MUGU LAGOON PLANE CRASH SITE
BENTHIC MACROINVERTEBRATE JULY 2011 SURVEY

July 2012 Report

Under Contract With:

California Department of Fish and Game
Office of Spill Prevention and Response

Prepared For:

Point Mugu NRDA Trustees
And
Omega Air, Inc

MUGU LAGOON PLANE CRASH SITE
BENTHIC MACROINVERTEBRATE JULY 2011 SURVEY

July 2012 Report

Prepared For:

Point Mugu NRDA Trustees
and
Omega Air, Inc
10315 Wetmore Road
San Antonio, TX 78216

Prepared By:

Weston Solutions, Inc.
2433 Impala Drive
Carlsbad, California 92010
and
California Department of Fish and Game (CDFG)
Office of Spill Prevention and Response (OSPR)
Aquatic Bioassessment Laboratory (ABL)
9300 Elk Grove Florin Road
Elk Grove, California 95624

TABLE OF CONTENTS

1.0 EXECUTIVE SUMMARY 1
2.0 INTRODUCTION 2
2.1 Incident Background and Summary of Response Actions 2
2.2 Point Mugu Marsh & Lagoon Habitats and Plant Community (with prior conditions, as available) 4
2.2.1 Topography/Hydrology 5
2.2.2 Biology 5
2.3 NRDA Injury Assessment Zones 5
2.3.1 Zone 1 5
2.3.2 Zone 2 6
2.3.3 Zone 3 7
2.3.4 Zone 4 7
2.3.5 Reference Zones 7
2.4 Overview of Potential Impacts on Biota 9
2.4.1 Chemical and Physical Impacts from the Crash and Response Actions 9
2.4.2 Potential Impacts to BMI: Water Quality Conditions at Point Mugu 9
3.0 BMI Study Rationale and Objectives 10
3.1 BMI Study Roles and Responsibilities 11
4.0 METHODS 12
4.1 BMI Study Design 12
4.2 Field Sampling 19
4.3 Field Sample Processing 19
4.4 Laboratory Sample Processing 20
4.4.1 BMI Taxonomy and Identification 20
4.4.2 Analytical Quality Control 21
4.4.3 Subsampling Quality Assurance (Sample Remnant Evaluation) 21
4.4.4 Internal Taxonomic Identification QA 21
4.4.5 Contract or External Taxonomic Identification QA 21
4.5 Data Analysis 22
5.0 RESULTS 23
5.1 BMI Field Survey Observations 23
5.2 Water Quality and Physical Habitat Information 26
5.2.1 Water Quality Data 26
5.2.2 Sediment Total Organic Carbon (TOC) and Sediment Particle Size Data 29
5.2.3 Zone Habitat Types 31
5.3 BMI Laboratory Observations 31
5.4 BMI Community Composition and Metrics 35
5.4.1 Including & Excluding Ostracoda Taxa 35
5.4.2 BMI Community at Affected Zones 1 through 4 35
5.4.3 BMI Community at Reference Zones 6 and 7 38

5.4.4 Comparison of BMI Communities at Affected Zones 1 through 4 with Reference Zones 6 and 7 39
Top Five Dominant Taxa (%) 41
5.5 BMI Community Condition Analysis 46
5.6 Cluster Analysis 48

6.0 SUMMARY 50

7.0 CONCLUSION 52

8.0 REFERENCES 54

APPENDICES
A: Site Reconnaissance Photograph Log
B: BMI Site Survey Photograph Log
C: Water Quality Data
D: Grain Size and Total Organic Carbon (TOC) Laboratory Reports
E: Taxonomic Listing of Benthic Macroinvertebrates
F: Metric and Summary Metric Values of Benthic Macroinvertebrates
G: Material Safety Data Sheets (MSDS)
H: BMI Site Sampling and Analysis Plan
I: Physical Habitat Data Sheets and Field Notes
J: Laboratory Bench Sheets
K: Quality Assurance/Quality Control Data Sheets
L: Chain of Custody (COC) Forms

LIST OF FIGURES

Figure 1. Aerial photograph of site with Injury Assessment Zones and Impact Types. 8
Figure 2. BMI Sampling Locations, Zones 1 and 2. 1
Figure 3. BMI Sampling Locations, Zone 3 1
Figure 4. BMI Sampling Locations, Zone 4. 1
Figure 5. BMI Sampling Locations, Reference Zone 6 and Reconnaissance (Water Quality Location), Reference Zone 5. 1
Figure 6. BMI Sampling Locations, Reference Zone 7. 1
Figure 7. Silver and rainbow sheen observed in Zone 1 (Debris Pool). Field crews noted petroleum odor at this boundary area. Photo taken on 28 June 2011 by A. Montalvo, CDFG-OSPR. 24
Figure 8. Note abundant, empty gastropod casings (California Horn Snail / *Cerithidea californica*) and some recent vegetation growth (Pickleweed / *Salicornia*) in Zone 1 (Debris Pool). Photo taken on 28 June 2011 by A. Montalvo, CDFG-OSPR. 25
Figure 9. Fourth of five dead crabs observed in Zone 1 (Debris Pool). Note burned exoskeleton and dead vegetation with clear physical fire injury. Photo taken on 28 June 2011 by A. Montalvo, CDFG-OSPR. 26
Figure 10. Mean Water Chemistry Data Recorded at Reconnaissance (Reference Zone 5) and Benthic Core Sampling Zones (all other zones) in Response to the Point Mugu Plane Crash Incident. Samples were collected on 19-20 July 2011 at the Point Mugu NBVC, California. 28
Figure 11: Mean Grain Size and Total Organic Carbon (TOC) Data Recorded at Reconnaissance and Benthic Core Sampling Zones in Response to the Point Mugu Plane Crash Incident. Samples were collected on 19-20 July 2011 at the Point Mugu NBVC, California 30
Figure 12. Presence and abundance of recent dead snails within BMI samples from Zones 1 and 2 for individual site replicates. Percentages were based on the number of recent dead to the number of total dead for that taxonomic group. No recent dead snails were present in BMI samples from Zones 3 and 4. 33
Figure 13. Presence and abundance of recent dead snails within BMI samples from Reference Zone 7 for individual site replicates. Percentages were based on the number of recent dead to the number of total dead for that taxonomic group. No recent dead snails were present in BMI samples from Reference Zone 6. 34
Figure 14. Relative abundance data (excluding Ostracoda Taxa) presented as zone means for benthic core samples collected at reference and impact zone boundaries in response to the Point Mugu Plane Crash Incident. Samples were collected on 19-20 July 2011 at the Point Mugu NBVC, California. 36
Figure 15: Top five metric data results (excluding Ostracoda Taxa) presented as zone means for benthic core samples collected at reference and impact zones in response to the Point Mugu Plane Crash Incident. Samples were collected on 19-20 July 2011 at the Point Mugu NBVC, California 43
Figure 16: Composition measure data results (excluding Ostracoda Taxa) presented as zone means for benthic core samples collected at reference and impact zones in

response to the Point Mugu Plane Crash Incident. Samples were collected on 19-20 July 2011 at the Point Mugu NBVC, California 44
Figure 17. BMI Sampling Locations with Percent Composition Metrics (without Ostracoda Taxa) of BMIs Collected from the Point Mugu Crash Site, July 2011. 1
Figure 18: Cluster Analysis of Sites and BMI Taxa Collected from the Point Mugu Crash Site, July 2011 49

LIST OF TABLES

Table 1: Point Mugu BMI technical subgroup. 11
Table 2: Benthic station descriptions and waypoint data collected during the BMI assessment conducted in response to the Point Mugu Plane Crash Incident. Samples were collected on 19-20 July 2011 at the Point Mugu NBVC, California..... 13
Table 3: Primary Bioassessment Metrics Used to Describe Characteristics of the BMI Community at Sites Collected for the Point Mugu Plane Crash Incident on 19-20 July 2011, Ventura County, California 23
Table 4. Point Mugu Crash Site Sediment Particle Size Analysis Results, 19-20 July 2011 Survey. 29
Table 5. Occurrence and Abundance of Recent Dead Snails in BMI Samples by Site and Taxonomic Group 32
Table 6. Results of BMI metrics for mean taxonomic richness, Shannon Diversity, mean relative abundance and top five taxa presented by as site averages within each zone for the Pt. Mugu Plane Crash NRDA Study conducted in July 2011, Ventura County, CA 41
Table 7: Benthic Community Condition Analysis for Samples Collected from the Point Mugu Crash Site, July 2011 47
Table 8: Common Names, Relative Tolerance, and Feeding Groups for Taxa Collected from the Point Mugu Crash Site, July 2011. Taxa are included in order from cluster analysis above. 50
Table 9. Summary of observed physical and biological impacts and differences in BMI sediment community by assessment zone 52

1.0 EXECUTIVE SUMMARY

The overall objective of the study was to assess possible impacts to the existing benthic macroinvertebrate (BMI) assemblages inhabiting the Mugu Lagoon salt marsh system after an emergency crash landing of a Boeing 707 aircraft on May 18, 2011. The overall hypothesis being tested is whether the crash (and associated impacts) adversely affected the BMI community within and between the four assessment zones. Zone 1 was directly and physically impacted by the crash overall and corresponding clean-up, whereas Zones 2, 3 and 4 were primarily exposed to changes in hydrology and fuel. Neighboring areas on base that were not impacted by the crash or clean-up efforts were evaluated as baseline or reference zones (Reference Zones 6 and 7; no BMI samples were collected from Reference Zone 5). The study assessed the BMI benthic community, primarily the *in situ*, sedentary BMI present in sediment cores with incidental (non-systematic) field observations of motile and/or water column species. The study also characterized the sediment and water quality conditions for each zone. A reconnaissance survey was conducted on 28 June 2011, followed by the benthic sampling survey on 19-20 July 2011, approximately 2 months after the crash.

BMI samples were collected from marsh habitats which included organisms that reside on surface sediments (epifauna) and others that live beneath the surface and other substrata of the sediment-water interface (infauna) using a six-inch diameter by four-inch deep coring device. Following standardized methods, a target count of 500 organisms (where possible) were processed and identified in the laboratory according to Surface Water Ambient Monitoring Program (SWAMP) methods (http://swamp.mpsl.mlml.calstate.edu/). Sediment was analyzed for grain size and total organic carbon, and water quality parameters included temperature, pH, conductivity, salinity, dissolved oxygen, and turbidity. Additional field observations were made during site reconnaissance and BMI sampling visits documenting physical habitat (sediment characteristics) and site observations (petroleum odor, presence of hydrocarbon petroleum sheen, dead BMI organisms (dead crabs and snails) or high abundance of specific insect groups, woody debris, and/or algae mats on the water surface) were also recorded at each benthic station.

Tables and figures were created to visually present and summarize benthic metric data for each sampled location. Statistical analyses consisted of a two-way cluster analysis of taxa and stations, and a Benthic Community Condition Analysis that categorized sites into disturbance levels based on BMI community structure. These different lines of evidence were considered in determining the overall condition of the benthic communities and differences between impacted/affected zones as compared to non-impacted/baseline reference zones.

Major findings:

- Dead crabs and snails were observed on-site in Zone 1 during the initial response, BMI reconnaissance visit and benthic sampling survey. Clusters of dead crabs were also observed in Zones 3 and 4 during the initial response. In addition, recent dead snails were present in BMI sediment core samples in greater numbers from Zones 1 and 2 than from Reference Zone 7. No recent dead snails were present in BMI samples collected from Zone 3, Zone 4, or Reference Zone 6. All other aspects of the BMI study were based upon live organisms present in benthic sediment core samples.

- Zone 1, in the immediate vicinity of the crash site debris field, had a lower quality benthic community than Reference Zones 6 and 7, as well as Zones 2, 3, and 4. This finding is based on the fact that Zone 1 had the lowest organism diversity and very few burrowing infaunal organisms. This finding was corroborated by the cluster analysis, which placed the Zone 1 sites in a distinctly separate cluster from all other zones. Zone 1 was populated almost entirely with Ostracoda (seed shrimp), a moderately motile organism with high fertility rates that would have re-colonized the zone shortly after the plane crash. Ostracods are very tolerant, commonly inhabit highly disturbed areas, and are a transitory group. One sample in Zone 1 was in very poor condition, with a total abundance of two organisms representing one taxon of Ephydridae (brine flies). Zones 2, 3, and 4 had higher quality BMI communities than Zone 1 and both reference zones. Greater tidal exchange at these sites is likely the primary driver of increased benthic community quality. Since a reference zone that more closely matched these conditions at Zones 2 to 4 was not available, it is unknown whether a less predominant impact associated with the temporary change in hydrology and fuel exposure would have been evident. These findings were also independent of the observations of dead crabs in Zones 3 and 4 immediately following the crash since *Hemigrapsis* and *Pachygrapsis*, the two crab species observed in the lagoon, are primarily shoreline dwellers and would not likely have been captured in a subtidal benthic core.
- The baseline conditions present at Mugu Lagoon overall are naturally stressed by the ecological conditions, such as sediment grain size and organic carbon and salinity, and generally vary based on extent of tidal exchange. Reference Zones 6 and 7 had very limited to no tidal exchange and had distinctly different BMI communities from one another. Based on a Benthic Community Condition Analysis, all of the sites in the study area showed moderate to high disturbance levels, including the reference zones.

2.0 INTRODUCTION

2.1 Incident Background and Summary of Response Actions

On the evening of 18 May 2011, a Boeing K707 aerial refueling tanker, carrying jet fuel, operated by Omega Air, Inc., crashed during take-off on Runway 21 into Mugu Lagoon at the end of Taxiway Alpha. Up to 10,000 gallons of the fuel (JP-8) may have been lost in the crash, an unknown portion of which was released into the marsh (meeting, 23 May 11, 1330). The crash scattered debris and different portions of the plane throughout the overall Omega Air Crash (OAC) site, scoured tracks into the marsh, and left the remaining fuselage partially buried in the mudflat. A Unified Command (UC) was instituted immediately following the incident on 18 May 2011 consisting of staff from Naval Base Ventura County (NBVC), California Department of Fish and Game Office of Spill Prevention and Response (CDFG-OSPR), U.S. Coast Guard (USCG), U.S. Fish and Wildlife Service (USFWS), and the aircraft owner Omega Air, Inc. The Unified Command was established to oversee the emergency response, clean-up operations and to mitigate potential impacts to the entire 2,500-acre Mugu lagoon. A high tide had occurred overnight when darkness limited actions to control and document fuel transport. Response actions conducted on 19 May 2011 were more extensive and included (1) installation of sandbags at the various culverts to reduce further transport of fuel through Mugu Lagoon and (2) surveys to identify presence of fuel, debris, and any oiled wildlife. Dead biota observed during the initial response included dead crabs and snails in Zone 1 and dead crabs in Zones 3 and 4. As

a result of the containment dams, average tidal fluctuations at the OAC Site changed from an estimated 0 to +5 feet mean sea level (msl) before placement to +2 to +3 feet msl after installation (Insight, 2011c).

Salvage operations to remove the crash debris and the plane fuselage were conducted by Patriot Environmental Services in early June (Patriot, 2011). Phase I involved debris removal by hand and with limited use of heavy equipment. Based on planning conducted in Phase II, Phase III activities included the salvage and removal of the remaining major components of the airframe from the waterway areas adjacent to the end of the runway. Those actions required the (1) placement of temporary roadways (crane mats) at both ends of the plane, (2) use of cranes to move larger pieces whereas smaller pieces were dragged via a truck winch, (3) removal of fuel from the wing, and (4) additional containment and sorbent boom across the adjacent marsh/mudflat.

Following the removal of the aircraft fuselage and crash debris from the lagoon, an Initial Assessment Study (IAS) was conducted in June 2011 to identify and assess the sites potential threat to human health and/or the environment. The contaminants of potential concern (COPCs) include metals, volatile organic compounds (VOCs), extractable petroleum hydrocarbons (TPH-e), and semivolatile organic compounds (SVOCs). The IAS involved the collection and analysis of surface and subsurface sediment samples to evaluate potential contamination resulting from the plane crash. Detailed results of the IAS are presented in the *Sediment Sampling Technical Memorandum, Omega Air Crash (OAC) Site, NBVC Point Mugu* (Insight, 2011a). Based on the sediment sample data, the COPCs in sediment at OAC Site were antimony, arsenic, cadmium, lead, molybdenum, vanadium, total petroleum hydrocarbons extractable (TPH-e), benzene, toluene, ethylbenzene, and xylenes (BTEX), and semi-volatile organic compounds (SVOC) (Insight, 2011c). Project Action Limits (PALs) for COPC to support the continued RAA were developed by the Navy Clean-up Program Managers in consultation with CDFG for sediment from 0 to 3 ft below ground surface to protect ecological receptors and human health.

A pre-excavation topographic survey was performed on 21 September 2011 to establish existing grades and to assess the pre-removal site topographic features, such as high and low points. Once the temporary road had been constructed, excavation of the contaminated sediment at the OAC Site began on 6 October 2011. The effectiveness of the remedial action was quantified by analyzing confirmation soil samples obtained from the bottom of each excavation grid cell for site-specific COPCs. Based on those results, two additional rounds of site excavations occurred between 13 and 19 October 2011. On 26 October 2011, all sediment removal activities ceased and no further excavation was necessary. Overall, 2,035 yds^3 total of contaminated sediment were removed (Insight, 2011b; Insight, 2011c). The extent of the excavation and locations of other features are shown on Figures 3-1 and 3-2 of that report (Insight, 2011c).

At the completion of sediment excavation activities, a topographic survey was used to delineate the extents of excavation and the associated backfill required. Backfilling operations at the OAC Site began on 26 October 2011 and concluded on 10 November 2011 (Insight, 2011c). Excavations were backfilled with two sources of material, sediment at the bottom of several excavations within the OAC site and an on-site upland borrow area, a stockpile of former Mugu Lagoon dredge material. The lower portion of the excavation up to 6-8 inches below grade was backfilled with sandier material imported from the borrow site. Due to the unique physiochemical soil characteristics of the Mugu Lagoon mudflat sediment, sediment at the bottom of excavations within cells D1, D2, C2, C3 and B3, once the defined depth of contamination was removed, was used as backfill material. The harvested mudflat sediment was temporarily stockpiled in two areas within the excavation extents in the vicinity of cells D1/E1 and F2 as shown in Figure 3-1 (Insight, 2011c). Following the mechanical backfilling, a 6-inch hydraulic submersible sand/slurry pump was used to place a slurry of the remaining sandy backfill material and upper harvested top cover material (Figure 3-2; Insight, 2011c). Overall, approximately 1,450 yds^3 of imported sediment from the existing on-base borrow site and 585 yds^3 of harvested mudflat material were used during the backfilling event, during which approximately 34,182 ft^2 of mudflat was restored to approximate pre-crash ground surface.

At the completion of all backfill activities, a post-topographic survey was performed during a low tide to assess the post-removal site topographic features. The post-removal survey included areas outside of the excavation where the Aircraft traversed the lagoon creating scour trenches along the path to where it finally came to rest (Figure 1). Re-contouring of the excavations and a post-excavation topographical survey of plane and wing trenches and excavation area were completed by January 2012. Overall, the crash resulted in a fire, the scattering of aircraft debris, and the introduction of fuel and other contaminants into the wetland. Other potential sources of impact include the deposition of ash, the use of fire retardant, changes to hydrology, and cleanup activities, such as removal of debris, excavation of contaminated sediment, and associated equipment use and personnel.

2.2 Point Mugu Marsh & Lagoon Habitats and Plant Community (with prior conditions, as available)

The OAC Site is located on the southern end of the NBVC Air Field, southeast of Runway 3 and Taxiway Alpha, on the western arm of Mugu Lagoon (Figure 1). The Mugu Lagoon has been described and investigated as part of NBVC Installation Restoration Program. In particular, Section 3, Ecological Characterization of the *2005 Environmental Risk Assessment Addendum* provides information regarding habitats and biota present at Mugu Lagoon prior to the crash (Tetra Tech, 2005).

2.2.1 Topography/Hydrology

The OAC Site is at mean sea level (msl) within the Mugu Lagoon mudflats. The topography surrounding the crash site is relatively flat with slightly mounded vegetated wetland areas at 2 feet above msl. Hydrology at the site is influenced by tidal fluctuations from Mugu Lagoon. The tide flows in through the mouth of Mugu Lagoon and then enters the more interior areas through the wider dredged channels and culverts at M St. and L. St. Open water habitats were generally less than one meter deep except in dredged channel areas, and tidal exchange was limited in many parts of the study area. Marsh areas with little or no tidal exchange were subject to seasonally variable salinities. Substrate sediment throughout the study area consisted mostly of unconsolidated fine particulates that were high in organic matter with anoxic conditions occurring very near the substrate surface.

2.2.2 Biology

In the lower intertidal salt marsh, California horn snails (*Cerithidea californica*), lined shore crabs (*Pachygrapsus crassipes*), and yellow shore crabs (*Hemigrapsus oregonensis*) are abundant, and Light-footed Clapper Rails *(Rallus longirostris levipes)* forage (Tetra Tech, 2005). Channels and tidal creeks at Mugu Lagoon are important foraging and resting areas for a variety of bird life, including shorebirds, dabbling and diving ducks, and wading birds. Several special-status species utilize Mugu Lagoon, including the Light-footed Clapper Rail. Tables 3-1 to 3-3 of the 2005 report (Tetra Tech, 2005) list the typical species present within the salt marsh, mud/sand flats, and tidal creek habitats of Mugu Lagoon.

Much of the habitat in the study area is typical of Southern California low salt marsh habitat, and is dominated by halophytic plant species such as pickleweed (*Salicornia* spp.), salt grass (*Distichlis spicata*), and jaumea (*Jaumea carnosa*). The distribution of habitat types within Mugu Lagoon is shown on Figure 3-1 of the 2005 report (Tetra Tech, 2005)

2.3 NRDA Injury Assessment Zones

Four broad injury assessment zones have been identified for the purposes of the NRDA overall and were delineated based on the geographical extents of potential impact types, observations of fuel and dead biota during the response, habitat features, and existing roads/levees (Figure 1). In general, two habitat types occur within these zones: (1) shallow marsh habitat with muted tidal influence that is permanently wetted; and (2) dredged channel habitat with greater tidal influence and currents. The habitat at the Zone 1 crash pool specifically is more distinct with saline mudflat with little tidal influence and subject to periodic inundation and drying. In addition to the impacts associated with the incident, this area is potentially stressed by natural ecological conditions.

2.3.1 Zone 1

Zone 1 is bounded by the runway, Beach Rd., M St., and by the sand bags that restricted flow into Zone 2. It contains the crash pool, debris pool, grounded crash trajectory, and immediately

adjacent areas contained within the sandbag containment berms. The sandbags were placed around the crash site and at the M St. culvert on 19 May 2011. These areas were most likely exposed to immediate, direct physical impacts of the crash and fire, removal of the plane and associated debris, and fuel and fire retardant. The NRDA team agreed to exclude an upland area to the west that was not likely affected by the crash trajectory, fuel or other chemical contaminants, fire and smoke, fire retardant, or debris and sediment removal ("excluded area" on Figure 1). The NRDA team later subdivided Zone 1 based on the extent of excavation in Zone 1A (footprint of the excavation) and 1B (not excavated). However, this sub-zonal distinction was not made for Zone 1 in the BMI assessment since the excavation occurred in October 2011, following the BMI field effort.

1. Crash and Debris Pools: This portion of Zone 1 is the area immediately impacted by the actual final resting place of the plane and a wing, which separated from the main body of the plane. These two sites, or pools, were the most immediately affected by fuel and contaminants leaking from the plane after it landed, melting equipment in the fire, and removal of approximately 2,035 yds^3 of contaminated sediment. Petroleum hydrocarbon sheen (rainbow and silver), ash, plane fragments and debris, and fire retardant residues were observed in Zone 1 during the BMI reconnaissance site visit on 28 June 2011. Dead biota were also observed including shore crabs (*Hemigrapsus nudus*) and horn snails (*Cerithidea californica*), several of which were burnt (Section 5.1 and Appendix A). The sandbags placed around the crash site to restrict flow through the small drainage channels were left in place until mid-November. The excavation and backfill activities are described in Section 1.1 above. The NRDA Team identified the portion of Zone 1 that was excavated as Zone 1A.

2. Remainder of Zone 1: The remaining area of Zone 1 outside of the crash and debris pools contains the trenches caused by wing and plane trajectory through the marsh (see Figure 1) and immediately adjacent areas within the most proximate set of sandbag containment berms that were installed on 19 May 2011. These areas were the most likely exposed to immediate, direct physical impacts of the crash and fire (and associated changes in water quality), removal of the plane and associated debris, and fuel and fire retardant. Surface water flow was restricted or muted (water flow was never completely eliminated) to facilitate ongoing remediation until it was completed in mid-November 2011. Turbidity/silt curtain booms were placed across the marsh/mudflats around the sediment excavation areas to minimize transport of fuel and suspended sediment (Figure 3-1, Insight, 2011c). The NRDA Team identified this area, in addition to the non-excavated areas of the crash and debris pools, as Zone 1B.

2.3.2 Zone 2

Zone 2 is bounded by the runway, M St., 17th St., and to the South by the sand bags restricting flow from Zone 1 into Zone 2. Sand bags at the M St. Culvert were removed 26 May 2011, whereas those around Zone 1 were removed following excavation and backfill in mid-November 2011. This area was less likely to be exposed to direct impacts of fire, but was exposed to fuel and potential hydrological changes. Disturbances to physical habitats and hydrology due to cleanup actions in the adjacent areas of Zone 1 likely occurred.

2.3.3 Zone 3

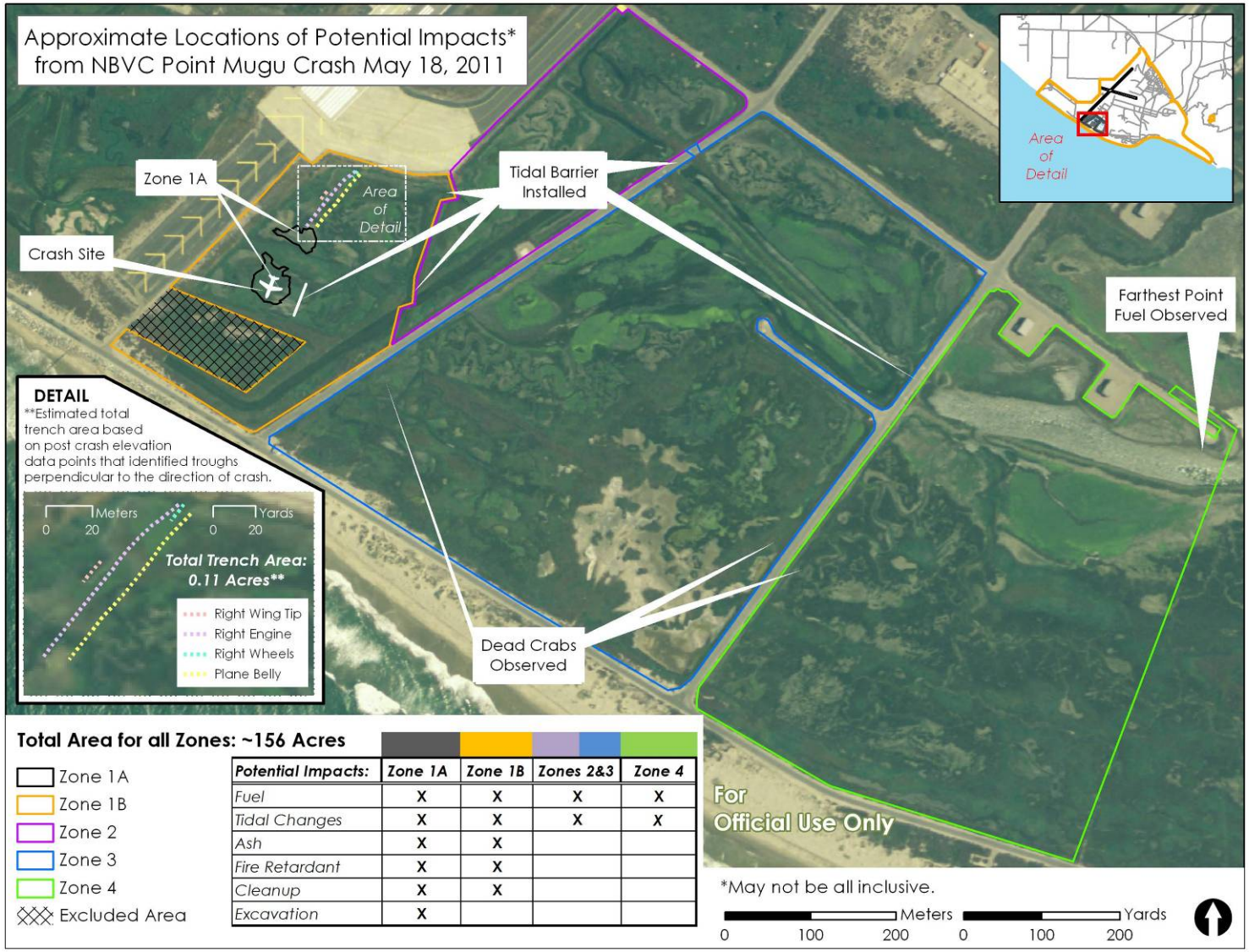
Zone 3 is bounded by M St., L St., 17th St., and Beach Road. Surface water flow into and out of this area is through culverts at M St. and L St. Sand bags reduced flow from 19-20 May for M St. and L St. culverts, respectively until they were removed on 26 May 2011. This area likely lacks direct physical impacts from the crash and fire, but contains locations where fuel sheen and dead crabs were observed and collected by NBVC staff during the initial response.

2.3.4 Zone 4

Zone 4 is bounded by L St., 17th St., Beach Road, and to the east by the end of 17th St. (the furthest east fuel sheen was observed). The eastern boundary of Zone 4 was a line extending from the end of 17th St. down to Beach Road approximately parallel to M St. and L St. Surface water flow into this area from the west (Zone 3) was reduced until the L St. culvert was opened 26 May 2011. Zone 4 includes locations where dead crabs were observed and collected by NBVC staff during the initial response.

2.3.5 Reference Zones

In addition to available information on the pre-spill, baseline conditions of Mugu Lagoon, reference areas were also included to compare post-spill conditions between the affected zones and nearby areas with similar habitats (*i.e.*, Reference Zones), to the extent available. The specific areas selected are described in Section 4.1.



Potential Impacts:	Zone 1A	Zone 1B	Zones 2&3	Zone 4
Fuel	X	X	X	X
Tidal Changes	X	X	X	X
Ash	X	X		
Fire Retardant	X	X		
Cleanup	X	X		
Excavation	X			

Figure 1. Aerial photograph of site with Injury Assessment Zones and Impact Types.

2.4 Overview of Potential Impacts on Biota

Overall, the crash resulted in a fire, the scattering of aircraft debris, and the introduction of fuel and other chemical contaminants into the wetland. Other potential sources of impact include the deposition of ash, the use of fire retardant, changes to hydrology, and clean-up activities, such as removal of debris, excavation of contaminated sediment, and associated equipment use and personnel. Additional details on these potential impacts to biota associated with the incident are described below.

2.4.1 Chemical and Physical Impacts from the Crash and Response Actions

The crash resulted in a release of jet fuel from the cargo. Jet-propulsion fuel 8 (JP-8) is a kerosene-based multipurpose fuel that is in wide use by the U.S. military (NRC, 2003). Per the material safety data sheet (MSDS) for this product, JP-8 is complex combination of hydrocarbons including naphthenes, paraffins, and aromatics (www.hovensa.com/pdf/jp8.pdf; Appendix G). The primary components are 100% kerosene [Chemical Abstracts Service (CAS) # 8008-20-6] and 0.04% naphthalene (CAS# 91-20-3). Numerous studies have demonstrated the toxicity of the aviation fuel mixture and kerosene and naphthalene individually to both freshwater and marine biota. For example, kerosene exposure to marine invertebrates (periwinkles and marine snails) altered their ability to attach to substrate and find food (Straughan *et al*., 1978; Jacobson and Boylan, 1973). As noted in Section 1, the COPCs in sediment within the debris and crash pools (Zone 1) included metals, BTEX, and SVOCs (in addition to petroleum hydrocarbons) that exceeded project action limits (Insight, 2011c). In general, Zone 1 areas that had contaminant exceedances were subsequently excavated to depths below contamination.

The fire, use of fire retardant, and ash residues had associated chemical and physical impacts. In addition to water, a fire retardant was used to control the fire resulting from the plane crash. The fuel was then allowed to burn without any further addition of retardant. The MSDS for the specific chemical mixture used is provided in Appendix G (http://www.vanguard-fire.com/msds/afff/6(AFC-3)MaterialSafetyDataSheet.pdf).

As described above, the plane crashed through the marsh with the main fuselage skidding through the northern debris pool, through the vegetated berm separating the two pools and coming to rest in the southern crash pool. The other major pieces of wreckage were found in the debris pool although other debris was scattered throughout Zone 1. The initial impact, the subsequent removal of the wreckage (by hand, crane, or dragged via winch), and movement of personnel and heavy equipment, physically injured the marsh/mudflat habitat in the immediate vicinity. The placement and maintenance of containment features, such as silt currents, boom, and sandbags, also had direct impacts to the underlying habitat. In addition to the direct physical impacts, disturbance to wildlife in adjacent areas would also be expected from the initial crash and fire, and the subsequent response that lasted for almost 7 months following the spill.

2.4.2 Potential Impacts to BMI: Water Quality Conditions at Point Mugu

Background water quality and biological conditions present at Point Mugu are variable and naturally stressed due to the physical and ecological surroundings. Baseline conditions include

anoxic (dark soils) silty-clay sediments and minimal to no tidal flushing or freshwater inputs yielding warmer water temperatures, low dissolved oxygen levels, high conductivity, and high salinity.

The plane crash, fire, and associated response actions altered the pre-existing hydrology and water quality within the assessment zones. Several wetted channels and small drainages in Zone 1 (Crash Site and Debris Pool) were impacted by fires that significantly increased water and sediment temperatures, altered water quality, and caused physical injury to marsh habitats. During the initial phases of response operations, flow between areas of Point Mugu was altered by placement of sandbags, which altered the amount and mechanism of tidal inputs and flushing. These conditions likely resulted in rapidly changing and artificially higher water temperatures, increased salinity and conductivity levels, low percent oxygen (% O_2), and dissolved oxygen (DO) levels.

Water bodies with elevated daily water temperature have a reduced ability to hold oxygen and approach near anaerobic environmental conditions, thus decreasing dissolved oxygen levels that are vital to sustain aquatic biota. These conditions result in a shift in the benthic assemblage to pollution tolerant insect groups. Insects must get all oxygen directly from the atmosphere in oxygen compromised systems. Organisms occupying these harsh and extreme habitats usually range from moderate to highly tolerant insect taxa and have adapted to these conditions by developing highly transitory or short-lived life cycles, being highly motile, and having the ability to reproduce in high numbers. These insect groups can tolerate a wide range of salinities and can survive temperatures from 0º C to 30º C. Taxa that are indicators of mid-range water quality include: Isopoda (sow bug), Amphipoda (scuds), Bivalvia (clams and mussels) and Tipulidae (crane flies). Insect groups that are indicators of poor water quality would include: oligochaetes (aquatic worms), Chironomidae (midge-fly), Syrphidae (flower fly), Physidae (left-handed snail), and Tricladida (planariid flatworms).

3.0 BMI STUDY RATIONALE AND OBJECTIVES

Overall, the NRDA seeks to identify injuries to natural resources present at the OAC resulting from the crash and associated impacts. A large portion of the habitat present at the OAC site is mudflat. The NRDA team considered BMI as an important component of that community and an indicator of potential injuries. Therefore, the NRDA team proceeded to plan and implement a BMI study, led by CDFG-OSPR and Weston scientists.

The overall objective of the study was to assess possible impacts to the existing BMI assemblages in the Mugu Lagoon salt marsh system from the crash landing of a Boeing 707 aircraft. This assessment documented the abundance, diversity, and taxa present throughout different injury assessment zones potentially affected by the crash (and associated impacts) as well as appropriate reference areas. The overall hypothesis being tested is whether the crash (and associated impacts) adversely affected the BMI community at the site, and secondarily, if the degree of adverse effects varies with the expected extent and severity of potential impacts between the four zones.

In general, the NRDA team preferred to conduct the study relatively soon after the crash occurred, but prior to sediment excavation in Zone 1. However, access to the site was restricted

until after salvage operations occurred and outside periods of active air operations. Due to these and other factors, field reconnaissance work for the BMI study did not begin until late June 2011. The subsequent BMI sampling occurred in mid-July, approximately two months after the crash. Given the variable life-history of BMIs, this delay likely differentiated individual insect groups and the overall benthic assemblage that were more diverse and stable, less tolerant to chemical pollution and habitat degradation, less mobile and longer-lived when compared to insect groups that were more motile, highly reproductive with short life cycles. However, the expected change in BMI due to seasonality and differences in environmental conditions between mid-May and mid-July is likely *de minimus*. A second BMI survey that would have been conducted following sediment excavation occurred was considered initially, but no further planning or implementation resulted.

In order to meet these objectives, the following actions were conducted by OSPR and Weston staff: (1) an initial reconnaissance visit, (2) development of a Sampling and Analysis Plan (SAP), (3) field sampling, (4) laboratory processing and taxonomic identification, (5) data analysis, and (6) report preparation. This report details the methodology used and presents the results of the BMI site sampling and laboratory analysis.

3.1 BMI Study Roles and Responsibilities

Table 1 identifies those individuals who were responsible for the major tasks of this project or are part of the Point Mugu BMI technical subgroup.

Table 1: Point Mugu BMI technical subgroup.

Title	Name (Affiliation)
Program Manager	Lisa Markovchick [Naval Facilities Engineering Command (NAVFAC) Southwest (SW)]
Environmental Scientist	Angie Montalvo (CDFG-OSPR)
Contractor Biologist	Bill Isham (Weston Solutions, Inc.)
Staff Toxicologist	Beckye Stanton (CDFG-OSPR)
Senior Toxicologist	Mike Anderson (CDFG-OSPR)
Natural Resource Specialist	Valerie Vartanian (NBVC)
Natural Resource Manager	Martin Ruane (NBVC)
Omega Air Point of Contact	Roger Hewlett (Omega Air)
Fish and Wildlife Biologist	Denise Steurer (USFWS)

4.0 METHODS

4.1 BMI Study Design

The four injury assessment zones described above formed the overall basis for spatial distribution of BMI sampling locations. A reconnaissance survey was conducted on 28 June 2011 to evaluate the crash site and debris pool, assess areas surrounding the crash site, identify potential reference areas, and to identify locations of benthic sampling stations. Field crew members included Angie Montalvo (CDFG-OSPR), Bill Isham (Weston Solutions, Inc.), Lisa Markovchick (NAVFAC SW), Martin Ruane, and Valerie Vartanian (both NBVC). Based upon the reconnaissance visit, three areas on Point Mugu outside of Mugu Lagoon were considered potential reference zones for the BMI assessment and were designated Reference Zones 5, 6, and 7. These areas were deemed reference for the purpose of this study because they would not have been impacted by the plane crash and had environmental conditions similar to the affected areas.

Information from the reconnaissance survey was used to create a BMI sampling and analysis plan (SAP), establishing methodologies to be used for the study (Weston, 2011; Appendix H). The proposed study focused primarily on the assessment of in situ, sedentary BMI present in sediment cores with incidental (non-systematic) field observations of motile and/or water column species. All planned benthic sediment core stations were placed in targeted areas within each of the Zone boundaries. However, exact locations were determined in the field based on site accessibility (restricted areas and safety measures), habitat type and to accompany preceding sampling efforts (chemistry and sediment samples), visual observations of sheen, petroleum odor, and observations of dead crabs and snails in areas of each zone. All samples targeted wetted areas that lacked emergent vegetation (i.e., similar to the habitats in the immediate vicinity of the OAC Site).

The field survey and BMI sample collection was conducted on 19-20 July 2011 by biologists from the CDFG-OSPR, NAVFAC SW, NBVC, and Weston Solutions, Inc. All four assessment zones (Zones 1 to 4) had three sites each, whereas Reference Zone 6 had two sites and Reference Zone 7 had one site. This lower number of sites within the reference zones was based, in part, on the relatively smaller size of the reference zones and general desire to conserve effort. Zone 4 BMI Sites 1 and 2 (408PMZ4S1 and 408PMZ4S2) are in open water areas more open to tidal exchange than the other zones, while Site 3 includes shallow marsh habitats similar to those in Zones 1, 2, and 3. Reference Zone 5 was eliminated during the BMI sampling survey due to differences in substrate characteristics (*i.e.* hard and compact), very high salinity and conductivity values, and an apparent lack of observed BMI. Three replicate samples (R1, R2 and R3) were collected within each sampling site where each replicate location was selected using a random approach during the survey. A list of sampling Zones and Sites are listed in Table 1 and maps of the study area, including BMI sampling locations, are shown in Figures 2 through 6.

Table 2: Benthic station descriptions and waypoint data collected during the BMI assessment conducted in response to the Point Mugu Plane Crash Incident. Samples were collected on 19-20 July 2011 at the Point Mugu NBVC, California.

BMI Site Code	Laboratory Sample Code	Site Description	Latitude/ Longitude	Sampling Date
		Zone 1		
Z1S1R1-3	**408PMZ1S1**	Zone 1, Site 1 (Crash Pool, Affected Zone, Replicates 1 - 3)	34.106696 / -119.134744	19 July 2011
Z1S2R1-3	**408PMZ1S2**	Zone 1, Site 2 (Crash Pool, Affected Zone, Replicates 1 - 3)	34.106927 / -119.135136	19 July 2011
Z1S3R1-3	**408PMZ1S3**	Zone 1, Site 3 (Debris Pool, Affected Zone, Replicates 1 - 3)	34.107249 / -119.134251	19 July 2011
		Zone 2		
Z2S1R1-3	**408PMZ2S1**	Zone 2, Site 1 (Affected Zone, Replicates 1 - 3)	34.108268 / -119.132078	19 July 2011
Z2S2R1-3	**408PMZ2S2**	Zone 2, Site 2 (Affected Zone, Replicates 1 - 3)	34.109030 / -119.130356	19 July 2011
Z2S3R1-3	**408PMZ2S3**	Zone 2, Site 3 (Affected Zone, Replicates 1 - 3)	34.106172 / -119.133281	20 July 2011
		Zone 3		
Z3S1R1-3	**408PMZ3S1**	Zone 3, Site 1 (Affected Zone, Replicates 1 - 3)	34.105935 / -119.133285	19 July 2011
Z3S2R1-3	**408PMZ3S2**	Zone 3, Site 2 (Affected Zone, Replicates 1 - 3)	34.106364 /-119.126290	19 July 2011
Z3S3R1-3	**408PMZ3S3**	Zone 3, Site 3 (Affected Zone, Replicates 1 - 3)	34.105103 / -119.127433	19 July 2011
		Zone 4		
Z4S1R1-3	**408PMZ4S1**	Zone 4, Site 1 (Affected Zone, Replicates 1 - 3)	34.105870 / -119.126489	19 July 2011
Z4S2R1-3	**408PMZ4S2**	Zone 4, Site 2 (Affected Zone, Replicates 1 - 3)	34.105259 / -119.122916	19 July 2011
Z4S3R1-3	**408PMZ4S3**	Zone 4, Site 3 (Affected Zone, Replicates 1 - 3)	34.104068 / -119.128012	19 July 2011
		Reference Zones		
RZ5S1R1	**408MRZ5S1**	Reference Zone 5, Site 1 (Water and Sediment Quality only, No BMI collected)	34.119807 / -119.156728	20 July 2011
RZ6S1R1-3	**408MRZ6S1**	Reference Zone 6, Site 1 (Replicates 1 - 3)	34.109856 / -119.140281	20 July 2011
RZ6S2R1-3	**408MRZ6S2**	Reference Zone 6, Site 2 (Replicates 1 - 3)	34.111320 / -119.140120	20 July 2011
RZ7S1R1-3	**408MRZ7S1**	Reference Zone 7, Site 1 (Replicates 1 - 3)	34.106997 / -119.102848	20 July 2011

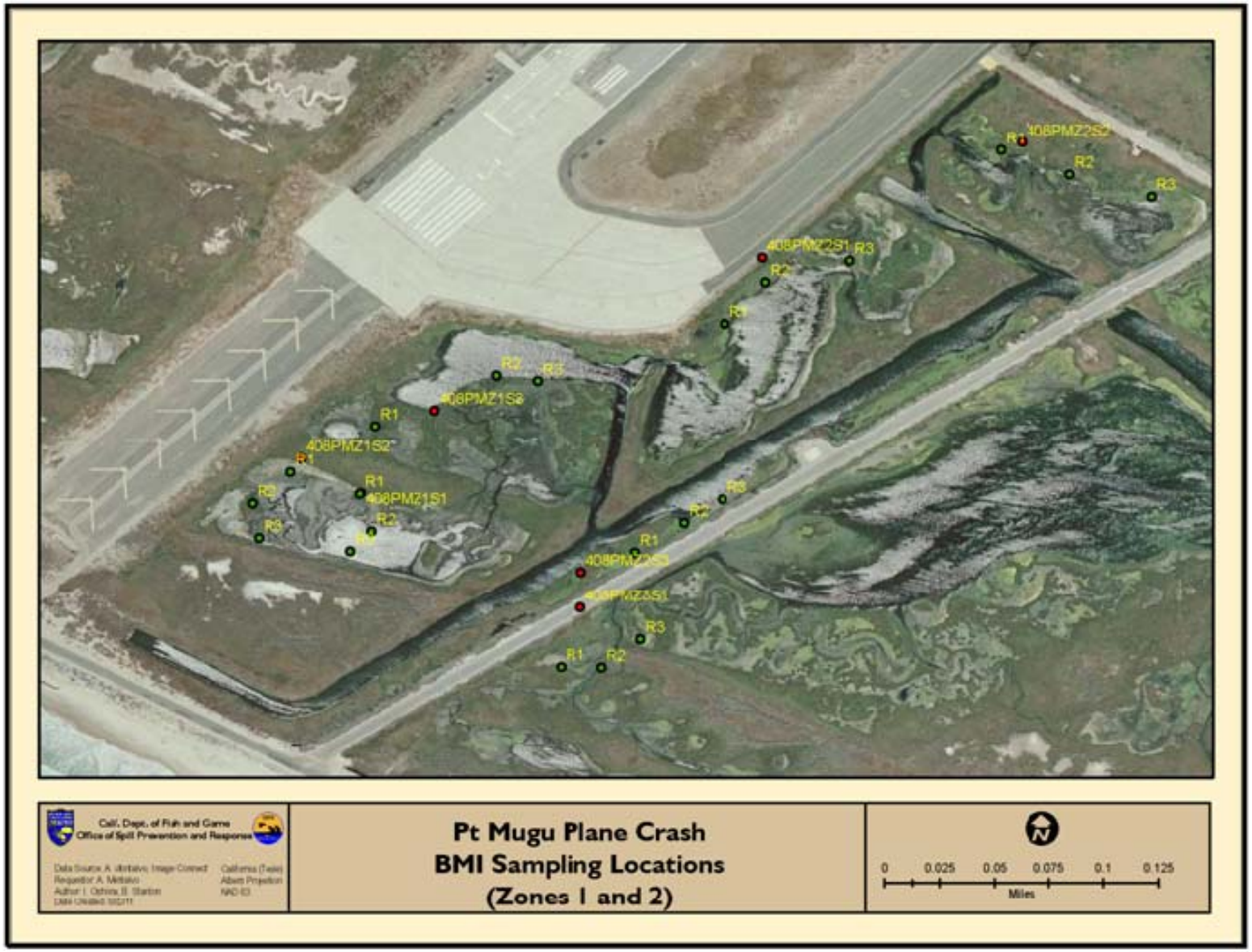


Figure 2. BMI Sampling Locations, Zones 1 and 2.

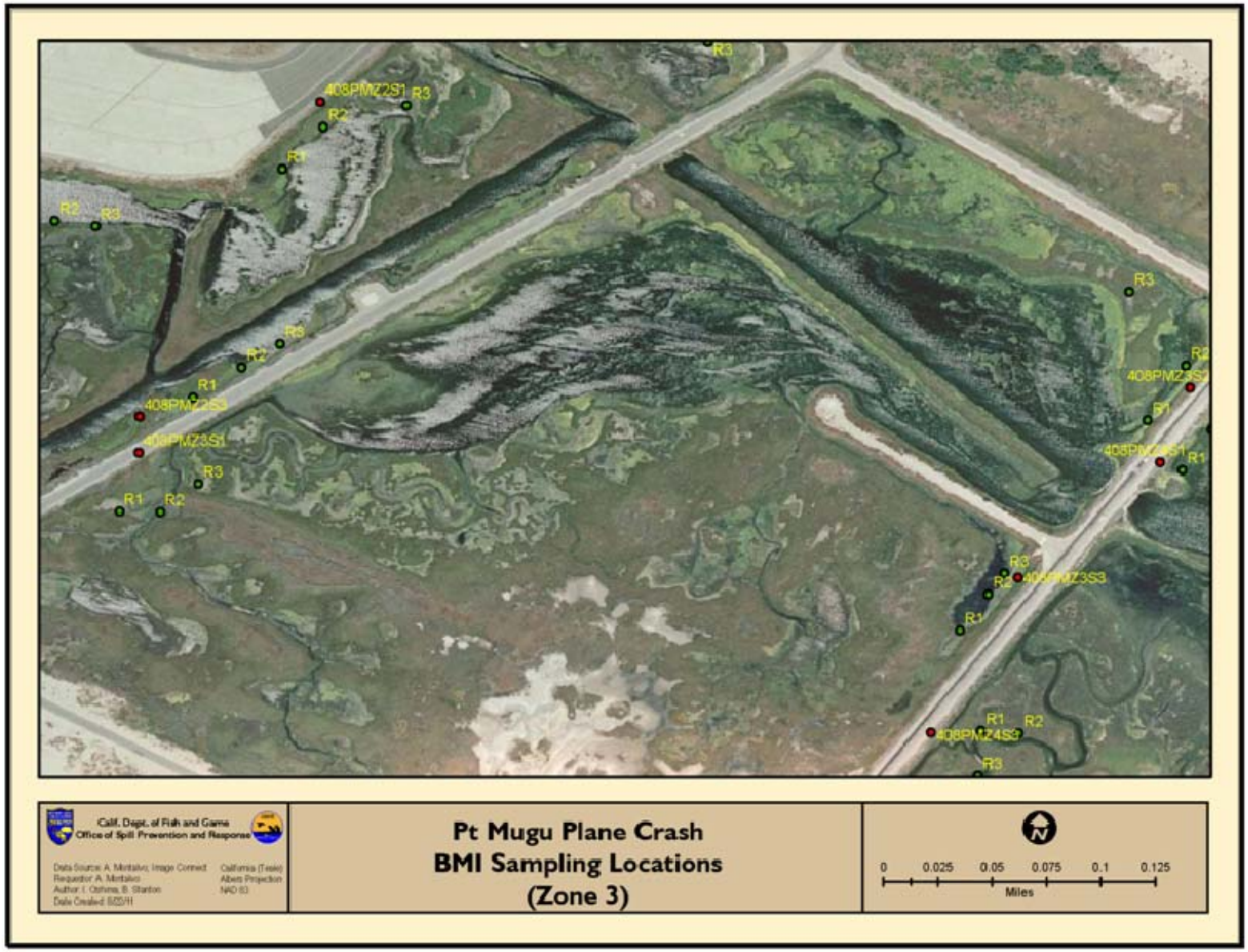


Figure 3. BMI Sampling Locations, Zone 3

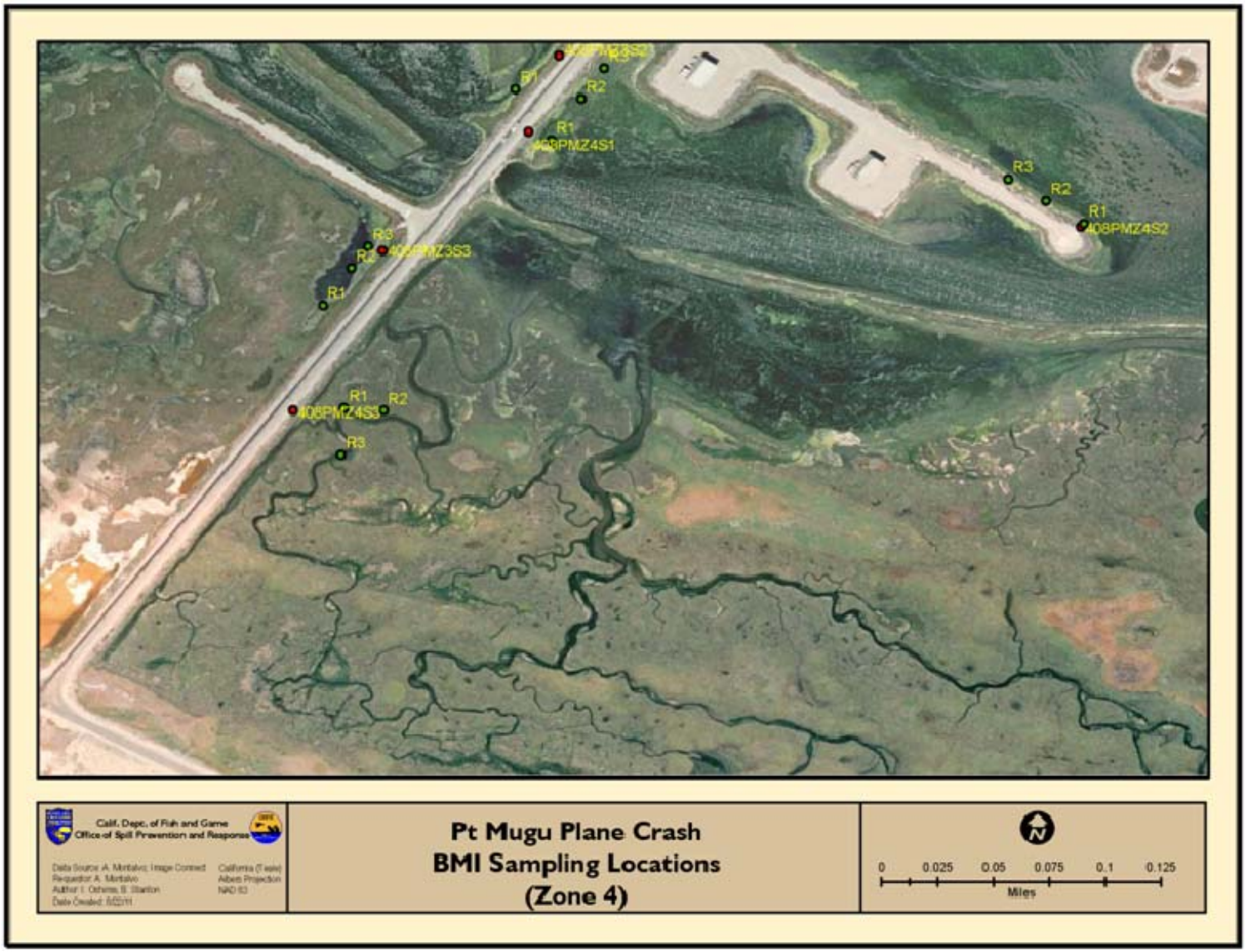


Figure 4. BMI Sampling Locations, Zone 4.

Figure 5. BMI Sampling Locations, Reference Zone 6 and Reconnaissance (Water Quality Location), Reference Zone 5.

Figure 6. BMI Sampling Locations, Reference Zone 7.

4.2 Field Sampling

Benthic sampling was conducted on 19-20 July 2011, three weeks after the reconnaissance visit and two months after the crash occurred. Field crew members included Angie Montalvo and Jennifer Gold (both CDFG-OSPR), Bill Isham (Weston Solutions, Inc.), and Lisa Markovchick (NAVFAC SW). Sampling locations were located in shallow subtidal margins, generally within five to 10 feet from the shoreline. Benthic core samples were collected at areas where water depths ranged from 18 to 20 inches (0.46 to 0.51 meters), or approximately knee level. All samples were collected using a 6-inch (0.15 meter) diameter polyvinyl chloride (PVC) core sampler to sample a benthic surface area of 182.4 cm^2. Core samples were obtained by pushing the sampler into the bottom sediment to a depth of 4 inches (0.10 meter). If the sampler recovered more than 4 inches of sediment, then only the top 4 inches of sample material was collected. Three replicate core samples (R1, R2 and R3) were collected at each site within a zone. Additional sediment samples were randomly collected from the top three inches of sediment at a sub-set of sites to document sediment particle size and total organic carbon (TOC). This analysis was performed to characterize sediment characteristics present at the BMI sampling locations. Water quality data (water temperature, conductivity, salinity, dissolved oxygen, percent oxygen, pH, and turbidity) were recorded at each sampling location immediately prior to collecting the BMI sample to avoid increases in suspended sediment. Bill Isham (Weston Solutions, Inc.) used a calibrated YSI™ 6820 V2 water quality analyzer and Angie Montalvo (CDFG-OSPR) used a calibrated YSI™ Model 85 multi-parameter water quality analyzer and an Oakton Waterproof pHTestr 30 for all water quality data collection. In addition to water quality data, basic physical habitat data (sediment characteristics) and site observations (visual observations of sheen, petroleum odor, dead organisms or high abundance of specific insect groups, woody debris, and/or algae mats on the water surface) were also recorded at each benthic station. Physical habitat conditions at each sampling location were assessed using U. S. Environmental Protection Agency field data forms provided in the National Coastal Conditions Assessment: Lll000 Field Operations Manual (USEPA, 2009). Copies of the physical habitat field data sheets are included in Appendix I.

4.3 Field Sample Processing

After removing the 6-inch sediment core from the sampler, each sample was elutriated to reduce the volume of sediment. The sample was placed into a d-frame kick net with a 500-micron mesh and washed to remove as much fine sediment as possible. If necessary, the sample was then transferred to a 500-micron mesh sieve (#35) for additional washing. The remaining contents (organisms and sample material) were placed into a 500 ml or 1.0 L wide-mouth jar with an identification label, and preserved in 95% denatured ethanol. All samples were properly labeled and standard Chain of Custody (COC) forms were completed on-site following the completion of benthic survey work on 20 July 2011. All samples collected in the field were transported by following standard COC procedures and by employing appropriate forms providing accountability and documentation of sample integrity. The samples were distributed to one of two laboratories for further analysis. Fifty percent of the BMI sampled stations were sent to the OSPR Aquatic Bioassessment Laboratory (ABL; Zones 1, 3, and Reference Zone 6; 24 samples) and 50% (Zones 2, 4, and Reference Zone 7; 21 samples) were sent to Weston Solutions' Carlsbad Benthic Laboratory.

4.4 Laboratory Sample Processing

Both OSPR ABL and Weston Solutions bioassessment laboratories processed the BMI core samples according to Surface Water Ambient Monitoring Program (SWAMP) methods (http://swamp.mpsl.mlml.calstate.edu/). BMI samples were logged in and each given a unique identification number. Benthic samples were then retrieved from the laboratory sample depository and sample numbers were cross-checked with a bioassessment laboratory number on COC forms. The contents of the sample jar were emptied into a 500-micron mesh sieve (#35), and thoroughly rinsed with water. After the sample was rinsed, debris larger than ½-inch was manually cleaned and removed including leaves, twigs and rocks. Filamentous algae and skeletonized leaves were not removed from the sample. Additional information (odor, type of sheen, soil type, empty shells and recent dead snail counts, condition of sample, etc.) was recorded during subsampling and noted on the Laboratory Bench Sheet (Appendix J and Table 5). After the sample was cleaned, material was placed into a plastic tray marked with equally sized, numbered grids. Excess water was not allowed to enter the tray. The moist, cleaned debris was then spread evenly on the bottom of the tray covering as many grids as necessary to obtain an approximate thickness of ½-inch. All samples were sorted until 500 organisms had been picked, or if less than 500 organisms were obtained, the entire sample was sorted. The organisms were then placed in a clean Petri dish containing 70% denatured ethanol. The remaining organisms in the last grid(s) were then counted as extras, but were not included with the 500 organisms used for identification. Debris obtained from the processed grids (remnant material) was stored in a clean jar labeled “remnant” and the remaining or “un-picked” contents of the tray were placed back into the original sample jar. Both jars were filled with fresh 70% denatured ethanol, labeled with the bioassessment laboratory number, all data recorded on the original data label, and designated as either original or remnant. The jars were then returned to the sample depository. The final counts for each sample were recorded on a Microsoft Excel® (Excel) spreadsheet.

4.4.1 BMI Taxonomy and Identification

At both laboratories, all benthic organisms sorted from each sample were identified to the lowest practicable taxon using appropriate taxonomic keys, as recommended by the Southwest Association of Freshwater Invertebrate Taxonomists (SAFIT, 2011) for freshwater taxa, and the Southern California Association of Marine Invertebrate Taxonomists (SCAMIT, 2011) for marine taxa. Identified BMIs were placed in individual glass vials for each taxon. Each vial contained a label with the taxonomic name, bioassessment laboratory number, project name, water body name, county, collection date, and taxonomist’s name. This voucher collection was also labeled and stored in the sample depository. Taxonomic information was recorded on a Macroinvertebrate Laboratory Bench Sheet (Appendix J). The bench sheet also included the watershed or project name; sampling date; sample ID number; bioassessment laboratory number; date of subsampling; name of subsampler; portion of sample sorted; remnant jar number; taxonomy completion date; name of taxonomist; taxonomic list of organisms and enumeration; total number of organisms; total number of taxa; list of unknowns, problem taxonomic groups, and comments. Some organisms were in error or difficult to identify due the following reasons: poor condition, very young or early in-star, and group unfamiliarity.

4.4.2 Analytical Quality Control

Internal Quality Control (QC) was conducted by both ABL and Weston Solutions taxonomists on samples that were processed by laboratory staff at the ABL Chico facility and Weston Solutions' Carlsbad benthic laboratory. Internal QC procedures were conducted to address two specific stages of sample processing: the subsampling ("picking" and "sorting") stage and taxonomic identification stage.

4.4.3 Subsampling Quality Assurance (Sample Remnant Evaluation)

All remnant samples collected for this pollution incident were examined by a QC taxonomist at the time subsampling was completed by ABL Chico and Weston Solutions laboratory staff. These samples were examined for organisms that may have been overlooked during subsampling. The number of unpicked BMIs (if any) and their identity was recorded on a Quality Control Worksheet. For subsamples containing 500 or more organisms, the remnant sample should contain fewer than 10% of the total organisms subsampled. These remnants should contain fewer than 50 organisms for samples containing fewer than 500 organisms. Quality Control data results for remnant sample checks are presented in Appendix K and are also retained as archived hardcopy files at the OSPR ABL facilities located in Elk Grove and Chico and Weston Solutions' Carlsbad Laboratory.

4.4.4 Internal Taxonomic Identification QA

Taxonomic identifications were evaluated by the ABL QC taxonomist with the goal of checking the accuracy and consistency of individual taxonomists. Twenty percent of ABL's portion of 24 samples were randomly selected and then checked for taxonomic accuracy. All taxa from each of the randomly selected samples were re-identified by the ABL QC taxonomist and the number of specimens in each vial was re-checked and verified. Any errors in taxonomy, including misidentification, multiple taxa per vial, counting error, and deviation from standard taxonomic effort (STE) were recorded in spreadsheet form. These data were analyzed with QC MANAGER, an ACCESS© program that summarizes the types of discrepancy and their frequencies.

4.4.5 Contract or External Taxonomic Identification QA

It is standard protocol that the ABL be contracted to perform external QA/QC on other independent labs working on special studies, ambient water quality projects, and enforcement or pollution incidents. Therefore, 20% of the samples (as with internal QA above) processed at the Weston benthic laboratory were evaluated for accuracy of taxonomic identifications and specimen counts at OSPR ABL. In addition to the standard 20% of samples that underwent QC, questionable organisms were sent to Tony Phillips, a regional expert in Southern California marine invertebrate taxonomy, for confirmation. QC identifications and counts were compared with the original identifications, any discrepancies were checked to verify that the ABL is not responsible for the error, and a final report was sent to Weston Solutions.

4.5 Data Analysis

Following the completion of sample processing, taxonomic identification, and QA/QC by both laboratories, both data sets were combined. OSPR ABL received all Weston Solutions replicate data with SWAMP level taxonomy and combined it with the OSPR ABL data to produce a joint taxonomic dataset. This new combined dataset was then QC checked by both OSPR and Weston Solutions staff to ensure that all data was accurately transferred to the new spreadsheet. The joint dataset, and a corresponding taxonomic list, was then compiled into an Excel workbook file and entered into an Excel spreadsheet program to calculate and summarize BMI community based metrics and indices. Standard statistical methods were used for all data analyses presented in this report. Data are presented as means of replicates by site (*i.e.*, "site-wide means") and as means of site-wide means by zone (*i.e.*, "zone-wide means"). In general, the results as zone-wide means are presented in the Results section below and the data as site-wide means and/or as individual replicate results are included in the appendices.

The list of BMI metrics and their general responses to impairment are described below (Table 3). Initial evaluation of the BMI data revealed that the group Ostracoda had a patchy distribution with very low (or absent) to very high abundances even between nearby sites. In addition, Ostracods can reproduce rapidly and prolifically, are relatively motile, and may colonize a disturbed site very quickly. The extreme abundances and patchiness of the Ostracods could disproportionally affect the statistical analyses. Therefore, their inclusion could obscure changes in more sensitive, less motile, or taxa that are slower to colonize. In order to address these issues, the group Ostracoda was excluded from the BMI metric calculations. This decision was discussed with the NRDA BMI technical sub-group (Table 1).

In order to compare the overall quality of the BMI communities at each site, two statistical methods were used. The first was the benthic community condition assessment. This is a multimetric technique that incorporates BMI community metrics, organism stressor (or disturbance) tolerance, and feeding strategies to provide a quantitative summary index for each site. The final index value is then converted into a qualitative rating for each site (e.g., low disturbance or high disturbance). The second method was a cluster analysis, which consists of a two-way comparison of taxa present by site. This technique shows which sites are similar (or dissimilar) based on BMI community composition, independent of physical factors or organism stressor tolerance.

In addition to the BMI sampling metric data results, information collected during reconnaissance work at Mugu Lagoon was also incorporated into a joint dataset. This additional information included habitat data for all zones and observations of petroleum sheen or dead organisms within Zones 1 through 4 as part of the BMI study. Information collected by OSPR and Weston Solutions during the selection and sampling of BMI stations was used to determine habitat types, which were based primarily on channel type, vegetation, salinity levels, and tidal inputs influencing flushing events. Estimates of degree of potential impact by zone were based on field observations and data collected by the response, BMI reconnaissance surveys, BMI assessment as well as sediment and water quality data.

Table 3: Primary Bioassessment Metrics Used to Describe Characteristics of the BMI Community at Sites Collected for the Point Mugu Plane Crash Incident on 19-20 July 2011, Ventura County, California

BMI Metric	Description	Response to Impairment
Taxonomic Richness	Total number of individual taxa	Decrease
Cumulative Taxa	Total number of cumulative taxa	Decrease
Abundance (#/ sample)	Estimated number of BMIs in sample calculated by extrapolating from the proportion of organisms counted in the subsample	Variable
Percent Dominant Taxon	Percent composition of the most abundant single taxon	Increase
Shannon Diversity Index	General measure of sample diversity that incorporates richness and evenness (Shannon and Weaver, 1963)	Decrease
Tolerance Value (TV)	Value between 0 and 10 weighted for abundance of individuals designated as pollution tolerant (higher values) or intolerant (lower values)	Increase
Percent Insect Taxa	Percent composition of taxa in Class Insecta	Variable
Percent Non-Insect Taxa	Percent composition of non-insect taxa	Increase
Percent Marine Infauna Taxa	Percent composition of fauna typical of marine environments; these taxa are a component of the non-insect taxa group	Variable
Percent Oligochaeta	Percent composition of aquatic worm individuals; these taxa are a component of the non-insect taxa group	Variable

5.0 RESULTS

5.1 BMI Field Survey Observations

During the BMI reconnaissance effort conducted on 28 June 2011, dead BMI organisms (crabs and snails) were observed within and surrounding the Debris Pool area in Zone 1 and along the edges of pools at the Crash Site section of Zone 1. The dead organisms consisted of shore crabs (*Hemigrapsus nudus*) and California horn snails (*Cerithidea californica*), and included several that demonstrated evidence of physical burn and fire injury to the exoskeleton (Figure 10; Photo 9, Appendix A). The BMI field team noted five dead shore crabs (Photos 6-9; Appendix A) in a 15-meter by 15-meter area and estimated several hundred dead and/or empty horn snail casings (Figure 9; Photos 11-12, Appendix A) in an area of the crash trajectory in Zone 1 (Crash Site and Debris Pool; Affected Sites).

During the benthic assessment conducted on 19-20 July 2011, additional dead crabs and empty snail shells were observed in Zone 1 (Crash Pool, Debris Pool, and crash trajectory area); however, none were observed in Zones 2 through 4 nor in Reference Zones 6 and 7. As described above, dead crabs were previously observed in Zones 3 and 4 during the initial response (Section 1.4 and Figure 1).

Both rainbow and silver sheen were observed and noted in wetted areas and in moist sediments of Zone 1 (Figure 8; Photo 5, Appendix A and I) during both the BMI site reconnaissance and benthic sampling visits. In particular, rainbow sheen was observed at Zone 1, Site 1, Rep 2 and Zone 1, Site 3, Rep 2 (Appendix I), and a petroleum odor was noted at all benthic core sites sampled at Zone 1. Fire retardant and small fragments of plane crash debris were also observed in wetted areas, along pool margins, and submerged in sediments in Zone 1 (Crash Site and Debris Pool; Affected Sites).

Figure 7. Silver and rainbow sheen observed in Zone 1 (Debris Pool). Field crews noted petroleum odor at this boundary area. Photo taken on 28 June 2011 by A. Montalvo, CDFG-OSPR.

Figure 8. Note abundant, empty gastropod casings (California Horn Snail / *Cerithidea californica*) and some recent vegetation growth (Pickleweed / *Salicornia*) in Zone 1 (Debris Pool). Photo taken on 28 June 2011 by A. Montalvo, CDFG-OSPR.

Figure 9. Fourth of five dead crabs observed in Zone 1 (Debris Pool). Note burned exoskeleton and dead vegetation with clear physical fire injury. Photo taken on 28 June 2011 by A. Montalvo, CDFG-OSPR.

5.2 Water Quality and Physical Habitat Information

5.2.1 Water Quality Data

Water quality data were collected during the BMI sampling visit in July 2011 and are presented as zone-wide means in Figure 10 and as individual replicate results in Appendix C. Dissolved oxygen levels (and temperatures) were lower at sites sampled early in the morning (*i.e.*, Z2S3R1-3, RZ5S1R1, RZ6S1R1-3). This condition is normal as oxygen is produced during the day by photosynthesis and oxygen levels drop at night because of respiration by plants and animals. As daytime water temperatures increase, the ability to hold oxygen (O_2) decreases and insects must get all O_2 directly from the atmosphere.

Overall, water quality measurements for all zones were within the ranges that might be expected for a lagoon of this type: conductivity between 50 and 100 mS/cm; salinity between 30 and 70 ppt; pH between 7 and 9. Salinity in Zones 2 to 4 and Reference Zone 6 was consistent with that of seawater (~35 ppt), whereas Zone 1 and Reference Zone 7 were hypersaline. This difference is within expectations, due to the varying conditions within the lagoon with regard to tidal flushing

or lack of tidal input. For example, the tide flows into the lagoon at the mouth and then flows through Zone 4. Migration of flow from Zone 4 into Zone 3 and subsequently Zone 3 to Zone 2 was restricted by flow through the culverts at L St. and M St., respectively.

Potential Reference Zone 5 had no tidal inputs or flushing and yielded noticeably higher conductivity (175 mS/cm) and salinity (145 ppt) readings. In addition, Reference Zone 5 had unique substrate characteristics (*i.e.*, hard and compact) and an apparent lack of observed BMI when coring a test sample near the water quality site (RZ5S1R1; Photos 65 through 67, Appendix B). Therefore, Reference Zone 5 was excluded from further evaluation including subsequent BMI sampling due to these differences in water quality and physical habitat parameters.

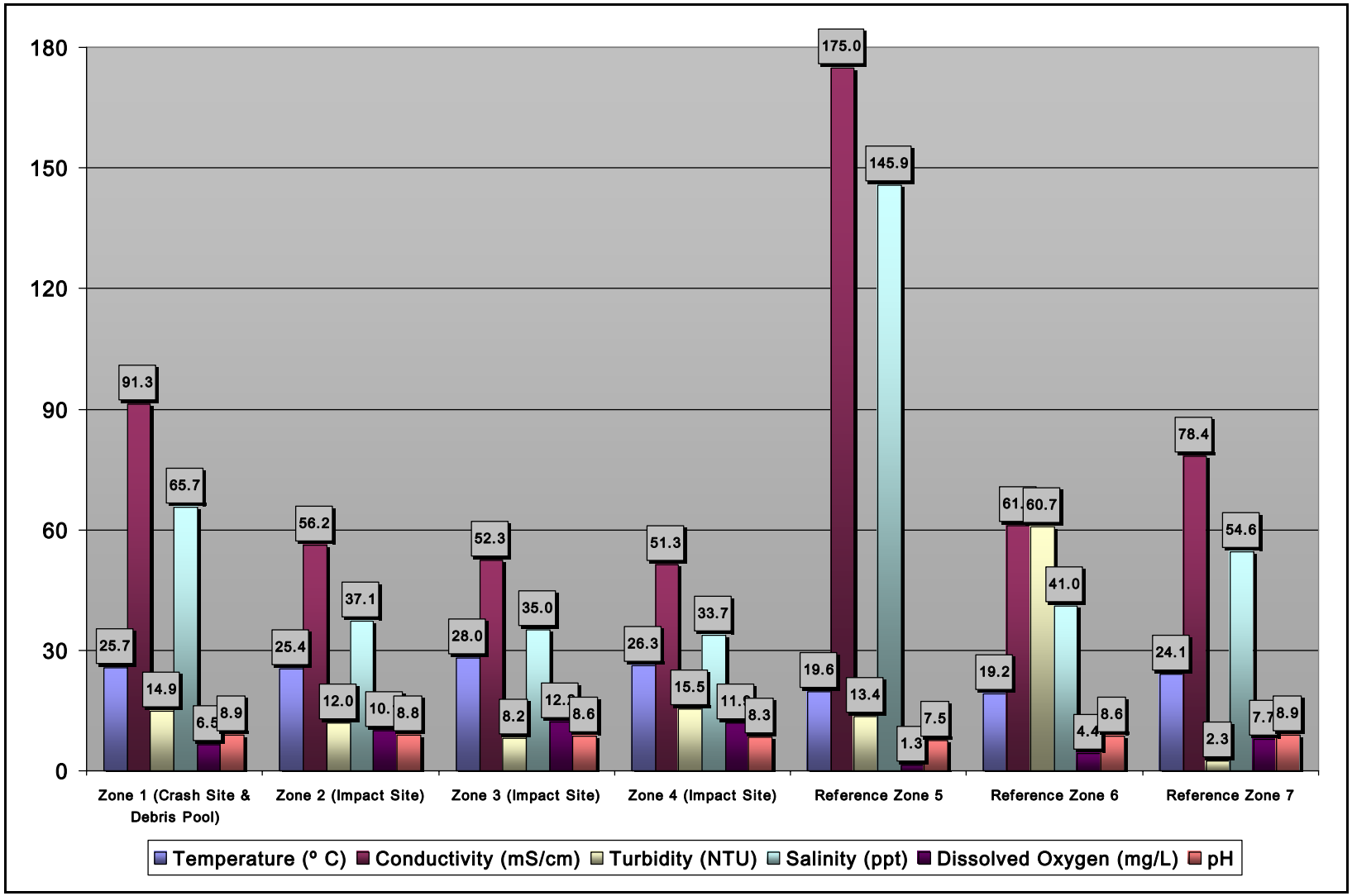


Figure 10. Mean Water Chemistry Data Recorded at Reconnaissance (Reference Zone 5) and Benthic Core Sampling Zones (all other zones) in Response to the Point Mugu Plane Crash Incident. Samples were collected on 19-20 July 2011 at the Point Mugu NBVC, California.

5.2.2 Sediment Total Organic Carbon (TOC) and Sediment Particle Size Data

Sediment TOC and particle (grain) size data are presented as zone-wide means in Table 4 and graphically in Figure 11 and the laboratory reports containing all TOC and grain size data are presented in Appendix D. These two substrate constituents can have substantial effects on the BMI community. In particular, a combination of high amounts of decaying organic material and fine sediment may create anoxic conditions and produce hydrogen sulfide, which can be toxic to BMI. This type of substrate generally has a thin surface zone suitable for BMI colonization and is dominated by stress tolerant organisms.

All of the sites in the study area had high to very high TOC values (3.0% to 10%), and were dominated by fine particulate sediments (silt plus clay; 53.2% to 92.6%). By comparison, the 2008 Southern California regional average in estuaries was 1.6% TOC and 60.6% fines (Schiff *et al.*, 2011). Some locations (*e.g.*, Zone 2) showed higher TOC relative to grain size. As described above, Reference Zone 7 did not differ greatly from other zones based on water quality, but did differ somewhat from the other zones with regard to grain size. Specifically, Reference Zone 7 had a higher content of sand and gravel and a lower content of silt, although the sample was also comprised of 53% fines. Reference Zone 7 also had a lower TOC value than all of the other sites. Due to its overall similarity with Zone 1, Reference Zone 7 will be retained in further analyses, but its differences with regard to TOC and grain size were noted and considered in analyses, where relevant. The differences between TOC and grain size at the affected sites (Zones 1 through 4) and Reference Zone 6 were not ecologically significant. In addition, the variations in TOC between zones noted above are not likely related to the presence of residual fuel-related contamination in Zone 1. Though the analysis of TOC may detect petroleum hydrocarbons as well, the relative concentrations of organic carbon (in %) compared to the Zone 1 sediment Total Petroleum Hydrocarbons (TPH, in ppm) (Insight, 2011a) demonstrates that the potential contribution would be negligible.

Table 4. Point Mugu Crash Site Sediment Particle Size Analysis Results, 19-20 July 2011 Survey.

Site	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Totals (%)	Fines (%, Silt + Clay)	TOC (%)
Z1S1	0.8	18.3	39.9	41.0	100.0	80.9	5.7
Z2S2	1.1	6.3	46.4	46.2	100.0	92.6	10
Z3S2	0.9	27.6	30.7	40.7	100.0	71.5	6.4
Z4S1	0.1	14.9	41.1	43.9	100.0	85.0	4.2
RZ5S1	0.2	31.4	36.7	31.7	100.0	68.4	3
RZ6S1	0.3	22.7	46.2	30.8	100.0	76.9	7.7
RZ7S1	5.1	41.7	5.8	47.4	100.0	53.2	3

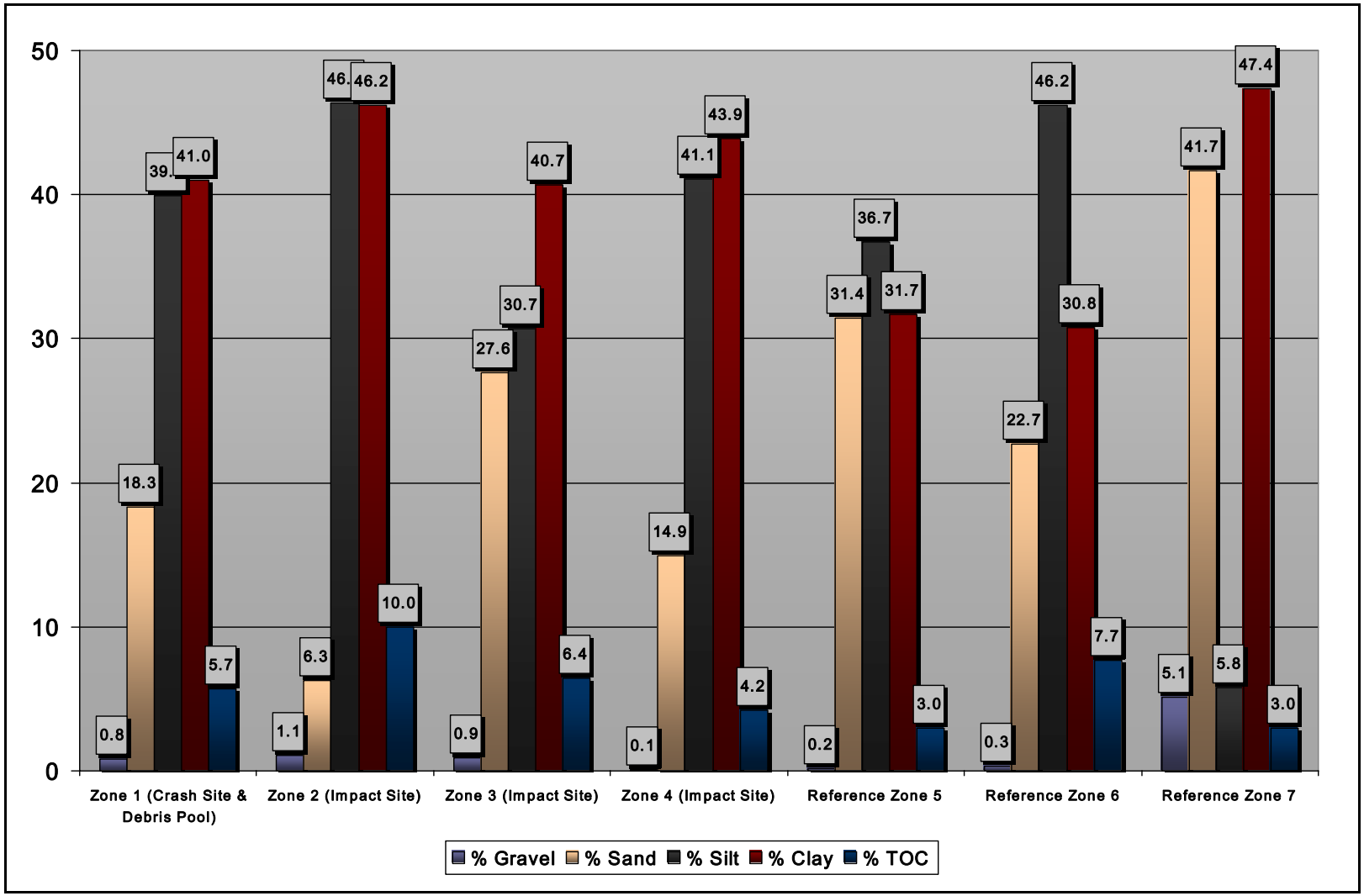


Figure 11: Mean Grain Size and Total Organic Carbon (TOC) Data Recorded at Reconnaissance and Benthic Core Sampling Zones in Response to the Point Mugu Plane Crash Incident. Samples were collected on 19-20 July 2011 at the Point Mugu NBVC, California

5.2.3 Zone Habitat Types

Throughout the study area, the BMI field team endeavored to sample sites with similar habitat conditions. Most sites had shallow water, limited tidal exchange, and similar vegetation and substrate characteristics, as demonstrated with the water quality and sediment characteristic data above (Section 4.1). The one exception to these criteria was Zone 4, Sites 1 and 2, which were located closest to the lagoon inlet from the Pacific Ocean and were where the furthest extent of the fuel sheen was observed. This area had much wider channels with greater tidal currents than the other sites. Zone 4, Site 2 had a more consolidated substrate bottom than all other sites. Zone 4, Site 3 was similar to most other sites with shallow water, reduced tidal exchange, and an unconsolidated fine particulate substrate. Reference Zone 6 received a limited amount of tidal exchange while Reference Zone 7 did not receive any. As mentioned above, Reference Zone 7 had substantially higher salinity and a "spongy" layer (presumed to be algal in origin) on the substrate surface (Photos 74 to 76, Appendix B) that likely inhibited colonization by infaunal organisms. Reference Zone 7 was selected for physical habitat similarities (*e.g.*, caking at margins, sediments, and vegetation) to Zone 1, prior to the crash incident (Photo 74, Appendix B).

5.3 BMI Laboratory Observations

During laboratory sample processing (Section 3.6), the presence of odor, sheen, ash, and burnt sand were recorded for each sample replicate (Appendix J). The number of empty Mollusca shells was recorded by species. In addition, a determination of recent dead or historic dead was made, when possible (Table 5, Figures 12 and 13). The samples from all three Zone 1 sites (Z1/S1/R1, Z1/S1/R2, Z1/S2/R1, Z1/S3/R1, Z1/S1/R3, Z1/S2/R2, Z1/S2/R3 and Z1/S3/R2) had petroleum or chemical odor noted during the subsampling stage of sample processing (Appendix J). Petroleum sheen was observed in four Zone 1 benthic core samples (Z1/S1/R1, Z1/S1/R2, Z1/S2/R1 and Z1/S3/R3) during the cleaning stage of subsampling. Ash was noted in benthic core sample collected at Zone 1 (Site 3, Rep 1). Zone 1 BMI samples had the highest number of empty shell casings with a significant number having physical evidence of burn and fire injury. These burned casings were charred and discolored, and were filled with a mix of ash or burnt sand inside them. In addition to Zone 1, recent dead snails were also present in samples from Zone 2 and Reference Zone 7. The occurrence and abundance of recent dead snails (as number of individuals and percent of total dead) present in BMI samples are shown by sites (Table 5) and by individual replicates (Figures 12 and 13).

Table 5. Occurrence and Abundance of Recent Dead Snails in BMI Samples by Site and Taxonomic Group

Zone[1]	Sample Station	Occurrence of Recent Dead Snails		Abundance of Recent Dead Snails	
		Replicates	Taxonomic Groups	Number	Percentage (%) of Total Dead[2]
Zone 1	Site 1	All	All[3]	1742	10
	Site 2	All	All	2318	10
	Site 3	All	All	1824	10
	Totals			**5884**	
Zone 2	Site 1	R1 and R3	*Cerithidea*	13	25
	Site 2	R1 and R2	*Cerithidea*	17	52
	Site 3	R1 and R2	*Cerithidea*	10	12
	Totals			**40**	
Reference Zone 7	Site 1	R2 and R3	*Cerithidea*	14	33
	Totals			**14**	

[1] No recent dead snails were recorded for BMI samples from Zone 3, Zone 4, and Reference Zone 6.
[2] Percentage of recent dead snails of the total number of dead snails for that taxonomic group (cumulative site totals with all replicates included).
[3] For Zone 1, recent dead snails were present in all taxonomic groups with any dead snails.

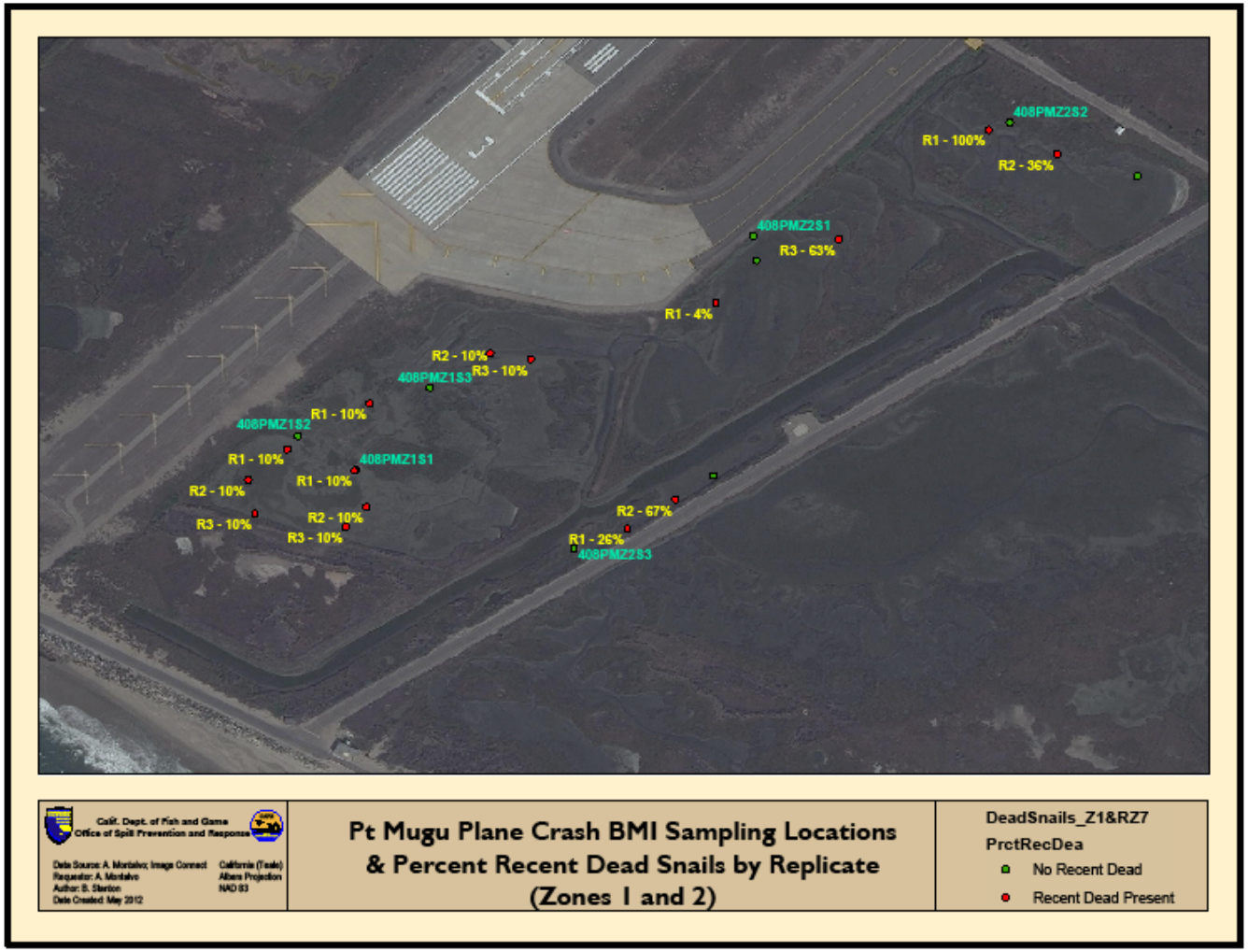


Figure 12. Presence and abundance of recent dead snails within BMI samples from Zones 1 and 2 for individual site replicates. Percentages were based on the number of recent dead to the number of total dead for that taxonomic group. No recent dead snails were present in BMI samples from Zones 3 and 4.

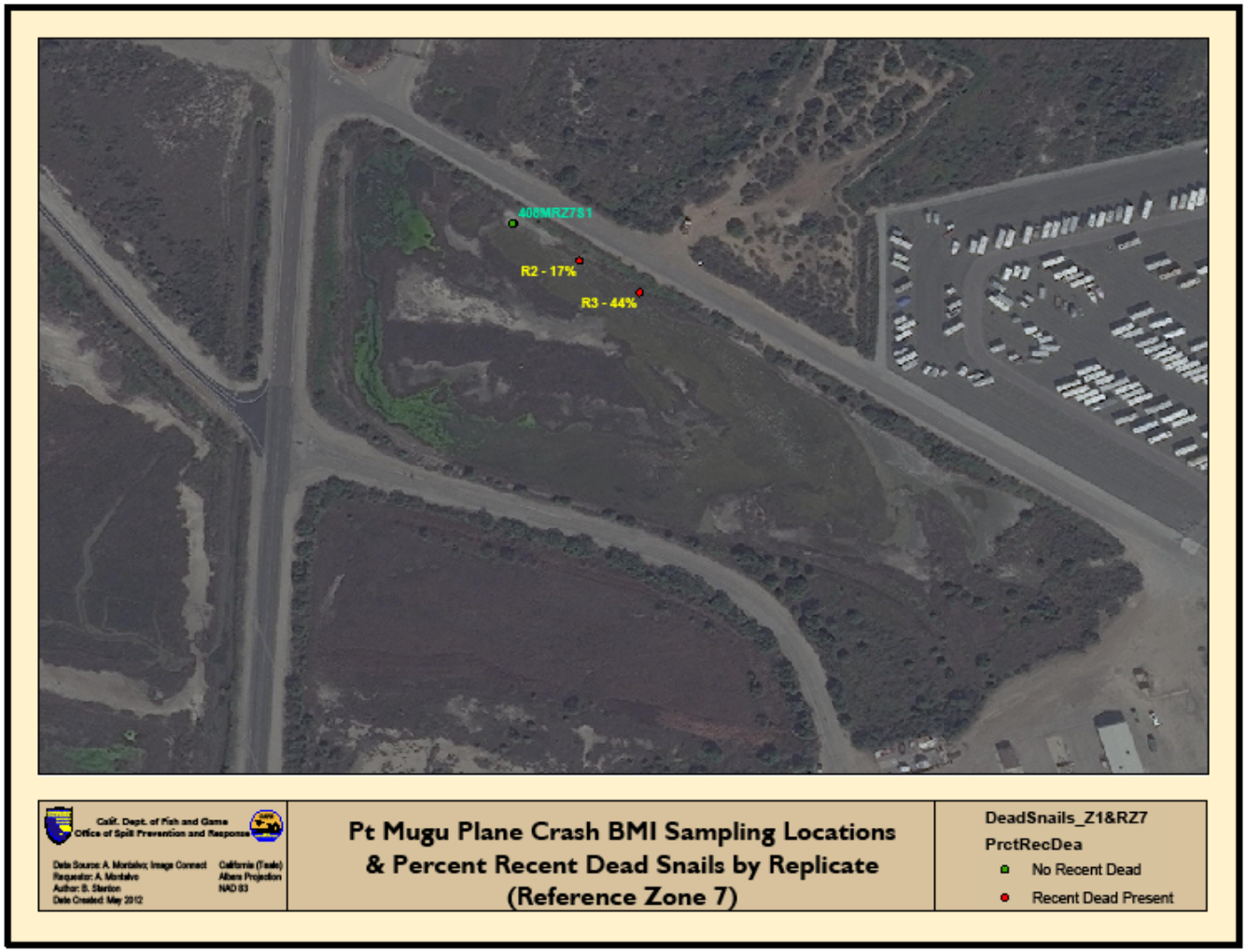


Figure 13. Presence and abundance of recent dead snails within BMI samples from Reference Zone 7 for individual site replicates. Percentages were based on the number of recent dead to the number of total dead for that taxonomic group. No recent dead snails were present in BMI samples from Reference Zone 6.

5.4 BMI Community Composition and Metrics

As described in Section 4.5 and on Table 3, numerous metrics were included to describe the benthic community and identify any potential differences between sites within zones and between zones. The number and distribution of taxa are described using (1) abundance, the cumulative number of individuals; (2) cumulative taxa, the overall number of taxa by site/zone; and (3) percent dominant taxa, the percent of total individuals that belong to the most abundant taxa. The distribution of taxa present was evaluated as (1) taxonomic richness and (2) Shannon diversity. Finally, the tolerance value identifies the mean sensitivity of the taxa present to disturbance.

Combining the 45 benthic sites sampled, a total of 15,663 organisms representing 21 distinct taxa were identified (Table 6 and Appendix E). Taxa collected were a mix of marine/estuarine species as well as salt-tolerant insect taxa. Overall taxa richness was relatively low for estuarine habitats in general, and most of the BMI collected are known to be tolerant to ecological stressors and disturbance.

The following were the most abundant taxa in order of highest numbers: (1) seed shrimp (ostracods; 6,254 individuals), (2) earthworms (oligochaetes; 2,508 individuals), (3) the amphipod (*Monocorophium insidiosum*; 1,908 individuals), and (4) the polychaete (*Streblospio benedicti*; 1,623 individuals). All of the most abundant organisms were in the collector/detritivore feeding group, which feed on organic detritus, algae, and various microorganisms (Smith, 2001; Usinger, 1956).

5.4.1 Including & Excluding Ostracoda Taxa

As discussed in Section 3.5 above, data analyses were conducted based on the dataset once ostracods were excluded on an individual replicate basis. The complete taxa list with abundance with and without ostracods is included in the appendices.

5.4.2 BMI Community at Affected Zones 1 through 4

The BMI communities at Zones 1 through 4 were affected by multiple impact types (chemical and physical) with Zone 1 having the greatest exposure to and number of potential impact types (Section 1.4 and Figure 1).

Abundance:
In general, abundance numbers in the affected zones were highly variable and many of the abundant organisms were patchy in their distribution between sites (Figure 10 and Table 6). However, mean abundance was extremely low at Zone 1 with only seven (7) total organisms recovered from all three sampled replicates. Zone 1 abundance numbers ranged from zero (0) to 38 insect taxa per replicate. In contrast, mean abundances for Zones 2, 3 and 4 were 1031, 842, and 1442 organisms per site, respectively. Zone 2 replicate mean abundances ranged from 174 to 1618 organisms per sample. Zones 3 and 4 ranged from 178 to 2140 and 1212 to 1902 organisms per replicate, respectively.

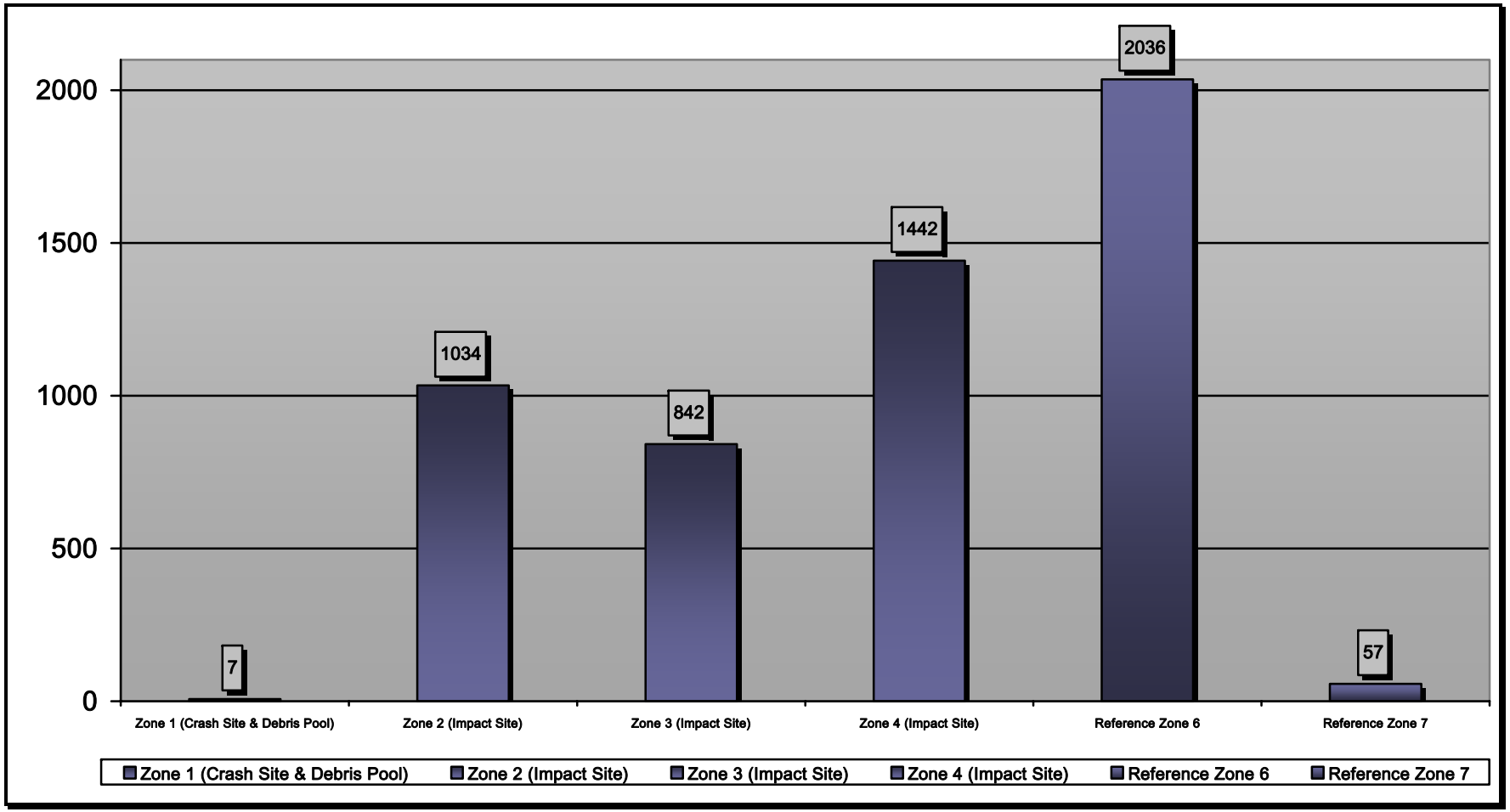


Figure 14. Relative abundance data (excluding Ostracoda Taxa) presented as zone means for benthic core samples collected at reference and impact zone boundaries in response to the Point Mugu Plane Crash Incident. Samples were collected on 19-20 July 2011 at the Point Mugu NBVC, California.

Taxonomic Richness:
Zone 1 had the least diverse BMI community of the affected zones (Appendix E and Table 6). Replicate 1 of Zone 1, Site 1 (Z1S1R1) had a single taxon present, a brine fly (Ephydridae), with only two individuals. Ostracods were the only taxa present for all three replicates in Zone 1, Site 2 and the number of individuals was extremely high. The third replicate of Zone 1, Site 1 had only three taxa and 86% of the individuals were ostracods. As noted above, ostracods are highly tolerant and can reproduce rapidly and prolifically, are relatively motile, and may colonize a disturbed site very quickly.

Zones 2, 3 and 4 overall had much higher taxa richness values, although Zone 2, Site 1 had very low diversity and abundance of infaunal organisms, and the community was mostly comprised of the more motile insect taxa (*e.g.*, Corixidae).

Cumulative Taxa:
Cumulative taxa richness is the total diversity of organisms in all samples combined from each zone, and the results were similar to taxonomic richness. Values were lowest at Zone 1 (one taxon) and highest in Zones 2, 3 and 4 (12, 14, and 10 taxa, respectively).

Percent Dominant Taxon:
Dominance by a single taxon typically increases with disturbance. When ostracods were excluded, none of the sites in this study area showed extreme dominance. Zone 1 had the lowest dominance, although if ostracods were included, dominance was as high as 100% in individual samples. Zones 2, 3, and 4 had relatively moderate dominance values with 57%, 45%, and 44%, respectively.

Shannon Diversity Index:
The Shannon diversity index was relatively low at all of the zones and followed the same pattern as the taxa richness and cumulative taxa richness. Zone 1 had the lowest index (0.4) and Zones 2, 3, and 4 had higher values (1.2, 1.5, and 1.3, respectively; Table 6).

Tolerance Value (TV):
Average community tolerance values are generally higher in more degraded or stressed BMI communities. Zone 1 had an average tolerance value of 6.1, which was lower than Zone 2 (6.3), but higher than Zones 3 and 4 (5.7 and 5.0, respectively).

Percent Insect Taxa:
Percent insect taxa metric is considered to correlate positively to BMI community quality in freshwater systems, but insects are usually rare in estuarine systems. Mugu Lagoon is somewhat unique because many sites in the study area had relatively high numbers of salt-tolerant insect taxa. Most aquatic insects have aerial adult forms that are capable of traveling to colonize new habitats. Zone 1 had the highest percent insect taxa where they comprised 63% of the community when ostracods were excluded. One site in Zone 1 was 100% insect taxa with only two individuals (Site 1, Rep 1) (Appendix C1). Insect taxa comprised 34%, 27%, and 0% of the BMI community at Zones 2, 3 and 4, respectively.

Percent Non-Insect Taxa:
Percent non-insect taxa are considered to correlate negatively to BMI community quality in freshwater systems. In estuarine systems, however, they typically indicate good conditions,

depending on the taxa present. Zone 1 had 37% non-insect taxa, which was considerably lower than Zones 2, 3 and 4 that had 66%, 73%, and 100%, respectively.

Percent Marine Infauna Taxa:
Marine infauna taxa, like the non-insect taxa, are more typical of estuarine systems, and a higher percent generally indicates a better BMI community. The percent marine infauna taxa followed a similar pattern to percent non-insect taxa with Zone 1 considerably lower than Zones 2, 3, and 4. Sites 2 and 3 of Zone 2 had a BMI community that was more similar to Zones 3 and 4, which were characterized by having greater diversity of infaunal taxa including polychaetes, gastropods, and amphipods.

Percent Oligochaeta:
Percent Oligochaeta may correlate negatively to BMI community quality in freshwater systems (dependent on species), typically increasing in abundance with fine particulate sediment deposition. It is unclear what the metric signifies in an estuarine system. Community percent composition of oligochaetes was relatively high at Zones 1 to 4, with values of 19%, 11%, 20%, and 36%, respectively.

5.4.3 BMI Community at Reference Zones 6 and 7

Abundance:
Relative abundance values in the reference zones were highly variable between the two zones (Figure 14 and Table 6). Reference Zone 6 had a mean abundance of 2036 organisms per sample while Reference Zone 7 had a mean abundance of 57 organisms per sample. Reference Zone 6 ranged from a low of 112 organisms to a high of 10,272 organisms per sample (Appendix F-2). Reference Zone 7 ranged from 27 to 102 taxa per sample.

Taxonomic Richness:
Taxonomic richness at the reference zones was relatively low (Figure 15 and Table 6). Reference Zone 6 had a mean of three taxa per sample and Reference Zone 7 had a mean of four taxa per sample. Both sites were dominated by the more motile insect taxa (*e.g.*, Corixidae).

Cumulative Taxa:
Cumulative taxa richness values were equivalent at the two reference zones, with a total of six taxa collected within each zone (Figure 15).

Percent Dominant Taxon:
Dominance by a single taxon was moderately high at the two reference zones (Figure 15). Reference Zone 6 had 72% of the community represented by a single taxon while Reference Zone 7 had 71 % of the community represented by a single taxon. If ostracods were factored in, Reference Zone 6 had higher dominance (roughly 95%) while ostracods were absent from Reference Zone 7 (Appendix E).

Shannon Diversity Index:
The Shannon diversity index was relatively low at both of the reference zones (Figure 15 and Table 6). Reference Zone 6 had a diversity index of 0.6, and Reference Zone 7 had a diversity index of 0.8.

Tolerance Value (TV):
The average community tolerance values were similar and were relatively high at the two reference zones (Figure 15). The average at Reference Zone 6 was 7.9 and the average at Reference Zone 7 was 7.7.

Percent Insect Taxa:
The percent of insect taxa was variable between the two reference zones (Figure 16). Reference Zone 6 had 74% insect taxa and Reference Zone 7 had 98% insect taxa. Corixidae (water boatman) were the most abundant insect at both sites (Appendix E).

Percent Non-Insect Taxa:
Reference Zone 6 had a higher percent on non-insect taxa than Reference Zone 7 (Figure 16). Non-insect taxa comprised 26% of the community at Reference Zone 6 and comprised 2% of the community at Reference Zone 7.

Percent Marine Infauna Taxa:
The percent marine infauna taxa followed a similar pattern to percent non-insect taxa and Reference Zone 6 had considerably more marine infauna than Reference Zone 7 (25% and 2%, respectively) (Figure 16).

Percent Oligochaeta:
There were no oligochaetes collected at the reference zones.

Overall, the BMI communities in Reference Zones 6 and 7 were different from one another and represent a range of reference environmental conditions in Mugu Lagoon (Appendix E). Reference Zone 6 received a small amount of tidal exchange while Reference Zone 7 did not receive any. As mentioned above, Reference Zone 7 had substantially higher salinity and a "spongy" layer (presumed to be algal in origin) on the substrate surface that likely inhibited colonization by infaunal organisms.

5.4.4 Comparison of BMI Communities at Affected Zones 1 through 4 with Reference Zones 6 and 7

The benthic community of Zone 1 was significantly different from any other zone as demonstrated in the final BMI metrics (Table 6) and cluster analysis data (Section 5.6, Figure 18, and Appendix F). Benthic assemblage in Zones 2, 3, and 4 were comparable and shared similarities with Reference Zones 6 and 7 (Figure 18 and Appendix E). These similarities were partially the effect of habitat types being selected or limited to specific parameters (sediments, vegetation, water quality, hydrology, water depths, etc.) between selected zones. As described in Section 5.2.3, these sites had shallow water, limited tidal exchange, and similar vegetation and substrate characteristics with the exception of Zone 4, Sites 1 and 2, which had much wider channels with greater tidal currents.

Ostracods dominated the BMI community in Zone 1 (85% to 100% per site) and Reference Zone 6 (97% to 98% per site), but were completely absent from Zones 2 and 4 and Reference Zone 7. Ostracods ranged from 1% to 56% per site in Zone 3. Zone 3 (Site 3) and both reference zones (all sites) had relatively abundant insect taxa, with water boatmen (Corixidae) being the most dominant (Table 6 and Appendix E) taxonomic group represented. Neither reference zone had

abundant marine infaunal organisms, with a few individual polychaetes collected in each zone, two taxa of gastropods collected at Reference Zone 6 only, and amphipods were absent from both sites. Oligochaeta (aquatic worms) were highly abundant in Zone 4 (all sites), Zone 1 (Site 3), and Zone 3 (Site 2). Mean Abundances were highest in Reference Zone 6 (Site 1), Zone 3 (Site 2), and Zone 4 (Site 3) with 3525, 2140 and 1902 individuals per sample, respectively. Zone 1 (all sites) yielded the lowest mean abundance scores with only 6, 0 and 15 individuals per sample, correspondingly (Table 6 and Appendix E).

Table 6. Results of BMI metrics for mean taxonomic richness, Shannon Diversity, mean relative abundance and top five taxa presented by as site averages within each zone for the Pt. Mugu Plane Crash NRDA Study conducted in July 2011, Ventura County, CA

Site Code	Potential Impacts by Zone	Taxa Richness (Replicate[1])	Shannon Diversity (Replicate[1])	Abundance (Replicate[1])	Top Five Dominant Taxa (%)				
					1	2	3	4	5
RZ6S1	None	**3.0** (2.0 to 5.0)	**0.8** (0.3 to 1.4)	**3525** (112 to 10272)	Corixidae (46)	*Tryonia imitator* (30)	*Capitella capitata* (16)	Ephydridae (3)	*Acteocina inculta* (3)
RZ6S2		**2.3** (2.0 to 3.0)	**0.5** (0.3 to 0.8)	**547** (352 to 872)	Corixidae (81)	*Trichocorixa reticulata* (8)	*Tryonia imitator* (8)	*Corisella decolor* (2)	*Acteocina inculta* (2)
RZ7S1	None	**4.3** (4.0 to 5.0)	**0.8** (0.6 to 1.0)	**57** (27 to 102)	Corixidae (73)	*Trichocorixa reticulata* (19)	*Berosus sp.* (6)	*Polydora nuchalis* (2)	Dolichopodidae (<1)
Z1S1	Fuel, tidal changes, ash, fire retardant, cleanup, excavation (Zone 1A only)	**1.3** (0.0 to 2.0)	**0.4** (0.0 to 0.7)	**6** (0 to 16)	Ephydridae (60)	*Acteocina inculta* (40)	-	-	-
Z1S2		**0.0**[2]	**0.0**[2]	**0**[2]	-[2]	-[2]	-[2]	-[2]	-[2]
Z1S3		**2.7** (2.0 to 3.0)	**0.6** (0.2 to 1.0)	**15** (4 to 38)	Oligochaeta (78)	Ephydridae (11)	Corixidae (9)	Rhabdocoela (2)	-
Z2S1	Fuel, tidal changes	**5.0** (4.0 to 6.0)	**0.6** (0.3 to 0.8)	**174** (86 to 241)	Corixidae (84)	Ephydridae (7)	*Trichocorixa reticulata* (4)	Oligochaeta (2)	*Tryonia imitator* (1)
Z2S2		**8.7** (7.0 to 10.0)	**1.4** (1.3 to 1.5)	**1309** (276 to 2560)	*Monocorophium insidiosum* (31)	*Streblospio benedicti* (26)	*Acteocina inculta* (17)	Oligochaeta (15)	*Capitella capitata* (5)
Z2S3		**11** (8.0 to 13.0)	**1.7** (1.6 to 1.8)	**1618** (179 to 2470)	*Streblospio benedicti* (31)	*Capitella capitata* (27)	*Monocorophium insidiosum* (14)	Oligochaeta (12)	Corixidae (5)
Z3S1	Fuel, tidal changes	**9.3** (7.0 to 11.0)	**1.6** (1.5 to 1.7)	**178** (48 to 315)	*Polydora nuchalis* (24)	*Monocorophium insidiosum* (24)	Oligochaeta (22)	*Capitella capitata* (13)	Rhabdocoela (4)
Z3S2		**10.3** (10.0 to 11.0)	**1.5** (1.4 to 1.6)	**2140** (496 to 4184)	*Monocorophium insidiosum* (41)	Oligochaeta (22)	*Streblospio benedicti* (14)	*Capitella capitata* (11)	*Acteocina inculta* (4)

Site Code	Potential Impacts by Zone	Taxa Richness (Replicate[1])	Shannon Diversity (Replicate[1])	Abundance (Replicate[1])	Top Five Dominant Taxa (%)				
					1	2	3	4	5
Z3S3		**10.0** (8.0 to 11.0)	**1.5** (1.3 to 2.0)	**207** (33 to 396)	Corixidae (48)	Ephydridae (25)	Oligochaeta (11)	*Monocorophium insidiosum* (6)	*Acteocina inculta* (3)
Z4S1	Fuel, tidal changes	**7.3** (6.0 to 9.0)	**1.3** (1.1 to 1.5)	**1212** (42 to 2575)	Oligochaeta (39)	*Streblospio benedicti* (34)	*Capitella capitata* (15)	*Monocorophium insidiosum* (7)	*Polydora sp.* (1)
Z4S2		**8.0** (7.0 to 10.0)	**1.5** (1.5 to 4.6)	**1213** (475 to 2175)	Oligochaeta (27)	*Acteocina inculta* (24)	*Streblospio benedicti* (23)	*Monocorophium insidiosum* (15)	*Capitella capitata* (8)
Z4S3		**5.7** (5.0 to 6.0)	**1.2** (1.2)	**1902** (707 to 3142)	Oligochaeta (34)	*Monocorophium insidiosum* (24)	*Capitella capitata* (23)	*Acteocina inculta* (16)	*Polydora nuchalis* (1)

Notes:
*Benthic data presented in this table are without Ostracoda taxa.
[1] Range of results across 3 replicates per site
[2] Zone 1, Site 2 had only ostracods present

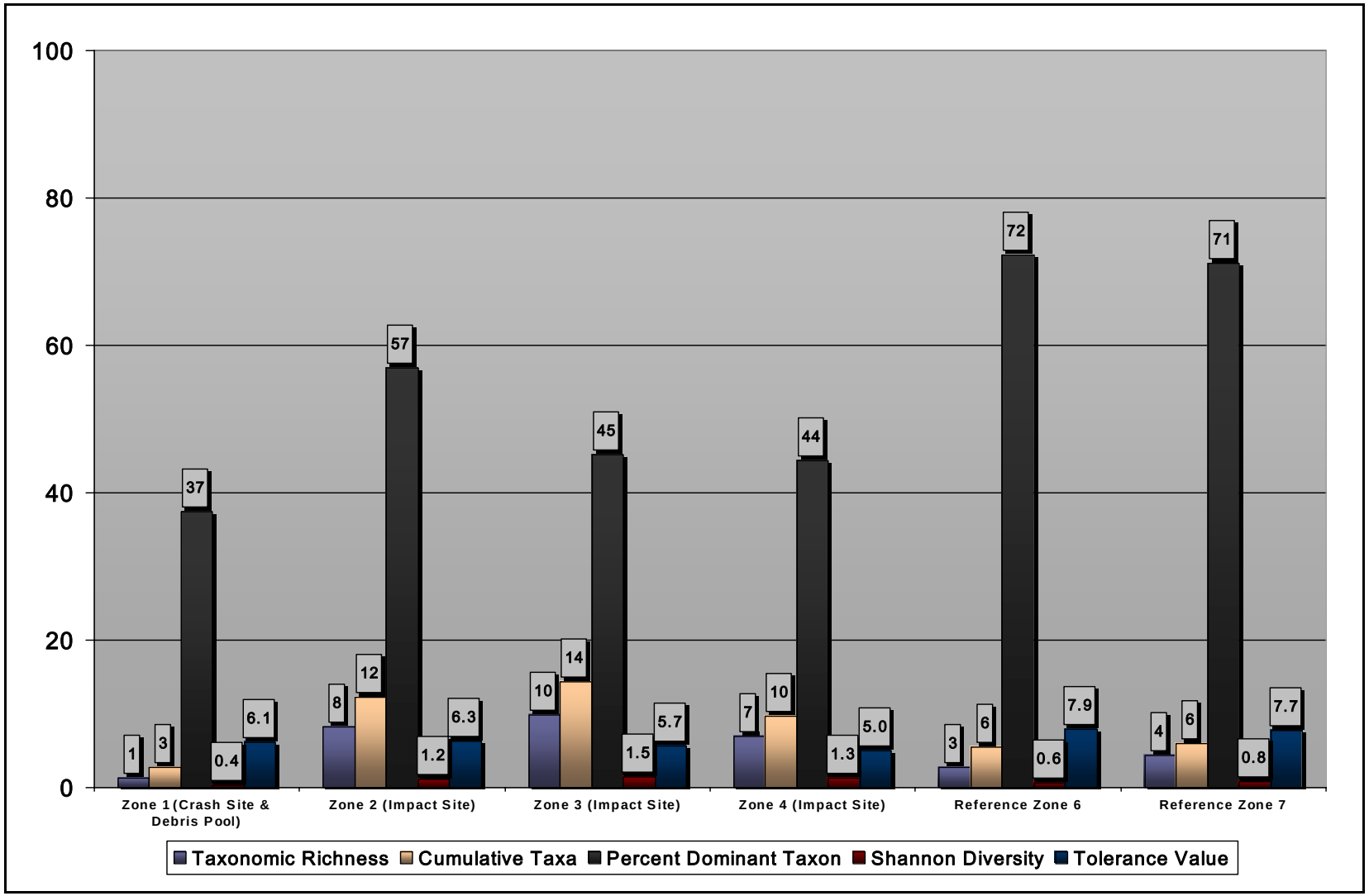


Figure 15: Top five metric data results (excluding Ostracoda Taxa) presented as zone means for benthic core samples collected at reference and impact zones in response to the Point Mugu Plane Crash Incident. Samples were collected on 19-20 July 2011 at the Point Mugu NBVC, California

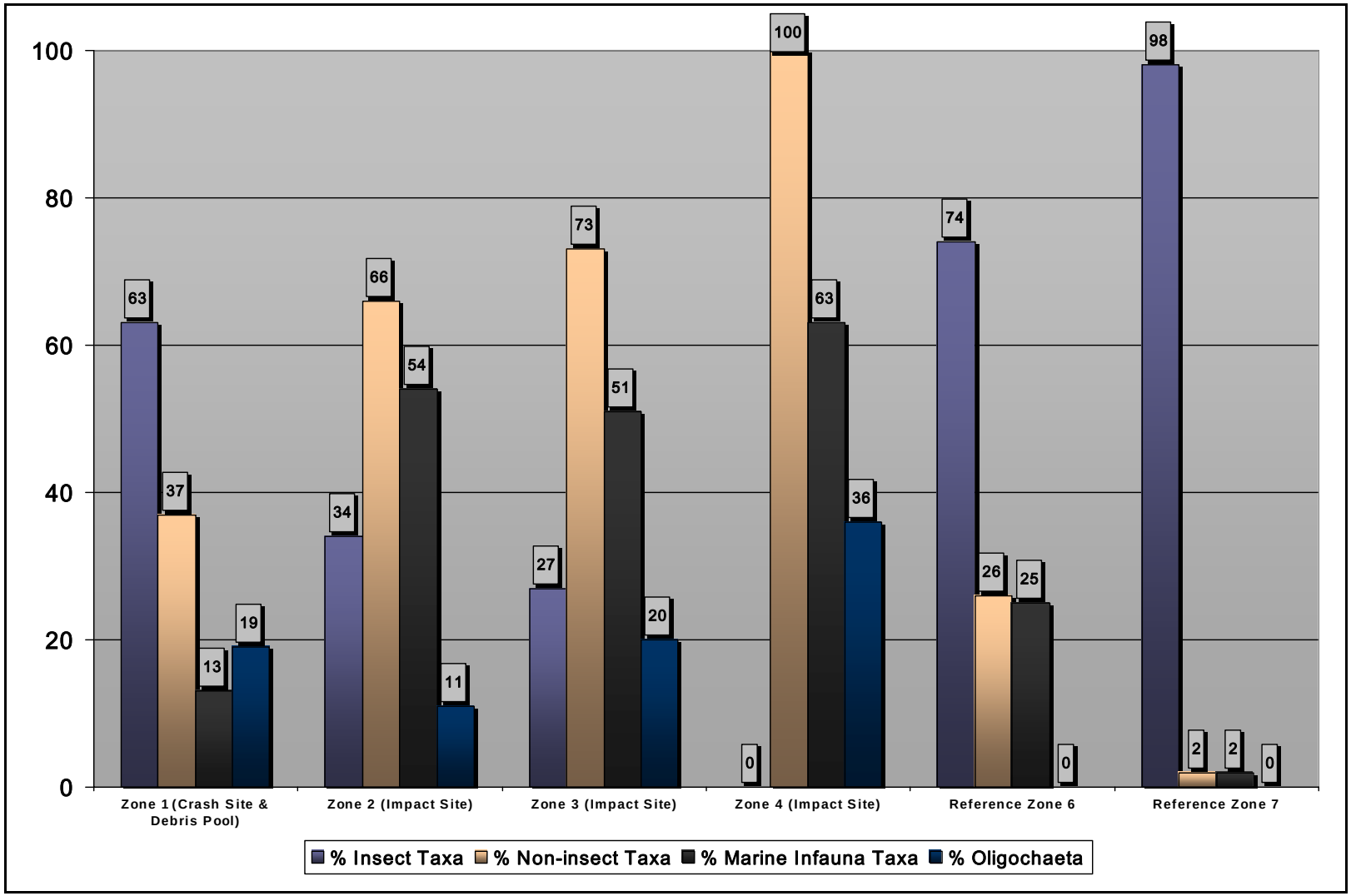


Figure 16: Composition measure data results (excluding Ostracoda Taxa) presented as zone means for benthic core samples collected at reference and impact zones in response to the Point Mugu Plane Crash Incident. Samples were collected on 19-20 July 2011 at the Point Mugu NBVC, California

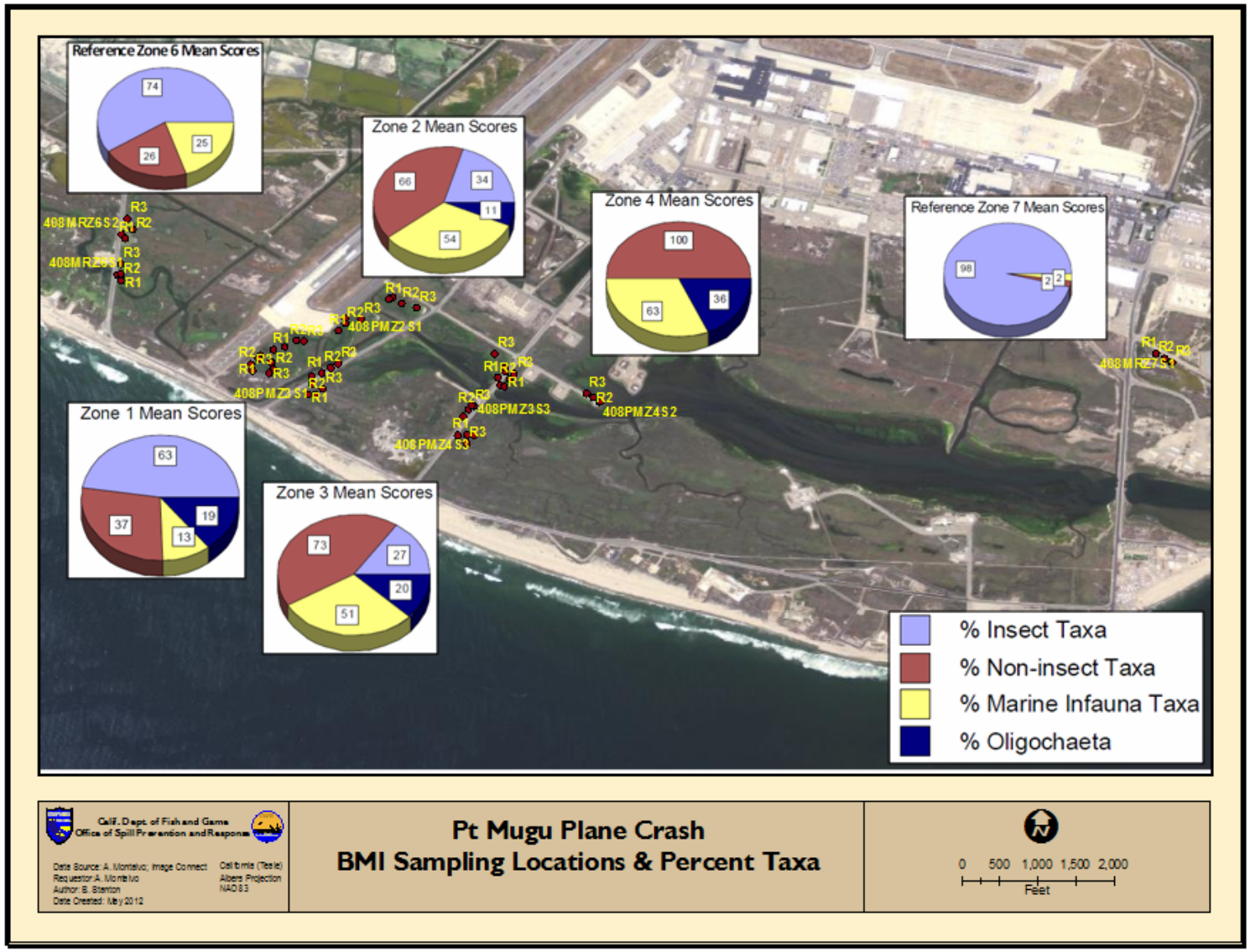


Figure 17. BMI Sampling Locations with Percent Composition Metrics (without Ostracoda Taxa) of BMIs Collected from the Point Mugu Crash Site, July 2011.

5.5 BMI Community Condition Analysis

Benthic community condition was assessed using a combination of four benthic indices: the Benthic Response Index (BRI), Relative Benthic Index (RBI), Index of Biotic Integrity (IBI), and a predictive model based on the River Invertebrate Prediction and Classification System (RIVPACS). The assessment was performed following the guidance provided by Southern California Coastal Water Research Program (SCCWRP) entitled *Determining Benthic Invertebrate Community Condition in Embayments* for southern California marine bays (SCCWRP, 2008). Each benthic index result was categorized according to four levels of disturbance, on a scale of 1 to 4: reference (1), low disturbance (2), moderate disturbance (3), and high disturbance (4). The final benthic disturbance value is calculated as the mean of the four indices.

This analysis for benthic community condition was developed specifically for Southern California marine bays. This habitat type, Habitat C in Ranasinghe et al. (2008), has generally high tidal exchange and stable salinities ranging between 27 ppt and 40 ppt. As described in Section 3.2.1 and on Figure 7, salinity ranges for Zones 2, 3, and 4 and Reference Zone 6 ranged from 33.7 to 41.0 ppt. However, Zone 1 and Reference Zone 7 had salinities of 65.7 and 54.6 ppt, respectively. Although the benthic community condition method is not entirely appropriate, an alternative analytical tool applicable to the specific habitat conditions in the study area, particularly Zone 1 and Reference Zone 7, has yet to be developed. Given those circumstances, the benthic community indices were considered the best approach available to determine the relative benthic community condition at each site, but the results should be interpreted with caution. Furthermore, one of the scientists who developed the benthic index method recommended the community condition method should be used as a secondary line of evidence with the standard metrics approach (Section 3.4 above) as the primary source (J.A. Ranasinghe, personal communication).

Results of the benthic community condition analysis are presented for individual site replicates by zone in Table 7 below. All sites in the study area, including both affected and reference zones, were rated to have either Moderate or High levels of disturbance. These disturbance levels were based on low taxa richness, lack of stress-sensitive taxa, and a predominance of stress-tolerant taxa as noted in Section 3.4 above. All sites in Zone 1 and Reference Zones 6 and 7 had High levels of disturbance, while Zones 2, 3, and 4 had a mix of Moderate and High levels of disturbance. There did not appear to be any correlation in disturbance level between the sites and their distance relative to the crash site, or affected zone sites versus reference zone sites in general based on this analysis. It may be inferred from this analysis that sites in the study area overall were likely stressed by natural environmental conditions including anoxic sediment with high organic content and fine particulates, salinity above 40 ppt, and limited tidal exchange.

Table 7: Benthic Community Condition Analysis for Samples Collected from the Point Mugu Crash Site, July 2011

		Category Score for Individual Indices				Final Benthic Disturbance Score	Level of Disturbance
Zone	Station	IBI	RBI	BRI[1]	RIVPAC		
Zone 1	Z1/S1/R1	4	4	*	4	4	High
	Z1/S1/R2	3	4	1	4	4	High
	Z1/S1/R3	4	4	*	4	4	High
	Z1/S2/R1	4	4	*	4	4	High
	Z1/S2/R2	4	4	*	4	4	High
	Z1/S2/R3	4	4	*	4	4	High
	Z1/S3/R1	4	4	*	4	4	High
	Z1/S3/R2	4	4	*	4	4	High
	Z1/S3/R3	4	4	1	4	4	High
Zone 2	Z2/S1/R1	2	4	1	4	3	Moderate
	Z2/S1/R2	3	3	1	4	3	Moderate
	Z2/S1/R3	4	4	2	4	4	High
	Z2/S2/R1	2	2	4	4	3	Moderate
	Z2/S2/R2	3	1	4	4	4	High
	Z2/S2/R3	2	2	4	4	3	Moderate
	Z2/S3/R1	2	2	4	4	3	Moderate
	Z2/S3/R2	3	1	3	4	3	Moderate
	Z2/S3/R3	4	2	3	4	4	High
Zone 3	Z3/S1/R1	2	2	4	4	3	Moderate
	Z3/S1/R2	4	1	3	4	4	High
	Z3/S1/R3	4	3	3	4	4	High
	Z3/S2/R1	3	1	3	4	3	Moderate
	Z3/S2/R2	4	1	3	4	4	High
	Z3/S2/R3	4	1	3	4	4	High
	Z3/S3/R1	4	2	1	4	3	Moderate
	Z3/S3/R2	3	3	2	4	3	Moderate
	Z3/S3/R3	4	4	1	4	4	High
Zone 4	Z4/S1/R1	3	2	3	4	3	Moderate
	Z4/S1/R2	3	2	4	4	4	High
	Z4/S1/R3	4	4	3	4	4	High
	Z4/S2/R1	3	1	4	4	4	High
	Z4/S2/R2	2	2	4	4	3	Moderate
	Z4/S2/R3	3	3	4	4	4	High
	Z4/S3/R1	3	2	4	4	4	High
	Z4/S3/R2	2	2	4	4	3	Moderate
	Z4/S3/R3	3	1	4	4	4	High
Reference Zone 6	Z6/S1/R1	3	4	2	4	4	High
	Z6/S1/R2	4	4	*	4	4	High
	Z6/S1/R3	4	4	1	4	4	High
	Z6/S2/R1	4	4	1	4	4	High
	Z6/S2/R2	4	4	*	4	4	High
	Z6/S2/R3	3	4	1	4	4	High
Reference Zone 7	Z7/S1/R1	4	4	1	4	4	High
	Z7/S1/R2	4	4	1	4	4	High
	Z7/S1/R3	4	4	1	4	4	High

[1] *, BRI score could not be calculated

5.6 Cluster Analysis

In addition to the analyses above, a cluster analysis was performed to test for similarities between site location and BMI community structure. The analysis is based on a two-way Bray–Curtis similarity matrix calculated on relative abundances of taxa (excluding Ostracods) by site. Since the analysis is based only on the taxa and sites, it is independent of other factors such as physical parameters or organism stressor tolerance. As such, the analysis is unrelated to the above methods (Sections 4.4 and 4.5) that are based on metric analyses and provides an independent line of evidence on the dissimilarity of the sites in the study area. In a cluster analysis, sites with similar communities of taxa will cluster together; likewise, taxa that occur at the same sites will cluster together. Taxa for each of the three replicate samples were combined into a single site taxa list. Since ostracods were the only taxa present across all three replicates in Zone 1, Site 2, this site was not included in the analysis.

The results of the analysis are portrayed in a two-way matrix that shows the relative abundance of each taxonomic group by site (Figure 18). Results of the cluster analysis showed four major taxa clusters and four site clusters, labeled 1 through 4 and A through D, respectively, and are bounded by bold red lines in the figure. An overall taxa list with common names, tolerance values/pollution tolerance scores, and feeding methods are presented in Table 8.

Overall site clustering showed that site cluster D had the greatest degree of separation (*i.e.* distance between clusters) from clusters A, B and C. The sites in cluster D were comprised of all three Zone 4 sites as well as Zone 2, Sites 1 and 2 and Zone 3, Sites 1 and 2. The sites in cluster D generally had greater taxa richness than the remaining sites, were best characterized by taxa in clusters 1 and 3, and had polychaetes, amphipods, and molluscs as the most abundant taxa.

Site cluster A had the next greatest degree of separation from clusters B and C. Cluster A was limited to Zone 1, Sites 1 and 3, which were characterized by very low diversity and abundance of non-ostracod taxa. As noted previously, Zone 1, Site 2 had only ostracods present. Taxa in site cluster A were limited to taxa cluster 1.

Site cluster B had a mix of Zone 2, Zone 3, and Reference Zone 7 sites. This site cluster was characterized by moderate taxa richness in taxa clusters 1 and 2, and water boatmen (*i.e.*, immature Corixidae and *Trichcorixa reticulata*) were most abundant at these sites.

Site cluster C was limited to the Reference Zone 6 sites, which had low taxa richness and low to moderate abundance of non-ostracod taxa, primarily in taxa cluster 1.

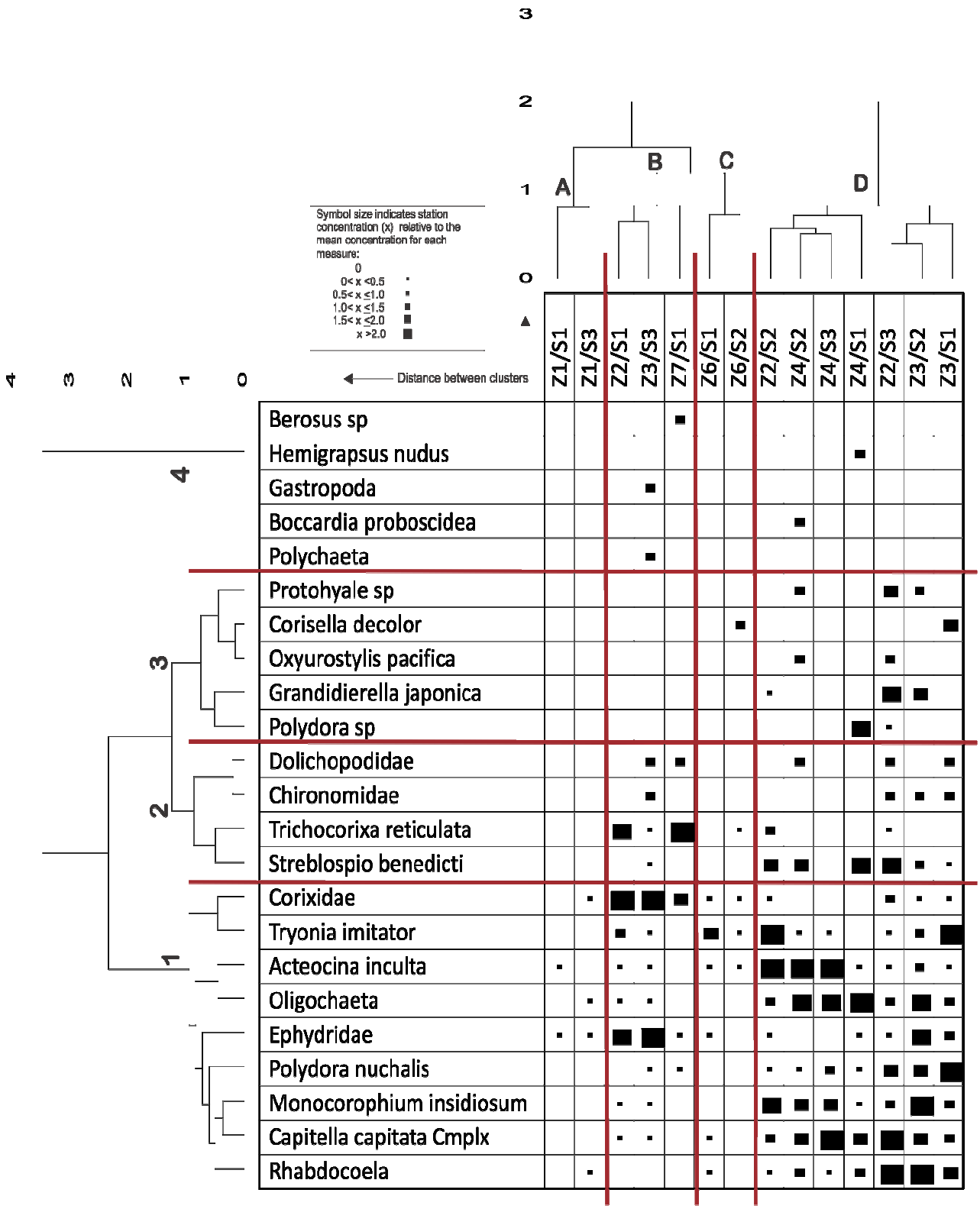


Figure 18: Cluster Analysis of Sites and BMI Taxa Collected from the Point Mugu Crash Site, July 2011

Table 8: Common Names, Relative Tolerance, and Feeding Groups for Taxa Collected from the Point Mugu Crash Site, July 2011. Taxa are included in order from cluster analysis above.

Taxon (in order by cluster)	Common name	Tolerance Value[1]	Pollution Tolerance Score[2]	Functional Feeding Group
Cluster 4				
Berosus sp	water scavenger beetle	5	-	predator
Hemigrapsus nudus	shore crab	-	unknown	collector-gatherer
Gastropoda	snail	-	variable	scraper
Boccardia proboscidea	spionid polychaete (marine worm)	-	unknown	surface deposit-filterer
Polychaeta	polychaete		variable	surface deposit
Cluster 3				
Protohyale sp	amphipod	-	unknown	surface deposit
Corisella decolor	water boatman	8	-	predator
Oxyurostylis pacifica	cumacean	-	62	surface deposit
Grandidierella japonica	amphipod	-	48	surface deposit
Polydora sp	spionid polychaete	-	unknown	surface deposit
Cluster 2				
Dolichopodidae	dance fly	4	-	predator
Chironomidae	midge	6	-	collector-gatherer
Trichocorixa reticulata	water boatman	8	-	predator
Streblospio benedicti	spionid polychaete	-	71	surface deposit-filterer
Cluster 1				
Corixidae	water boatman	8	-	predator
Tryonia imitator	snail	-	unknown	scraper
Acteocina inculta	snail	-	unknown	scraper
Oligochaeta	earthworm	5	-	collector-gatherer
Ephydridae	brine fly	6	-	variable
Polydora nuchalis	spionid polychaete	-	unknown	surface deposit
Monocorophium insidiosum	amphipod	-	unknown	collector-gatherer
Capitella capitata complex	polychaete	-	88	surface deposit
Rhabdocoela	flatworm	-	unknown	predator

[1]Tolerance Value for insects and oligochaetes; scale is from 0 (highly sensitive) to 10 (highly tolerant).
[2] Pollution Tolerance Score for marine taxa; scale is from -106 (highly sensitive) to 227 (highly tolerant).

6.0 SUMMARY

In response to the crash of a Boeing K707 aerial refueling tanker operated by Omega Air, Inc, an aquatic BMI (BMI) survey was conducted in Mugu Lagoon. The goal of the survey was to document possible impacts to the biological resources in the lagoon from the crash. To accomplish this, BMI were sampled in six separate zones, four of which were potentially impacted by the crash and two of which were established as reference zones that were not impacted by the crash. Zone 1 was in the immediate vicinity of the crash, and Zones 2, 3 and 4 were in areas where fuel sheen was observed and hydrology was altered. Reference Zone 6 was not impacted by the crash or cleanup efforts and characterized ambient conditions most comparable to Zones 2, 3 and 4. Reference Zone 7 was not impacted by the crash and

represented ambient lagoon conditions most similar to Zone 1. In addition to the BMI assessment, samples for sediment grain size and total organic carbon (TOC) were analyzed and physical water quality parameters were measured. The results of the BMI study are summarized in the text below and in Table 9.

Dead crabs and snails were observed on-site in Zone 1 during the BMI reconnaissance visit. In addition, recent dead snails were present in BMI samples in greater numbers from Zones 1 and 2 than from Reference Zone 7. No recent dead snails were present in BMI samples collected from Zone 3, Zone 4, or Reference Zone 6. All other aspects of the BMI study were based upon live organisms present in the BMI samples. These findings are also independent of the observations of dead crabs in Zones 3 and 4 immediately following the crash since *Hemigrapsis* and *Pachygrapsis*, the two crab species observed in the lagoon, are primarily shoreline dwellers and would not likely be captured in a subtidal benthic core.

The BMI assessment sampled a total of six zones, with one to three sites within each zone, and three replicate samples within each site, for a total of 45 samples. Nine of the samples were taken in reference zones. A total of 15,663 organisms representing 21 distinct taxa were identified. The taxa were a mix of marine/estuarine species and salt tolerant insect taxa. Ostracoda (seed shrimp) were the most abundant organism across the study area, followed by aquatic worms, amphipods, and polychaetes. Ostracoda were very patchy in distribution and were highly abundant in some areas and absent in adjacent areas. Most of the organisms collected are known to be tolerant to ecological stressors and were collector/detritivore feeders.

Results of the water quality measures indicated that Zones 2, 3 and 4 had conditions typical of tidal marshes, with salinity similar to seawater and all other parameters within expected ranges. Zone 1 and Reference Zones 6 and 7 had elevated salinities, but other parameters were similar to Zones 2, 3 and 4. Results of the grain size and TOC analyses indicated that the sites in Mugu Lagoon had elevated percent fine particulate sediments and organic carbon relative to other marine bays in Southern California. These constituents may have a negative effect on BMI community diversity when elevated and can be the result of natural processes.

BMI metric values calculated from the taxonomic list indicated that Zone 1 had lower abundance and diversity of organisms than all other zones. Zones 2, 3 and 4 had the highest diversity of all sampled zone areas, including the reference zones, while abundance at these sites was lower than Reference Zone 6, but greater than Reference Zone 7. The increased tidal exchange and improved water quality levels at these three zones (Zones 2, 3, and 4) are the plausible rationale for a more abundant, stable and diverse benthic assemblage. Cumulative taxa richness and Shannon diversity values followed a similar pattern as raw taxa richness values, with the lowest values at Zone 1 and the highest values at Zones 2, 3 and 4.

BMI metrics based on community composition indicated that Zone 1 had the lowest number of total individuals, but the highest percent insect taxa of the affected zones when ostracods were excluded from the data set. Zone 1 had a lower community composition than both reference zones. The insect taxa collected have aerial adult forms that can colonize new habitats much more readily than the non-insect benthic taxa. Percent non-insect taxa and percent marine taxa comprised greater proportions of the BMI community at Zones 1 to 4 than at Reference Zones 6 and 7, and this may have been due to closer proximity to the open channels of the lagoon.

Results of the Benthic Community Condition Analysis showed that all sites in the study area had a disturbance level of Moderate or High. Zone 1 (all sites) and all of the reference zones had disturbance levels of High and Zones 2, 3 and 4 were a mix of Moderate and High disturbance levels. Based on the results from the reference zones, this analysis indicated that the study area had pre-existing ecological stressors that could suppress BMI community quality relative to other marine bays in Southern California.

A cluster analysis of the taxa and sites sampled showed that the sites of Zone 1 had distinctly different BMI communities than any of the other sites. Reference Zone 6 was also unique, and those sites were in a distinct cluster. Zones 2, 3 and 4 tended to cluster together, mostly due to greater taxa richness and higher abundances of marine taxa. Some sites of Zones 2 and 3 clustered with Reference Zone 7, and these sites had higher abundances of insect taxa.

Table 9. Summary of observed physical and biological impacts and differences in BMI sediment community by assessment zone.

Zone	Field Observations			Laboratory Observations in Sediment Core Samples (July 2011)[1]	BMI Metric Community[2]		
	Initial Response (May 2011)	BMI Reconnaissance Survey (June 2011)	BMI Sampling Survey (July 2011)		Composition and Metrics	Condition Analysis	Cluster Analysis
Section	*Section 2.1*	*Section 5.1*	*Section 5.1*	*Section 5.3*	*Section 5.4*	*Section 5.5*	*Section 5.6*
Zone 1	Fuel[3] Fire[4] Dead biota[5] (crabs & snails)	Fuel[3] Fire[4] Dead biota[5] (crabs & snails)	Fuel[3] Fire[4] Dead biota[5] (crabs & snails)	Fuel[3] Fire[4] Dead biota (snails)[6]	Decreased abundance and diversity; high percentage of dominant taxon	-	Difference in overall community assemblage; high abundance of ostracods
Zone 2	Fuel[3]	-	-	Dead biota (snails)[6]	-	-	-
Zone 3	Fuel[3] Dead biota[5] (crabs)	-	-	-	-	-	-
Zone 4	Fuel[3] Dead biota[5] (crabs)	-	-	-	-	-	-

[1] Motile invertebrates, including crabs, are not expected to be found in sediment core samples.
[2] BMI metric community assessment done on live, sediment-associated *in situ* BMI only.
[3] Fuel observation includes petroleum sheen and odor.
[4] Fire observation includes burnt materials, chemical contaminants, fire retardant, and ash.
[5] Dead biota refers to BMI organisms, including crabs and snails. Specific groups observed by zone are in parentheses.
[6] Dead snails were also observed in Reference Zone 7, but in lower numbers than Zones 1 and 2.

7.0 CONCLUSION

The results of this study indicate that it was highly probable that the crash and associated impacts resulted in mortality to the benthic communities within the study area. Dead biota (including crabs and snails) were observed on-site during the initial response (Zones 1, 3, and 4) and BMI field work (Zone 1), including several dead organisms in Zone 1 during the BMI reconnaissance visit that had visible evidence of physical burn and fire injury to the exoskeleton. A greater number of recent dead snails were found during laboratory processing of BMI samples from Zones 1 and 2 than Reference Zone 7, with none being recovered in other zones.

In addition to observed mortality of individual organisms, the benthic community present two months after the spill in Zone 1 had lower abundance and diversity of organisms than all other zones. Zone 1 had the lowest taxonomic diversity and largely consisted of Ostracoda that are highly motile and have elevated fertility rates. Zone 1 also had the lowest abundance scores of all zones when ostracods were removed from the data set. This genus would have re-colonized the area between the time of the crash and the BMI survey. Zones 2, 3, and 4 were exposed to fewer and less severe impacts (primarily fuel floating on the water surface and changes in hydrology). In addition, the BMI communities in these zones generally reflect the difference in baseline conditions, particularly tidal flushing and associated water quality improvements, when compared to Reference Zones 6 and 7, which had minimal to no tidal flushing or exchange and reduced or restricted water quality ranges. In particular, Zones 2, 3, and 4 had a much higher diversity of marine taxa that tend to have limited mobility, are associated with sediments, and have longer recovery rates following mortality.

8.0 REFERENCES

Carlton, J. T. 2007. The Light and Smith Manual. Intertidal invertebrates from central California to Oregon. Fourth Edition. Edited by James T. Carlton. University of California Press, 2007.

Insight, 2011a. Sampling And Analysis Plan (Field Sampling Plan And Quality Assurance Project Plan) June 23, 2011 Sediment Sampling At Omega Crash Site Naval Base Ventura County, Point Mugu Point Mugu, California. Prepared for: U.S. Department of the Navy Naval Facilities Engineering Command Southwest Division. Prepared by: Insight Environmental, Engineering and Construction, Inc. Under contract to: Omega Air, Inc. 10315 Wetmore Road San Antonio, Texas, 78216.

Insight, 2011b. Sediment Removal Work Plan At Omega Plane Crash Site Naval Base Ventura County Point Mugu, Point Mugu, California. September 26, 2011. Prepared for Omega Air, Inc.

Insight, 2011c. Final Remedial Action Activity Report For Omega Air Crash Site Naval Base Ventura County Point Mugu, Point Mugu, California. March 23, 2011 Rev. 01. Prepared for Omega Air, Inc.

Jacobson, Steward M. and Boylan, D.B. 1973. Effect of seawater soluble fraction of kerosene on chemotaxis in a marine snail, Nassarius obsoletus. Nature 241:213-215.

Merritt, R. and K. Cummins. 1996. *An Introduction to the Aquatic Insects of North America*. Third Edition. Kendall Hunt Publishing Company, Dubuque, Iowa.

National Research Council (NRC). 2003. Toxicologic Assessment of Jet-Propulsion Fuel 8 Subcommittee on Jet-Propulsion Fuel 8, Committee on Toxicology, National Research Council. http://www.nap.edu/catalog/10578.html

Patriot Environmental Services, Inc., 2011.Work Plan III B Salvage For Omega Air / Point Mugu 707 Site(s). Dated as of June 5, 2011

Ranasinghe, J.A., K.I. Welch, P.N. Slattery, D.E. Montagne, D.D. Huff, H. Lee, II, J.L. Hyland, B. Thompson, S.B. Weisberg, J.M. Oakden, D.B. Cadien and R.G. Velarde. Habitat related benthic macrofaunal assemblages of bays and estuaries of the western United States. pp. 199-210 *in*: S.B. Weisberg and K. Miller (eds.), Southern California Coastal Water Research Project 2008 Annual Report. Costa Mesa, CA.

Ranasinghe, J.A. 2012. Personal communication with Bill Isham via email. February 15, 2012.

SAFIT (Southwest Association of Freshwater Invertebrate Taxonomists). 2011. *List of Macroinvertebrate Taxa from California and Adjacent States and Ecoregions; and Standard Taxonomic Effort*. Accessed at: http://www.safit.org/ste.html. Edited by A. Richards and D. Rogers. Updated March 2011.

SCAMIT (Southern California Association of Marine Invertebrate Taxonomists). 2011. A taxonomic listing of macro- and mega-invertebrates from infaunal and epibenthic programs in the Southern California Bight. Edition 5. Southern California Association of Marine Invertebrate Taxonomists. Los Angeles, California, USA. Updated July 2011.

Schiff, K., Richard Gossett, Kerry Ritter, Liesl Tiefenthaler, Nathan Dodder, Wenjian Lao, and Keith Maruya, 2011. Southern California Bight 2008 Regional Monitoring Program: III. Sediment Chemistry. Southern California Coastal Water Research Project, Costa Mesa, CA.

Shannon, C., and W. Weaver. 1963. *The Mathematical Theory of Communication, Shannon Diversity Index*.

Southern California Coastal Water Research Program (SCCWRP). 2008. *Determining Benthic Invertebrate Community Condition in Embayments*. available at: ftp://sccwrp.org/pub/download/TOOLS/SQO/calc_BI_embayments.pdf

Straughan, D., and Hadley, D. 1978. Experiments with Littorina species to determine the relevancy of oil spill data from southern California to the Gulf of Alaska. Marine Environmental Research 1:135-163.

Tetra Tech EM Inc., 2005. Final Ecological Risk Assessment Addendum for Installation Restoration Program Sites 5 and 11 Naval Air Station Point Mugu Naval Base Ventura County, California. December 2005. Prepared by: Tetra Tech EM Inc. Prepared under Naval Facilities Engineering Command

USEPA. 2009. National Coastal Condition Assessment: Field Operations Manual. Epa-841-R-09-003. U.S. Environmental Protection Agency, Washington, DC. water.epa.gov/type/oceb/upload/ncca_field_manual_23apr10.pdf

Usinger, R. 1956. *Aquatic Insects of California*. University of California Press, Berkeley, California.

Weston Solutions, Inc. 2011. Mugu Lagoon Plane Crash Site Benthic Macroinvertebrate Survey Sampling and Analysis Plan (SAP). July 2011.Prepared for Point Mugu NRDA Team and Omega Air, Inc.