CALLEGUAS CREEK
WATERSHED MONITORING PROGRAM

2011 MUGU LAGOON
BENTHIC INFAUNA REPORT

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INTRODUCTION

The benthic infauna, invertebrates that live in the bottom sediments, are an important part of the marine ecosystem. These animals are a major food source for fish and other larger invertebrates, and contribute to nutrient recycling. Some species are highly sensitive to effects of human activities, while others thrive under altered conditions. The assessment of the benthic community is, therefore, a major component of many marine monitoring programs.

As part of the Calleguas Creek watershed Total Maximum Daily Load (TMDL) monitoring program, the benthic infaunal community of Mugu Lagoon, an estuarine embayment at the mouth of the creek, was sampled (Figure 1). Benthic sampling was included in the monitoring program to assess infaunal community condition, a potential indicator of exposure to contaminants in the sediments. Infaunal community composition, in conjunction with toxicity testing and chemical analysis, form a triad of standardized tools to determine sediment quality in potentially impacted habitats and provide managers and regulators a means to assess and evaluate local conditions in comparison to regional Sediment Quality Objective (SQO) criteria.

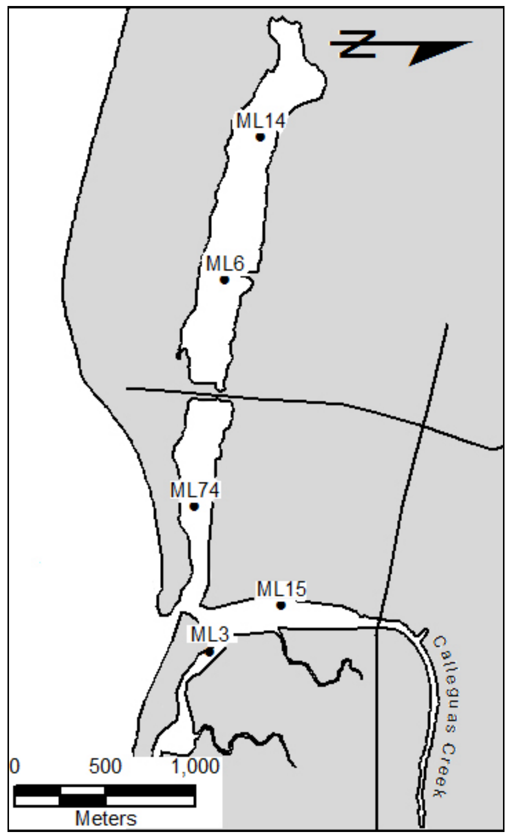

Figure 1. Mugu Lagoon infauna sampling stations.

MATERIALS AND METHODS

Benthic samples for the analysis of infauna community were collected in conjunction with sediment monitoring on 16 through 18 August 2011 at five stations within Mugu Lagoon (Figure 1, Table 1). A single grab for infauna analysis was collected at each station using a chain-rigged, 0.1 square meter (m^2) van Veen grab. Each sample was washed in the field using a 1.0-mm U.S. Standard Sieve, labeled, relaxed in an isotonic solution of magnesium sulfate for a minimum of thirty minutes and fixed in buffered 10% formalin-seawater.

In the laboratory, samples were transferred to 70% ethyl alcohol, sorted to major taxonomic groups, identified to the lowest practical taxonomic level, and counted. Identifications and nomenclature followed the 2011 usage accepted by the Southern California Association of Marine Invertebrate Taxonomists (SCAMIT 2011). Representative specimens were added to MBC's reference collection. Following identification, the weight of organisms for each major taxonomic group was measured. Specimens were placed on small, pre-weighed mesh screens that had been immersed in 70% ethyl alcohol, blotted on a paper towel, and air-dried for five minutes. Large organisms, if any, were weighed separately.

Table1. Mugu Lagoon station coordinates, date and time of sampling and water depth.

Infauna Station ID	Station Reference Number	Actual North Latitude	Actual West Longitude	Sample Date	Sample Time (hr)	Depth (m) at Time of Collection
ML3	01 BPT 3	34° 06.139'	119° 05.464'	17 August 2011	1315	1.4
ML6	01 BPT 6	34° 06.158'	119° 06.571'	18 August 2011	1050	1.4
ML14	01 BPT 14	34° 06.279'	119° 07.030'	18 August 2011	930	1.0
ML15	01 BPT 15	34° 06.333'	119° 05.626'	17 August 2011	1030	1.4
ML74	01 SG 74	34° 06.044'	119° 05.769'	16 August 2011	1430	0.6

Following identification and enumeration of infaunal species, counts tabulated by taxonomists on laboratory bench sheets were entered into MBC's in-house, Microsoft Access-based infauna database. All information was double entered for accuracy and species names were compared with both the in-house database and the current SCAMIT nomenclature list to validate usage. Data were compared among stations using both summary information and mathematical analysis. Analytical methods included: Shannon-Wiener species diversity (H'); comparison of community composition among stations using Euclidean distance; and four indices of benthic community condition (Southern California Benthic Response Index [BRI], Index of Biotic Integrity [IBI], Relative Benthic Index [RBI], and River Invertebrate Prediction and Classification System [RIVPACS]). Since these four indices use different species constituents and methods to evaluate community conditions (BRI and IBI are based on community measures, while RBI and RIVPACS on species composition) relative impact levels may differ between methods. To account for these differences and provide a comprehensive evaluation of condition, the median of the four index category scores for each station was used to determine the Benthic Community Index Integration score, which is used in the SQO evaluation. Descriptions of methods are presented in Appendix A.

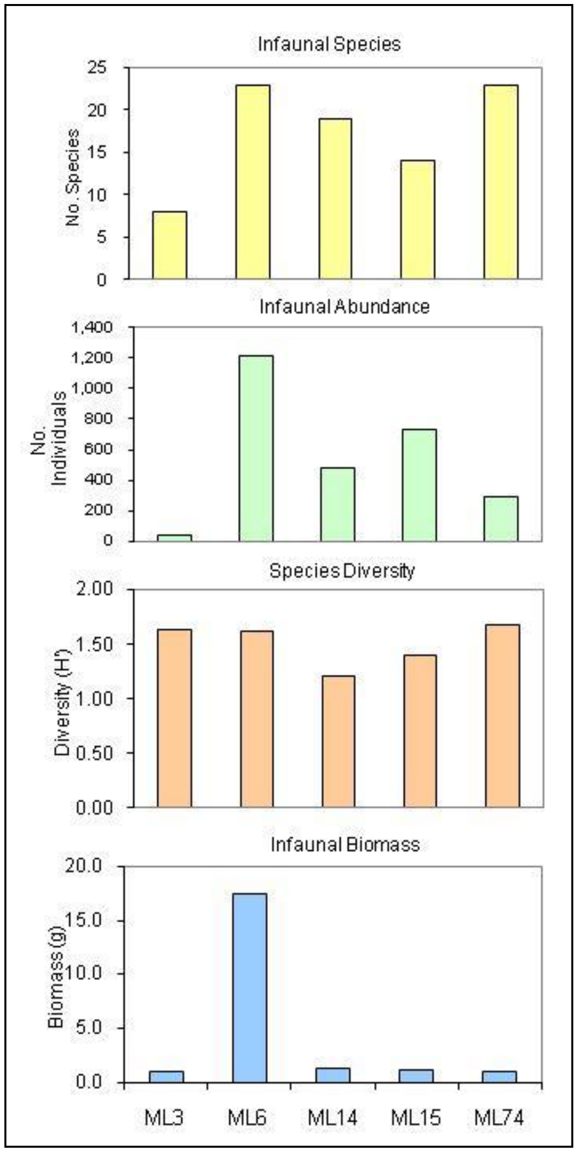

Figure 2. Infauna community characteristics by station.

RESULTS

Species Composition. A total of 2,754 individuals in 49 species (or taxa) and ten phyla (major groups) were taken in the benthic infauna sampling at Mugu Lagoon (Figure 2, Table 2 and Appendix B). Annelids (segmented worms) were the most diverse phylum, with 21 species (43% of the total), followed by arthropods with 14 species (29%), mollusks with nine species (18%), and nemertean (ribbon) worms with three species (6%). The remaining two phyla, nematodes (round worms) and phoronids (horseshoe worms), were each represented by a single taxon. Arthropods were the most abundant phylum with 1,352 individuals, 49% of the individuals in the samples. Nematodes, annelids and mollusks were next most abundant with 717 (26%), 580 (21%), and 84 (3%) individuals, respectively. The two remaining phyla comprised less than 1% of the total abundance.

Table 2. Infaunal community parameters and community indices.

	Station						
Parameter	ML3	ML6	ML14	ML15	ML74	Total	Mean
Number of species							
Total	8	23	19	14	23	49	17
Number of individuals							
Total	42	1,209	482	731	290	2,754	551
Density (#/m^2)	420	12,090	4,820	7,310	2,900		5,508
Diversity (H')							
Total	1.63	1.62	1.21	1.39	1.68	2.37	1.51
Biomass (g)							
Total	1.02	17.41	1.36	1.24	1.01	22.04	4.41
g/m^2	10.19	174.11	13.63	12.40	10.10		44.08
Index							
Benthic Response Index (BRI)							
Total	51.3	50.0	46.2	77.2	32.6	48.3	51.5
Category Score	3	2	2	4	1	2	2
Index of Biotic Integrity (IBI)							
IBI Score	3	2	1	2	2	2	2
Category Score	4	3	2	3	3	3	3
Relative Benthic Index (RBI)							
RBI Score	0.01	0.09	0.09	0.04	0.06	0.23	0.06
Category Score	4	3	3	4	4	2	4
River Invertebrate Prediction and Classification System (RIVPACS)							
RIVPACS Score (P > 0.5)	0.00	0.86	0.57	0.29	0.57		0.46
Category Score	4	2	3	4	3		3
Benthic Community Index Integration							
	4	3	3	4	3		3

Category Scores: 1 = Reference, 2 = Low Disturbance, 3 = Moderate Disturbance, 4 = High Disturbance

Species Richness. Species richness averaged 17 species per station, and ranged from 8 species at Station ML3, the easternmost station in the lagoon, to 23 species at both Station ML6 in the middle of the western arm of the lagoon, and Station ML74 in the central lagoon (Figure 2, Table 2 and Appendix B). Species richness was somewhat variable by station in the lagoon.

Abundance. Abundance averaged 551 individuals per station (a density of 5,508 individuals/m^2) and ranged from 42 individuals at Station ML3, to 1,209 individuals at Station ML6 (Figure 2, Table 2 and Appendix B).

Species Diversity. Shannon-Wiener species diversity (H') averaged 1.51 per station and ranged from 1.21 at Station ML14, in the western arm, to 1.68 at Station ML74 (Figure 2, Table 2 and Appendix B).

Biomass. Infauna biomass totaled 22 g and averaged 4.4 g per station (44.1 g/m^2) (Figure 2, Table 2 and Appendix B). Values ranged from 1.0 g at Stations ML3 and ML74 to 17.4 g at Station ML6. Mollusks contributed 65% to the biomass, a larger share than their proportion of the abundance due to occurrence of a few large individuals. Annelids contributed another 26% to the total followed by arthropods, the most abundant group, with 8%. The remaining phyla together contributed 1% to the total biomass.

Benthic Response Index. The Southern California Benthic Response Index (BRI) is the abundance-weighted average pollution tolerance of species occurring in a sample. For the evaluation the pollution tolerance scores (p_i) for northern (Point Conception to Newport Bay) bay and harbor habitats were used. BRI values averaged 51.5 for the study area, and ranged from 32.6 (Category 1, Reference Level) at Station ML74 to 77.2 (Category 4, High Disturbance) at Station ML15, the station closest to Calleguas Creek in the eastern arm of the lagoon (Table 2, Appendices A and B).

Index of Biotic Integrity. The Index of Biotic Integrity (IBI) uses species diversity and abundance of key taxa to distinguish impacted benthic communities from reference benthic conditions. In Mugu Lagoon, IBI scores ranged from 1 (Category 2, Low Disturbance) at Station ML14 to an IBI score of 3 (Category 4, High Disturbance) at Station ML3 (Table 2, Appendices A and B).

Relative Benthic Index. Relative Benthic Index (RBI) values are calculated as a weighted sum of four community parameters (number of species, number of crustacean species, number of crustacean individuals and number of mollusk species) and abundances of positive and negative indicators. RBI values in the lagoon ranged from 0.09 (Category 3, Moderate Disturbance) at Stations ML6 and ML14 to 0.01 (Category 4, High Disturbance) at Station ML3 (Table 2, Appendices A and B).

River Invertebrate Prediction and Classification System. The River Invertebrate Prediction and Classification System (RIVPACS) uses presence or absence of expected species based on habitat variables including station location and depth. RIVPACS scores in the lagoon ranged from 0.86 (Category 2, Low Disturbance) at Station ML6 to 0.00 (Category 4, High Disturbance) at Stations ML3 (Table 2, Appendices A and B).

Benthic Community Index Integration. The Benthic Community Index Integration is the median value (rounded up in value for all fractions) of the Category scores for the four indices at each station. Integration values at Mugu Lagoon ranged from 3 (Moderate Disturbance) at Stations ML6 and ML14, both in the western arm, and Station ML74 in the central lagoon, to 4 (High Disturbance) at Stations ML3 and ML15 in the eastern lagoon (Table 2, Appendices A and B).

Community Composition. Twelve species each comprised 1% or more of all individuals collected; together they totaled about 24% of the species but 93% of the individuals in the infauna collection (Table 3, Appendix B). They included six arthropods, four annelids, and one each of mollusk and nematode. Nematodes were the most abundant taxa accounting for 26% of all individuals collected. Though taken at all stations, abundance was overwhelmingly highest at Station ML6. The cumacean *Oxyurostylis pacifica,* the second most abundant species in 2011 with more than 17% of all individuals, occurred almost exclusively at Stations ML6 and ML14 in the western arm of Mugu Lagoon, and was not found at eastern arm stations. Similarly, the amphipod *Monocorophium acherusicum*, which accounted for 11% of all individuals were nearly all from Station ML15, with only two individuals reported at Station ML6. Oligochaetes, accounting for another 11% of abundance, and the amphipod *Grandidierella japonica* with 10% of the total, also showed preference based on location in the lagoon. The remaining taxa each contributed less than 10% to the total abundance, with most taxa showing strong preference for a station or region of the lagoon. Only nematods were reported at all five stations during the survey.

Table 3. The 12 most abundant species by station.

Phylum	Species	Station ML3	ML6	ML14	ML15	ML74	Total	Percent (%) Total	Cumulative % Total
NT	Nematoda	11	632	26	42	6	717	26.03	26.03
AR	*Oxyurostylis pacifica*	-	178	300	-	3	481	17.47	43.50
AR	*Monocorophium acherusicum*	-	2	-	306	-	308	11.18	54.68
AN	Oligochaeta	-	159	108	15	20	302	10.97	65.65
AR	*Grandidierella japonica*	4	-	-	282	-	286	10.38	76.03
AR	Harpacticoida	-	-	-	-	176	176	6.39	82.43
AN	*Notomastus tenuis*	6	97	-	-	3	106	3.85	86.27
MO	*Acteocina inculta*	-	20	26	-	-	46	1.67	87.94
AR	*Monocorophium uenoi*	-	-	1	36	8	45	1.63	89.58
AN	*Capitella capitata* Cmplx	1	-	-	34	1	36	1.31	90.89
AR	*Allorchestes angusta*	-	17	-	2	15	34	1.23	92.12
AN	*Hemipodia borealis*	16	-	-	-	14	30	1.09	93.21

AN = Annelida; AR = Arthopoda; MO = Mollusca; NT = Nematoda

Cluster Analyses. The 12 most abundant species were used for the normal (site-group) and inverse (species-group) cluster analyses (Figure 3). Cluster diagrams were drawn based on dissimilarities with a value of 1.5 determined *a priori* as the minimal value indicating a significant separation between faunal and station groups. Stations ML3 and ML74 (Group I) and Stations ML6 and ML14 (Group III) clustered together at similar levels based on the similarity of communities between the two stations in each group. Station ML15 (Group II), nearest Calleguas Creek, clustered more closely to the Group I stations in the eastern arm than to the western arm stations. Group I stations clustered together based a similar contribution by species comprising Group A, along with low abundances of many of the common species. Group III was clustered based on species in Groups D and E, while Group II was influenced by the high abundances of Group C species that occurred in low to moderate abundances, if at all, at the other stations.

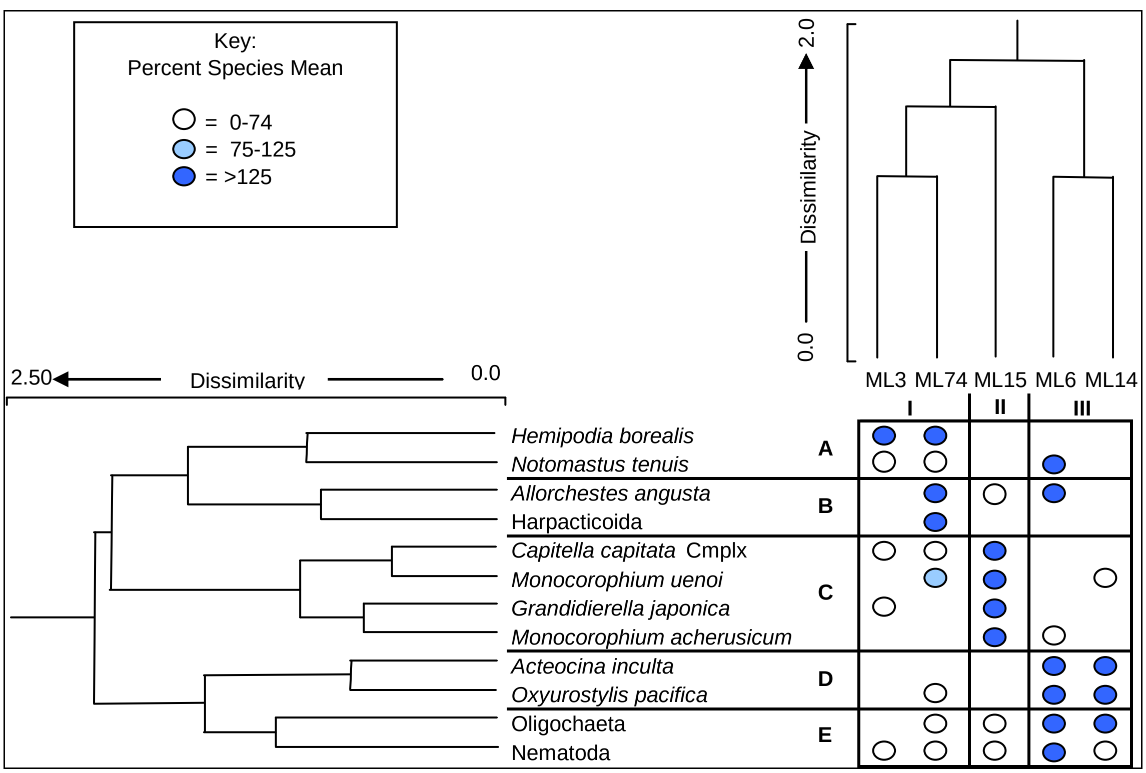

Figure 3. Two-way coincidence table resulting from normal (station) and inverse (species) classification dendrograms for the top one percent of infaunal species.

The most abundant species clustered into five groups based on their occurrences (Figure 3). Group A included the annelids *Hemipodia borealis*, which was found only at Group I stations and *Notomastus tenuis*, which was found in similar abundances at the Group I stations but was most abundant at Station ML6 in Group III. Group B taxa included the amphipod *Allorchestes augusta* and hapacticoid copepods, both of which occurred frequently at Station ML74 in Group I. Group C was composed of four species, an annelid and three amphipods that were most abundant at Station ML15 (Group II). Group D included the gastropod *Acteocina inculta* and the amphipod *Oxyurostylis pacifica*, which were taken almost exclusively at Group II stations. Group D was formed by oligochaets and nematodes, the two most frequently observed taxa during the survey, although both were most abundant at Group III stations.

DISCUSSION

The infauna communities in the study area in 2011 were composed predominantly of nematodes, small arthropods, annelid worms and gastropods. Community composition was most similar between Stations ML6 and ML14 in the western arm of the lagoon, and between Stations ML3 and ML74 in eastern arm and the central lagoon, respectively. Greatest number of taxa was reported at both Stations ML6 and ML74, although abundance at Station ML6 was about 60% higher than found at the station with the second highest abundance. Biomass was also greatest at Station ML6 where a few large individual mollusks contributed to a biomass that was nearly 13 times greater than was found at any other station. While number of taxa and individuals were lowest at Station ML3, diversity was lowest at Stations ML14 and ML15, the stations farthest west and north, respectively, from the central lagoon.

Compared to 2008, number of taxa reported at the five stations in the lagoon declined by about 40% in 2011 (MBC 2009). The greatest declines were observed at Stations ML6 and ML14 in the western arm of Mugu Lagoon where the number of taxa in 2011 was less than one-half those reported in 2008. The number of taxa also declined slightly at the western arm stations; however, in the central lagoon, number of taxa at Station ML74 more than tripled compared to 2008. Still, seven of the most abundant taxa reported in 2008 were among the community dominants again this year, including the same top three species. Similar to number of taxa, overall abundance in 2011 was notably lower than reported previously, with only slightly more than one-quarter of the 2008 abundance. The greatest difference was found at Station ML14 where less than 10% of the individuals reported in 2008 were taken this year. Abundance was reduced by about one-half at all of the remaining stations except for Station ML74, where, like taxa, number of individuals was higher than reported in 2008. Biomass in 2011 was similar to that found in 2008, with mollusks accounting for most of weight during both surveys, although in the previous survey larger individuals were found at both stations in the western arm of the lagoon. As a result of these differences between years, diversity was lower at all stations except Station ML74 in 2011, although the overall diversity for all stations combined was the same during both surveys.

Within Mugu Lagoon the western arm is separated from the rest of the lagoon by a causeway with culverts that mute tidal exchange and likely reduce exposure to contaminants washed downstream from Calleguas Creek. Though the western arm may be subject to inputs from the military base and nearby airfield, in general the western arm is buffered from surface runoff by marsh. In 2008, all community parameters, including species richness, abundance, diversity and biomass were highest at the western arm stations, with highest abundance and biomass values reported at Station ML14 farthest from the causeway (MBC 2009). In 2011, these community parameters were reduced at the stations in the western arm, particularly at Station ML14. In 2008, the infauna communities of the western arm stations indicated the least disturbance of the stations sampled in the lagoon, with all indices suggesting Reference or Low Disturbance levels at both stations and an overall integrated Benthic Community Index value of Low Disturbance for both western arm stations. In 2011, the stations in the western arm were still among the least disturbed in the lagoon, however, at levels indicating Low-to-Moderate

Disturbance for all indices, with an overall integrated Benthic Community Index value of Moderate Disturbance at both western arm stations.

In the main lagoon, lowest species richness and abundance were reported at Station ML3, the easternmost station in the lagoon, while lowest biomass and diversity were found at Station ML74 in the central lagoon. Still the communities found at Stations ML3 and ML74 were as similar to each other as were the two stations in the western arm. In 2008, the results of the community indices were mixed between Low and High Disturbance at Station ML3 resulting in an overall rank of Moderately Disturbed (MBC 2009). In 2011, however, only the BRI indicated Moderate Disturbance while three indices and the overall integrated Benthic Community Index value indicated that the community at Station ML3 was Highly Disturbed. In 2011, Station ML74 was the only station to show improvement from the 2008 results. The station is influenced by inputs from both the creek and a nearby storm drain. In 2008 community indices ranged from Moderate to High Disturbance, with an overall integrated rank of High Disturbance, while in 2011 indices were highly variable, ranging from reference condition for the BRI to High Disturbance for the RBI, with an overall integrated Benthic Community Index of Moderate Disturbance. Also in the eastern arm of the lagoon, Station ML15 is the closest to Calleguas Creek. While species richness was the second lowest here in 2011, abundance was the second highest. In 2008, community indices suggested Low to Moderate Disturbance at Station ML15, with an overall integrated level of Moderate Disturbance. In 2011, though, only the IBI indicated Moderate Disturbance while three indices and the overall integrated Benthic Community Index value indicated that the community at Station ML15 was Highly Disturbed.

Changes in the infaunal communities such as those noted this year are not unusual in lagoon habitats. Coastal lagoons are subject to a variety of influences on daily, seasonal and annual timescales. These influences include changes in water level, salinity and temperature as a result of tides, seasonal runoff during winter rainstorms and periodic unusually large storms or very wet years. While all of these influence the communities, large-scale events can have considerable impacts on the infaunal community. These impacts could include changes in sediment characteristics such as deposition of new sediments or scouring of existing sediments, dramatic short-term changes in salinity, or physical removal of individuals in stormwater flow. All of these can result in the reduction of individuals and alteration or elimination of existing communities. Timing of sampling following a dramatic reduction in the previous community is important because species that are more likely to be among the first to re-colonize an area are also generally among species known to be tolerant of ongoing disturbance and pollutants. In addition, modifications of the habitat following a large-scale event could promote re-colonization by different species than found in the area existed prior to the storm impacts

Differences in the infaunal community between years have been observed previously at Mugu Lagoon, with these changes chiefly associated with large-scale storm events and re-colonization and recovery following these events (Onuf 1987). A review of rainfall in the project area indicates that during the year previous to the 2011 sampling, rainfall in the area was the highest in six years, and more than double the amount recorded in the year previous to the 2008 sampling (VCWPD 2011). These records, along with the previous observations of changes in the infauna community following storms suggests that the differences noted in the community and the resultant reduction in the community indices are likely related to the affects of an unusually wet year previous to the 2011 survey.

CONCLUSION

In 2011, infaunal community parameters at most stations were reduced compared to results found during the 2008 survey, with overall number of taxa reduced by 40%. Total abundance only represented about 25% of the previous total. The Benthic Community Index Integration indicted that the stations in the western arm of Mugu lagoon were Moderately Disturbed in 2011 compared to the Low Disturbance found in 2008. In the main lagoon, the benthic communities at the stations in the eastern arm indicated High Disturbance this year, which was also a reduction in condition compared to 2008. In the central lagoon, which is influenced by inputs from both the creek and a nearby storm drain, indices suggested that conditions had improved and are now considered Moderately Disturbed compared to the High Disturbance previously found. While higher levels of disturbance to the infauna community were indicated in 2011 than in 2008, the source of the disturbance is likely related to the affects of an unusually wet year previous to the 2011 survey.

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Appendix A
Analysis Methods

Appendix A. Analysis Methods

Summary statistics developed from the biological data included the number of individuals, number of species, and Shannon-Wiener (Shannon and Weaver 1962) species diversity (H') index. The diversity equation is as follows:

Shannon-Wiener

$$H' = -\sum_{j=1}^{S} \frac{n_j}{N} \ln \frac{n_j}{N}$$

where: H' = species diversity
n_j = number of individuals in the j^{th} species
S = total number of species
N = number of individuals

Cluster Analysis

Infauna data were subjected to log transformations (when necessary) and classified (clustered) using NCSS 2000 Hierarchial Clustering (Hintze 1998). Cluster analysis provides a graphic representation of the relationship between species, their individual abundance, and spatial occurrence among the stations sampled. In theory, if physical conditions were identical at all stations, the biological community would be expected to be identical as well. In practice this is never the case, but it is expected that the characteristics of adjacent stations would be more similar than those distant from one another. The dendrogram shows graphically the degree of similarity (and dissimilarity) between observed characteristics and the expected average. The two-way analysis utilized in this study illustrates groupings of species and stations, as well as their relative abundance, expressed as a percent of the overall mean. Two classification analyses are performed on each set; in one (normal analysis) the sites are grouped on the basis of the species which occurred in each, and in the other (inverse analysis) the species are grouped according to their distribution among the sites. Each analysis involves three steps. The first is the calculation of an inter-entity distance (dissimilarity) matrix using Euclidean distance (Clifford and Stephenson 1975) as the measure of dissimilarity.

Euclidean Distance:

$$D = \left[\sum_{1}^{n} \left(x_1 - x_2 \right) \right]^{1/2}$$

where: D = Euclidean distance between two entities
x_1 = score for one entity
x_2 = score for other entity
n = number of attributes

The second procedure, referred to as sorting, clusters the entities into a dendrogram based on their dissimilarity. The group average sorting strategy is used in construction of the dendrogram (Boesch 1977). In step three, the dendrograms from both the site and species classifications are combined into a two-way coincidence table. The relative abundance values of each species are replaced by symbols (Smith 1976) and entered into the table. In the event of extreme high abundance of a single species, abundance data are transformed using a natural log transformation [ln(x)].

Southern California Benthic Response Index (BRI)

The Southern California Benthic Response Index (BRI) is an abundance-weighted average pollution tolerance of species occurring in a sample, and is a measure of the condition of marine and estuarine benthic communities (Smith et al. 2003). It classifies benthic communities as undisturbed (reference) or one of four levels of response to increased disturbance: Level 1, marginal deviation, or minimal disturbance; Level 2, biodiversity loss, in which more than 25% of species typical of undisturbed sites are not present; Level 3, community function loss, more than 90% of echinoderm and 75% of arthropod species at undisturbed sites are not present; and Level 4, defaunation, more than 90% of species found at undisturbed sites are not present. The formula is:

Benthic Response:

$$BRI_s = \frac{\sum_{i=1}^{n} \sqrt[4]{a_{si}\, p_i}}{\sum_{i=1}^{n} \sqrt[4]{a_{si}}}$$

where: BRI_s = BRI value for sampling unit s_i
n = number of species with pollution tolerance scores in s_i
p_i = pollution tolerance of species i
a_{si} = abundance of species i in s

Species pollution tolerances p_i were determined during BRI development as the position of the abundance distribution of species i on a gradient between the most and least disturbed sites. Species without pollution tolerance values are not included in the calculation. Pollution tolerance values were not assigned to species if the data were insufficient to assign a value. The index was developed for benthic samples that were sieved through a 1-mm mesh screen. Pollution tolerance scores were derived for coastal shelf samples for shallow (10-30 m deep), mid-depth (>30-120 m deep), and deep (>120-324 m deep) habitats, and for bay and harbor habitat samples, northern (Point Conception to Newport Bay) and southern (Dana Point to the U.S.-Mexico border). The species names for which scores are available are based on Edition 6 of the Southern California Association of Marine Invertebrate Taxonomists (SCAMIT) list of invertebrate species (SCAMIT 2011).

The BRI score is compared to the BRI thresholds.

Table 1. BRI Category Thresholds

BRI Score	Category	Category Score
< 39.96	Reference	1
> 39.96 to < 49.15	Low Disturbance	2
> 49.15 to < 73.27	Moderate Disturbance	3
> 73.27	High Disturbance	4

Index of Biotic Integrity (IBI)

To calculate IBI the total number of taxa, number of mollusk taxa, abundance of *Notomastus* sp., and the number of sensitive species is needed. The sensitive species list should be from the list for the station's habitat. There are three steps needed to determine the IBI category and score (SCCWRP 2008).

Step one: calculate the percentage of sensitive taxa present.

Percent (%) sensitive taxa = (number of sensitive taxa/total number of taxa) X 100

Step two: compare the values from step one to the reference ranges for IBI (Table 2). When the value falls out of these ranges the IBI score is increased by one (with a starting value of zero).

Table 2. Reference Ranges for IBI

Metric	Reference Range
Total Number of Taxa	13 to 99
Number of Mollusk Taxa	2 to 25
Abundance of *Notomastus* sp	0 to 59
Percentage of Sensitive Taxa	19 to 47.1

Step three: compare the IBI score determined in step two with the IBI category thresholds (Table 3).

Table 3. IBI Category Thresholds

IBI Score	Category	Category Score
0	Reference	1
1	Low Disturbance	2
2	Moderate Disturbance	3
3 or 4	High Disturbance	4

Relative Benthic Index (RBI)

The RBI is the weighted sum of: (a) four community metrics related to biodiversity (total number of taxa, number of crustacean taxa, abundance of crustacean individuals, and number of mollusk taxa), (b) abundances of three positive indicator taxa, and (c) the presence of two negative indicator species (SCCWRP 2008). The positive indicator species are: *Monocorophium insidiosum*, *Asthenothaerus diegensis*, and *Goniada littorea*. The negative indicator species are *Capitella capitata* complex and Oligochaeta.

Step one: normalize the values for the benthic community metrics. Use the formulas below for the scaled values.

Total number of taxa / 99
Number of mollusk taxa / 28
Number of crustacean taxa / 29
Abundance of crustaceans / 1693

Step two: use the scaled values to calculate the Taxa Richness Weighted Value (TWV). TWV = Scaled total number of taxa + Scaled number of mollusk taxa + Scaled number of crustacean taxa + (0.25 X Scaled abundance of Crustacea)

Step three: calculate the negative indicator taxa (NIT) value. The NIT starts at a zero value. If *Capitella capitata* complex and / or Oligochaeta are present in any amount the NIT decreases by 0.1. If neither were found the NIT = 0, if both are found the NIT = -0.2.

Step four: calculate the value for the positive indicator taxa (PIT). Use the following formulas to calculate the PIT value for each species:

$$\frac{\sqrt[4]{\text{Monocorophium insidiosum abundance}}}{\sqrt[4]{473}}$$

$$\frac{\sqrt[4]{\text{Asthenothaerus deigensis abundance}}}{\sqrt[4]{27}}$$

$$\frac{\sqrt[4]{\text{Goniada littorea abundance}}}{\sqrt[4]{15}}$$

The individual species PIT values are summed to calculate the PIT sample value. If none of the three species are present, then the sample PIT = 0.

Step five: calculate the raw RBI:

Raw RBI = TWV + NIT + (2 X PIT)

Step six: calculate the RBI Score, normalizing the Raw RBI by the minimum and maximum Raw RBI values in the index development data:

RBI Score = (Raw RBI - 0.03)/4.69

The final step is to compare the RBI Score to the RBI thresholds, determining the RBI category.

Table 4. RBI Category Thresholds

RBI Score	Category	Category Score
> 0.27	Reference	1
> 0.16 to ≤ 0.27	Low Disturbance	2
> 0.08 to ≤ 0.16	Moderate Disturbance	3
≤ 0.08	High Disturbance	4

River Invertebrate Prediction and Classification System (RIVPACS)

The RIVPACS index calculates the number of reference taxa present in the test sample (observed or "O") and compares it to the number expected to be present ("E") in a reference sample from the same habitat (SCCWRP 2008).

Step one: Determine the probability of the test sample belonging to twelve Southern California Marine Bays reference sample groups. The sampling bottom depth, latitude, and longitude are needed for this step.

Step two: determine the identity and expected number of reference species for each sample, based on the probabilities of group membership calculated in Step 1 and the distribution of reference species in each group.

Steps one and two use a computer program to calculate the values. The calculations can be made at the Utah State University Western Center of Monitoring and Assessment of Freshwater Ecosystems website (USU 2009). To use this site data must be put into a format that the program recognizes. There are five files necessary to run the program. Two files, one with habitat data and the second file with macrofauna data are prepared by the user. Three files are provided that contain relevant southern California information on the reference sample group means, inverse covariance matrix, and macrofauna data (SCCWRP 2008). The data are entered into the Utah State University site and the RIVPACS scores determined are compared to the threshold categories and be given a Category Score.

Table 5. RIVPACS Category Thresholds

RIVPACS Score	Category	Category Score
> 90 to <1.10	Reference	1
> 0.74 to ≤ 0.90 or > 1.10 to < 1.26	Low Disturbance	2
>0.32 to ≤ 0.74 or > 1.26	Moderate Disturbance	3
≤ 0.32	High Disturbance	4

Integrate Benthic Index Category Scores

The four benthic index category scores were combined to create a single benthic index. The integrated scores were calculated by taking the median of the four individual index category scores. If the median falls between two categories the value is rounded up.

Table 6. Index Category Score

Category	Category Score
Reference	1
Low Disturbance	2
Moderate Disturbance	3
High Disturbance	4

Appendix B
Survey Results

Appendix B-1. Infaunal master species list. Mugu Lagoon, 2011.

PHYLUM
- Subphylum or Class
  - Species

NEMERTEA (NE)
- Anopla
  - Lineidae
- Enopla
  - Hoplonemertea
  - *Paranemertes californica*

NEMATODA (NT)
  - Nematoda

MOLLUSCA (MO)
- Gastropoda
  - *Acteocina inculta*
  - *Haminoea vesicula*
  - *Tryonia imitator*
- Bivalvia
  - *Cumingia californica*
  - *Leukoma staminea*
  - *Macoma nasuta*
  - *Macoma secta*
  - *Rochefortia tumida*
  - *Tagelus* sp

ANNELIDA (AN)
- Polychaeta
  - *Armandia brevis*
  - *Capitella capitata* Cmplx
  - *Ctenodrilus serratus*
  - *Glycera macrobranchia*
  - *Glycinde polygnatha*
  - *Hemipodia borealis*
  - *Mediomastus ambiseta*
  - *Mediomastus californiensis*
  - *Notomastus tenuis*
  - *Ophiodromus pugettensis*
  - *Paranoides platybranchia*

PHYLUM
- Subphylum or Class
  - Species

ANNELIDA (AN) (Cont.).
- Polychaeta
  - *Pectinaria calforniensis*
  - *Platynereis bicanaliculata*
  - *Polydora cornuta*
  - *Polyophthalmus pictus*
  - *Prionospio (Minuspio) lighti*
  - *Pseudopolydora paucibranchiata*
  - *Spiochaetopterus costarum* Cmplx
  - *Spiophanes duplex*
  - *Streblospio benedicti*
- Oligochaeta
  - Oligochaeta

ARTHROPODA (AR)
- Maxillopoda
  - Harpacticoida
- Malacostraca
  - *Allorchestes angusta*
  - Dolichopodidae (pupa)
  - *Excirolana chiltoni*
  - *Grandidierella japonica*
  - *Haplocytheridea maia*
  - *Monocorophium acherusicum*
  - *Monocorophium* sp
  - *Monocorophium uenoi*
  - *Neotrypaea* sp
  - *Oxyurostylis pacifica*
- Ostracoda
  - *Cyprideis miguelensis*
  - *Cyprideis stewarti*
  - Podocopida

PHORONA (PR)
- Phoronida
  - *Phoronopsis* sp

Appendix B-2. Infauna results by station. Mugu Lagoon, 2011.

		Station						Percent
Phylum	Species	ML3	ML6	ML14	ML15	ML74	Total	Total
NT	Nematoda	11	632	26	42	6	717	26.03
AR	*Oxyurostylis pacifica*	-	178	300	-	3	481	17.47
AR	*Monocorophium acherusicum*	-	2	-	306	-	308	11.18
AN	Oligochaeta	-	159	108	15	20	302	10.97
AR	*Grandidierella japonica*	4	-	-	282	-	286	10.38
AR	Harpacticoida	-	-	-	-	176	176	6.39
AN	*Notomastus tenuis*	6	97	-	-	3	106	3.85
MO	*Acteocina inculta*	-	20	26	-	-	46	1.67
AR	*Monocorophium uenoi*	-	-	1	36	8	45	1.63
AN	*Capitella capitata* Cmplx	1	-	-	34	1	36	1.31
AR	*Allorchestes angusta*	-	17	-	2	15	34	1.23
AN	*Hemipodia borealis*	16	-	-	-	14	30	1.09
AN	*Mediomastus ambiseta*	-	23	1	-	-	24	0.87
MO	*Macoma nasuta*	-	22	1	-	-	23	0.84
AN	*Streblospio benedicti*	-	16	1	3	-	20	0.73
NE	Lineidae	-	13	1	-	-	14	0.51
AN	*Mediomastus californiensis*	-	11	1	-	-	12	0.44
AR	*Cyprideis miguelensis*	-	-	-	-	12	12	0.44
AN	*Armandia brevis*	-	-	-	-	10	10	0.36
AN	*Pseudopolydora paucibranchiata*	-	1	-	-	9	10	0.36
AN	*Glycinde polygnatha*	-	6	2	-	1	9	0.33
AN	*Paranoides platybranchia*	-	-	-	5	-	5	0.18
NE	*Paranemertes californica*	-	1	2	1	1	5	0.18
MO	*Macoma secta*	1	-	2	-	1	4	0.15
AN	*Prionospio (Minuspio) lighti*	-	3	-	-	-	3	0.11
AN	*Spiophanes duplex*	-	1	2	-	-	3	0.11
AR	*Neotrypaea* sp	-	-	1	-	2	3	0.11
MO	*Tagelus* sp	-	1	2	-	-	3	0.11
AN	*Polydora cornuta*	-	-	-	2	-	2	0.07
AN	*Spiochaetopterus costarum* Cmplx	-	-	-	-	2	2	0.07
AR	*Monocorophium* sp	-	-	2	-	-	2	0.07
MO	*Cumingia californica*	2	-	-	-	-	2	0.07
MO	*Rochefortia tumida*	-	-	2	-	-	2	0.07
MO	*Tryonia imitator*	-	2	-	-	-	2	0.07
AN	*Ctenodrillus serratus*	-	1	-	-	-	1	0.04
AN	*Glycera macrobranchia*	-	-	-	1	-	1	0.04
AN	*Ophiodromus pugettensis*	-	-	1	-	-	1	0.04
AN	*Pectinaria californiensis*	-	1	-	-	-	1	0.04
AN	*Platynereis bicanaliculata*	-	-	-	-	1	1	0.04
AN	*Polyophthalmus pictus*	-	-	-	-	1	1	0.04
AR	*Cyprideis stewarti*	-	-	-	-	1	1	0.04
AR	Dolichopodidae (pupa)	-	1	-	-	-	1	0.04
AR	*Excirolana chiltoni*	-	-	-	1	-	1	0.04
AR	*Haplocytheridea maia*	-	-	-	-	1	1	0.04
AR	Podocopida	-	-	-	-	1	1	0.04
MO	*Haminoea vesicula*	-	-	-	1	-	1	0.04
MO	*Leukoma staminea*	-	1	-	-	-	1	0.04
NE	Hoplonemertea	-	-	-	-	1	1	0.04
PR	*Phoronopsis* sp	1	-	-	-	-	1	0.04
	Number of individuals	42	1209	482	731	290	2754	
	Number of species	8	23	19	14	23	49	
	Diversity (H')	1.63	1.62	1.21	1.39	1.68	2.36	

Appendix B-3. Infaunal wet weight biomass data (g). Mugu Lagoon, 2011.

	Station					
	ML3	ML6	ML14	ML15	ML74	Total
Annelida	0.9249	3.4849	0.1852	0.2731	0.9355	5.8036
Arthropoda	0.0150	0.3301	0.3795	0.9666	0.0742	1.7654
Mollusca	<0.0001	13.4826*	0.790	<0.0001	<0.0001	0.7904
Misc.	0.0789	0.1132	0.0076	<0.0001	<0.0001	0.1997
Total	1.0188	3.9282	1.3627	1.2397	1.0097	8.5591

Note: - = no animals

* 2 large Macoma nasuta weighing 8.1601 g