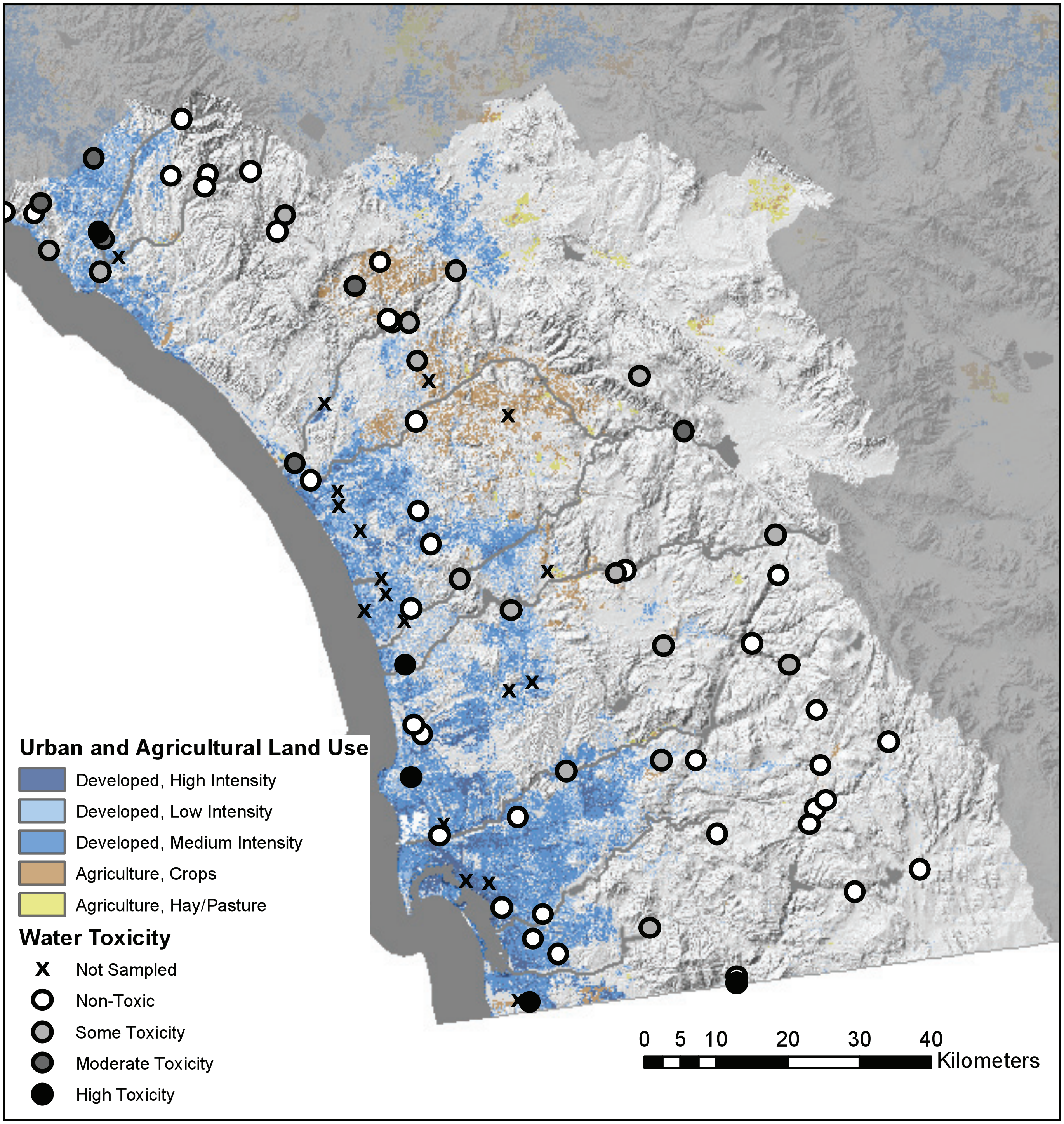


Figure 8. Magnitude of ambient water column toxicity at sites in the San Diego Region of California based on the most sensitive species (test endpoint) in water samples collected at each site.

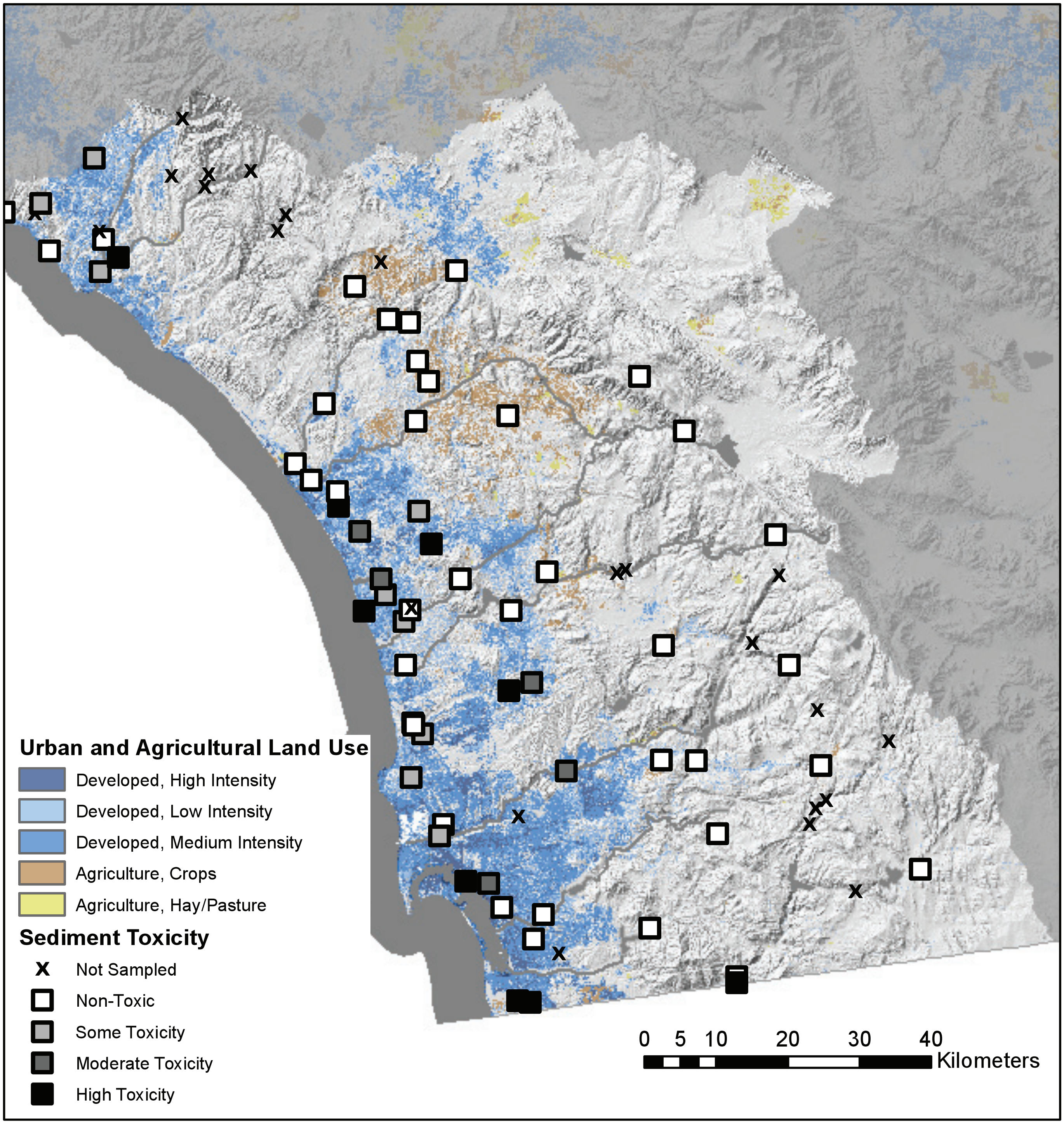


Figure 9. Magnitude of sediment toxicity at sites in the San Diego Region of California based on the 10-d survival of *H. azteca* in sediment samples collected at each site.

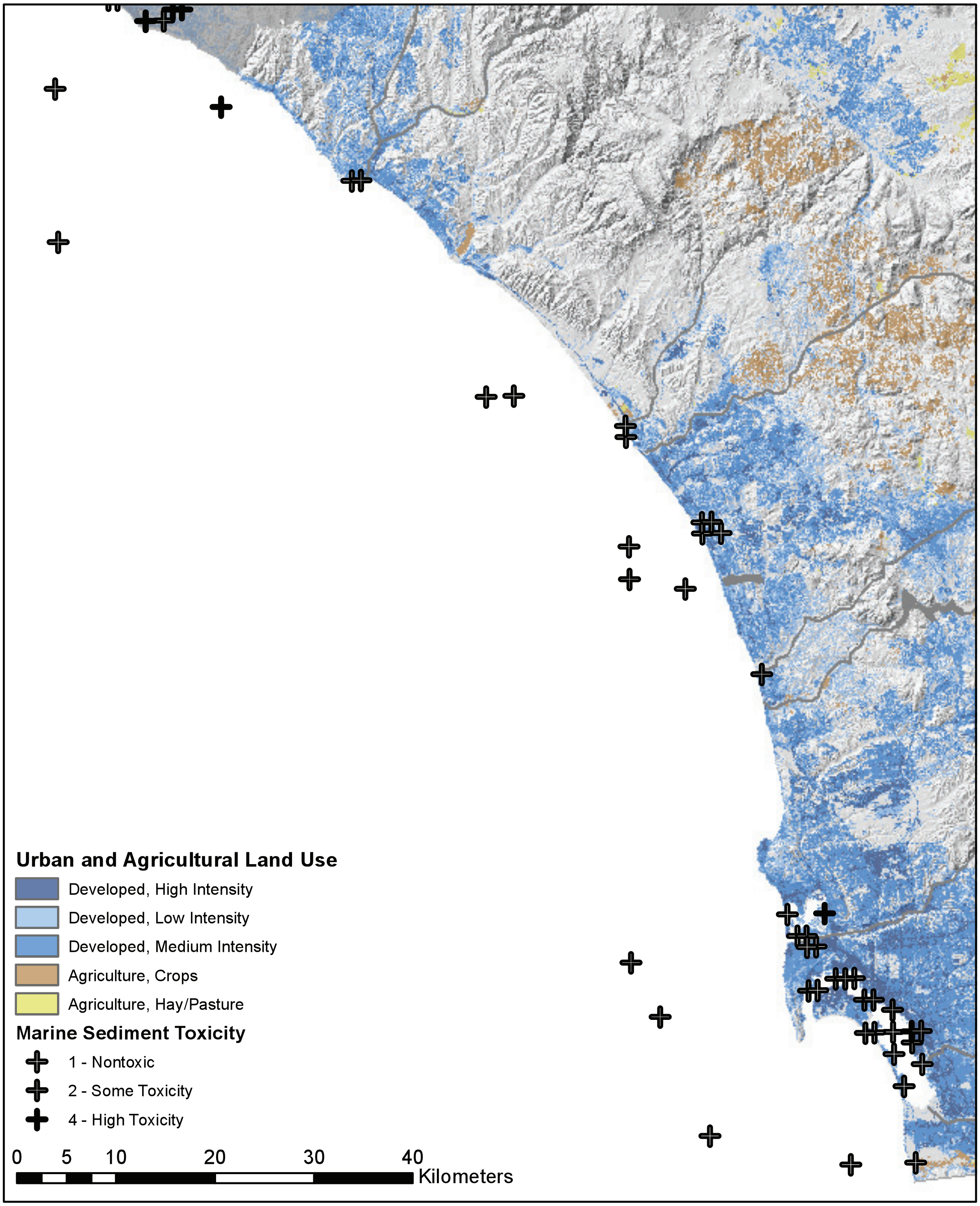


Figure 10. Magnitude of marine sediment toxicity at sites within 10 miles of the coast of the San Diego Region of California based on the survival of *E. estuarius*.

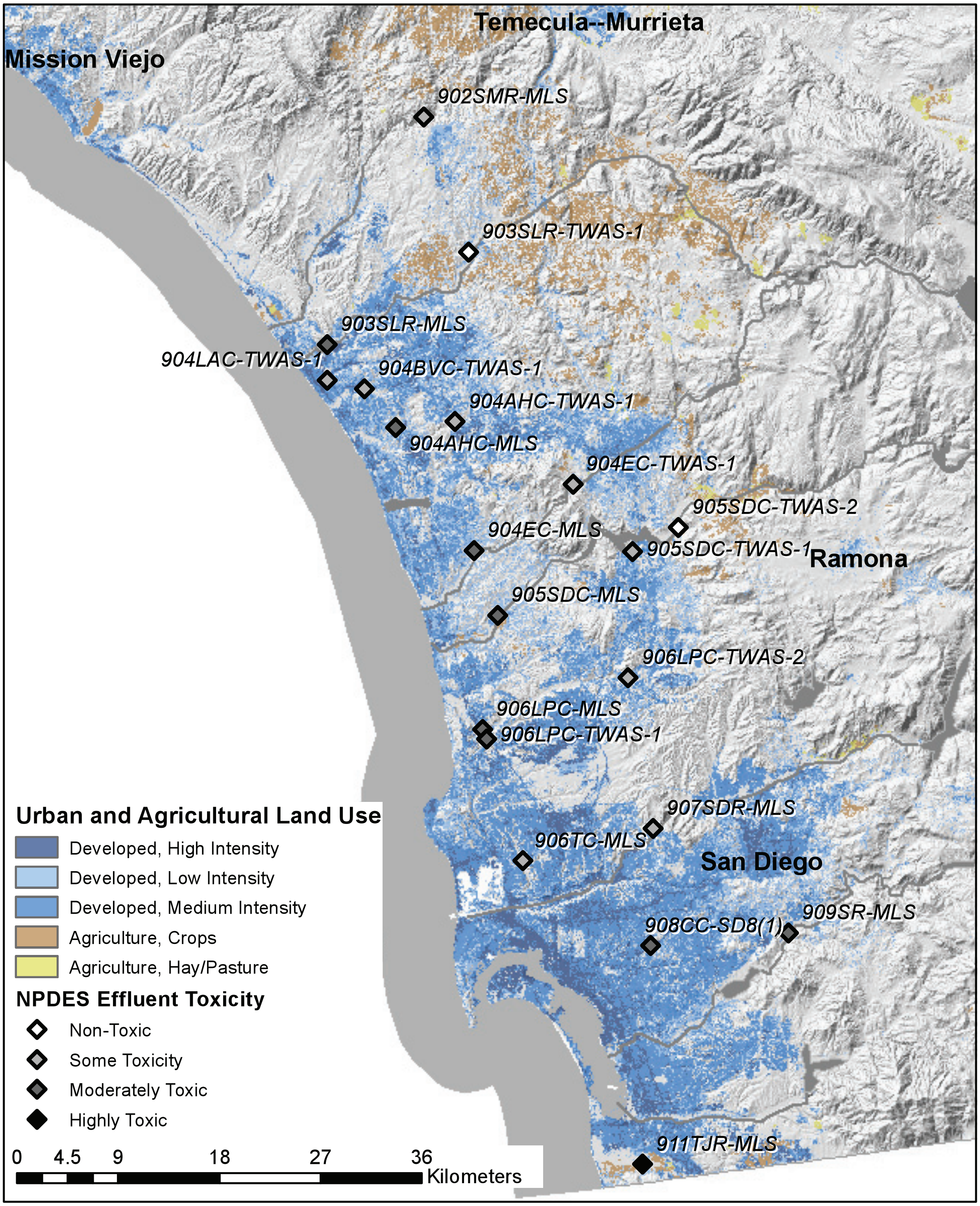


Figure 11. Magnitude of receiving water toxicity at sites monitored for NPDES stormwater permits in the San Diego region of California, based on the most sensitive species (test endpoint) examined at each site.

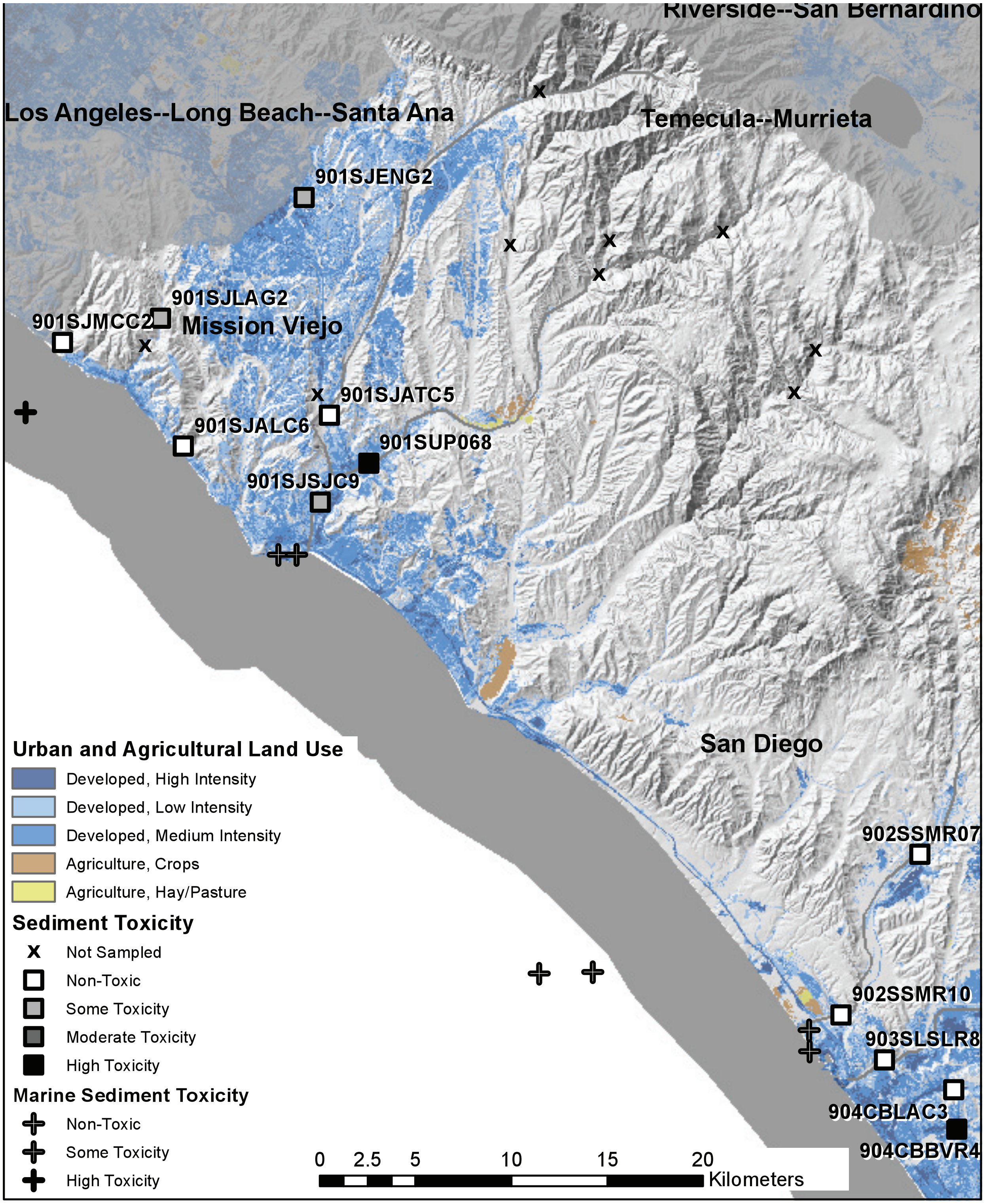


Figure 12. Magnitude of sediment toxicity at sites in the northwestern San Diego Region of California based on the survival of *H. azteca* in freshwater sediment samples and *E. estuarius* in marine sediment samples. Station identifiers are given for freshwater sediment sites.

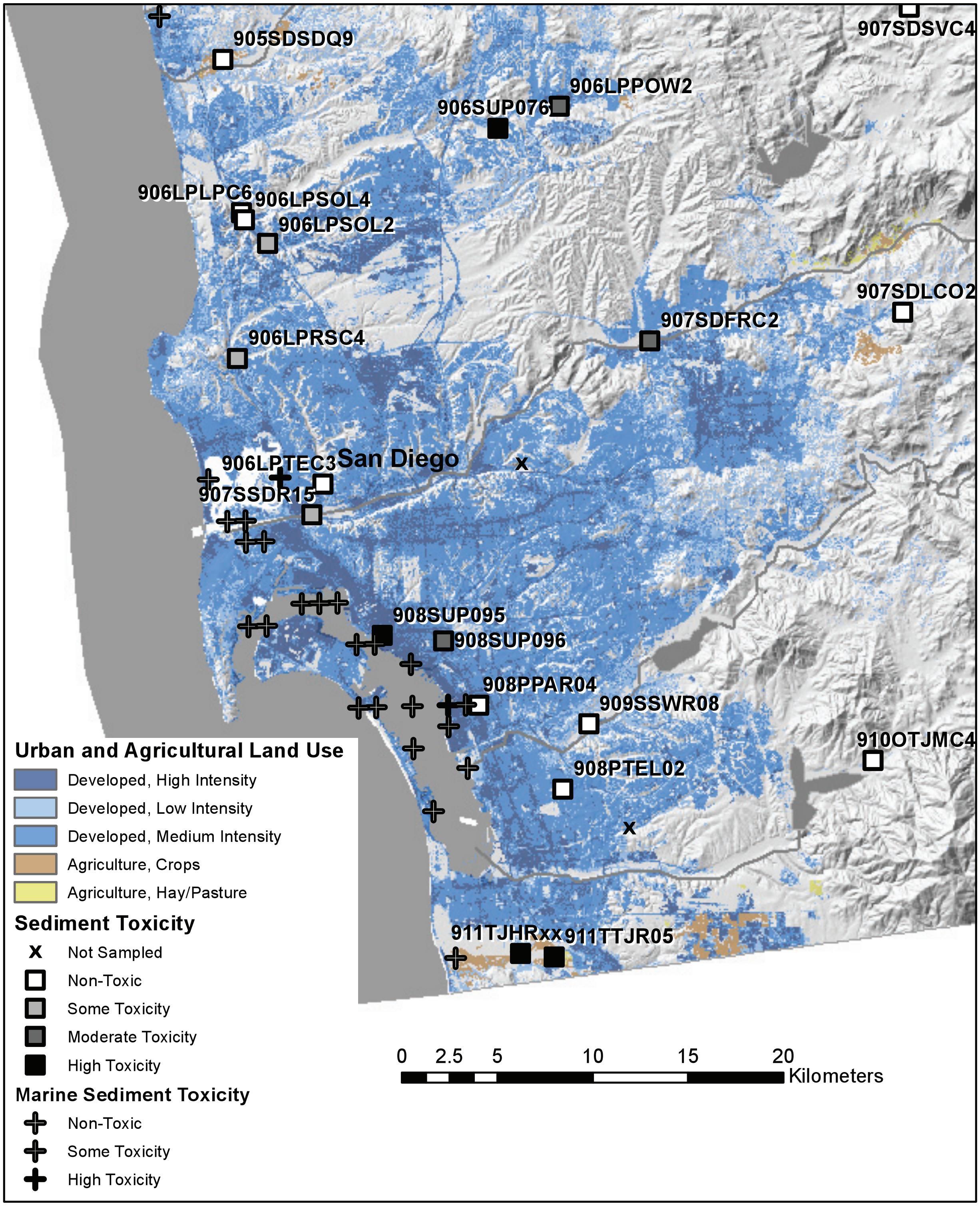


Figure 13. Magnitude of sediment toxicity at sites around the San Diego metropolitan area of California based on the survival of *H. azteca* in freshwater sediment samples and *E. estuarius* in marine sediment samples. Station identifiers are given for freshwater sediment sites.

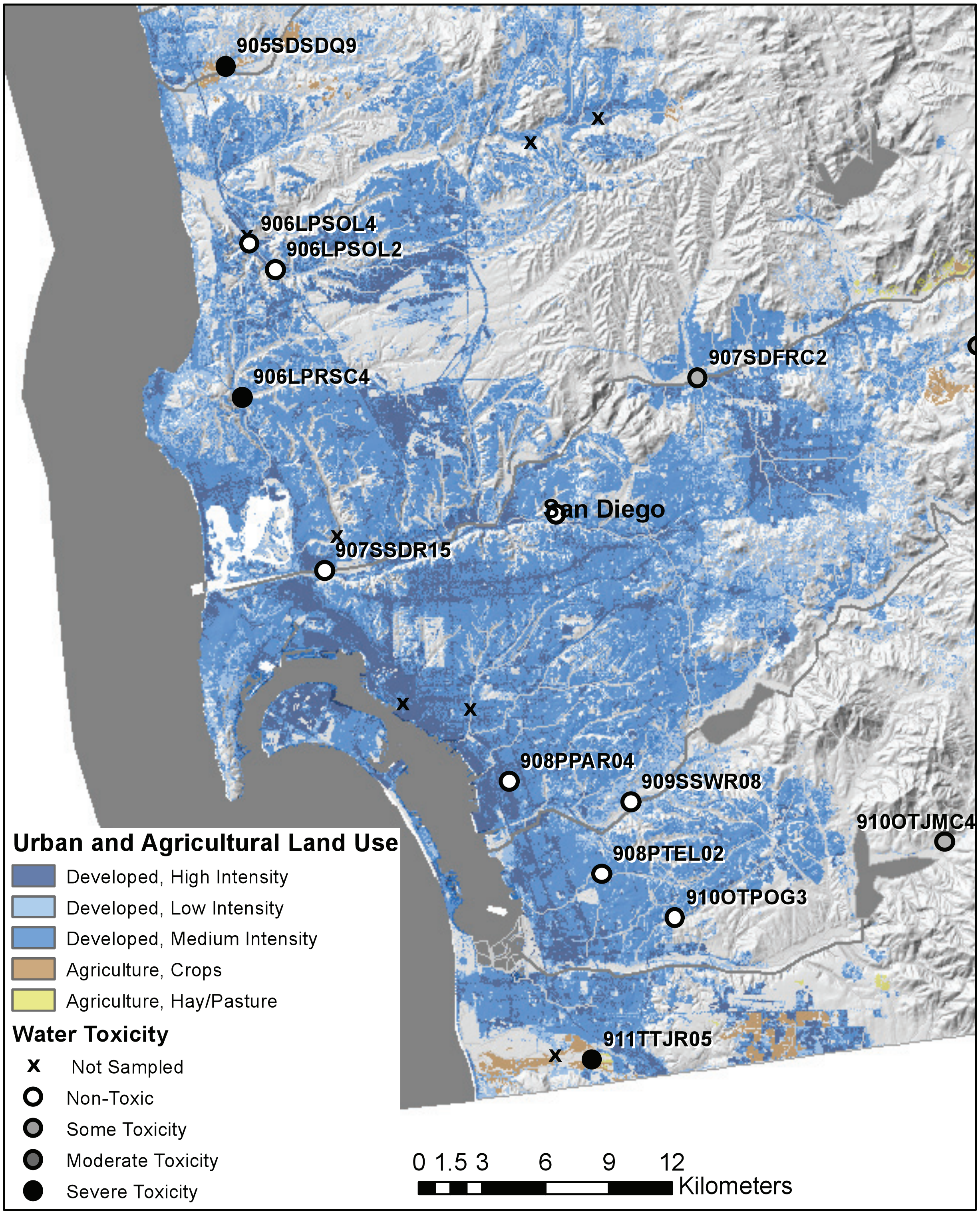


Figure 14. Magnitude of ambient water column toxicity at sites around the San Diego metropolitan area of California based on the most sensitive species (test endpoint) in water samples collected at each site.

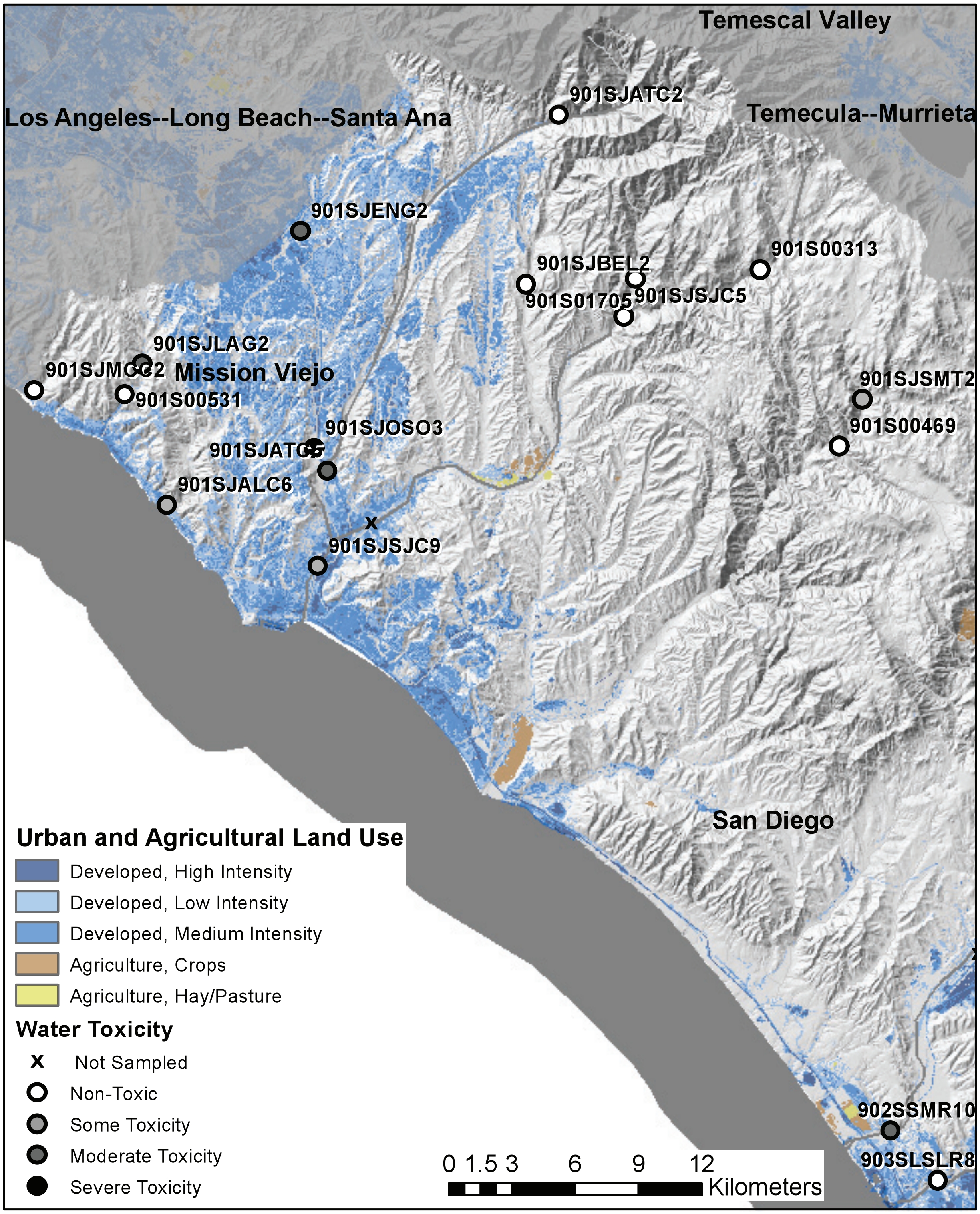


Figure 15. Magnitude of ambient water column toxicity at sites in the northwestern San Diego Region of California based on the most sensitive species (test endpoint) in water samples collected at each site.

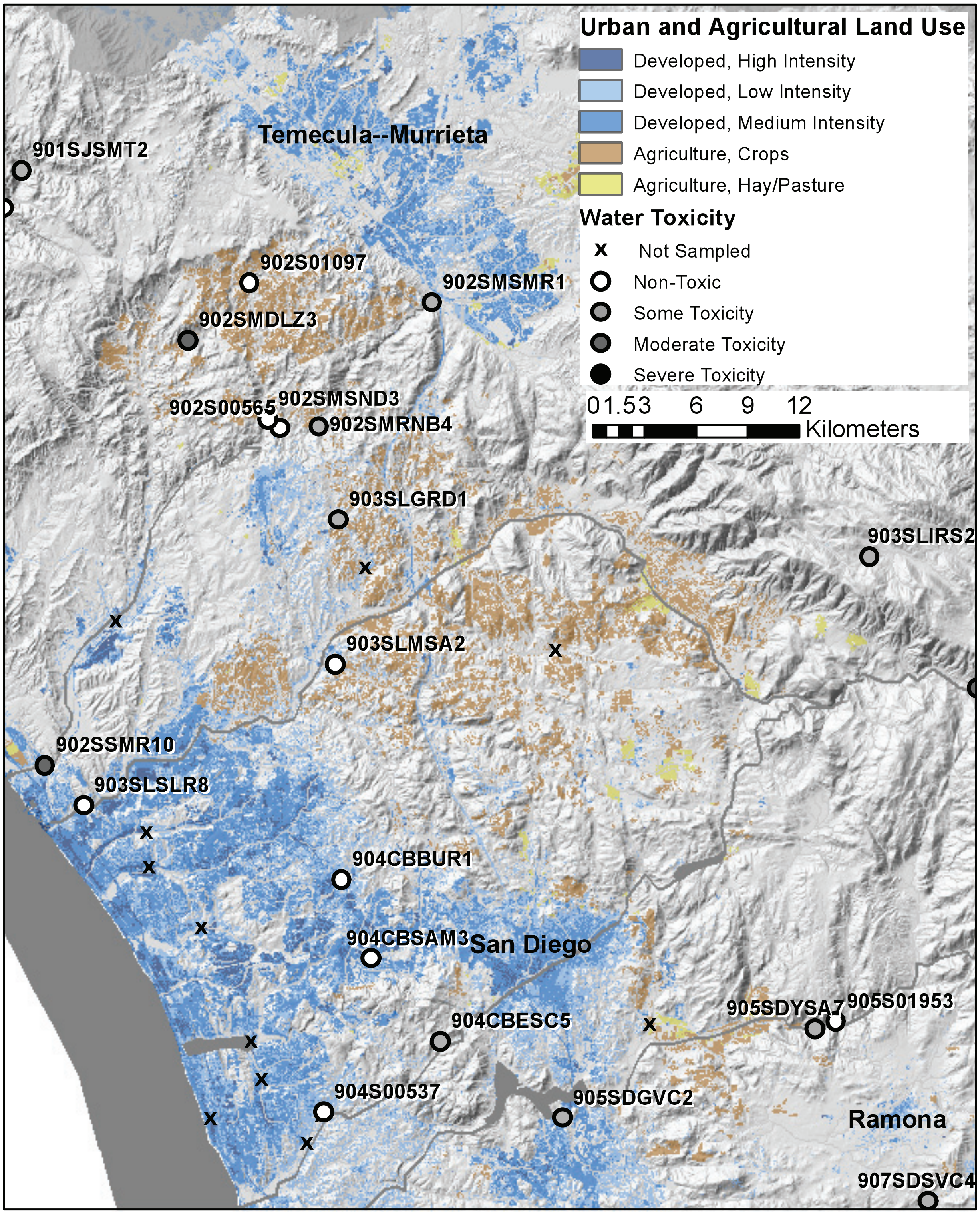


Figure 16. Magnitude of ambient water column toxicity at sites in the central western area of the San Diego Region of California based on the most sensitive species (test endpoint) in water samples collected at each site.

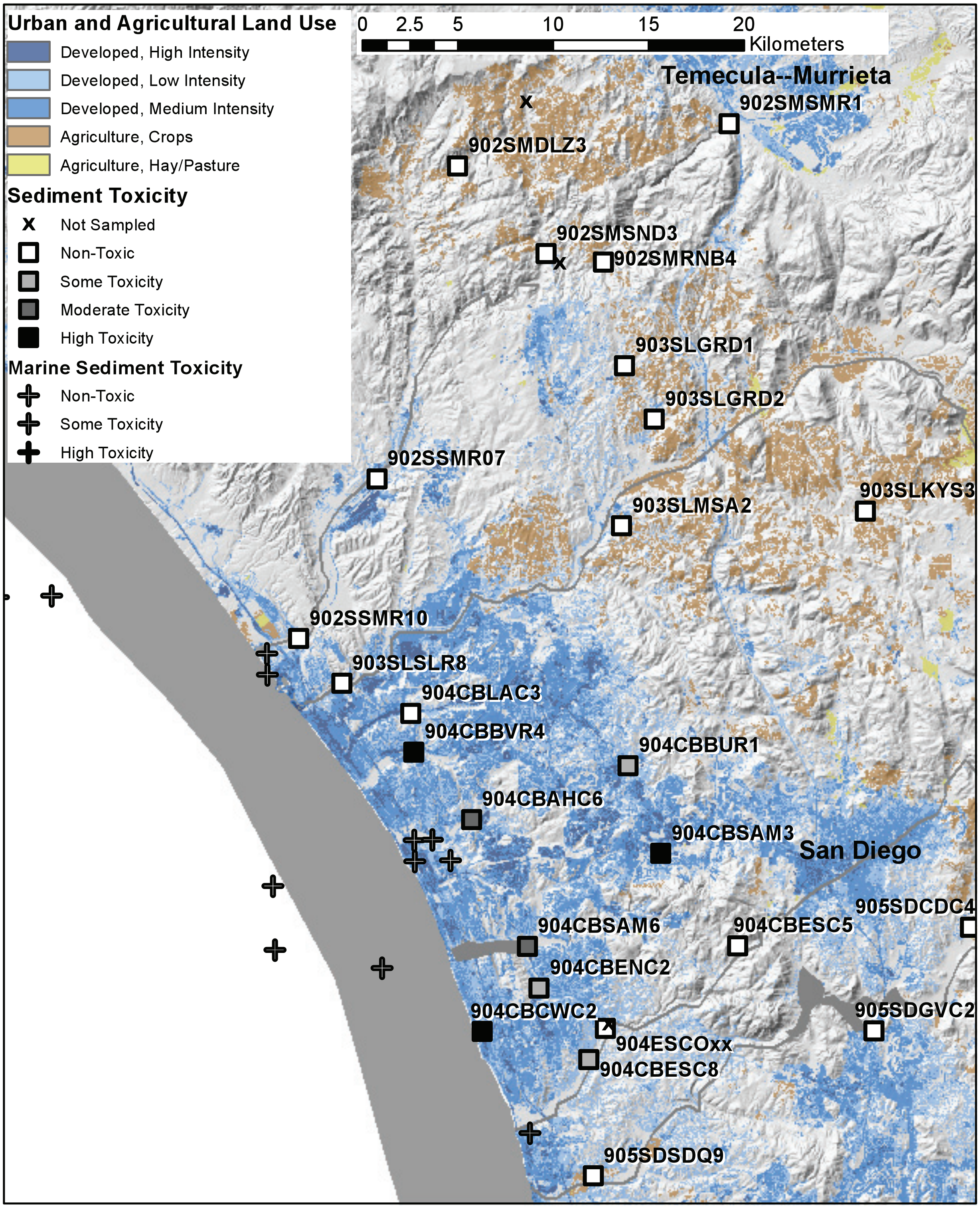


Figure 17. Magnitude of sediment toxicity at sites in the central western area of the San Diego region of California based on the survival of *H. azteca* in freshwater sediment samples and *E. estuarius* in marine sediment samples. Station identifiers are given for freshwater sediment sites.

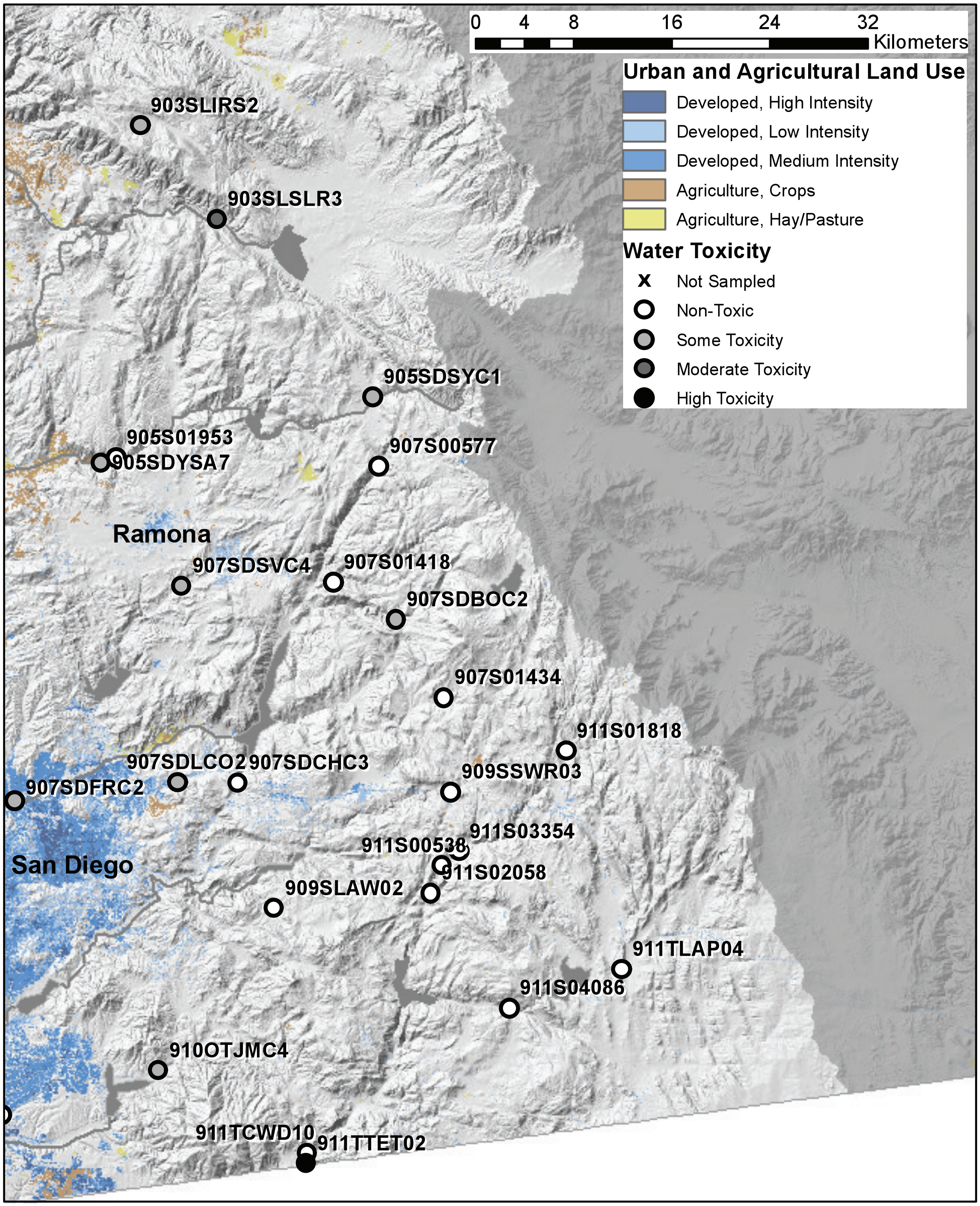


Figure 18. Magnitude of ambient water column toxicity at sites in the southeastern area of the San Diego Region of California based on the most sensitive species (test endpoint) in water samples collected at each site.

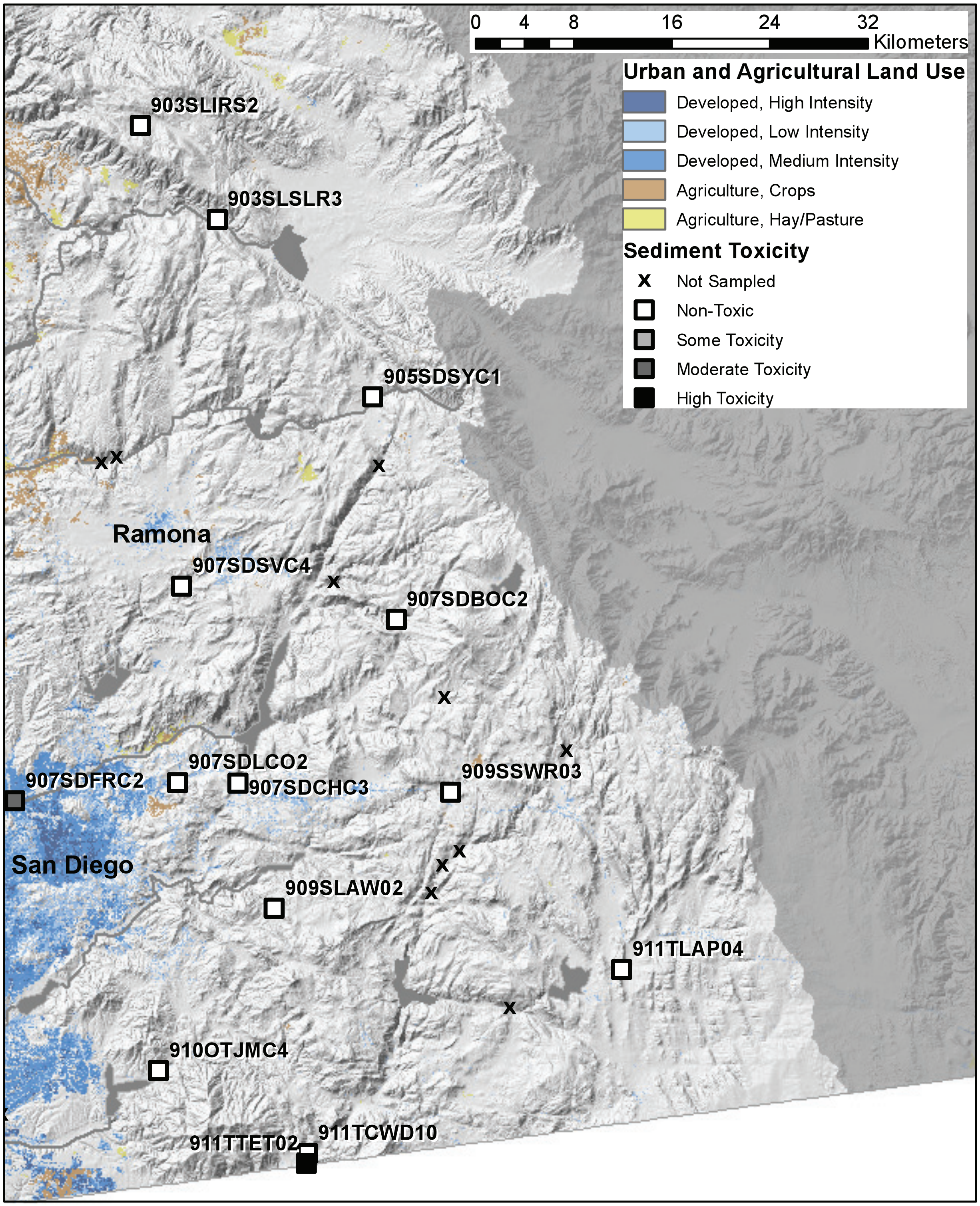


Figure 19. Magnitude of sediment toxicity at sites in the southeastern area of the San Diego region of California based on the 10-d survival of *H. azteca* in sediment samples collected at each site.

SECTION 6
CAUSES OF TOXICITY

Toxicity was seen somewhat frequently in the Region between 2001 and 2010. Freshwater and freshwater sediment toxicity can be attributed to pesticides, while marine water and marine sediment toxicity can be attributed to metals, pesticides, or a combination of both.

FRESHWATER

A series of municipal stormwater reports by Weston Solutions present trends in water toxicity data for various waterbodies surveyed throughout the San Diego Region as part of NPDES permit monitoring (http://www.projectcleanwater.org/index.php?option=com_content&view=%20article&id=80&Itemid=91). These reports include water toxicity, chemistry and toxicity identification evaluation (TIE) information gathered from monitoring conducted between 2004 and 2010. The freshwater toxicity patterns described for the San Diego Region coincide with those described for statewide monitoring in the decade between 2001 and 2010 (Anderson et al., 2011). During this period data suggests much of the toxicity to *C. dubia* in urban stormwater in the San Diego Region was attributed to organophosphate pesticides such as diazinon, and as diazinon concentrations decreased due to EPA residential use restrictions, increasing toxicity to amphipods *H. azteca* has been observed. Evidence suggests this has been due to pyrethroid pesticides, including bifenthrin. Data for some creeks previously listed as impaired due to organophosphate pesticides confirm this trend. Monitoring in Chollas Creek, for example, shows a trend of decreasing organophosphate pesticides, and increasing metals and pyrethroids. A TIE of Chollas Creek stormwater in 2005 showed that pyrethroids were the cause of toxicity to *H. azteca* (WestonSolutions, 2006).

FRESHWATER SEDIMENT

As part of a statewide survey of urban creeks, Holmes et al. (2008) surveyed sediments in Chollas Creek, Cottonwood Creek, Penasquitos Creek, Switzer Creek, San Juan Creek, and San Marcos Creek. All sediments were significantly toxic to *H. azteca*, and all contained toxic concentrations of pyrethroid pesticides. Comparisons between toxicity tests conducted at 23 and 15 °C showed an increase in toxicity at all sites when tests were conducted at the lower temperature, a result suggesting pyrethroids were the cause of toxicity (Ware and Whitacre, 2004). The pyrethroids most commonly detected at toxic concentrations in San Diego Region sediments were bifenthrin and cypermethrin. As part of this study, Phillips et al. (Phillips et al., 2010) conducted a TIE of sediment from Cottonwood Creek and verified toxicity was due to bifenthrin and cypermethrin.

In conjunction with the Southern California Monitoring Coalition and SWAMP, the Stream Pollution Trends Monitoring Program (SPoT) has been conducting sediment surveys in several San Diego Region watersheds. Of the seven sites SPoT monitored for chemistry and toxicity in the San Diego Region in 2008, only the Tijuana River was significantly toxic. SPoT monitoring in 2010 included assessments of toxicity at 23 and 15°C as a diagnostic for pyrethroid-associated toxicity. In addition to *high* toxicity detected in the Tijuana River, sediments from Escondido Creek, Penasquitos Creek, and the San Diego River were toxic when tested at 15°C (57% of SPoT stations toxic). Chemistry evidence showed pyrethroid concentrations exceeded toxicity thresholds at these sites. Although a number of pyrethroids were detected, bifenthrin and/or cypermethrin were the most common at toxic concentrations.

Brown et al. (Brown et al., 2010) monitored three freshwater wetlands in the San Diego Region using sediment toxicity tests (*H. azteca*), chemical analyses and TIEs. Monitoring in the San Elijo Lagoon and the Valeta Street marsh near the mouth of the San Diego River showed toxicity to amphipods. TIEs indicated toxicity was due to pyrethroid pesticides. The third site at the Dairy Mart Ponds in Southern San Diego showed no toxicity and no pyrethroids were detected in the samples.

MARINE WATER

Procedures to determine causes of toxicity in marine waters have relied on correlation analyses, comparisons of chemistry with established toxicity thresholds, and toxicity identification evaluations. There are some examples of these approaches applied to stormwater monitoring conducted in San Diego Harbor. Skinner et al. (1999) investigated fish embryo development using medaka (*O. latipes*) and silversides (*Menidia beryllina*) to assess toxicity of stormwater. This study found stormwater was toxic to fish embryo development, and there were low correlations between impaired hatching and fish mortality with specific metals in stormwater. There was a strong correlation between total metals and hatching inhibition. Schiff et al. (Schiff et al., 2003) used toxicity tests with sea urchin gametes, chemical analyses and TIEs to show that Chollas Creek stormwater created a toxic plume in the San Diego Harbor. Toxicity to urchin fertilization was likely due to metal constituents, primarily cations of zinc and copper. Katz et al. (Katz et al., 2006) conducted a comprehensive assessment of stormwater toxicity associated with Navy Facilities in San Diego Harbor. Monitoring was conducted on multiple storm events in 2004 and included toxicity testing using mysids, topsmelt and mussel embryos. Toxicity was conducted using stormwater from outfalls on five navy bases, and in San Diego Harbor receiving waters adjacent to the bases. The results showed that while stormwater from the various outfalls was sometimes toxic to all species, the greatest toxicity was observed using mussel embryo development, and first flush storm events were most toxic. Chemical analyses and TIE confirmed that toxicity was generally caused by metals (copper and zinc). This study also assessed the potential for receiving water toxicity by sampling plumes of stormwater in San Diego Harbor, and in one case, by using a shipboard flow-through bioassay system to assess receiving water toxicity. No receiving water toxicity was observed, and the results suggested that stormwater was rapidly diluted by receiving water as it entered the harbor.

MARINE SEDIMENT

The majority of large scale marine sediment toxicity monitoring in the San Diego Region have relied on correlation analyses to assess chemicals associated with sediment toxicity. Studies by Fairey et al. (1998) as part of the Bay Protection ad Toxic Cleanup Program found significant relationships between sediment toxicity and high concentrations of organochlorine pesticides, metals, and mixtures of chemicals exceeding sediment quality guideline quotient values. Similar statistical relationships have been reported for the Bight 2003 studies, and San Diego Harbor hotspot studies conducted by Anderson et al. (2005). There have been relatively few TIEs conducted using marine sediments in the San Diego Region. Anderson et al. (Anderson et al., 2010) conducted TIEs of sediment from harbor samples adjacent to Switzer Creek and found toxicity to amphipods (*E. estuarius*) was likely due to the pyrethroid pesticides bifenthrin and cyfluthrin. Greenstein et al. (Greenstein et al., 2011) used TIEs and correlation analyses to investigate chemicals responsible for amphipod mortality in harbor sediments adjacent to the 7th Street Channel (Chollas/Paleta Creek). Studies were conducted in 2004. The TIE results suggested organic chemicals were responsible for amphipod mortality. Correlation analyses indicated the likely chemicals of concern were chlordane and PAHs. Although chlordane is a common correlate with amphipod mortality in marine sediments, recent dose-response experiments have been conducted to establish toxicity thresholds for this pesticide, and these data, combined with the range of chlordane typically measured in marine sediments, have suggested chlordane is likely not responsible for *E. estuarius* mortality ((Phillips et al., 2011), Greenstein et al. personal communication).

SECTION 7 ECOLOGICAL IMPACTS ASSOCIATED WITH TOXIC WATERS

Field bioassessments provide information on the ecological health of streams and rivers, and bioassessments of macroinvertebrate communities have been used extensively throughout California. When combined with chemistry, toxicity, and TIE information, these "Triad" studies indicate linkages between laboratory toxicity and ecosystem impacts. Triad studies have been reported for freshwater systems in central California (Region 3), the Central Valley (Region 5), and the San Francisco Bay area (Region 2); and are summarized in Anderson et al., (2011).

FRESHWATER HABITATS

Triad studies combining bioassessments, toxicity testing, and chemical analyses have been conducted in freshwater habitats in several watersheds in the San Diego Region. In some cases these have included TIEs. Mazor and Schiff (Mazor and Schiff, 2008) reported results of SWAMP and NPDES monitoring conducted in numerous creeks throughout the San Juan hydrologic unit using toxicity tests, chemistry, and bioassessments. The results showed that the northern and coastal sections of this watershed were generally in poor ecological condition, and the southern interior sections were categorized as moderate to good condition. Many creeks in the Laguna Creek hydrologic subarea exceeded aquatic life criteria for multiple indicators, in most cases creeks with low Index of Biotic Integrity scores also demonstrated toxicity to algae (*P. subcapitata*), and sediment toxicity to *H. azteca*. Almost all coastal sites had low index of benthic integrity (IBI) scores, and physical habitat was much degraded in the northern and coastal sites. The majority of sites had high pesticide concentrations, and PCBs and PAHs were detected in nearly all of the sites. While demonstrating concordance between toxicity, elevated chemistry, and degraded benthic macroinvertebrate communities, the study did not allow separation of the relative contribution of degraded habitat, chemical and non-chemical stressors on benthic indicators.

An evaluation of biocriteria of streams in the San Diego region by Viswanathan et al. (Viswanathan et al., 2010) found similar patterns of low IBI scores. Biological condition generally decreases as sampling sites are located further downstream, and closer to the coast in more urbanized areas. Low IBI scores in the southern California region indicated that 77% of the stations were impaired, and 45% were very impaired. Very impaired condition was most prevalent in the Carlsbad watershed and sites farther south. Temporal studies indicated that IBI scores in southern California tended to be stable over time, but were generally better in the fall, possibly due to the fact that the San Diego Basin experiences the most rainfall during the winter season. Additionally, the data indicated that the biotic health of the sites investigated had not improved significantly during the study's time frame. The authors suggested that the absence of intolerant organisms from impaired streams indicates that some degree of pollution could be affecting stream health in these sites. Storm water and other nonpoint sources were identified as possible stressors affecting the sites.

As discussed above, Brown et al. (2010) conducted toxicity testing, chemistry, bioassessments and TIEs in 21 urban wetlands in southern California including three wetlands in the San Diego Region. Macroinvertebrates in 18 of 21 wetlands were found to be at risk due to sediment contaminant concentrations, which were high enough to cause toxicity to *H. azteca*. TIEs indicated that much of the *H. azteca* toxicity was caused by pyrethroid insecticides. There was a significant correlation between macroinvertebrate diversity and the "Probable Effects Concentration Quotient", a value that depicts mixtures of contaminants relative to their respective guideline values.

MARINE HABITATS

Examples of triad studies conducted in marine waters in the San Diego Region include those conducted at hotspots first identified through surveys conducted by Fairey et al. (1998) for the Bay Protection and Toxic Cleanup Program. These include studies by Anderson et al. (2004 and 2005) at the Switzer Creek, the B Street Pier, and the Downtown Anchorage areas of San Diego Bay. These studies showed that stations at Switzer Creek and the Downtown anchorage which demonstrated the greatest sediment contamination and toxicity also had the most degraded benthic communities, reference stations had the least contaminated sediments, low toxicity, and benthic communities representative of benthic conditions. Similar results were reported by Brown et al. (2011) in bay waters adjacent to the Chollas and Paleta Creek mouths as they entered the bay. This study showed linkages between sediment contamination, toxicity, and benthic impacts. Stations with the greatest contamination demonstrated the most consistent toxicity over time, and these stations had the greatest benthic community impacts, as measured by the Benthic Response Index (BRI). There was also consistency between the three lines of evidence at the reference stations. More variability between the three lines of evidence was observed at stations with moderate contamination.

Monitoring of sediments in the San Diego Region as part of Bight 2003 surveys found greater contamination in bays, harbors and estuaries relative to off-shore stations. Greater sediment toxicity was observed in samples from inland continental shelf habitats, and these stations had greater enrichment by anthropogenic contaminants. These stations also demonstrated greater disturbance of benthic macroinvertebrate communities, resulting in lower biodiversity (SCCWRP, 2007). A number of more recent monitoring studies conducted in San Diego Bay focused on ecological impairment by assessing macroinvertebrate communities and chemical contamination. Neira et al. (Neira et al., 2011) found relationships between copper enrichment and lower diversity due to lower abundances and diversity of amphipods, some polychaetes and some mollusks, in the Shelter Island area of San Diego Bay. Results of the Regional Harbor Monitoring Program by Weston Solutions (WestonSolutions, 2007) found that the primary benthic infaunal indicator, the Benthic

Response Index (BRI), was lower in both marina and freshwater-influenced strata. These habitats may be in poorer condition than had been historically observed throughout the harbors. This was corroborated by data for the secondary indicators (number of taxa and Shannon-Wiener diversity index).

SECTION 8
MONITORING RECOMMENDATIONS

An examination of toxicity monitoring sets with data recorded in the SWAMP/CEDEN databases shows that toxicity within the San Diego Region has been due to pesticides and metals. Based on these results, we offer the following recommendations:

- Increasing evidence of pyrethroid toxicity in freshwater suggests the need for more water column testing with the amphipod *Hyalella azteca*. This should be encouraged for SMC stormwater and other ambient NPDES monitoring in the San Diego Region, as well as water column toxicity monitoring in the marine environment adjacent to stormwater discharges, including stormwater outfalls, rivers and/or streams which enter the ocean, and coastal wetlands.

- Consider the importance of emerging contaminants of concern in future water and sediment monitoring (e.g., algal toxins, additional pesticides such as fipronil).

- Data from SWAMP regional and SPoT testing programs can be applied to detecting changes in toxicity patterns over larger spatial and temporal scales, as there is a need for consistency in monitoring to capture emerging trends.

- Continue coordination of SWAMP with other monitoring programs (e.g., SMC stormwater and other NPDES monitoring, Regional Monitoring Program, etc.). Linkages between SPoT measurements and bioassessments conducted as part of the SMC would help strengthen the in situ ecological context of toxicity and chemical monitoring data.

REFERENCES R

Anderson, B.S., Hunt, J.W., Markewicz, D., Larsen, K., 2011. Toxicity in California Waters, Surface Water Ambient Monitoring Program. California Water Resources Control Board. Sacramento, CA.

Anderson, B.S., Nicely, P.A., Phillips, B.M., Hunt, J.W., 2004. Sediment quality assessment study at the B Street/Broadway Piers, Downtown Anchorage, and Switzer Creek, San Diego Bay, California. Technical report, Regional Water Quality Control Board, San Diego, CA. 142 pp w/Appendices.

Anderson, B.S., Phillips, B.M., Hunt, J.W., 2005. Sediment quality assessment study at the B Street/Broadway Piers, Downtown Anchorage, and Switzer Creek, San Diego Bay, California. Phase II Final Report, Temporal variability, causes of impacts, and likely sources of contaminants of concern. Technical report, Regional Water Quality Control Board, San Diego, CA. p. 142.

Anderson, B.S., Phillips, B.M., Hunt, J.W., Clark, S.L., Voorhees, J.P., Tjeerdema, R.S., Casteline, J., Stewart, M., Crane, D., Mekebri, A., 2010. Evaluation of methods to determine causes of sediment toxicity in San Diego Bay, California, USA. Ecotoxicol Environ Safety 73, 534-540.

Bay, S.M., Mikel, T.M., Schiff, K., Mathison, S., Hester, B., Young, D., Greenstein, D., 2005. Southern California Bight 2003 Regional Monitoring Program: I. Sediment Toxicity. Technical Report 451. Southern California Coastal Water Research Project. Westminster, CA.

Brown, J., Bay, S.M., 2011. Temporal assessment of chemistry, toxicity and benthic communities in sediments at the mouths of Chollas Creek and Paleta Creek, San Diego Bay. Southern California Coastal Water Research Project, Technical Report 668.

Brown, J.S., Sutula, M., Stransky, C., Rudolph, J., Byron, E., 2010. Sediment contaminant chemistry and toxicity of freshwater urban wetland in southern California. Journal of the American Water Resources Association 46, 367-384.

de Vlaming, V., Connor, V., DiGiorgio, C., Bailey, H.C., Deanovic, L.A., Hinton, D.E., 2000. Application of whole effluent toxicity test procedures to ambient water quality assessment. Environ Toxicol Chem 19, 42-62.

Fairey, R., Roberts, C., Jacobi, M., Lamerdin, S., Clark, R., Downing, J., Long, E., Hunt, J., Anderson, B.S., Newman, J., Stephenson, M., Wilson, C.J., 1998. Assessment of sediment toxicity and chemical concentrations in the San Diego Bay region, California. Environ Toxicol Chem 17, 1570-1581.

Greenstein, D., Bay, S.M., Young, D., 2011. Sediment toxicity identification evaluation for the mouths of Chollas and Paleta Creek, San Diego. Southern California Coastal Water Research Project, Technical Report 669.

Holmes, R.W., Anderson, B.S., Phillips, B.M., Hunt, J.W., Crane, D., Mekebri, A., Blondina, G., Nguyen, L., Connor, V., 2008. Statewide Investigation of the Role of Pyrethroid Pesticides in Sediment Toxicity in California's Urban Waterways. Environ Sci Technol 42, 7003-7009.

Holmes, R.W., De Vlaming, V., Markewicz, D., Goding, K., 2005. Benthic macroinvertebrate colonization of artificial substrates in agriculture-dominated waterways of the lower Sacramento River watershed. Central Valley Regional Water Quality Control Board, Rancho Cordova, CA.

Katz, C.N., Rosen, G., Arias, E., 2006. Storm water toxicity evaluation at Naval Station San Diego, Naval Submarine Base San Diego, Naval Amphibious Base Coronado, and Naval Air Station North Island. SPAWAR Systems Center San Diego Technical Report 1938, May 2006, 151 pp.

Mazor, R.D., Schiff, K., 2008. Surface Water Ambient Monitoring Program (SWAMP) Report on the San Juan Hydrologic Unit. SCCWRP, prepared for SDRWQCB (Region 9), Technical report 507.

Neira, C., Mendoza, G., Levin, L.A., Zirino, A., Delgadillo-Hinojosa, F., Porrachia, M., Deheyn, D.D., 2011. Macrobenthic community response to copper in Shelter Island Yacht Basin, San Diego Bay, California. Mar Poll Bull 62, 701-717.

Phillips, B.M., Anderson, B.S., Lowe, S., 2011. RMP Sediment Study 2009-2010, Determining Causes of Sediment Toxicity in the San Francisco Estuary.

Regional Monitoring Program for Water Quality in the San Francisco Estuary. Contribution No. 626. San Francisco Estuary Institute. Oakland, CA.

Phillips, B.M., Anderson, B.S., Voorhees, J.P., Hunt, J.W., Holmes, R.W., Mekebri, A., Connor, V., Tjeerdema, R.S., 2010. The contribution of pyrethroid pesticides to sediment toxicity in four urban creeks in California, USA. Journal of Pesticide Science 35, 302-309.

SCCWRP, 2007. Southern California Bight 2003 Regional Monitoring Program: Executive Summary. Southern California Coastal Water Research Project. Technical report. 26 pp.

Schiff, K., Bay, S.M., Diehl, D.W., 2003. Stormwater toxicity in Chollas Creek and San Diego Bay, California. . Environmental Monitoring and Assessment 81:119-132. 81, 119-132.

SWAMP, 2008. Surface Water Ambient Monitoring Program - Quality Assurance Program Plan Version 1. California Water Boards, Sacramento, CA.

Viswanathan, S., Voss, K.A., Pohlman, A., Gibson, D., Purohit, J., 2010. Evaluation of the biocriteria of streams in the San Diego Hydrologic Region. Journal of Environmental Engineering 136, 627-637.

Ware, G.W., Whitacre, D., 2004. The Pesticide Book, 6th Edition. Thompson Publications, Fresno, CA.

Weston, D.P., You, J., Lydy, M.J., 2004. Distribution and toxicity of sediment-associated pesticides in agriculture-dominated water bodies of California's Central Valley. Environmental Science & Technology 38, 2752-2759.

WestonSolutions, 2006. Toxicity Identification Evaluation (TIE) of County of San Diego and Copermittees Chollas Creek Stormwater Sample. Technical Report prepared for County of San Diego.

WestonSolutions, 2007. San Diego County Municpal Copermittees 2005-2006 Urban Runoff Monitoring - Volume 1 - Final Report. http://www.projectcleanwater.org/html/wg_monitoring_05-06report.html. San Diego, CA.

WestonSolutions, 2010. Chollas Creek Total Maximum Daily Load Compliance Monitoring – 2009–2010 Water Quality Monitoring Final Report. Prepared for: City of San Diego, City of La Mesa, City of Lemon Grove, County of San Diego, San Diego Unified Port District, United States Navy, CalTrans.

SWAMP
Surface Water
Ambient Monitoring
Program

For more information, please contact:

Marie Stillway
Aquatic Health Program
University of California, Davis
Department of Anatomy, Physiology and Cell Biology
One Shields Ave
Davis, California

CALIFORNIA
Water Boards

www.waterboards.ca.gov/swamp