SWAMP Surface Water Ambient Monitoring Program

TOXICITY IN CALIFORNIA WATERS: CENTRAL COAST REGION

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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.

Freshwater toxicity and freshwater sediment toxicity were common in the Central Coast Region between 2001 and 2010. Sixty-nine percent (69%) of sampling sites showed *some* toxicity, with 51% of sites showing *moderate* to *high* freshwater toxicity. Fifty-two percent (52%) of sites showed *some* freshwater sediment toxicity, with 33% of sites showing *moderate* to *high* freshwater sediment toxicity. Sediments from harbor/bay sites were less toxic, with only 17% of sites showing *some* degree of toxicity.

A lower percentage of sites showed freshwater toxicity to fish than to either invertebrates or algae. Thirty one (31%) of sites showed *some* level of toxicity to fish, while 41% of sites showed toxicity to invertebrates and 48% of sites showed toxicity to algae. Toxicity to invertebrates was most intense. Out of the 65 sites that showed any degree of toxicity to invertebrates, 63 sites (40% of sites overall) showed toxicity of *moderate* to *high* intensity. Although algal toxicity was widespread, it tended to be less intense, with *moderate* to *high* algal toxicity at 32 out of 50 toxic sites (28% of sites overall). Toxicity to fish was far less intense, with *moderate* to *high* toxicity at only 10 out of 40 toxic sites, or 8% of sites overall.

Significant statistical relationships were found between urban and agricultural land uses and aquatic toxicity in the Central Coast Region, similar to the associations observed between land use and toxicity statewide. Land use/toxicity associations in the Central Coast Region were modeled using logistic regression to characterize the probability of observing *moderate* to *high* water or sediment toxicity at sites with various percentages of upstream agricultural and urban land uses. Probability contours produced by these models show that sediment toxicity at sites in the Central Coast was strongly associated with agricultural land use, and was also associated with urban land use (Agricultural Land

Effect: $P < 0.0001$, Urban Land Effect: $P = 0.0177$). Water column toxicity was strongly related to the percentage of agricultural land use in upstream buffer areas, but was not significantly related to percentage of urban land use (Agricultural Land Effect: $P = 0.0019$, Urban Land Effect: $P = 0.6907$).

Both water column and sediment toxicity were most intense in areas dominated by urban development and agriculture. Correlation analyses and Toxicity Identification Evaluations (TIEs) were used to determine causes of water and sediment toxicity statewide. The results of these analyses showed that the majority of toxicity was caused by pesticides.

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 in 2011 (Anderson et al., 2011a; 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. 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 Central Coast Region (Region 3). Source programs, test count and sample date ranges are outlined in Table 1.

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

Toxicity Test Type	Program	Test Count	Sample Date Range
Water Column	Salinas River Project	206	7/8/02 – 9/22/04
	Cooperative Monitoring Program	1357	3/22/02 – 3/31/10
	SWAMP – Central Coast Ambient Monitoring Program	449	12/3/01 – 9/22/09
	Other SWAMP	12	3/26/09 – 9/22/09
Sediment	Salinas River Project	62	5/15/02 – 9/22/04
	Cooperative Monitoring Program	195	5/14/06 – 4/22/09
	SWAMP – Central Coast Ambient Monitoring Program	67	3/29/04 – 5/3/06
	Statewide Urban Pyrethroid Monitoring	10	1/6/07 – 2/5/07
	Stream Pollution Trends (SPoT)	11	5/22/08 – 7/21/08

The Central Coast Region comprises 12,000 square miles and a number of major rivers, including the Salinas, San Benito, Pajaro and Santa Maria Rivers. The watersheds include areas of some of the most intensive agriculture production in the world, as well as several moderately large urban areas including the cities of Santa Barbara, Santa Maria, San Luis Obispo, Salinas, the Monterey Peninsula, Santa Cruz, Watsonville, and Hollister. The region is also characterized by large tracts of open space, rangeland, and forests. Watersheds in this region are therefore influenced by a mix of land uses, and the major rivers are impacted by both urban and agriculture runoff.

SECTION 2
SCOPE OF THE DATA USED IN THIS STUDY

This review 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 Management Plan (QAPrP) (SWAMP, 2008). The attached maps (Figures 4-20) show locations of sites sampled for toxicity by SWAMP and partner programs and the intensity of toxicity observed in the 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 (Table 2).

Table 2
Species-specific maximum levels of toxicity observed at sites tested with *H. azteca* sediment toxicity tests, and *P. promelas*, *C. variegatus*, *A. affinis*, *C. dubia*, *H. azteca*, *P. subcapitata* and *T. pseudonana* water column toxicity tests.

Species	Test Type	Number of Sites	Maximum Toxicity Level Observed			
			Non-Toxic	Some Toxicity	Moderately Toxic	Highly Toxic
H. azteca	Sediment	148	82	25	11	30
P. promelas	Water Column	127	89	28	9	1
C. variegatus		13	11	1	0	1
A. affinis		7	5	2	0	0
C. dubia		154	89	2	34	29
H. azteca		16	11	0	0	5
P. subcapitata		108	61	23	12	12
T. pseudonana		9	1	0	5	3

A range of species of fish, invertebrates and algae were used to test the toxicity of freshwater samples to examine toxic responses to contaminants across a range of trophic levels, and to match water samples of differing salinity with appropriate test species. The fathead minnow (*Pimephales promelas*) was the main fish species tested, while the sheepshead minnow (*Cyprinodon variegatus*) and topsmelt (*A. affinis*) were used as high salinity test species. The cladoceran *Ceriodaphnia dubia* was used as the main invertebrate test species, and high salinity samples were tested with the amphipod *Hyalella azteca*, a species more tolerant of high conductivity. The alga *P. subcapitata* was used to test low salinity samples, and the alga *Thalassiosira pseudonana* was used for higher salinity testing.

Freshwater toxicity is summarized by individual species in Figure 2. Only survival endpoints and algal growth are considered in the measures of toxicity reported here; therefore all sites identified as toxic showed a significant decrease in test animal survival or algal growth in one or more samples. Some *Pseudokirchneriella subcapitata* (formerly *Selenastrum capricornutum*) algal growth inhibition tests 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 unless an appropriate high conductivity control was performed, in which case the sample was compared to the appropriate control and included in the study.

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; US 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 Percent Minimum Significant Difference (PMSD), representing the lower end of test sensitivity across the distribution of PMSDs 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 3) 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*, *moderate* 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.

Effluent and stormwater toxicity data were collected in the Central Coast Region during 2001 - 2010, but were not included in the SWAMP and CEDEN databases, and were not examined in this study due to the difficulty of obtaining electronic replicate-level data in a timely fashion. Among the data that we have reviewed, *some*

Table 3
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 species-specific 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

effluent toxicity was found in the Central Coast Region: Seventeen WWTP NPDES permit violations due to toxicity were reported from 2005 - 2010. Most of the Central Coast monitors stormwater under a general permit that did not include requirements for toxicity testing during 2001 - 2010. However, the city of Salinas conducts stormwater toxicity monitoring, and records from 2008 - 2009 show that stormwater toxicity was common during that period. In addition, dry season flow and storm water toxicity was monitored at several stations in the Santa Cruz and Monterey areas as part of the Monterey Bay National Marine Sanctuary's First Flush Program. This testing was done in cooperation with the SWRCB's Marine Bioassay Project and showed dry season and storm water toxicity to marine mussel embryos and fish larvae (topsmelt *Atherinops affinis*) at a number of stations (Phillips et al. 2004).

SECTION 3
REGIONAL TOXICITY

Freshwater toxicity and freshwater sediment toxicity were common in the Central Coast Region during the 2001 - 2010 decade (Figure 1). Sixty-nine percent (69%) of sampling sites showed *some* toxicity, with 51% of sites showing *moderate* to *high* freshwater toxicity. Fifty-two percent (52%) of sites showed *some* freshwater sediment toxicity, with 33% of sites showing *moderate* to *high* freshwater sediment toxicity. Sediments from harbor/bay sites were less toxic, with only 17% of sites showing *some* degree of toxicity. The proportions of *moderate* to *high* water and sediment toxicity in the Central Coast Region were higher than those observed in a statewide summary of surface water toxicity over the same review period (Anderson et al., 2011).

TOXICITY BY SPECIES

A lower percentage of sites showed freshwater toxicity to fish than to either invertebrates or algae. Thirty-one percent (31%) of sites showed *some* level of toxicity to fish, while 41% of sites showed toxicity to invertebrates and 48% of sites showed toxicity to algae. Toxicity to invertebrates was most intense. Out of the 65 sites that showed any degree of toxicity to invertebrates, 63 sites (40% of sites overall) showed toxicity of *moderate* to *high* intensity. Although algal toxicity was widespread, it tended to be less intense, with *moderate* to *high* algal toxicity at 32 out of 50 toxic sites (28% of sites overall). Toxicity to fish was far less intense, with *moderate* to *high* toxicity at only 10 out of 40 toxic sites, or 8% of sites overall.

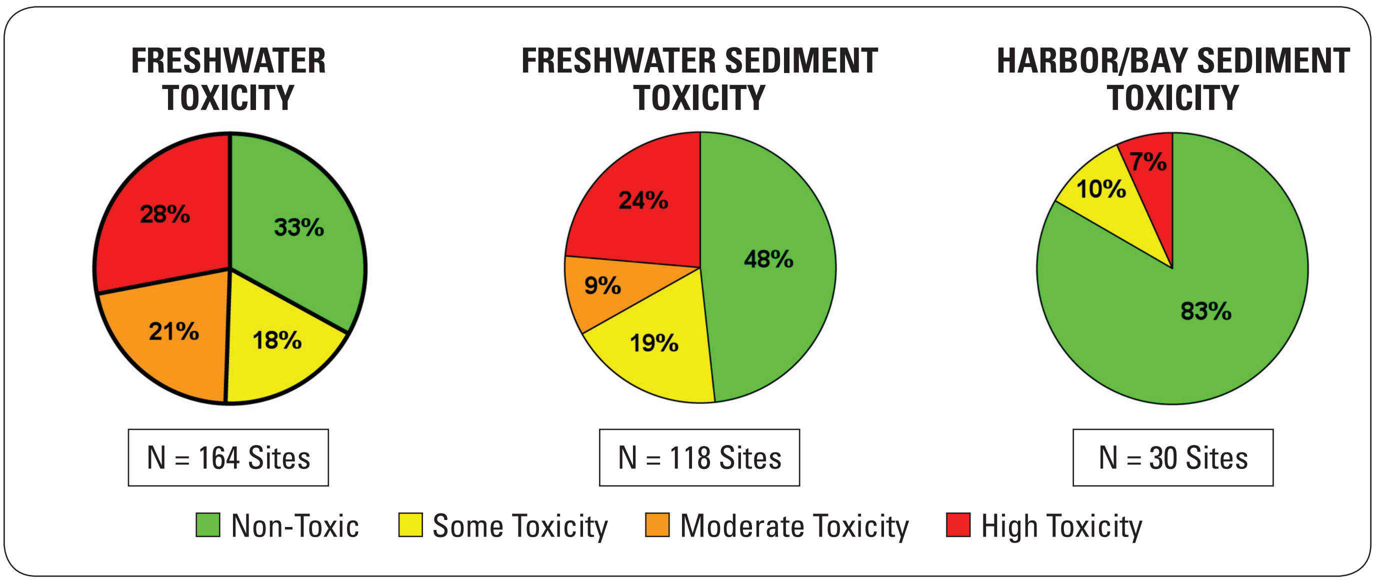

Figure 1. Magnitude of toxicity in water and sediment samples in the Central Coast Region of California.

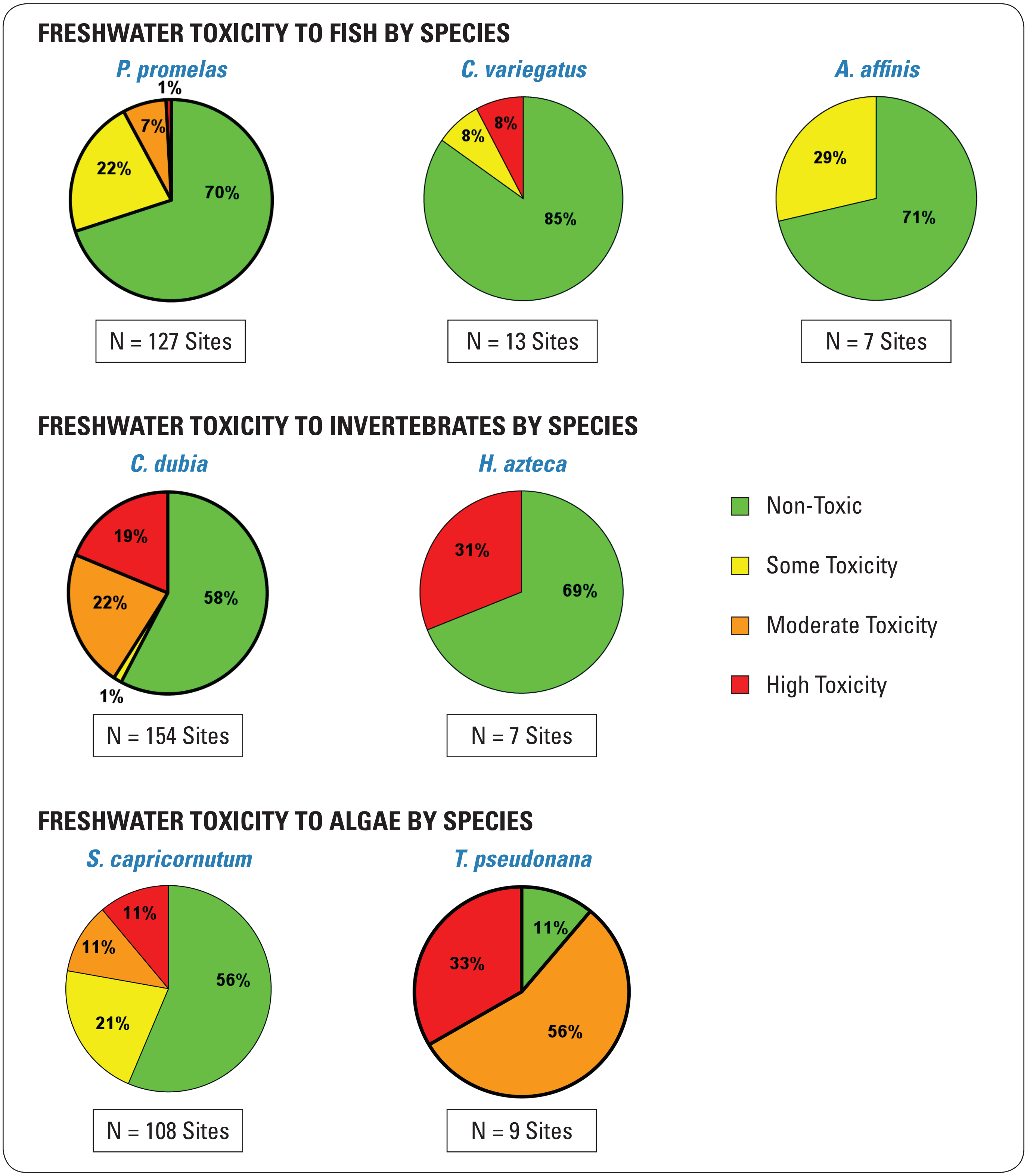

Figure 2. Magnitude of toxicity to individual freshwater species in water samples from the Central Coast of California.

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.

Significant statistical relationships were found between urban and agricultural land uses and aquatic toxicity in the Central Coast Region, similar to the associations observed between land use and toxicity statewide (Anderson et al., 2011a). Land use/toxicity associations in the Central Coast Region were modeled using logistic regression to characterize the probability of observing *moderate* to *high* water or sediment toxicity at sites with various percentages of upstream agricultural and urban land uses (Figure 3). Probability contours produced by these models show that sediment toxicity at sites in the Central Coast was strongly associated with agricultural land use, and was also associated with urban land use (Agricultural Land Effect: $P < 0.0001$, Urban Land Effect: $P = 0.0177$). Water column toxicity was strongly related to the percentage of agricultural land use in upstream buffer areas, but was not significantly related to percentage of urban land use (Agricultural Land Effect: $P = 0.0019$, Urban Land Effect: $P = 0.6907$). Examination of Figure 3 allows the estimation of the probability of finding *moderate* to *high* sediment or water toxicity at a given site depending on the land use immediately upstream of that site. The SWAMP/CEDEN data set used to construct this model did not include sampling of urban stormwater.

The probability contours of the water toxicity model indicate that sites with little upstream agricultural or urban land use were characterized by a substantial amount of water toxicity (approximately 30% predicted probability of *moderate* to *severe* toxicity at sites with no agricultural or urban land uses in a 1 km upstream buffer, Figure 3). It is likely that this finding originates from a combination of two patterns in the data. Some sites showing *moderate* to *high* water toxicity were located more than 1 km downstream of major agricultural and urban areas, but had a *high* potential for toxicity caused by runoff from further upstream, while a number of sites in undeveloped areas of the southern Central Coast showed *moderate* to *high* toxicity to the alga *P. subcapitata* for reasons that remain unknown. A model of water toxicity constructed without algal toxicity data predicted a dramatically lower probability of *moderate* to *high* toxicity (approximately 10%) at sites without urban and agricultural development.

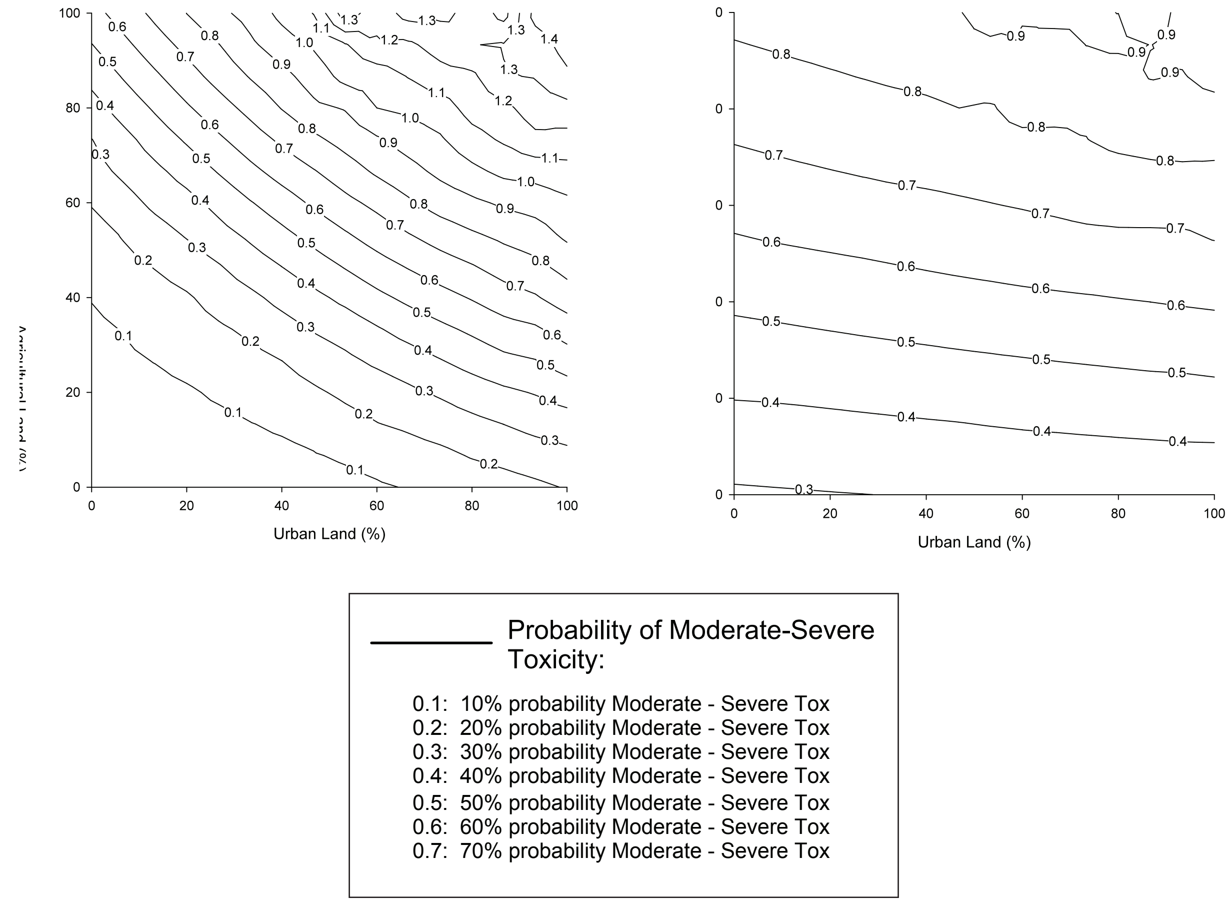

Figure 3. Contours indicating relationships between upstream agricultural and urban land uses and proportions of Central Coast sites predicted to show *moderate - severe* water and sediment toxicity based on logistic regression of toxicity data in California's CEDEN and SWAMP databases.

SECTION 5
GEOGRAPHICAL PATTERNS IN TOXICITY

From a first estimation, these differences in toxicity do not appear to spring from differences in land use characteristics between the sites tested with each class of organism. Among the sets of sites that were sampled for testing with the three classes of organisms, the average percentages of urban land in 1 kilometer upstream buffers ranged from 38.4% (invertebrates) to 40.3% (fish), and average percentages of agricultural land ranged from 30.4% (fish) to 36.1% (invertebrates).

Subregional maps showing land use and toxicity are consistent with the findings of the logistic regression model (Figures 4 - 20). Both water column and sediment toxicity were most intense in areas dominated by urban development and agriculture. Particularly *high* toxicity was found in the Salinas Valley, the Santa Maria area, and along the South coast. Sampling in the agricultural regions of the Salinas and Santa Maria River valleys, in particular, showed wide areas of pervasive water column and sediment toxicity. The South coast showed widespread water column toxicity in both developed and undeveloped areas, but less pervasive sediment toxicity.

The Pajaro River watershed, although heavily agricultural with a number of urban centers, showed less widespread toxicity (Figures 6 and 7). *Moderate* to *high* water column toxicity was found mainly in the center of the agricultural area located between Gilroy and Hollister, at a site between the Hollister urban area and the surrounding agricultural land, and around the Watsonville urban-agricultural area. Note that a recent report on toxicity in the Pajaro River Estuary showed that approximately 50% of the water and sediment samples were toxic to invertebrates (*C. dubia* and *H. azteca* - water, *H. azteca* - sediment). Although the chemistry data were not definitive, toxicity, chemistry and TIE evidence suggested that toxicity was caused by a combination of pyrethroid and organophosphate pesticides (Anderson et al., 2010a).

In the Salinas Valley, both water column and sediment toxicity were most intense around the city of Salinas and in agricultural areas immediately upstream of that city (Figures 8 - 11). The Salinas Valley has been intensively sampled between the coast and the city of Gonzales, and throughout this area, water column and sediment toxicity were *moderate* to *severe*. Although the agricultural area of the Salinas Valley continues for more than 40 miles upstream of the city of Gonzales, few sites have been sampled for toxicity in this upstream agricultural region. Agriculture south of King City is dominated by viticulture and pesticide usage in this region differs from the intensive row crop agriculture in the northern Salinas Valley. In addition, anecdotal information from growers suggest that soil characteristics differ between the southern and northern Salinas Valley and the combination of soil type and irrigation practices often results in lower runoff volumes in the southern Salinas Valley.

The watersheds of the Morro Bay - San Luis Obispo - Arroyo Grande area also showed less intense toxicity (Figures 13 and 14), with *moderate* toxicity found only in water column samples from Arroyo Grande (310AGV and 310USG). Sites in the urban areas of San Luis Obispo and Pismo Beach showed *some* water column toxicity (310SCN and 310PIS), while the urban areas around Morro Bay and Grover Beach were not sampled.

Moderate to *high* water column and sediment toxicity was pervasive in the area of urban development and agriculture around Santa Maria (Figures 15 - 18). Sites in areas with less upstream urban land and agriculture were less toxic or non-toxic. The Cuyama Valley agricultural area in the eastern part of the watershed was not sampled for toxicity testing. A recent study of the sources of toxicity in Oso Flaco Creek and Santa Maria River watersheds showed greater toxicity associated with agriculturally dominated waters in this area (Phillips et al. 2010a). Several sites around the city of Santa Maria showed water and sediment toxicity associated with mixtures of organophosphate and pyrethroid pesticides. It was not possible to determine the degree to which urban and agriculture sources of pesticides influenced these sites because the majority received agriculture runoff from east of the city, and urban runoff from adjacent residential and light commercial development. However, the pesticide signature at all but one of these sites suggested agriculture runoff contributed to toxicity (Phillips et al., 2010a).

The South coast showed a pattern of *moderate* to *high* water column toxicity, largely due to toxicity to the alga *P. subcapitata* (Figures 15, 16, 19, 20). This toxicity was found both in the urban areas around Santa Barbara and Carpinteria, and in the less developed watersheds of the western portion of the South coast. Although some of these findings of toxicity were the result of the analysis of water samples with conductivities exceeding the limit for optimal growth of *P. subcapitata* (1500 uS/cm), in all of these cases, toxicity was evaluated by comparing performance in the sample to performance in a control of similar conductivity. Algae TIEs were not within the scope of the monitoring that included these toxic samples and the causes of the toxicity remain unknown. Toxicity to invertebrates and fish along the South coast was limited. *Moderate* to *high C. dubia* toxicity was observed only at sites within and near the Eastern city of Carpinteria, and *moderate P. promelas* toxicity was observed only at site 315RSB near the mouth of the small Cañada del Refugio watershed, west of Santa Barbara.

Santa Cruz and Monterey were areas of low toxicity (Figures 4, 5, 12); with the exception of one site in a highly urbanized area along Highway 1 near Monterey, where *high* sediment toxicity was found (309SUP106). The Monterey-Seaside-Marina urban area is not well sampled, and would make a good target for future monitoring.

Sediments of harbors and bays throughout the central coast showed *some* to *no* toxicity.

SECTION 6
CAUSES OF TOXICITY

Correlation analyses and Toxicity Identification Evaluations (TIEs) were used to determine causes of water and sediment toxicity statewide (Anderson et al., 2011a). The results of these analyses showed that the majority of toxicity was caused by pesticides.

FRESHWATER

TIE studies in the Central Coast region also have demonstrated that water toxicity to *C. dubia* is caused primarily by the organophosphate pesticides chlorpyrifos and diazinon. These include studies in the Salinas River and its tributaries (Anderson et al., 2003a; Anderson et al., 2003b; Hunt et al., 2003; Phillips et al., 2004), studies in the Pajaro River watershed (Hunt et al., 1999), and studies in the Santa Maria River and its tributaries (Anderson et al., 2006a; Anderson et al., 2010a; Phillips et al., 2010a).

Use of diazinon has recently been restricted on lettuce crops by the U.S. EPA via a re-registration eligibility restriction which reduces the number and pounds of application. Chlorpyrifos continues to be used, particularly as a treatment for root maggots in broccoli. Both of these pesticides have been phased out for residential use since the early 2000s. The reduction in use of diazinon and chlorpyrifos has coincided with an increase in use of pyrethroid pesticides, and in some cases, an increase in alternative organophosphates such as malathion. Numerous recent studies have demonstrated that pyrethroid pesticide concentrations in water exceed the toxicity threshold for the amphipod *H. azteca*. Because this species is more sensitive to pyrethroids than *C. dubia*, its use in water monitoring is increasing. Recent studies in the Santa Maria River and Salinas Valley watersheds have shown that mixtures of pyrethroid pesticides in water exceed toxicity thresholds for *H. azteca* (Anderson et al., 2010a; Phillips et al. 2010a;).

FRESHWATER SEDIMENT

Sediment TIEs using *H. azteca* have been conducted in most regions of California where toxicity has been observed. As discussed above, the majority of these studies have demonstrated that sediment toxicity is due to pyrethroid pesticides. Other studies have shown sediment toxicity is due to the OP pesticide chlorpyrifos, or to mixtures of chlorpyrifos and pyrethroids. The majority of these studies have been conducted in the Central Valley and on the Central Coast. Sediment TIEs conducted in the Santa Maria River and its estuary demonstrated that toxicity to *H. azteca* was due to mixtures of chlorpyrifos and the pyrethroids cypermethrin and cyhalothrin (Anderson et al., 2006a; Anderson et al., 2010a; Phillips et al., 2010a). TIEs conducted in the Salinas River watershed have also reported sediment toxicity is due to the pyrethroids cyhalothrin and cypermethrin, and in some cases, the OP pesticide chlorpyrifos (Anderson et al., 2008; Hunt et al., 2008). These results have been corroborated by recent monitoring conducted as part of the central coast Cooperative Monitoring Program (http://www.ccamp.org/ccamp/Reports.html#AgReports).

COASTAL STORMWATER TOXICITY

As discussed above, TIE studies of stormwater toxicity were conducted on first-flush samples from two outfalls in the Cannery Row area of Monterey, and one outfall in Santa Cruz. TIE evidence indicated toxicity of these samples to mussel (*M. galloprovincialis*) embryo development and topsmelt (*A. affinis*) survival was due to mixtures of cationic metals. Chemistry of these waters confirmed that copper and zinc exceeded toxicity thresholds for these species (Phillips et al., 2004).

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 studies indicate linkages between laboratory toxicity and ecosystem impacts.

One of the most comprehensive series of studies linking water and sediment toxicity with impacts on resident macroinvertebrates in California was conducted in the Salinas River. In these studies, water and sediment toxicity was caused by diazinon and chlorpyrifos from agriculture runoff (Anderson et al., 2003a; Anderson et al., 2003b; Phillips et al., 2004). Bioassessments showed macroinvertebrate densities declined downstream of two agriculture drain water inputs, including densities of the resident amphipod *H. azteca* and of the mayfly genus Procloeon. A subsequent study demonstrated that Procloeon were sensitive to chlorpyrifos and bifenthrin at concentrations found in the river, and that this species was not influenced by suspended particles (Anderson et al., 2006b). The influence of habitat quality on macroinvertebrates was also assessed and it was concluded that habitat was a less important factor than pesticides (Anderson et al., 2003b).

A similar series of studies were conducted on the lower Santa Maria River. Toxicity studies and TIEs showed toxicity in the Santa Maria River was caused by mixtures of chlorpyrifos, diazinon, and pyrethroids (Anderson et al., 2006a; Phillips et al., 2006), and stations with the greatest contamination and toxicity also had the lowest macroinvertebrate densities. Because the amphipod *H. azteca* occurs naturally in freshwater systems throughout the central coast of California and is a standard toxicity test species, disappearance of these amphipods at the most toxic stations provides a key connection between laboratory toxicity and field impacts. Subsequent studies in the Santa Maria River Estuary have demonstrated that water and sediment toxicity due to OP and pyrethroid pesticides extend into this estuary (Anderson et al., 2010a; Phillips et al., 2010a). Stations with the greatest contamination in this estuary also have the lowest macroinvertebrate densities, have lower numbers of amphipods, and higher numbers of pollution-tolerant species (Anderson et al., 2010a). Similar studies in the Salinas and Pajaro River estuaries have also demonstrated impacts on macroinvertebrate communities, though to a lesser degree than that observed in the Santa Maria estuary. Toxicity and pesticide contamination in the Salinas River estuary was limited to the Blanco Drain tributary. As discussed above, a high proportion of water and sediment samples from the Pajaro River estuary were toxic, but the cause of this toxicity was less conclusive. TIE evidence suggested pyrethroid pesticides played a role, but low detections of these chemicals were observed. This was likely due to inadequate detection limits relative to the toxicity threshold of pyrethroids to *H. azteca* (Anderson et al., 2010a).

In addition to these studies, monitoring conducted as part of the Central Coast Cooperative Monitoring Program has also demonstrated relationships between laboratory water toxicity and macroinvertebrate community impacts. These results have confirmed there is a negative relationship between the numbers of Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies; = EPT Index) and water toxicity at CMP monitoring stations (Larry Walker and Associates, 2010). Previous work on the low elevation sandy bottom rivers in the Central Coast Region has shown that the EPT Index in these watersheds is largely driven by mayflies (Anderson et al., 2003a,b).

SECTION 8
MONITORING RECOMMENDATIONS

FRESHWATER

Sampling of freshwater from agricultural areas was sufficient to show a strong association between agricultural land use and freshwater toxicity. No such association was detected between freshwater toxicity and urban land use. In order to test the effects of urban land use more rigorously, we recommend that urban stormwater programs be expanded to require toxicity testing and that the results of this testing be integrated into statewide databases.

Pyrethroid pesticide use is increasing in both urban and agricultural applications. Because the amphipod *H. azteca* is more sensitive to pyrethroids than *C. dubia*, this species should be used in water toxicity monitoring in urban settings. While organophosphate pesticides have been phased out for urban use, they are still being used in agriculture. As resources allow, additional water toxicity monitoring with *H. azteca* should be conducted in conjunction with *C. dubia* in watersheds that receive agriculture runoff.

The standard SWAMP *H. azteca* water column toxicity tests examine 10d survival and are conducted at 23°C. This temperature is higher than the average temperatures in waterways of the Central Coast, and the test likely underestimates toxicity of pyrethroid pesticides because pyrethroids are more toxic at colder temperatures due to slower metabolic breakdown by test organisms. Where pyrethroid pesticides are of specific concern, we recommend revising the standard protocol to test at 15°C to obtain the most ecologically relevant evaluation of pyrethroid toxicity. To estimate the degree to which pyrethroid toxicity is impacting central coast watersheds, samples could be tested at 15 and 23°C or tested with and without the addition of the synergist PBO (Werner et al., 2010). It should be noted that the effects of temperature on the toxicity of some pyrethroids (e.g. cypermethrin) can be inconsistent (Weston and Lydy, 2010a). Where the presence of cypermethrin is suspected, PBO addition is the preferred experimental manipulation.

The widespread algal toxicity found along in the southern part of the Central Coast needs to be studied more intensively to ascertain the causes of reduced *P. subcapitata* growth when exposed to ambient water samples from this region. In most areas of the Central Coast and throughout California, the greatest effects of toxicity are usually seen in invertebrates such as *C. dubia* and *H. azteca*, and these toxic effects tend to be concentrated in agricultural and urban areas. However, in the vicinity of Santa Barbara, *P. subcapitata* growth was severely reduced both in urban areas and at sites in small, undeveloped watersheds such as Jalama Creek (315JAL), Cañada de la Gaviota (315GAI, 315GAV), Cañada del Refugio (315RSB), and Cañada del Capitan (315CAP), as well as at a site on the Santa Ynez River (315SYP) upstream of most agricultural and urban land uses (Figure 15). Possible causes of toxicity may include contamination from herbicides or metals in highway runoff, naturally occurring contaminants seeping from petroleum-producing rock formations, or unusual ionic balance. Based on comparisons to high conductivity controls, this reduced algal growth did not result solely from the effects of high conductivity. We recommend the use of *P. subcapitata* TIEs, chemical analysis and testing with the euryhaline alga *T. pseudonana* for further examination of the causes of algal toxicity at these sites.

FRESHWATER SEDIMENT

Freshwater sediment toxicity showed significant associations with both agricultural and urban land uses, but the overwhelming majority of sites at which freshwater sediment toxicity was examined were located in agricultural areas. Freshwater sediments in many urban centers of the Central Coast were examined at only one location, or not at all, even in areas where the surrounding agricultural area was extensively sampled. We recommend more comprehensive testing of urban sediments throughout the Central Coast region as a complement to urban stormwater testing.

Sediment toxicity assessments currently emphasize the 10d growth and survival toxicity test protocol with *H. azteca*. As in the water column test, the standard sediment test is conducted at 23 °C, and where pyrethroids are of concern we recommend testing at 15 °C to obtain the most ecologically relevant evaluation of pyrethroid toxicity. Where possible, testing should be conducted at 15 and 23 °C to estimate the degree to which pyrethroid toxicity is impacting central coast watersheds. In addition, research has shown that the 10d growth and survival protocol is less sensitive to contaminants than the 28d growth and survival protocol with *H. azteca*. Future sediment toxicity testing should incorporate the 28d protocol, where practical.

ESTUARINE MONITORING

Toxic concentrations of pesticides are impacting estuaries in the central coast. Recent studies in several southern California estuaries and harbors have also shown that toxic concentrations of pyrethroids accumulate in sediments in these habitats, and that sites with toxic sediments also have degraded benthic communities (see examples cited in Anderson et al. 2011a). Because these are critical coastal habitats, additional assessments should be conducted in Region 3 estuaries to delineate the extent of contamination and impacts. Of particular importance are the Elkhorn Slough, Pajaro River, and San Lorenzo River estuaries.

MANAGEMENT PRACTICE IMPLEMENTATION AND MONITORING

Recent research in the Salinas Valley has shown that diazinon, chlorpyrifos, and pyrethroid pesticide loading in tailwater runoff can be greatly reduced with implementation of vegetated treatment systems that incorporate a particle settlement section, a vegetated treatment section, and a Landguard™ enzyme treatment section (Anderson et al., 2011b; Phillips et al., in preparation). Landguard has been shown to be particularly effective at removing organophosphate pesticides, which are more water soluble. Regulatory hurdles should be addressed so that implementation of these systems can be encouraged on a wider scale. As these systems are implemented, receiving system monitoring should be conducted to demonstrate reduction in pesticide loading and toxicity.

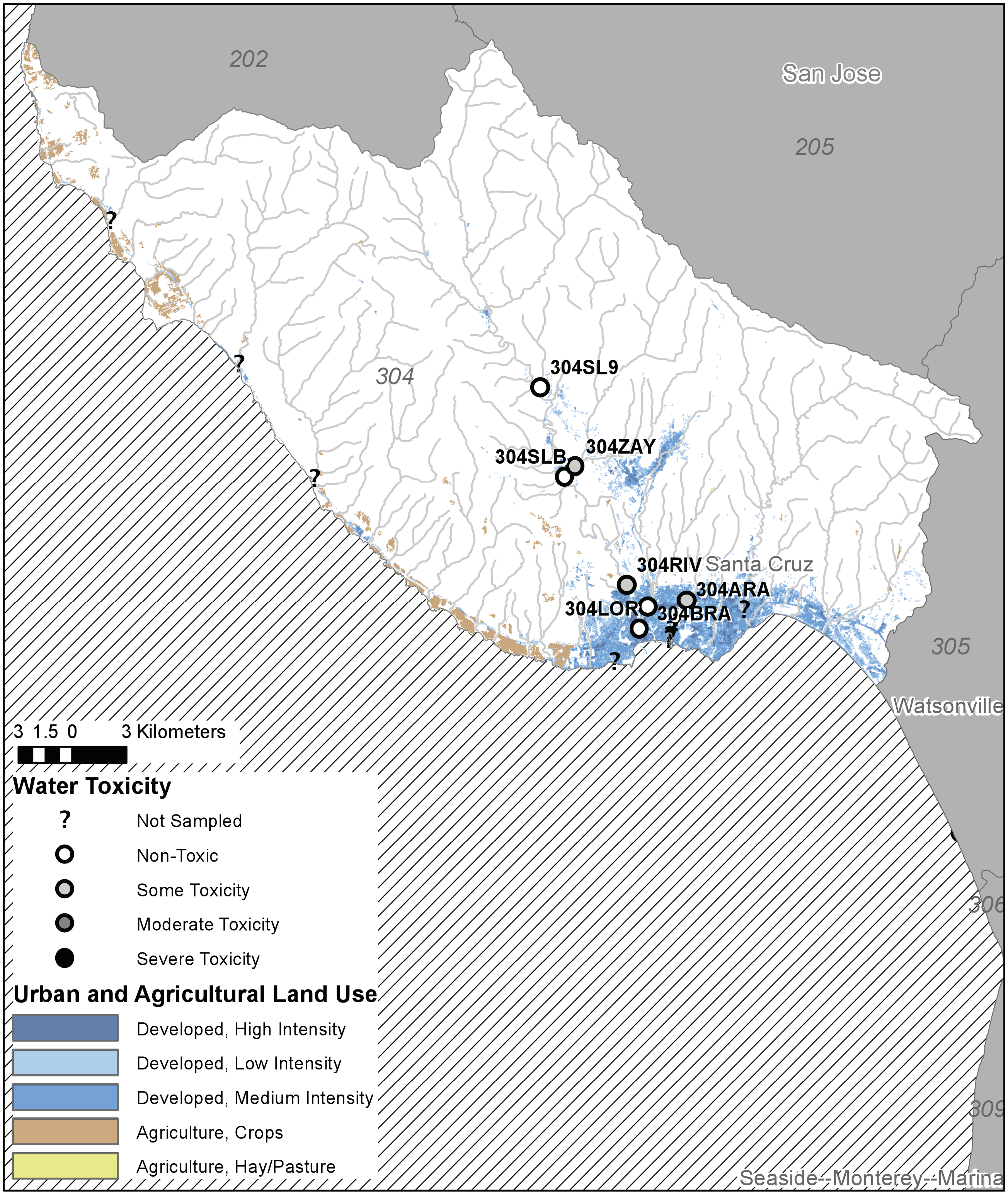

Figure 4. Magnitude of water column toxicity at sites in the Santa Cruz area of the Central Coast Region of California based on the most sensitive species (test endpoint) in water samples collected at each site.

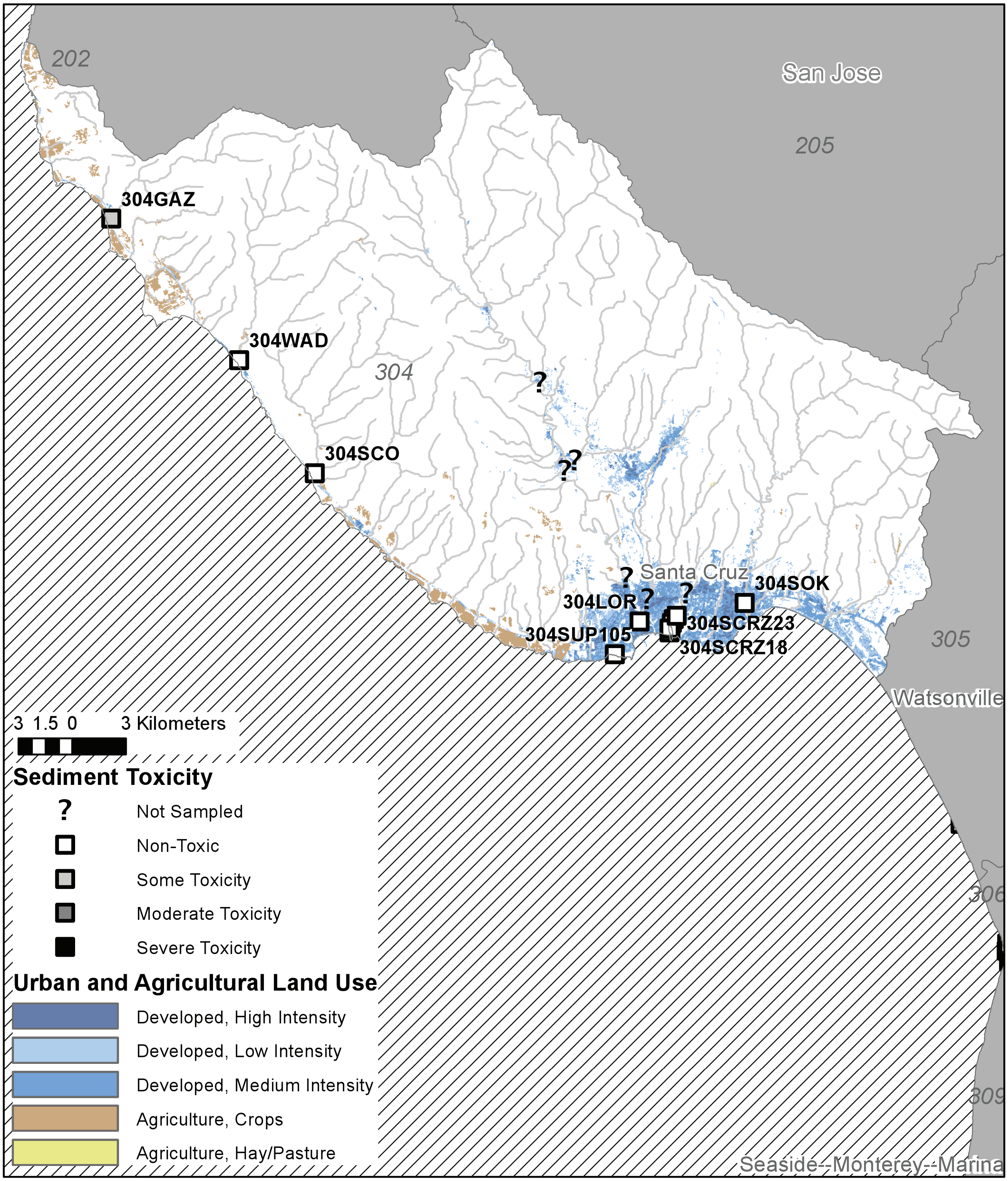

Figure 5. Magnitude of sediment toxicity at sites in the Santa Cruz area of the Central Coast Region of California based on the most sensitive species (test endpoint) in sediment samples collected at each site.

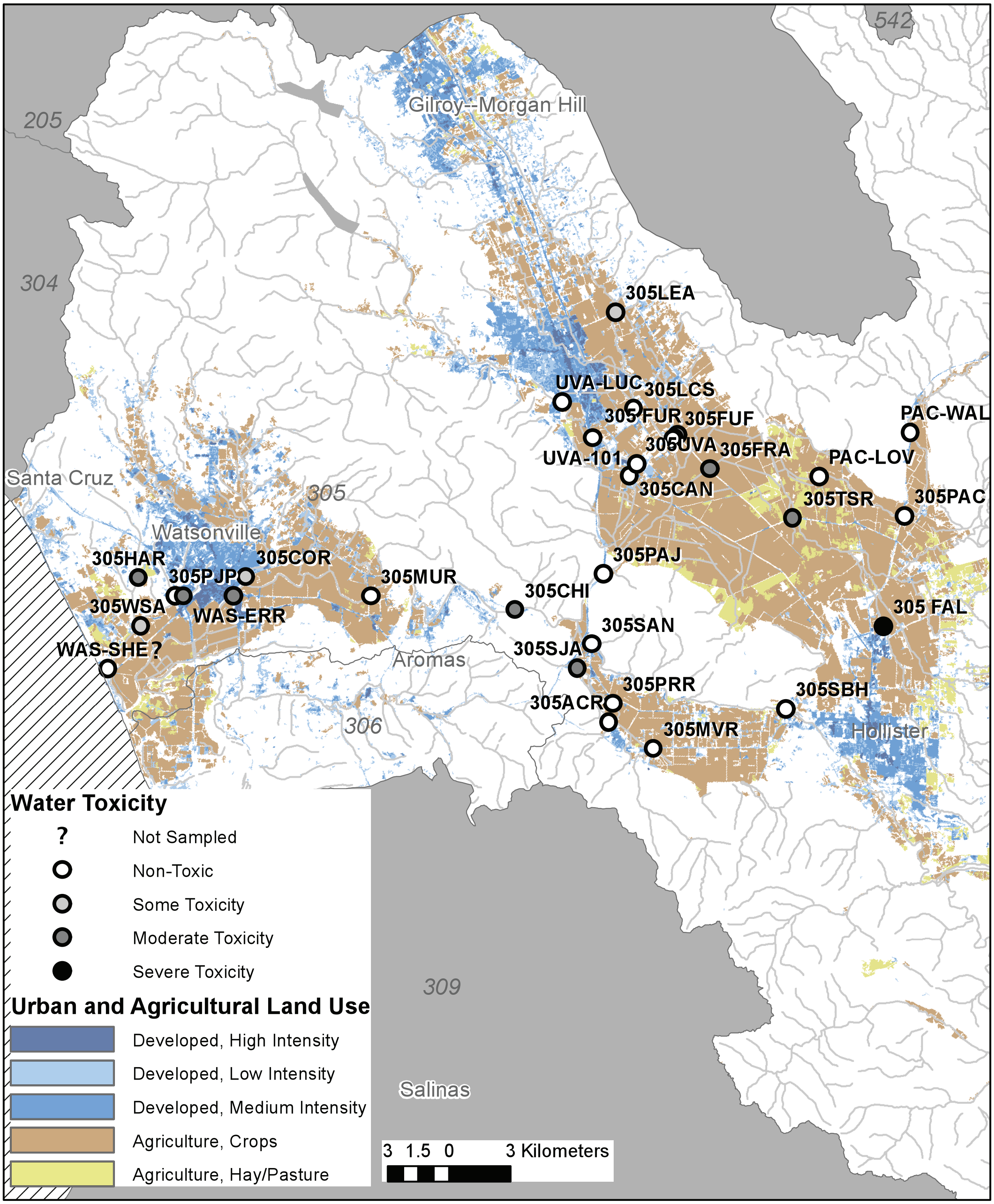

Figure 6. Magnitude of water column toxicity at sites in the Pajaro River area of the Central Coast Region of California based on the most sensitive species (test endpoint) in water samples collected at each site.

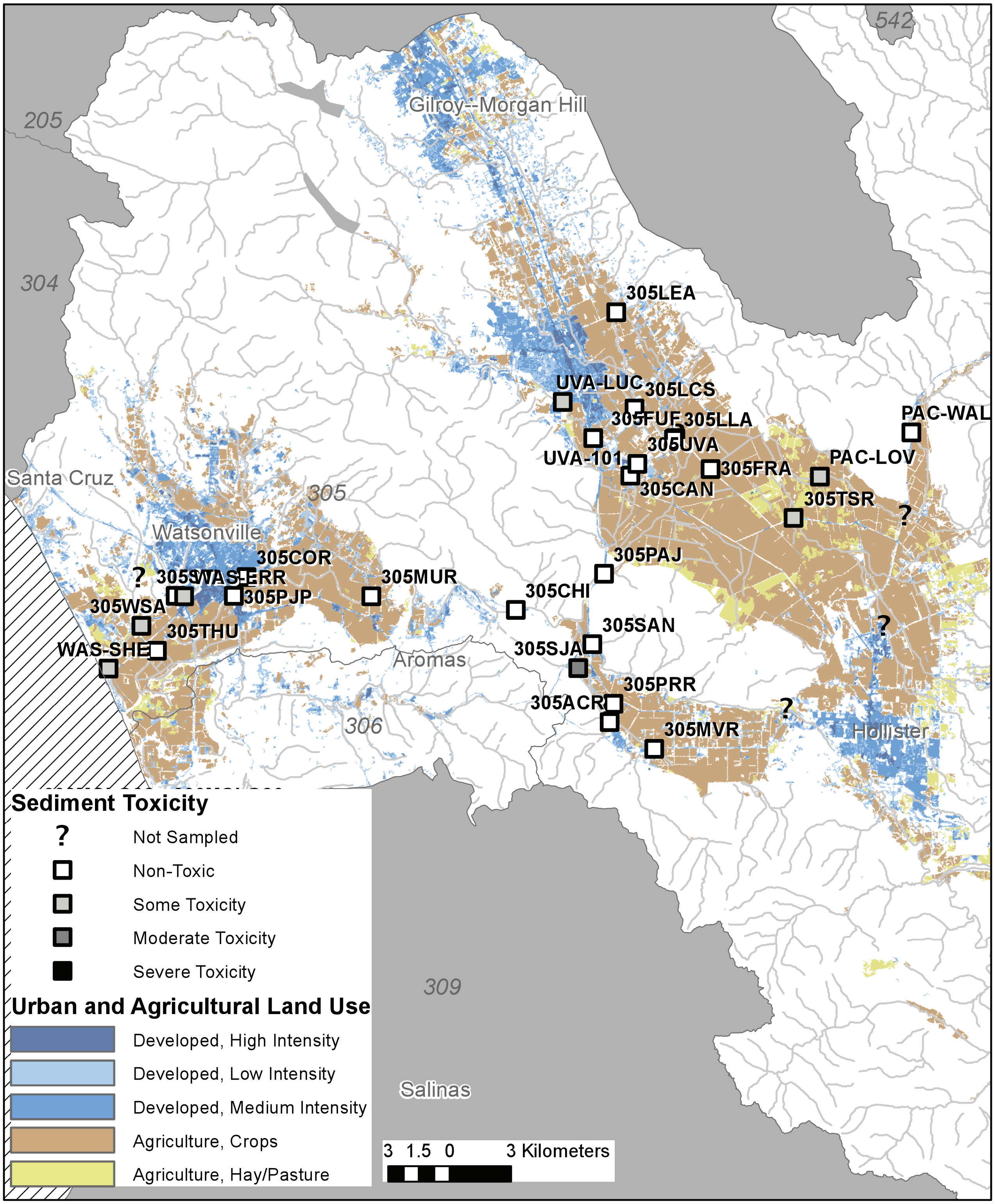

Figure 7. Magnitude of sediment toxicity at sites in the Pajaro River area of the Central Coast Region of California based on the most sensitive species (test endpoint) in sediment samples collected at each site.

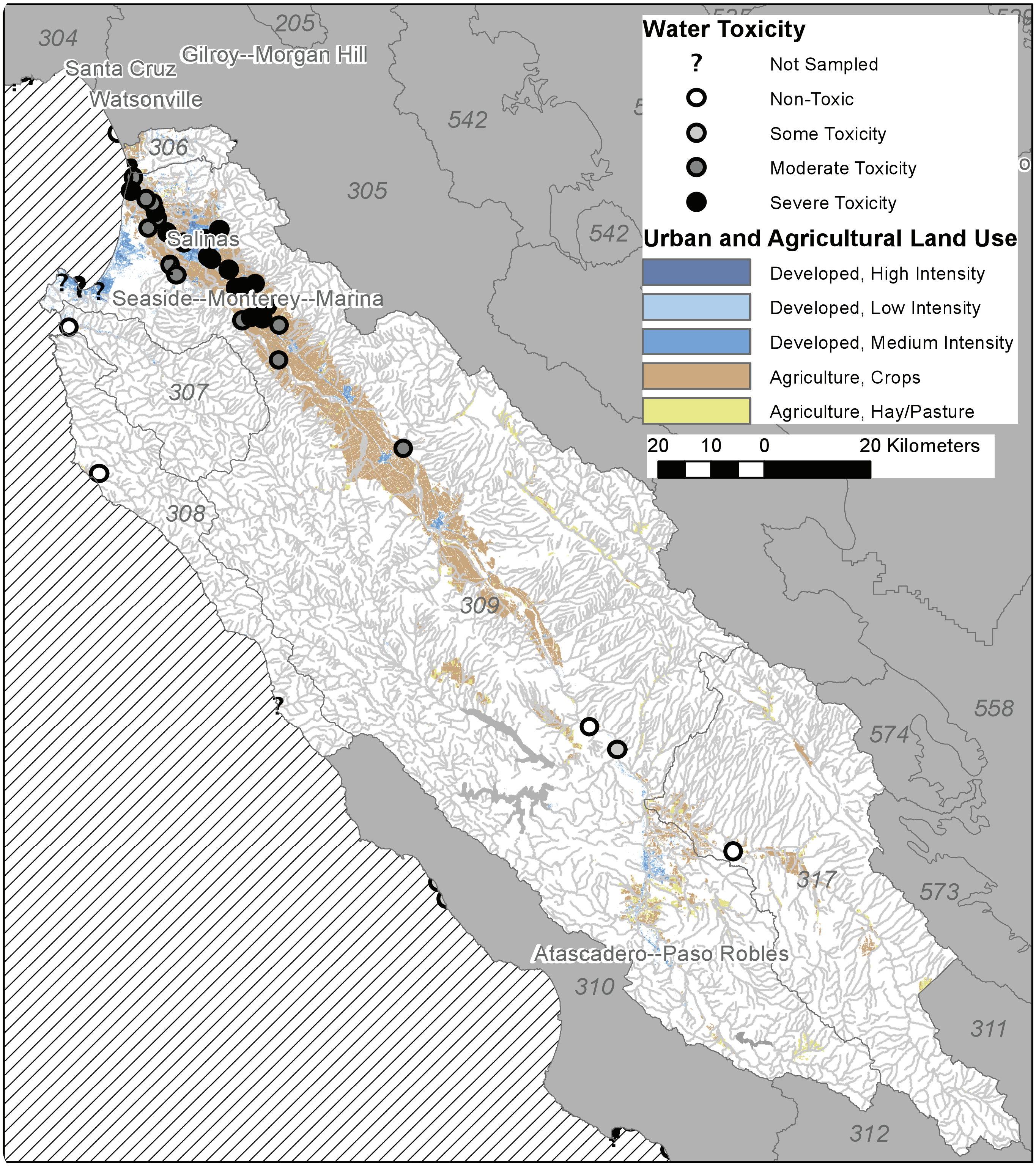

Figure 8. Magnitude of water column toxicity at sites in the Salinas River and Monterey areas of the Central Coast Region of California based on the most sensitive species (test endpoint) in water samples collected at each site.

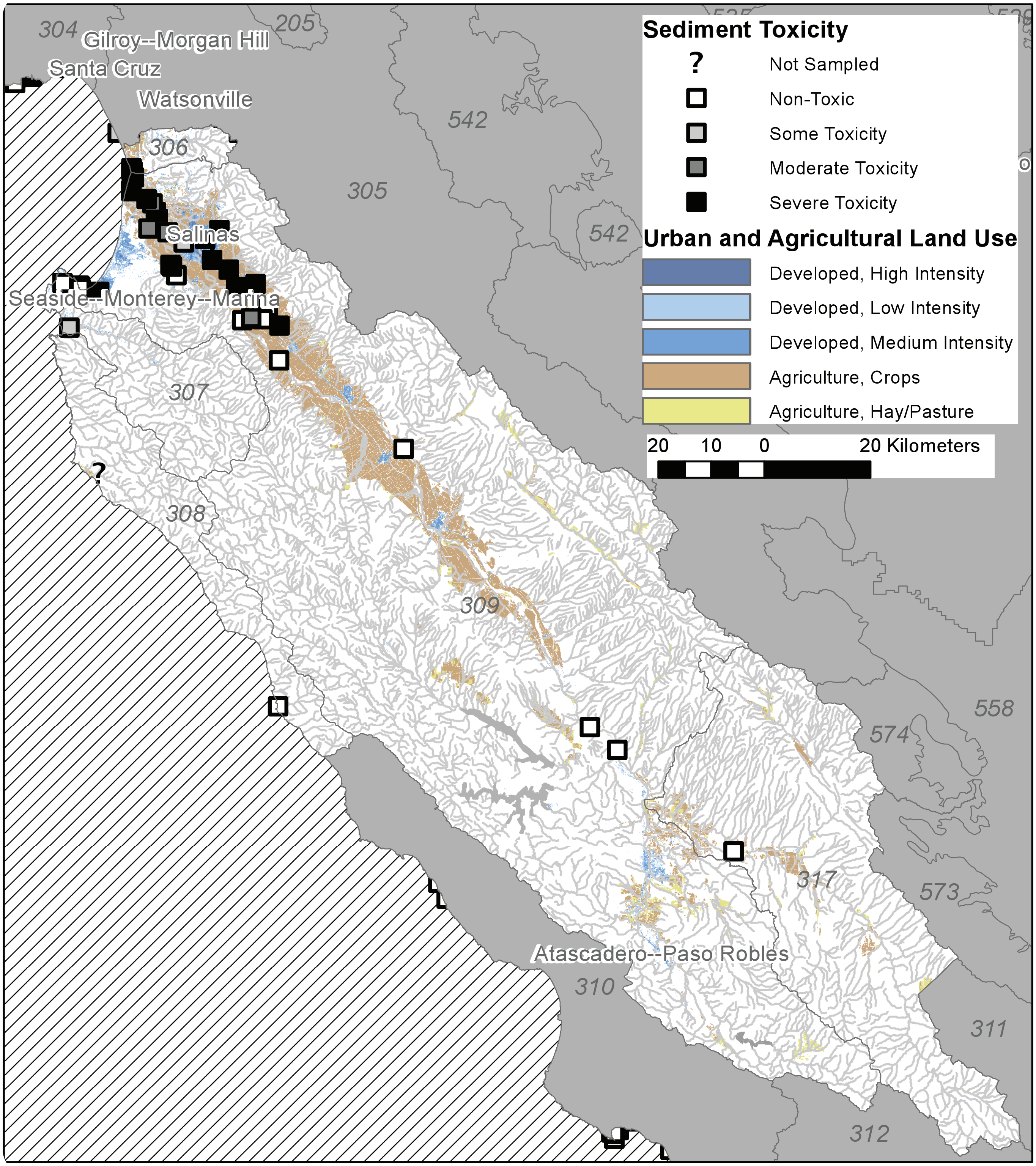

Figure 9. Magnitude of sediment toxicity at sites in the Salinas River and Monterey areas of the Central Coast Region of California based on the most sensitive species (test endpoint) in sediment samples collected at each site.

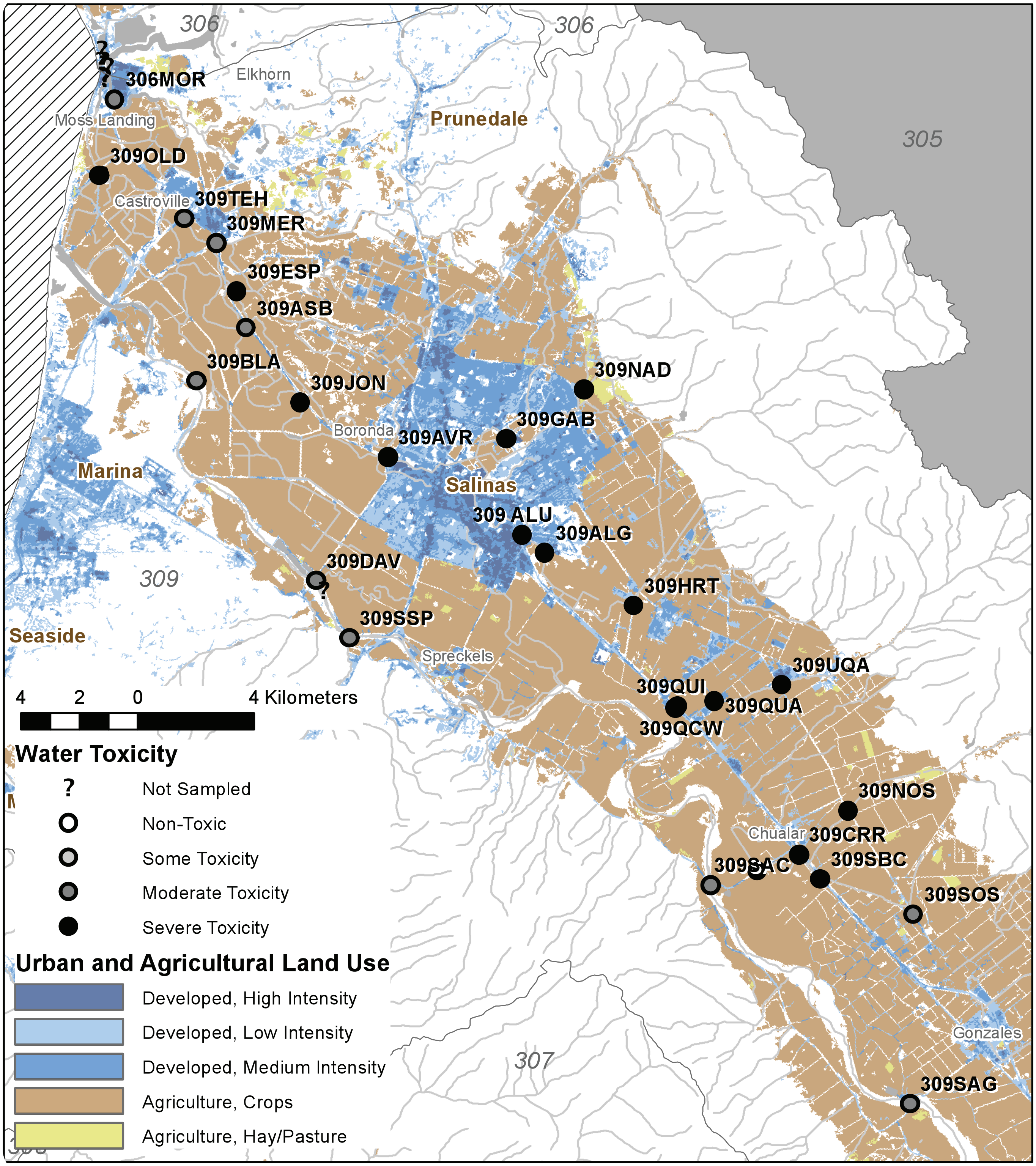

Figure 10. Magnitude of water column toxicity at sites in the Salinas area of the Central Coast Region of California based on the most sensitive species (test endpoint) in water samples collected at each site.

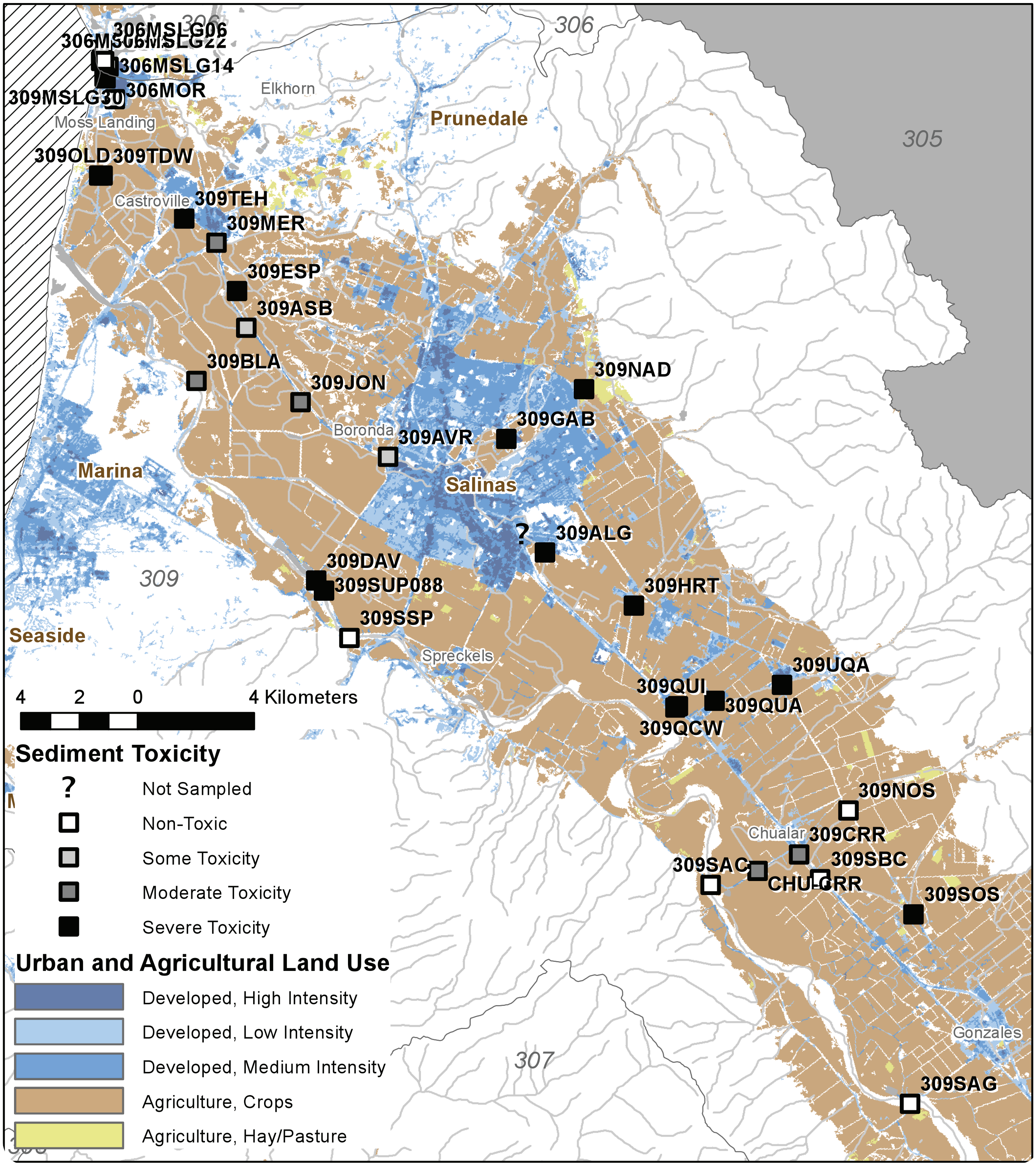

Figure 11. Magnitude of sediment toxicity at sites in the Salinas area of the Central Coast Region of California based on the most sensitive species (test endpoint) in sediment samples collected at each site.

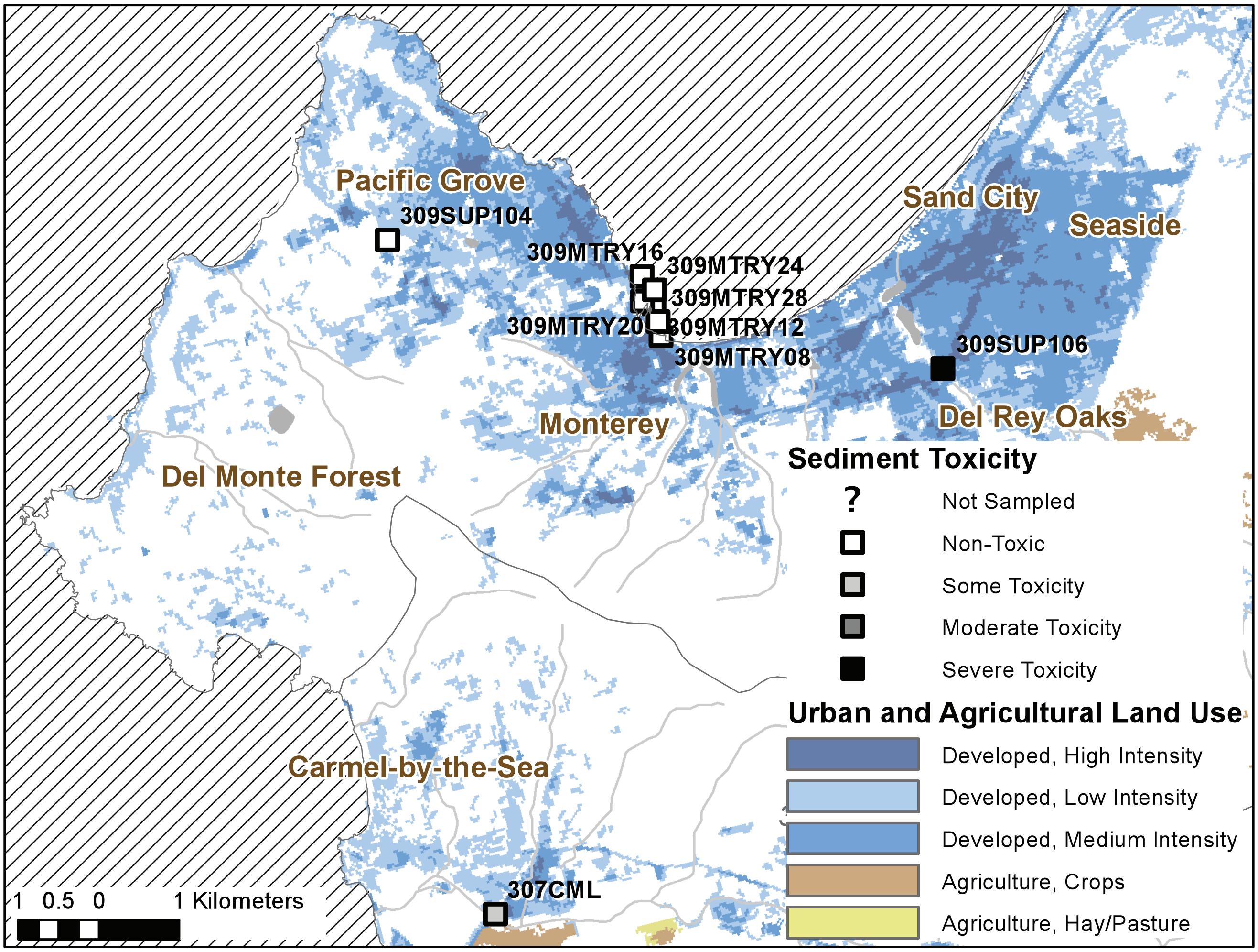

Figure 12. Magnitude of sediment toxicity at sites in the Monterey area of the Central Coast Region of California based on the most sensitive species (test endpoint) in sediment samples collected at each site.

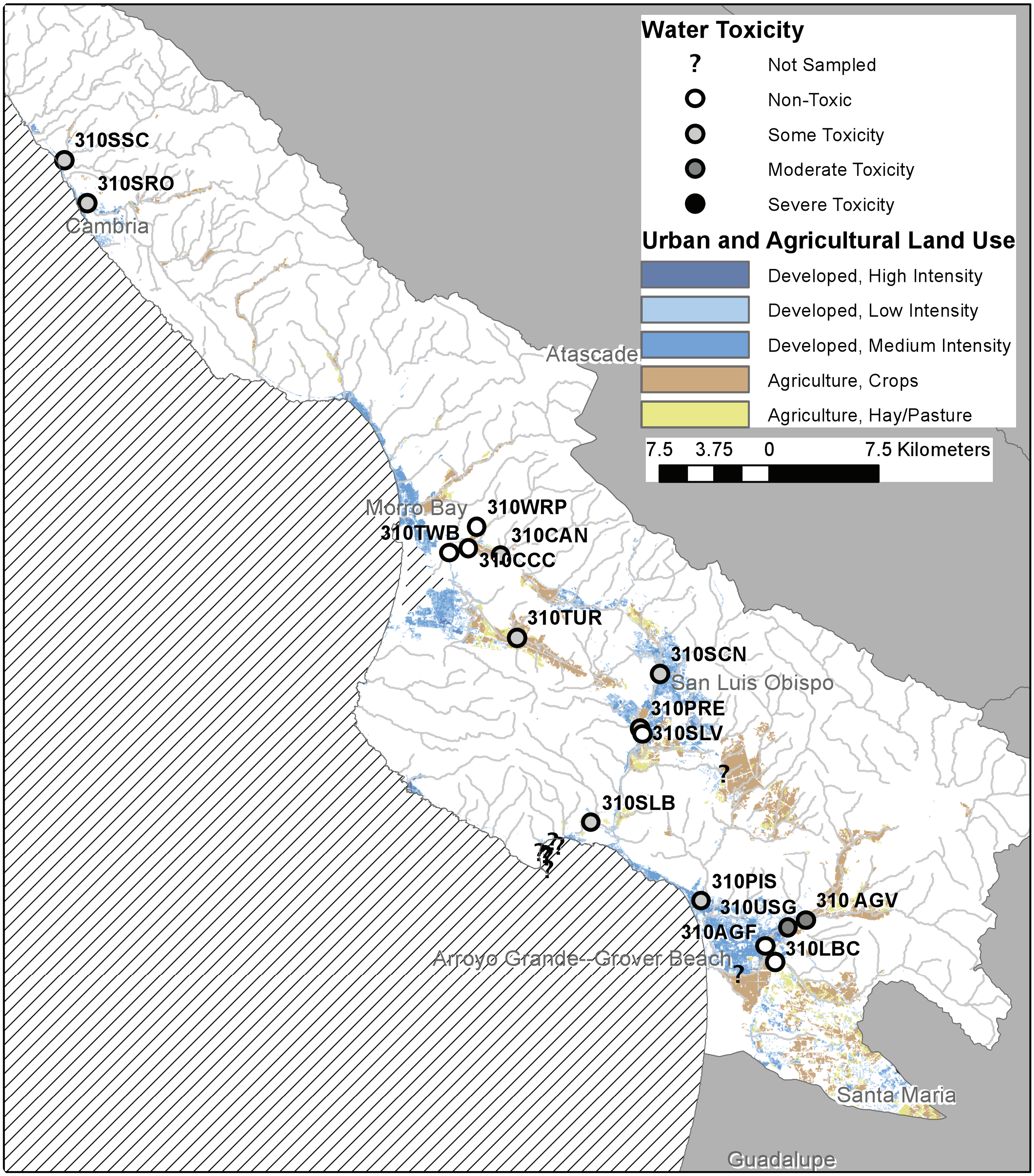

Figure 13. Magnitude of water column toxicity at sites in the Morro Bay and San Luis Obispo areas of the Central Coast Region of California based on the most sensitive species (test endpoint) in water samples collected at each site.

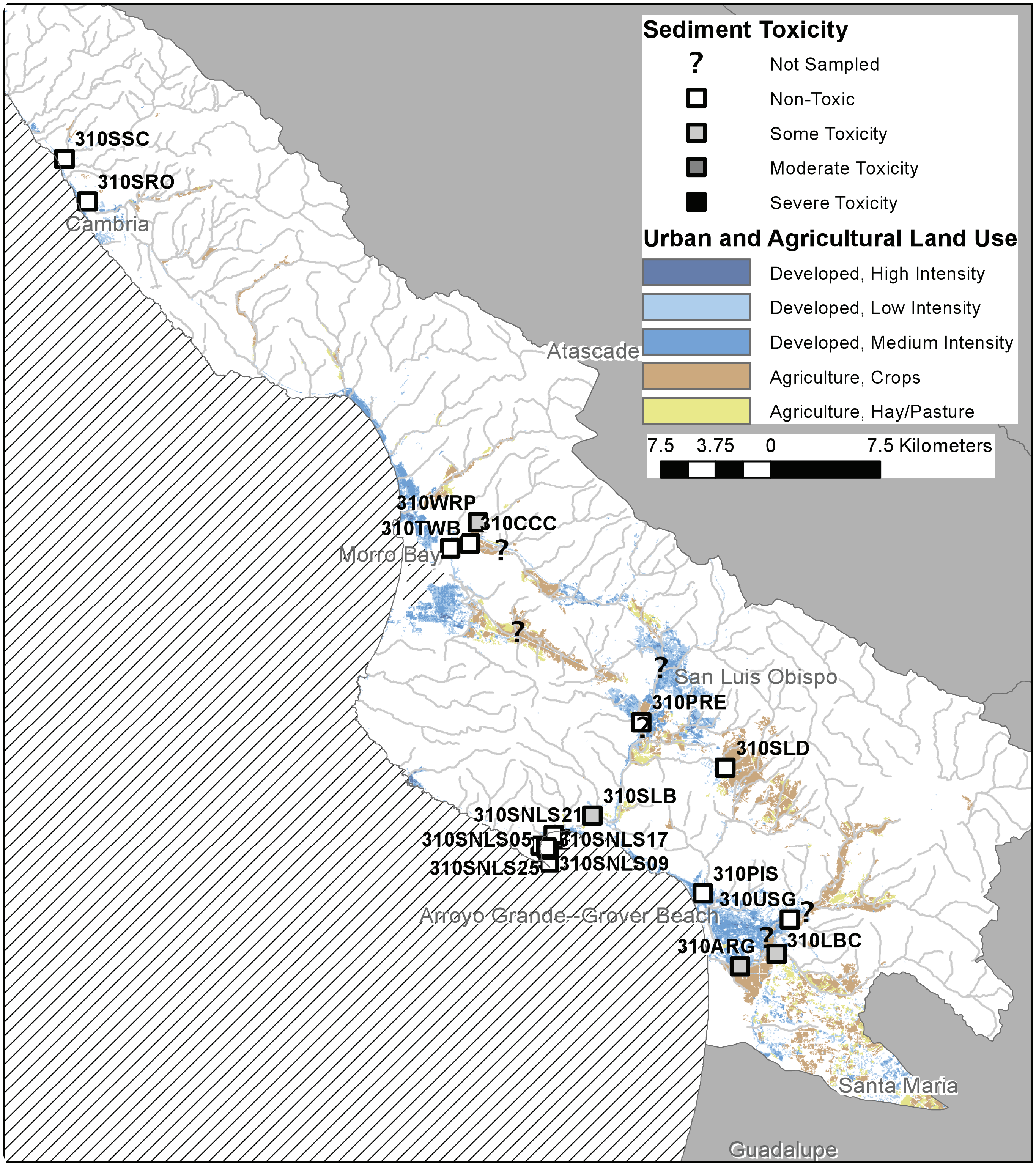

Figure 14. Magnitude of sediment toxicity at sites in the Morro Bay and San Luis Obispo areas of the Central Coast Region of California based on the most sensitive species (test endpoint) in sediment samples collected at each site.

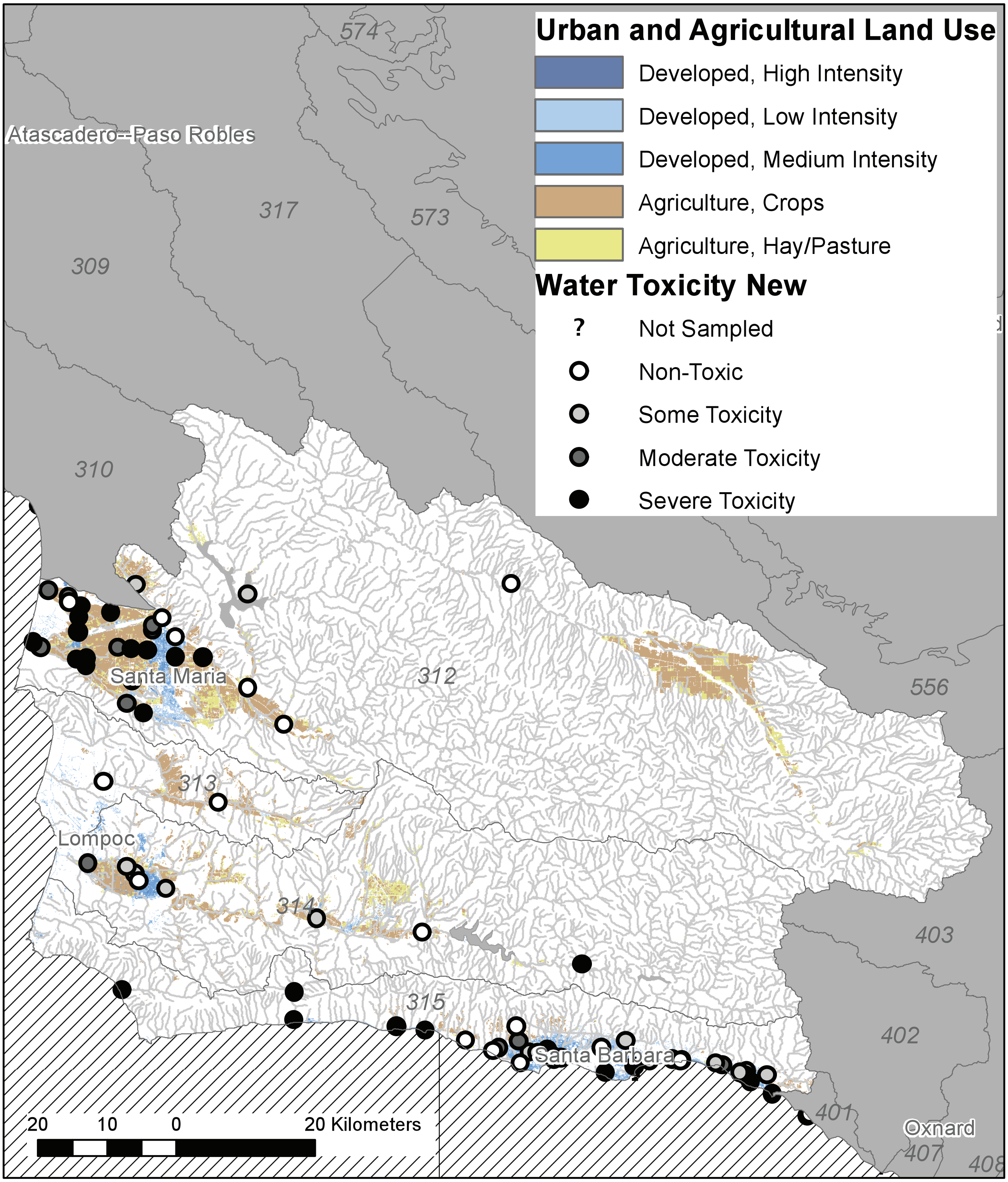

Figure 15. Magnitude of water column toxicity at sites in the Southern area of the Central Coast Region of California based on the most sensitive species (test endpoint) in water samples collected at each site.

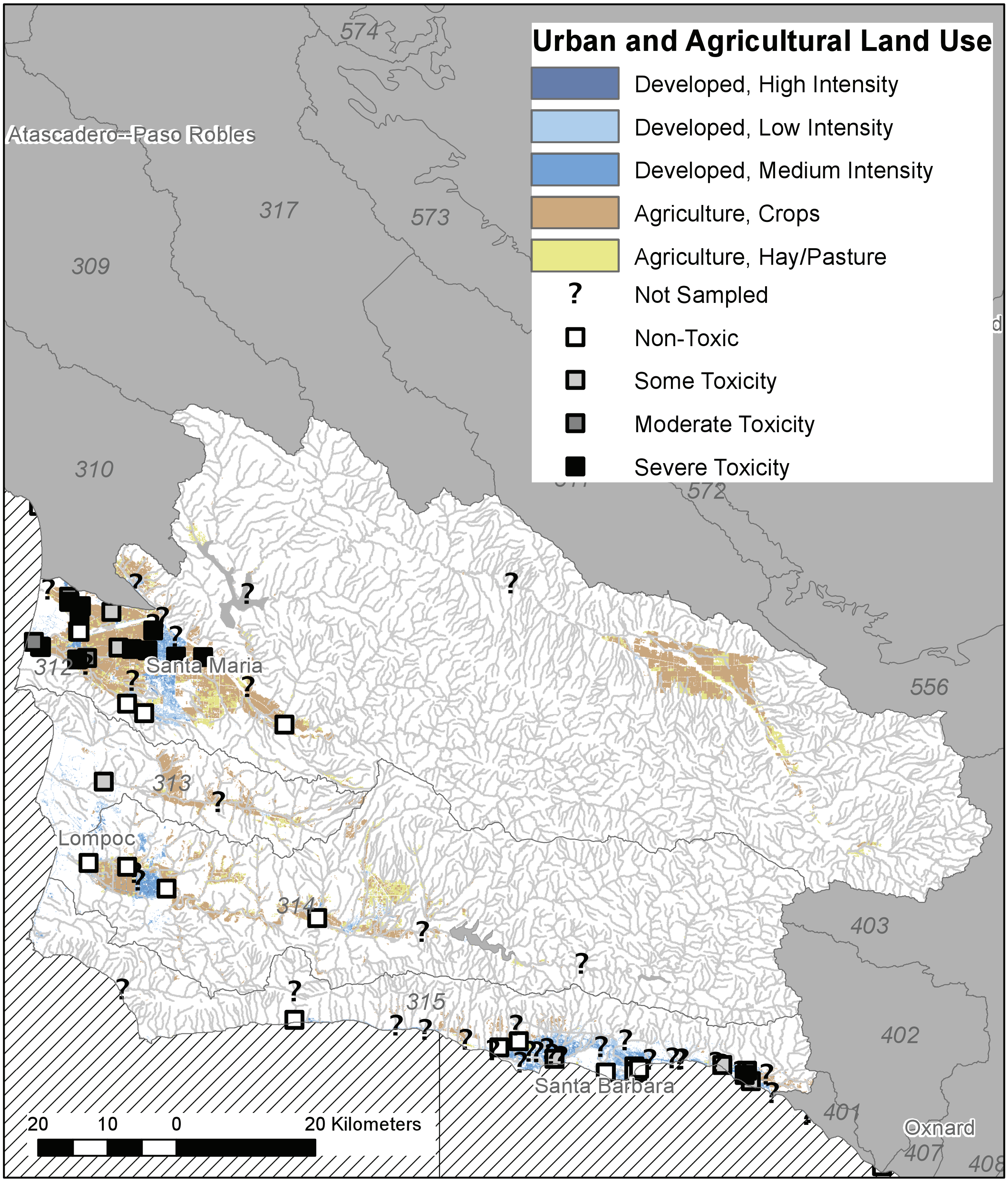

Figure 16. Magnitude of sediment toxicity at sites in the Southern area of the Central Coast Region of California based on the most sensitive species (test endpoint) in sediment samples collected at each site.

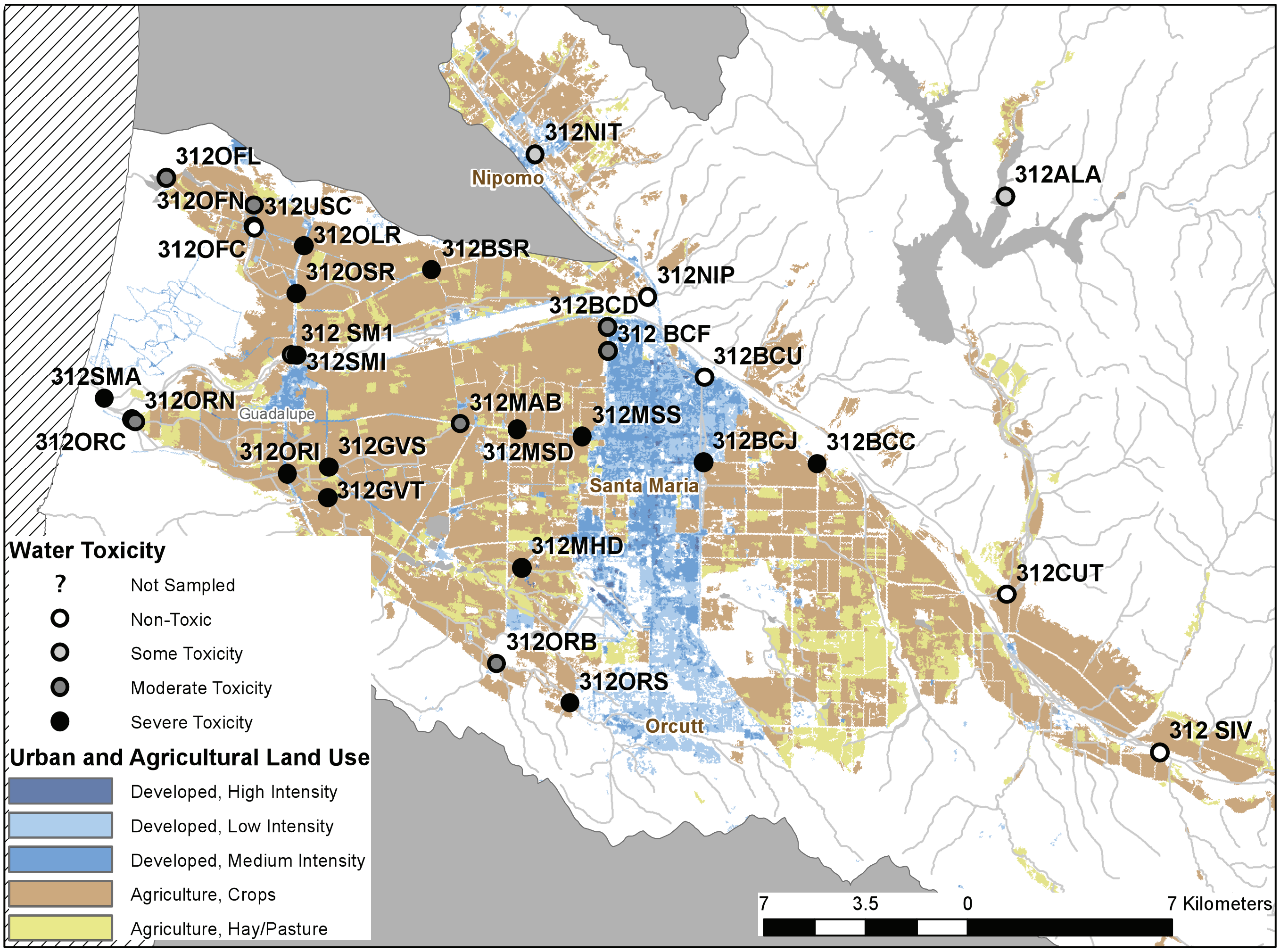

Figure 17. Magnitude of water column toxicity at sites in the Santa Maria area of the Central Coast Region of California based on the most sensitive species (test endpoint) in water samples collected at each site.

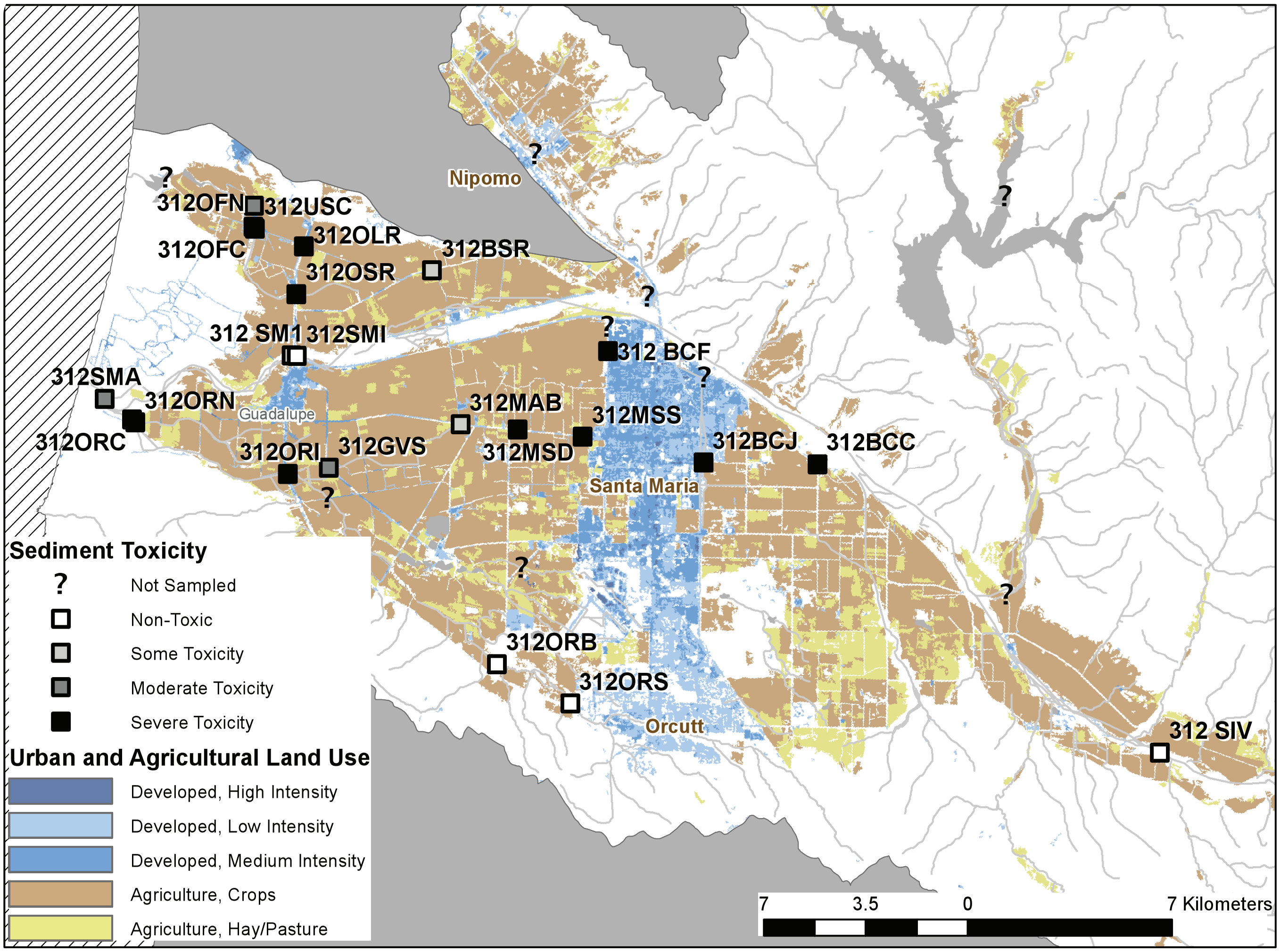

Figure 18. Magnitude of sediment toxicity at sites in the Santa Maria area of the Central Coast Region of California based on the most sensitive species (test endpoint) in sediment samples collected at each site.

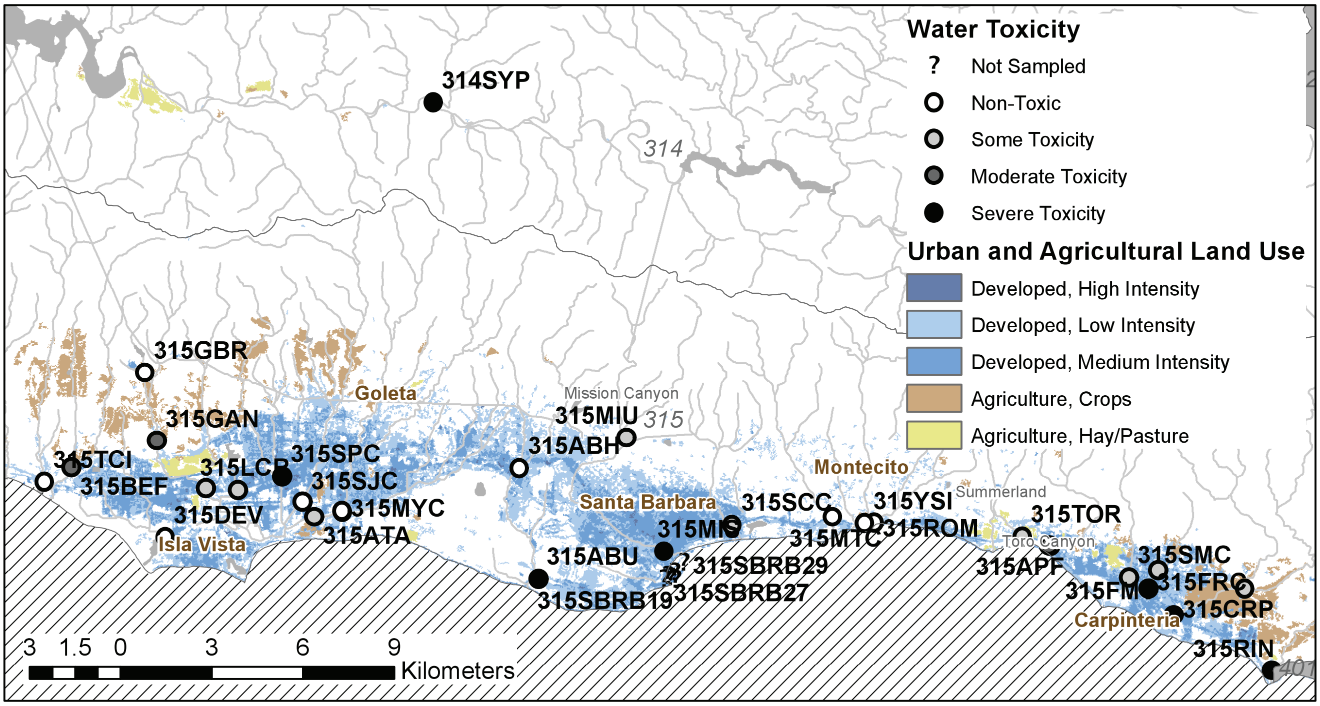

Figure 19. Magnitude of water column toxicity at sites in the Santa Barbara area of the Central Coast Region of California based on the most sensitive species (test endpoint) in water samples collected at each site.

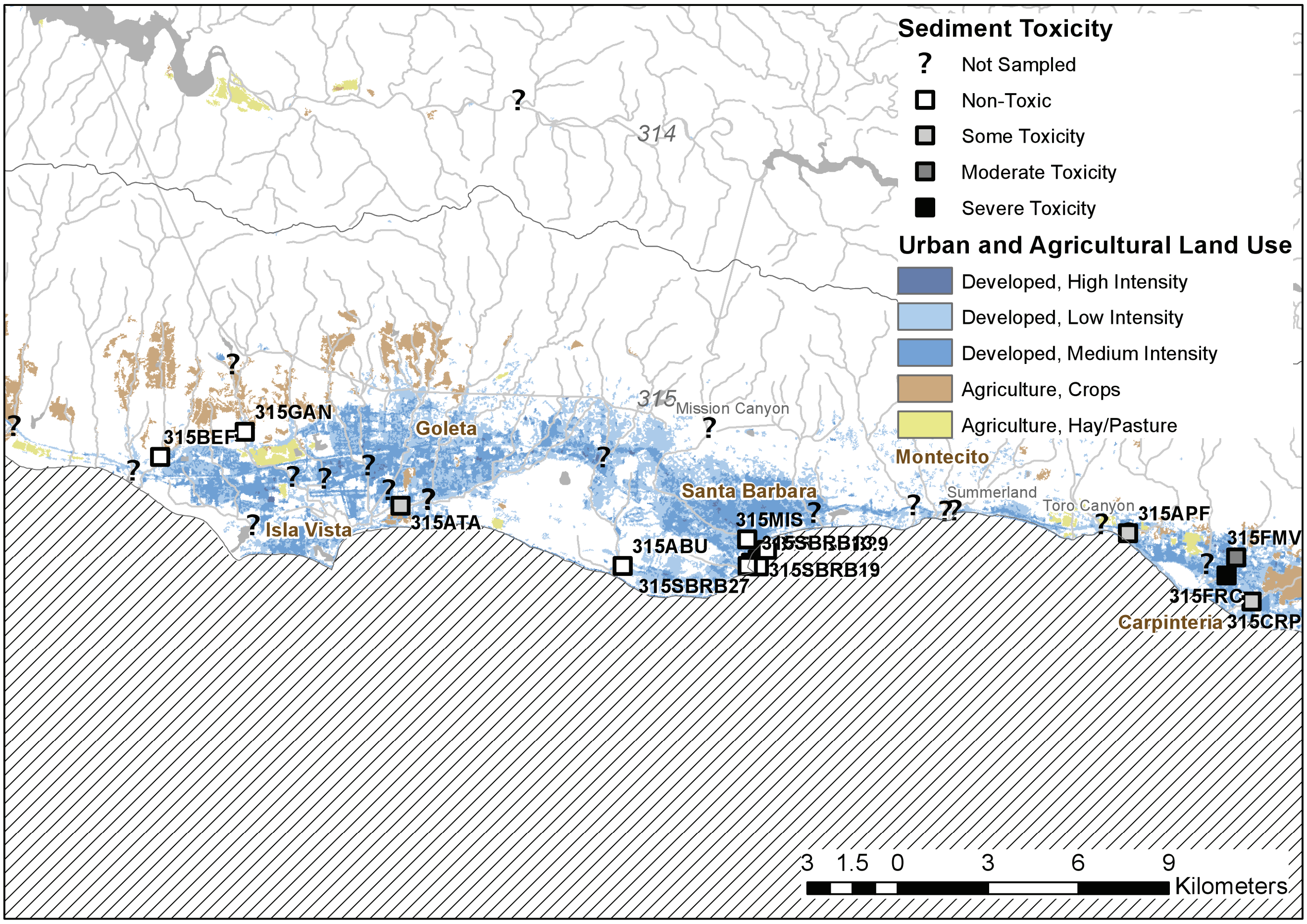

Figure 20. Magnitude of sediment toxicity at sites in the Santa Barbara area of the Central Coast Region of California based on the most sensitive species (test endpoint) in sediment samples collected at each site.

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