BIOLOGICAL COMMUNITY ASSESSMENT:

La Jolla and Scripps

Areas of Special Biological Significance

(ASBS 29 and 31)



Prepared and Submitted by Shannon Jarrell

Dayton Laboratory, Scripps Institution of Oceanography

October 2014

ABSTRACT

Four studies were implemented to describe and assess biological communities, human activity, and effects of trampling and urban effluent exposure on meiofauna within rocky intertidal areas of the La Jolla and Scripps Areas of Special Biological Significance (ASBS 29 and 31). These studies will add to current knowledge of anthropogenic impacts on ecologically important meiofauna (as bacterial-grazers, filters, and prey for higher trophic levels). In summary, laboratory studies performed during two storm events indicate that survival of meiofauna is decreased following acute exposure to storm effluent and freshwater in the laboratory; however, for the two specific storm events used in these studies, no statistical difference in survival was observed between storm effluent and freshwater treatments, suggesting that the decrease in salinity was responsible for the drop in survival. Results from an experimental trampling study demonstrate that meiofaunal abundance is greatly reduced in areas that receive even moderate foot traffic, and that recovery occurs over relatively short periods of time (< 3 months) once the trampled areas are left alone, but these impacts vary between taxonomic groups and sites. Monthly monitoring of meiofauna and turf depth was undertaken for three sites within the Scripps and La Jolla ASBS and one reference site (Cabrillo National Monument, Zone 3) to describe community composition and natural variations in meiofaunal abundance and turf depth over time among sites varying in types of anthropogenic stress regularly present. Turf depth and abundance of bivalves, gastropods, and polychaetes varied significantly between sites over the two years of monitoring. Abundance and turf depth was consistently lowest at the site having the highest level of trampling from public use of the tide pools. Finally, public use observations in three tide pool areas within ASBS 29 and 31 showed that easily accessible areas are heavily visited by the public and illegal activities (fishing, pestering, and collection of animals) occur in both easily accessible and more difficult to reach areas. Over the 241 days included in the study, visitation of tide pools corresponded better with tidal height rather than time of day and day of the week. By extension then, negative impacts on meiofaunal abundance and turf depth as seen in the trampling study, are probable in heavily visited tide pools of the ASBS and is therefore important to consider in the management of these sensitive areas.

TABLE OF CONTENTS

ABSTRACT……2

LIST OF FIGURES……7

LIST OF TABLES……10

INTRODUCTION……....11

STUDY 1: EFFECTS OF URBAN EFFLUENT ON MEIOFAUNAL SURVIVAL……13

1.1 BACKGROUND……13

1.2 METHODS: Field Component……14

1.2a Study Sites……..14

1.2b Sample Collection and Deployment……..….17

1.2c Data Analysis……21

1.3 METHODS: Laboratory Component……..…….21

1.3a Study Sites……..……21

1.3b Sample Collection and Deployment…….……..23

1.3c Data Analysis…….……23

1.4 RESULTS: Field Component 2012…….……...……..23

1.4a Dike Rock Cores…....……...23

1.4b Devil's Slide Cores……..…….23

1.5 RESULTS: Laboratory Component 2012……27

1.5a Dike Rock Cores…….....27

1.5b Devil's Slide Cores……..……..…..27

1.6 RESULTS: Field Component 2013- Immediate and Latent Mortality ……...…..31

1.6a Dike Rock Cores……...….31

1.6b Devil's Slide Cores……31

1.7 RESULTS: Laboratory Component 2013- Immediate and Latent Mortality…….…….35

1.7a Dike Rock Cores……35

1.7b Devil's Slide Cores……35

1.8 DISCUSSION……..41

STUDY 2: EFFECTS OF TRAMPLING ON MEIOFAUNAL ABUNDANCE AND TURF DEPTH……..44

2.1 BACKGROUND…….44

2.2 METHODS……..44

2.2a Study Sites……..44

2.2b Sample Collection and Experimental Trampling…….……..44

2.2c Data Analysis…….45

2.3 RESULTS: Devil's Slide (ASBS 29)……..48

2.4 RESULTS: Cabrillo Zone 3 (Reference site outside ASBS)……..55

2.5 DISCUSSION…….……61

STUDY 3: MEIOFAUNAL COMMUNITY MONITORING IN SCRIPPS AND LA JOLLA ASBS…….....62

3.1 BACKGROUND…….62

3.2 METHODS……..……62

3.2a Study Sites……..……62

3.3b Sample Collection……..64

3.3c Data Analysis…….64

3.3 RESULTS…….……...65

3.4 DISCUSSION……..81

STUDY 4: PUBLIC USE OF TIDE POOLS IN SCRIPPS AND LA JOLLA ASBS……...82

4.1 BACKGROUND…….82

4.2 METHODS…….…….83

4.2a Study Sites…….…….83

4.2b Data Collection and Analysis…..…….83

4.3 RESULTS: Dike Rock (ASBS 31)……..85

4.3a Total Number of Visitors and Time Spent in Tide Pools……...…85

4.3b Day of Week versus Tide Pool Visitation……..…….86

4.3c Tidal Height (ft) versus Tide Pool Visitation…….86

4.3d Time of Day versus Tide Pool Visitation…….……..86

4.3e Visitor Behaviors Observed …….…….86

4.4 RESULTS: Marine Room and Devil's Slide (ASBS 29)……91

4.4a Tide Pool Visitation at Marine Room versus Devil's Slide……...91

4.4c Visitor Behaviors Observed ……..91

4.5 DISCUSSION……..….93

REFERENCES……...…….95

LIST OF FIGURES

Figure 1.1: Map of Sites……...15

Figure 1.2: Image of Devil's Slide (ASBS 29)……..16

Figure 1.3: Image of the Marine Room (ASBS 29)……...……16

Figure 1.4: Image of Dike Rock (ASBS 31)……..……17

Figure 1.5: A) Small flow-through chamber, B) Large flow-through chamber, and, C) Game bag in shallow tide pool near storm drain……...18

Figure 1.6: Overview of exposure locations for the field studies……..19

Figure 1.7: Collecting effluent from Storm Drain 186 during 2012 storm……22

Figure 1.8: Box plot of crustacean % survival (Dike Rock cores), 2012 field study……24

Figure 1.9: Box plot of crustacean % survival (Devil's Slide cores), 2012 field study……25

Figure 1.10: Box plot of gastropod % survival (Devil's Slide cores), 2012 field study……26

Figure 1.11: Box plot of crustacean % survival (Dike Rock cores), 2012 laboratory study…….28

Figure 1.12: Box plot of bivalve, crustacean and gastropod percent survival (Devil's Slide cores), 2012 laboratory study……...29

Figure 1.13. Crustacean percent survival (Dike Rock cores) at 2 and 14 days post-exposure, 2013 field study……32

Figure 1.14. Crustacean percent survival (Devil's Slide cores) at 2 and 14 days post-exposure, 2013 field study……33

Figure 1.15. Gastropod percent survival (Devil's Slide cores) at 2 and 14 days post-exposure, 2013 field study……..34

Figure 1.16. Crustacean percent survival (Dike Rock cores) 2 and 4 days post-treatment, 2013 laboratory study……...36

Figure 1.17. Crustacean percent survival (Devil's Slide cores) 2 and 14 days post-treatment, 2013 laboratory study……...38

Figure 1.18. Box plot of gastropod percent survival (Devil's Slide cores) 2 and 14 days post-treatment, 2013 laboratory study……...39

LIST OF FIGURES (continued)

Figure 2.1: Map of Study Sites……..44

Figure 2.2: Trample Plot……...…….....47

Figure 2.3: Freshly-Trampled Plot…….…….……...…47

Figure 2.4: Bivalve Abundance, Control vs. Trample Plots, Devil's Slide..…….....49

Figure 2.5: Gastropod Abundance, Control vs. Trample Plots, Devil's Slide ……..…50

Figure 2.6: Polychaete Abundance, Control vs. Trample Plots, Devil's Slide……..51

Figure 2.7: Turf Depth, Trample versus Control Plots, Devil's Slide……54

Figure 2.8: Gastropod Abundance, Control vs. Trample Plots, Cabrillo Zone 3……..56

Figure 2.9: Polychaete Abundance, Control vs. Trample Plots, Cabrillo Zone 3…….…57

Figure 2.10: Turf Depth over course of study, Trample vs. Control Plots, Cabrillo Zone 3…....60

Figure 3.1: Map of Study Sites……..63

Figure 3.2: Monthly Meiofaunal Abundance at Cabrillo Zone 3…….....66

Figure 3.3: Monthly Meiofaunal Abundance at Dike Rock……..……67

Figure 3.4: Monthly Meiofaunal Abundance at the Marine Room……..…….68

Figure 3.5: Monthly Meiofaunal Abundance at Devil's Slide……...69

Figure 3.6: *Amphithalamus spp*…….70

Figure 3.7: *Caecum californicum*…….....70

Figure 3.8: Cumulative Gastropod Abundance for All Sites…….....71

Figure 3.9: Gastropod Species Richness for All Sites……..……72

Figure 3.10: *Lasaea sp*..……..…….74

Figure 3.11: Cumulative Bivalve Abundance for All Sites……...75

Figure 3.12: Polychaete Common to All Sites……...76

LIST OF FIGURES (continued)

Figure 3.13: Cumulative Polychaete Abundance for All Sites……..77

Figure 3.14: Cumulative Meiofaunal Abundance for All Sites…….78

Figure 3.15: Cumulative Mean Turf Depth (in) for All Sites……....79

Figure 3.16: Monthly Turf Depth for All Sites……..80

Figure 4.1: Map of Study Sites.…….85

Figure 4.2: Visitor Length of Time Spent in Tide Pools, Dike Rock (ASBS 29)…….87

Figure 4.3: Total Unique Visitors/Day vs. Day of the Week, Dike Rock (ASBS 29)……...88

Figure 4.4: Peak Visitation/Day vs. Tidal Height (ft), Dike Rock (ASBS 29)……..89

Figure 4.5: Peak Visitation/Day vs. Time of Day, Dike Rock (ASBS 29)……90

Figure 4.6: Number of Unique Visitors/Observation Period, Marine Room and Devil's Slide (ASBS 31)……..……92

LIST OF TABLES

Table 1.1: Locations of exposure sites and approximate proximity to storm drain……...…19

Table 1.2: Tukey HSD Results, Laboratory study, Devil's Slide 2012…….....30

Table 1.3: Tukey HSD Results, Laboratory study, Devil's Slide 2013, Day 2…….37

Table 1.4: Tukey HSD Results, Laboratory study, Devil's Slide 2013, Day 14……...40

Table 2.1: Welch's T-test results, Meiofaunal Abundance, Devil's Slide, Months 0-6…….....52

Table 2.2: Welch's T-test results, Meiofaunal Abundance, Devil's Slide, Months 10-18…….....53

Table 2.3: Welch's T-test results, Meiofaunal Abundance, Cabrillo Zone 3, Months 0-10……..58

Table 2.4: Welch's T-test results, Meiofaunal Abundance, Cabrillo Zone 3, Months 12-18……59

Table 3.1: Anthropogenic Stress Exposure for Each Site……..64

Table 3.2: Species List (Gastropods) by Study Site……..73

Table 3.3: Species List (Bivalves) by Study Site……...76

INTRODUCTION

In general, the rocky intertidal is an environment where natural, abiotic disturbances such as wave shock and desiccation occur frequently. Intermediate levels of disturbance have been shown to benefit intertidal communities by freeing up space, which may then be colonized by species that normally lose out to more dominant species (Connell 1978 and Paine 1969). In this way, moderate and predictable disturbances result in increased diversity in the area; however, the addition of anthropogenic stress on an environment already presented with frequent natural disturbances may push the system too hard. In fact, excessive disturbance can reduce diversity in an ecosystem by eliminating all but the hardier species (Ricketts et al. 1985). Since species diversity is positively correlated with the stability of an ecosystem (Worm et al. 2006, and Yachi and Loreau 1999), anthropogenic disturbances that compromise diversity and abundance of organisms could also pose a risk to the stability of the rocky intertidal itself. Anthropogenic stresses known to occur in the rocky intertidal of the La Jolla Area of Special Biological Significance (ASBS 29) and Scripps ASBS (31) include periodic exposure to urban storm effluent and disturbance from human visitors to their tidepools. To assess possible impacts of these stresses on biological communities within the two areas, four studies were implemented beginning in December 2011 through December 2013. The first two studies include manipulative components, meant to mimic and measure impacts of urban pollution and trampling, and the second two studies were observational and used to describe biological communities and human activities in the areas of interest (Scripps and La Jolla ASBS). Micro-invertebrates, or meiofauna (variably described as invertebrates <1-2mm in length), including crustaceans, bivalves, gastropods, and polychaete worms were used as study organisms.

Despite their size, these inconspicuous organisms play important ecological roles and should not be overlooked. For instance, some meiofauna are important bacterial grazers (McIntyre 1969) and are a major food source for larger invertebrates (Bell and Coull 1978, Gosselin and Chia 1994, Gosselin and Chia 1996) and juvenile fish in the system (Ebling and Laur 1986, Gee 1989, Coull 1990). Moreover, within a given rocky intertidal region, meiofauna can contribute 25% of secondary production (Gibbons and Griffith 1986) and their abundances may affect the structure of macrofaunal communities (Watzin 1983). While the magnitude and possible consequences of anthropogenic stress-induced declines in meiofaunal abundance are not

yet understood, their ecological roles likely are significant, so it is important to examine the pressures placed on them by anthropogenic stresses.

STUDY 1: EFFECTS OF STORM EFFLUENT EXPOSURE ON MEIOFAUNAL ABUNDANCE

1.1 BACKGROUND

The human population is steadily increasing, and swathes of people continue to migrate towards the coasts to live and to recreate. Along with humans and urbanization of the coastline come more cars that shed oils and brake dust on the roads, and more houses with toxin-laden roofing materials, as well as heavy use of fertilizers and pesticides to satisfy landscaping needs. An important characteristic of urban communities is the pervasive use of concrete and asphalt, materials that do not absorb rainfall. This "imperviousness" in urban areas results in higher volumes of storm runoff, water that would otherwise be largely absorbed by soil is instead redirected into storm drains (Schueler 2000, Walsh 2000, Dietz and Clausen 2008, EPA 2003). Further, this higher volume urban runoff has ample opportunities to collect various toxins (Chang et al. 2004, Makepeace et al. 2005, Gobel et al. 2007, Jartun et al. 2008) on its way to the ocean, and these anthropogenic pollutants enter intertidal zones along the coastline through storm drains during periods of rainfall. Unlike sewage, stormwater enters the system without treatment to remove discarded litter, fertilizers or dangerous chemicals, and these untreated inputs can be highly toxic to all organisms (Hall and Anderson 1986, Thompson 2002, Schiff, Bay, and Stransky 2002, Pridmore et al. 1992).

Many studies have evaluated the effects of toxin-laden urban runoff on freshwater organisms exposed through watersheds, but to date, few studies have focused on consequences of runoff exposure for marine invertebrate species. Those few studies that do consider marine species (Schiff, Bay, and Stransky 2002, Roberts et al. 2007, Roberts et al. 2008), focus mainly on organisms inhabiting deeper waters, where stormwater is more readily mixed with seawater. For instance, Roberts et al. (2007) found that invertebrates living on macroalgae in water 3-6m deep decreased in abundance up to 4 days following a significant storm event (> 50ml rain/ 24 hours). The authors acknowledged that the decreases in abundance may be attributed to mortality or to behavioral responses (e.g. fleeing the effluent plume or rougher conditions associated with a storm) and so in a follow-up study they examined the likely cause of the reduced abundance. In their later study, they reported that behavioral responses were common (many invertebrates were found in the water column following exposure to effluent while those exposed to control groups

remained on the algae) and they did not observe mortality during the plume exposures; however, the exposure time was limited to 5 minutes (to mimic brief plumes of effluent during a storm), which only decreased the salinity from 33ppt to 28ppt (Roberts et al. 2008). While such exposure may mimic what intertidal invertebrates would experience at periods of high tide, it does not examine impacts on invertebrates exposed to longer periods of low tides. That is, if high volumes of effluent are entering an intertidal area during a very low tide (MLLW<0.3ft), effluent will not readily dilute with seawater and many areas may effectively sit in effluent (freshwater plus contaminants) for much of the low tide period. Thus, for storm events occurring within a period of lower tidal height, organisms inhabiting intertidal areas could be exposed to more extreme drops in salinity and higher concentrations of any pollutants contained in the effluent for considerably longer than 5 minutes. Furthermore, while studies investigated effects on macrofauna (Pridmore et al. 1992, Shiff, Bay, and Stransky 2002), rather little attention has been focused on how the less-conspicuous meiofauna may respond to such exposure.

To investigate effects of urban pollution on meiofaunal survival within intertidal turf communities of La Jolla, field and laboratory studies were performed during storm events in 2012 and 2013. Field components were used to compare meiofaunal survival between intertidal areas varying in proximity to a large storm drain (Storm Drain 186, located in ASBS 29), while laboratory studies were employed to separate out any effects of broader effluent components such as sudden decreased salinity due to freshwater inundation and pollutants contained within the effluent. Finally, for the 2013 storm, percent survival was reassessed after 14 days to look for possible latent effects on meiofaunal survival.

1.2 METHODS: Field Component

1.2a Study Sites

Three sites in La Jolla, California were included in this study (Figure 1.1). Devil's Slide is located in the La Jolla ASBS 29 and is composed of a few boulders and flat sections of turf-covered sandstone (Figure 1.2). This site was of interest because of its location within the ASBS and due to the presence of a large storm drain that empties into the intertidal there. The second site is commonly known as the Marine Room (Figure 1.3) and is located directly adjacent to

Devil's Slide within ASBS 31. This intertidal area (boulder field and sandstone flats) served as a near reference site as it is approximately 200m from the storm drain at Devil's Slide. The third site, Dike Rock (Figure 1.4) is located approximately 1.8km north of the Marine Room and also includes a boulder field as well as a few flat sandstone sections with algal turf. Dike Rock served as a far reference site as it is some 2km away from the storm drain and is located within ASBS 31.



Figure 1.1: Map of the 3 sites: Dike Rock (ASBS 31), Marine Room, and Devil's Slide (ASBS 29). Storm Drain 186 is located within Devil's Slide.



Figure 1.2: Image of Devil's Slide (ASBS 29), location of the storm drain.



Figure 1.3: Image of the Marine Room (ASBS 29), Near Reference Site.



Figure 1.4: Image of Dike Rock (ASBS 31), Far Reference Site.

1.2b Sample Collection and Deployment

Samples were collected from the mid-intertidal by inserting a metal core (1.9cm in diameter) into algal turf until it reached rock and then removing all turf and sediment with a metal scraping device. Cores were collected from Dike Rock (tide pools of ASBS 31) and

Devil's Slide (tide pool of ASBS 29) at low tide (<0.0ft) before the start of a storm event in March of 2012 and February 2013. Each core was placed in an individual flow-through chamber fitted with 100um nitex nylon mesh to keep meiofauna of interest contained but also allow exposure to ambient water (Figure 1.5A). The small chambers were then housed within larger flow-through containers for protection from debris and mechanical damage throughout the storm (Figure 1.5B). Two larger chambers containing cores from both sites were placed into game bags (Figure 1.5C) and secured to boulders at 6 locations of varying distance from the Storm drain 186 (Figure 1.6).

Following completion of the storm event (approximately 25 hours later), all samples were retrieved and transported to Scripps Institution of Oceanography (SIO) where they were placed in clean saltwater (33ppt) and analyzed for meiofaunal survival.

Survival was determined while observing turf cores under a dissecting microscope. Meiofauna that were observed moving or that responded to stimulation were counted as "alive", and non-responsive individuals were recorded as "dead" and removed from the sample. In order to expediently process a sufficient number of samples, micro-invertebrates were only identified to the following taxonomic groups: gastropods, bivalves, and crustaceans.

For the storm event in 2013, only cores from the location nearest the storm drain and from the far reference, shallow tidepool location (Figure 1.6) were analyzed, due to the fact that the storm was not as large as predicted (<0.5 inches rainfall/24 hours), and because very little of the rainfall occurred while the tide was out, the exposure period was minimal. After observing samples from each site, it was apparent that survival was high in all cores, as they had not experienced exposure to effluent or rainwater while the tide was out. There was, however, just enough effluent exiting the storm drain for us to collect and still perform the laboratory component.



Figure 1.5: A) Small flow-through chamber; B) Large flow-through chamber; and, C) Game bag in shallow tidepool.



Figure 1.6: Overview of exposure locations for the field studies.

Table 1.1: Locations of exposure sites and approximate proximity to storm drain.

Exposure Location Name, Depth category	Site	Distance From Storm Drain
Storm Drain, Shallow	Devil's Slide	15m West
Storm Drain, Intermediate	Devil's Slide	25m West
Storm Drain, Deep	Devil's Slide	35m West
Near Reference, Shallow	Marine Room	200m North, 15m West
Far Reference, Shallow	Dike Rock	2km North, 15m West
Far Reference, Intermediate	Dike Rock	2km North, 25m West

1.2c Statistical analysis

Differences in survival were compared between site of core origin, taxonomic groups, and proximity to the storm drain using ANOVA (analysis was performed using R statistical language and computing). In order to satisfy the assumptions of ANOVA, percent survival was converted to a proportion and arcsine transformed before analysis. Wherever an ANOVA yielded statistically significant results, Tukey HSD post-hoc tests were used to distinguish where significant differences were present. Meiofaunal composition and abundance varied greatly between cores originating from Dike Rock and those collected at Devil's Slide. Specifically, while nearly all cores from Devil's Slide consisted of some bivalves, crustaceans, and gastropods, cores from Dike Rock overwhelmingly contained only crustaceans. For this reason, analyses were performed separately based on site origin of cores (Dike Rock or Devil's Slide) and only those taxonomic groups with abundances of >3 individuals/core were considered.

For the 2013 storm, only cores from the location nearest the storm drain and the far reference were analyzed. In this case, Welch's T-tests were used to discern differences in mean survival between proximity to the storm drain and taxonomic groups. Finally, survival was reassessed at 14 days post-exposure to look at possible latent effects.

1.3 METHODS: Laboratory Studies

1.3a Sample Collection

Turf cores (0.75 inches in diameter) containing meiofauna were collected from Dike Rock and Devil's Slide before the onset of a storm event in March 2012 and February 2013 and transported to SIO. Cores from each collection site were placed into individual containers, filled with clean saltwater (33ppt) and equipped with aerators to ensure proper oxygenation. Once a storm event was in progress, effluent was collected from Storm Drain 186 at Devil's Slide (Figure 1.7) and transported to SIO. Half of the stormwater was brined to 33ppt using laboratory-grade sea salts. After a 1-hour acclimation period, all containers were drained of clean saltwater and filled with one of four treatments: Stormwater (0ppt, collected from Storm Drain 186 during storm event); Brined Stormwater (33ppt); Clean Freshwater (0ppt); or Clean Saltwater (33ppt).

Following a 3-hour exposure period, all containers were drained of their treatments and again filled with clean saltwater. The exposure time aimed to simulate the length of time meiofauna would be exposed to effluent with minimal mixing with seawater due to the low tide (-0.43ft in 2012 and -1.35ft in 2013). Returning cores to clean saltwater post-treatment simulated the rising tide and mixing with seawater. Cores remained in clean saltwater for at least 19 hours to simulate high tide conditions and then observed for meiofaunal survival (alive vs. dead) as described in the field component above.

For the March 2013 storm event, meiofauna were returned to clean saltwater after initial observation and a second observation was performed at 14 days post-treatment to assess possible latent effects on survival. During the 14-day waiting period, each container was drained and refilled with clean saltwater daily and no food was added.



Figure 1.7: Collecting effluent from Storm Drain 186 during 2012 storm.

1.3b Statistical analysis

Analysis of survival was performed using ANOVA and Tukey HSD post-hoc tests as described in the field component of the study. Survival was calculated for each taxonomic group, site of core origin, and treatment received. Again, data were arcsine transformed in cases where ANOVA assumptions were not met.

1.4 RESULTS: Field Study 2012

1.4a Dike Rock cores

Mean crustacean survival (only crustaceans met the >3 individuals/core standard) was lowest near the storm drain (Figure 1.8); however, a one-way ANOVA (data were arcsine transformed to satisfy assumptions of ANOVA) was used to test differences in mean survival between locations varying in proximity to the storm drain and the results did not show a statistically significant difference in crustacean survival between sites, $F(5,18) = 0.46$, $p = 0.81$.

1.4b Devil's Slide cores

For crustaceans and gastropods (both groups met the minimum standard for inclusion), mean survival was lowest near the storm drain and in the shallow reference tidepools (Figure 1.9 and 1.10); however, a one-way ANOVA did not indicate a significant difference in mean survival for either group, Crustaceans: $F(5,18) = 2.72$, $p = 0.053$; Gastropods: $F(5,14) = 1.25$, $p = 0.34$.

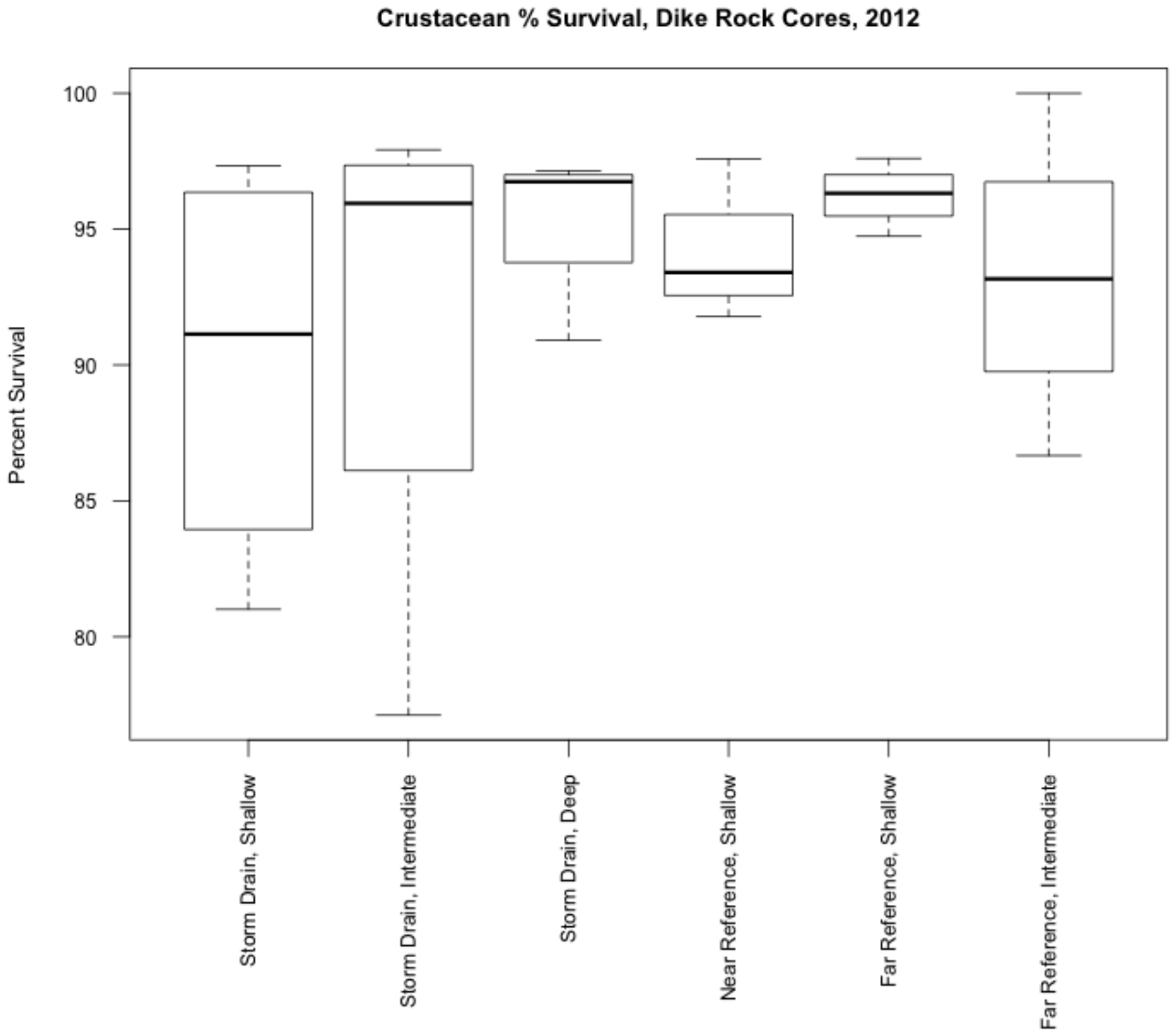


Figure 1.8: Box plot of crustacean percent survival (Dike Rock cores), 2012 field study.

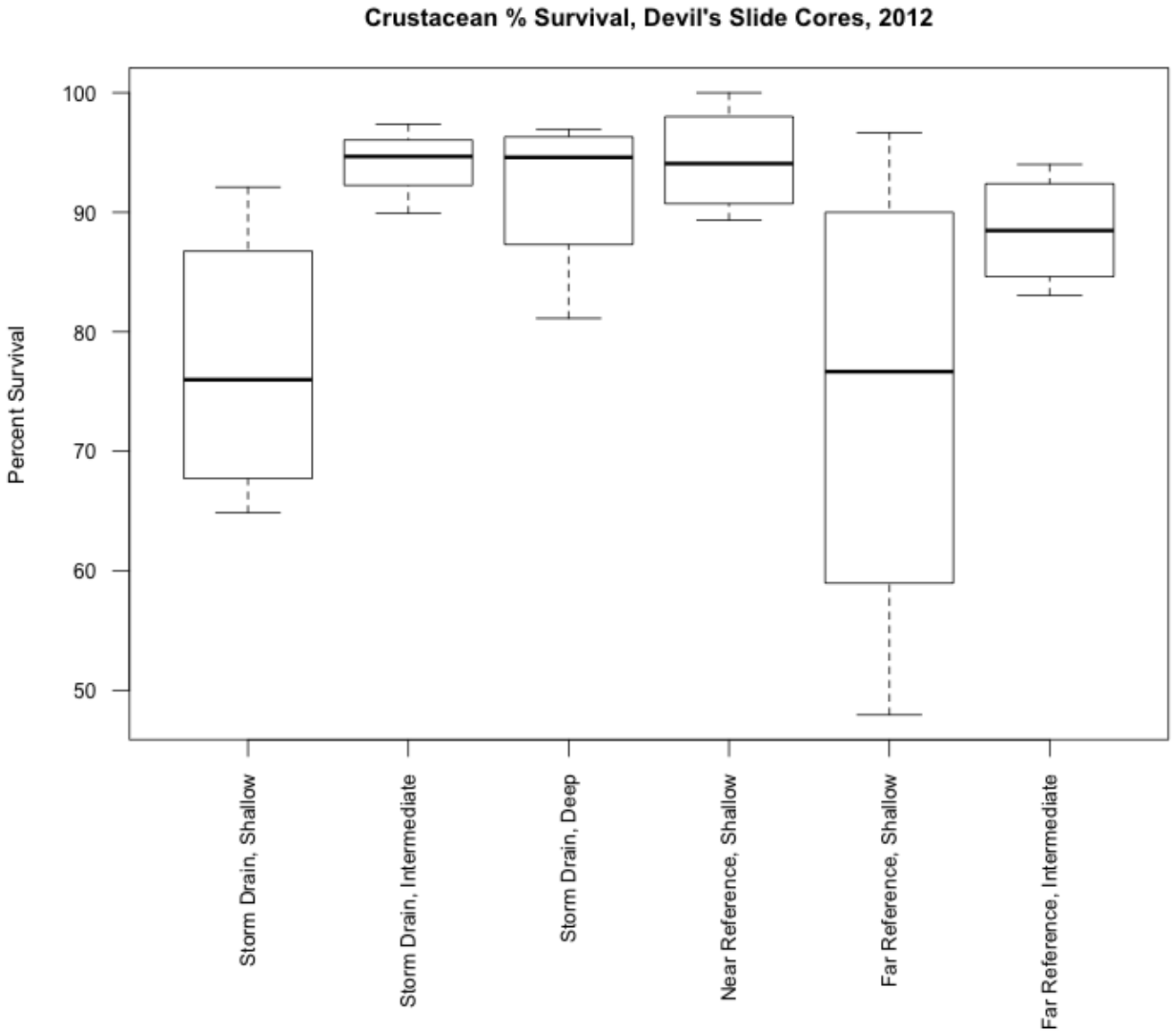


Figure 1.9: Box plot of crustacean percent survival (Devil's Slide cores), 2012 field study.

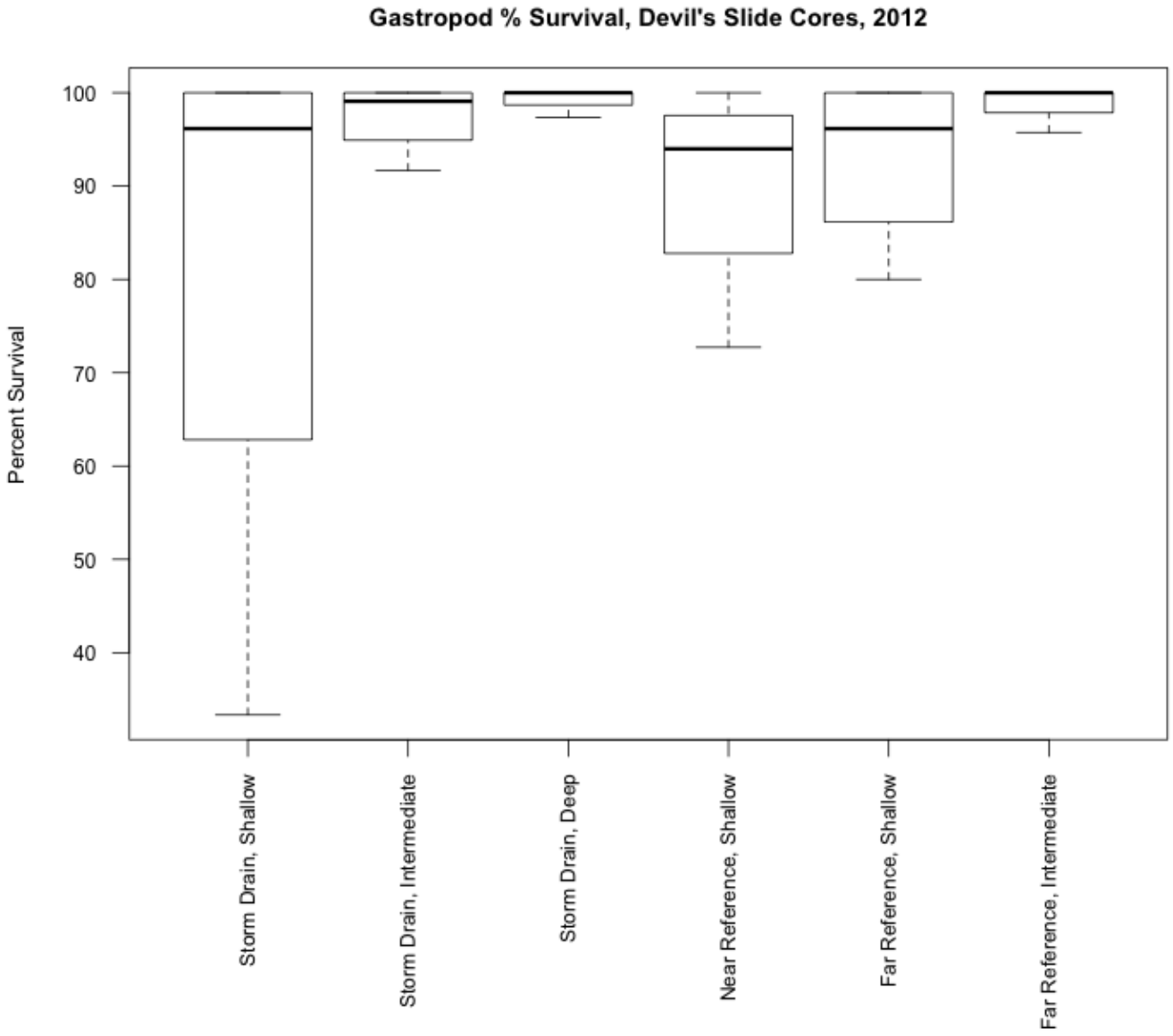


Figure 1.10: Box plot of gastropod percent survival (Devil's Slide cores), 2012 field study.

1.5 RESULTS: Laboratory Study 2012

1.5a Dike Rock cores

Only crustaceans met the criteria for analysis and those data were arcsine transformed to meet the assumptions of ANOVA. While percent survival was lowest in the freshwater treatment (Figure 1.11), a one-way ANOVA did not yield significant results, $F(3,4) = 0.076$, $p = 0.97$.

1.5b Devil's Slide cores

Bivalves, Crustaceans and Gastropods all met the criteria for analysis and all showed decreased survival in freshwater and stormwater treatments (Figure 1.12). A one-way ANOVA showed that mean survival differed significantly across treatments for all taxonomic groups: Bivalves, $F(3,4) = 7.73$, $p = 0.039$*; Crustaceans, $F(3,4) = 9.84$, $p = 0.026$*; and, Gastropods $F(3,4) = 7.75$, $p = 0.038$*.

Tukey HSD post-hoc comparisons showed that survival of bivalves, crustaceans and gastropods was significantly different between Stormwater and Clean Saltwater treatments, and between those exposed to Stormwater and Brined Stormwater (Table 1.2).

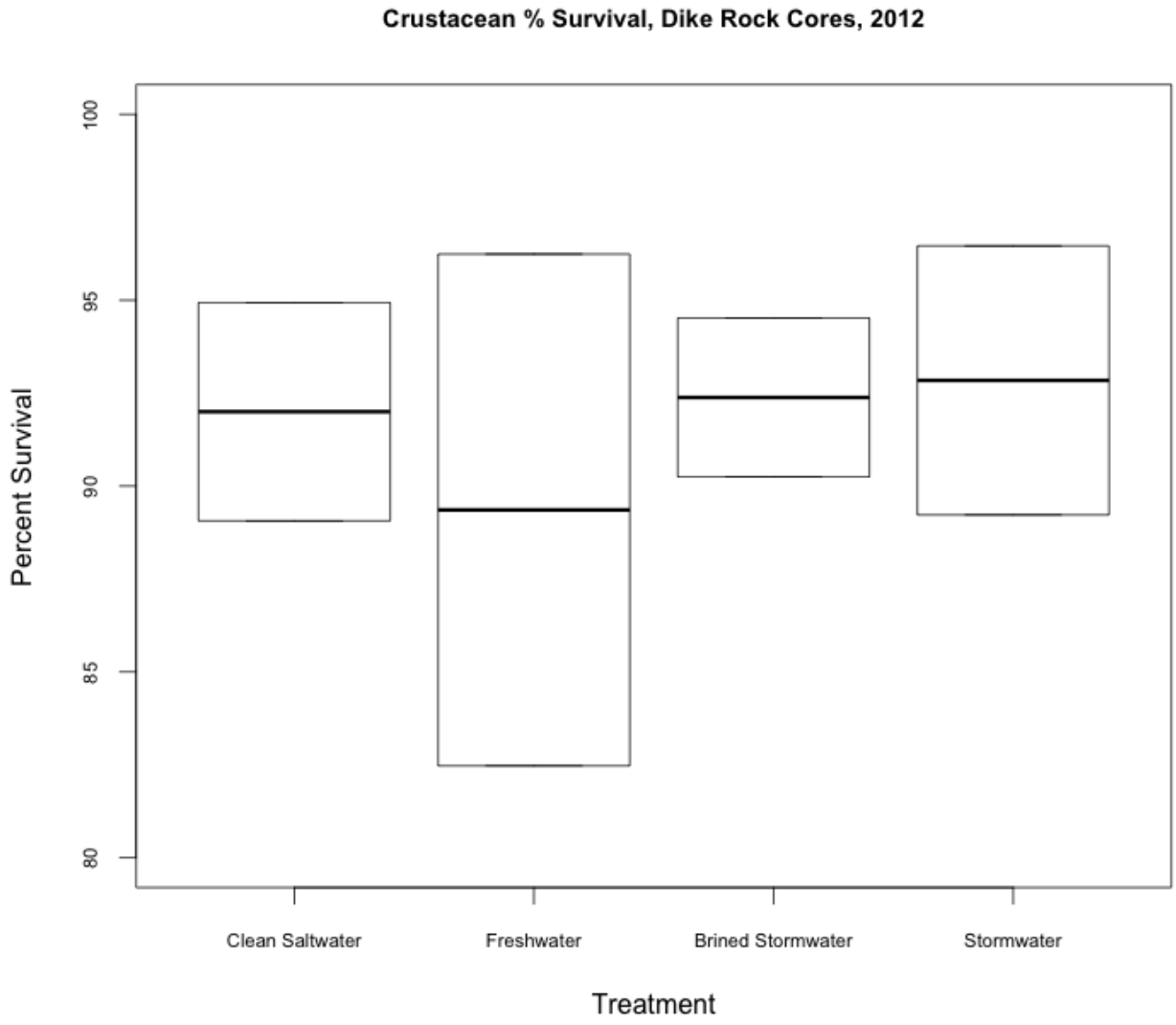


Figure 1.11: Box plot of crustacean percent survival (Dike Rock cores), 2012 laboratory study.

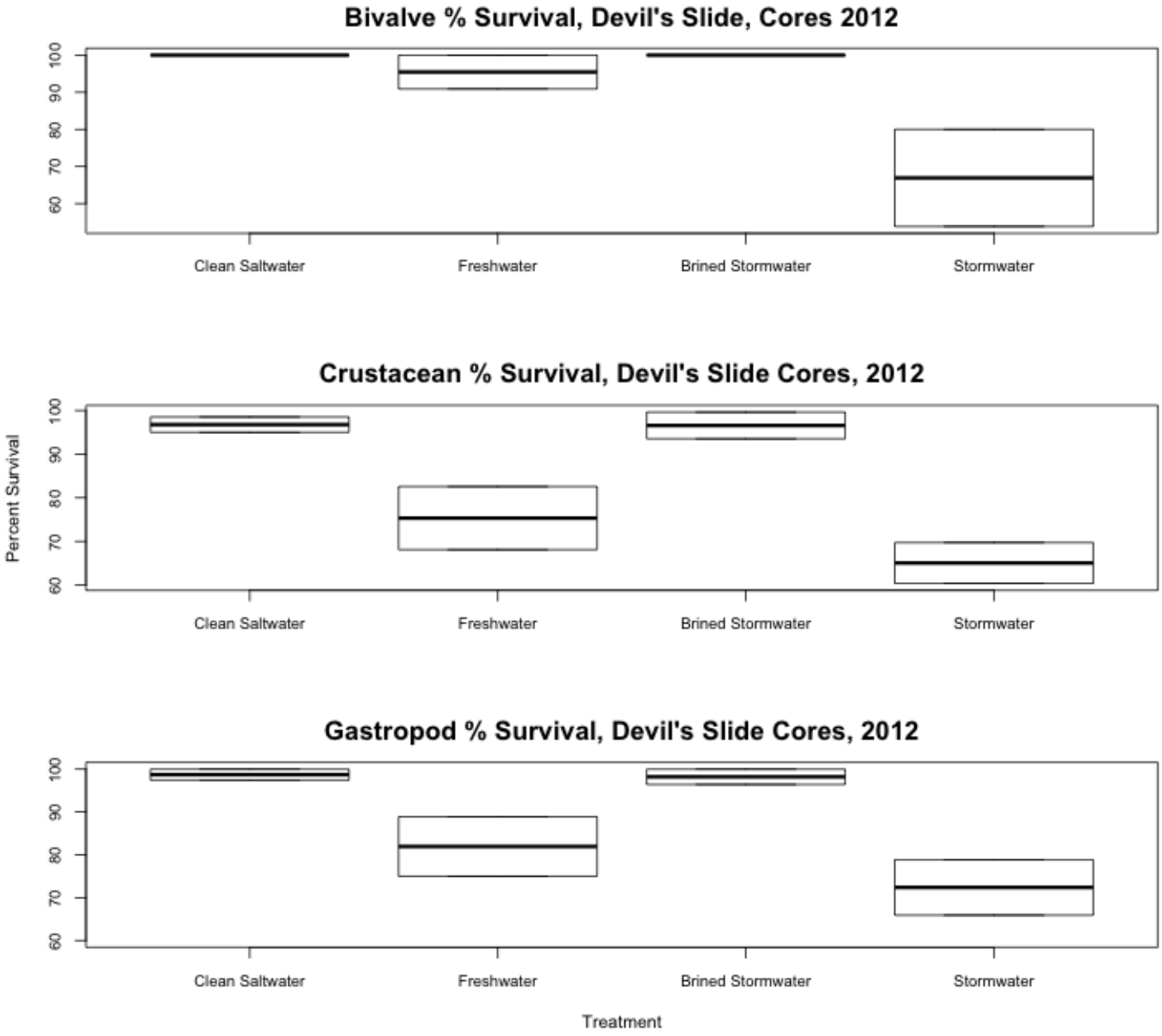


Figure 1.12: Box plot of bivalve, crustacean and gastropod percent survival (Devil's Slide cores), 2012 laboratory study.

Table 1.2: Tukey post-hoc test results, laboratory study, Devil's Slide 2012, P<0.05 emboldened.

Treatment Comparison	Taxonomic Group	95% CI		*P* value
		Lower	Upper	
Stormwater - Brined Stormwater	Bivalves	-1.63	-0.017	*0.047
	Crustaceans	-0.33	-0.015	*0.037
	Gastropods	-1.30	0.053	0.0645
Stormwater - Clean Saltwater	Bivalves	-1.32	0.030	*0.047
	Crustaceans	0.33	-0.016	*0.036
	Gastropods	-1.32	0.032	0.06

1.6 RESULTS: Field Study 2013- Immediate and Latent Mortality

1.6a Dike Rock Cores

There were no statistically significant differences in immediate or latent survival between crustaceans placed nearest the storm drain and at the shallow reference tide pool (Figure 1.13). T-test values, Crustaceans, Day 2: $t(5.81) = -0.16$, $p = 0.88$. Crustaceans, Day 14: $t(5.32) = -0.12$, $p = 0.91$.

1.6b Devil's Slide Cores

There were no significant differences in immediate or latent survival for crustaceans (Figure 1.14) and gastropods (Figure 1.15) placed nearest the storm drain and at the shallow reference tide pool. T-test values, Crustaceans, Day 2: $t(4.97) = -0.78$, $p = 0.47$; Gastropods, Day 2: $t(5.0) = 0.41$, $p = 0.70$; Crustaceans, Day 14: $t(2.47) = -0.41$, $p = 0.72$; Gastropods, Day 14: $t(4.43) = 1.9$, $p = 0.12$.

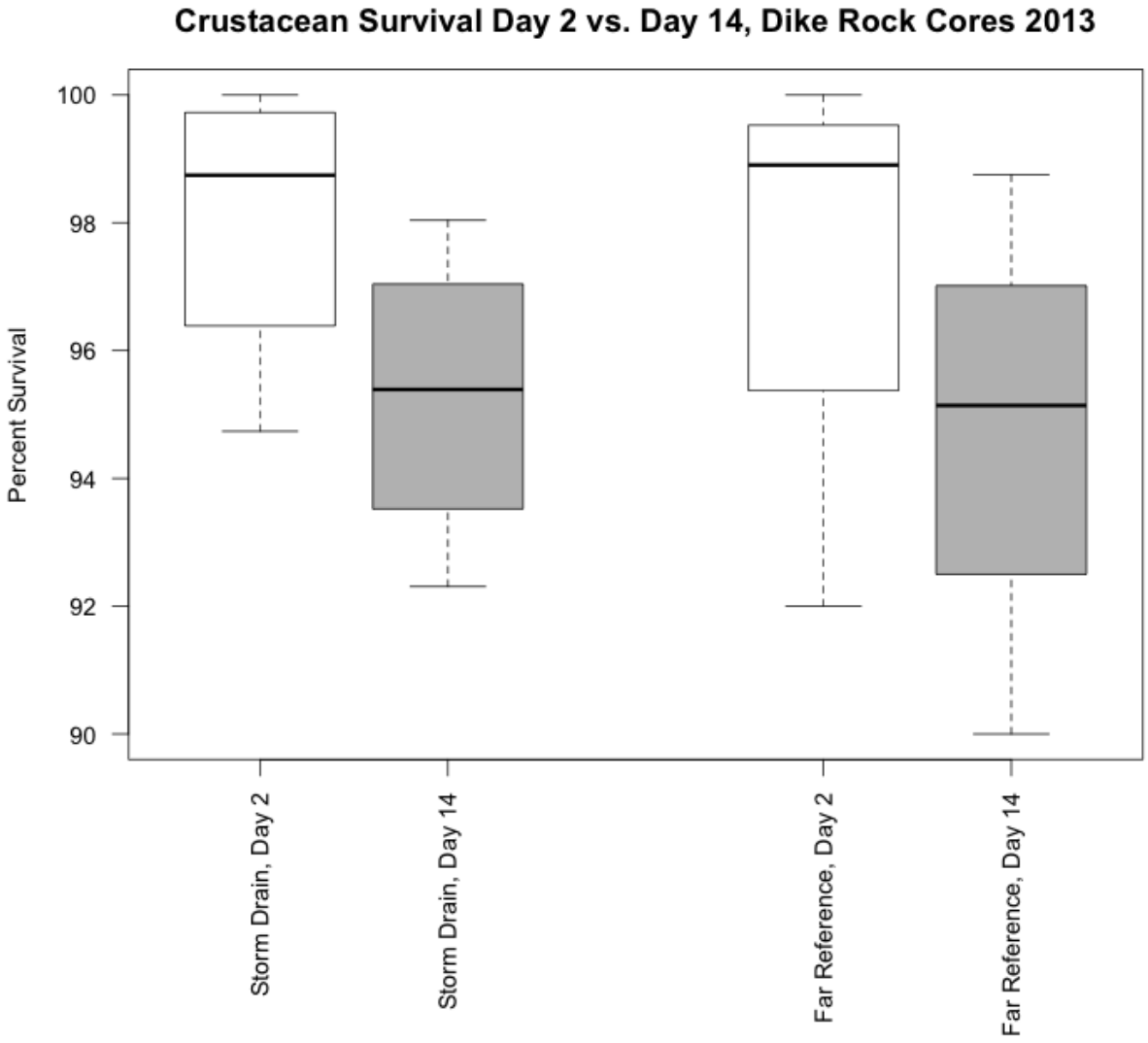


Figure 1.13: Box plot of crustacean percent survival (Dike Rock cores) at 2 and 14 days post-exposure, 2013 field study.

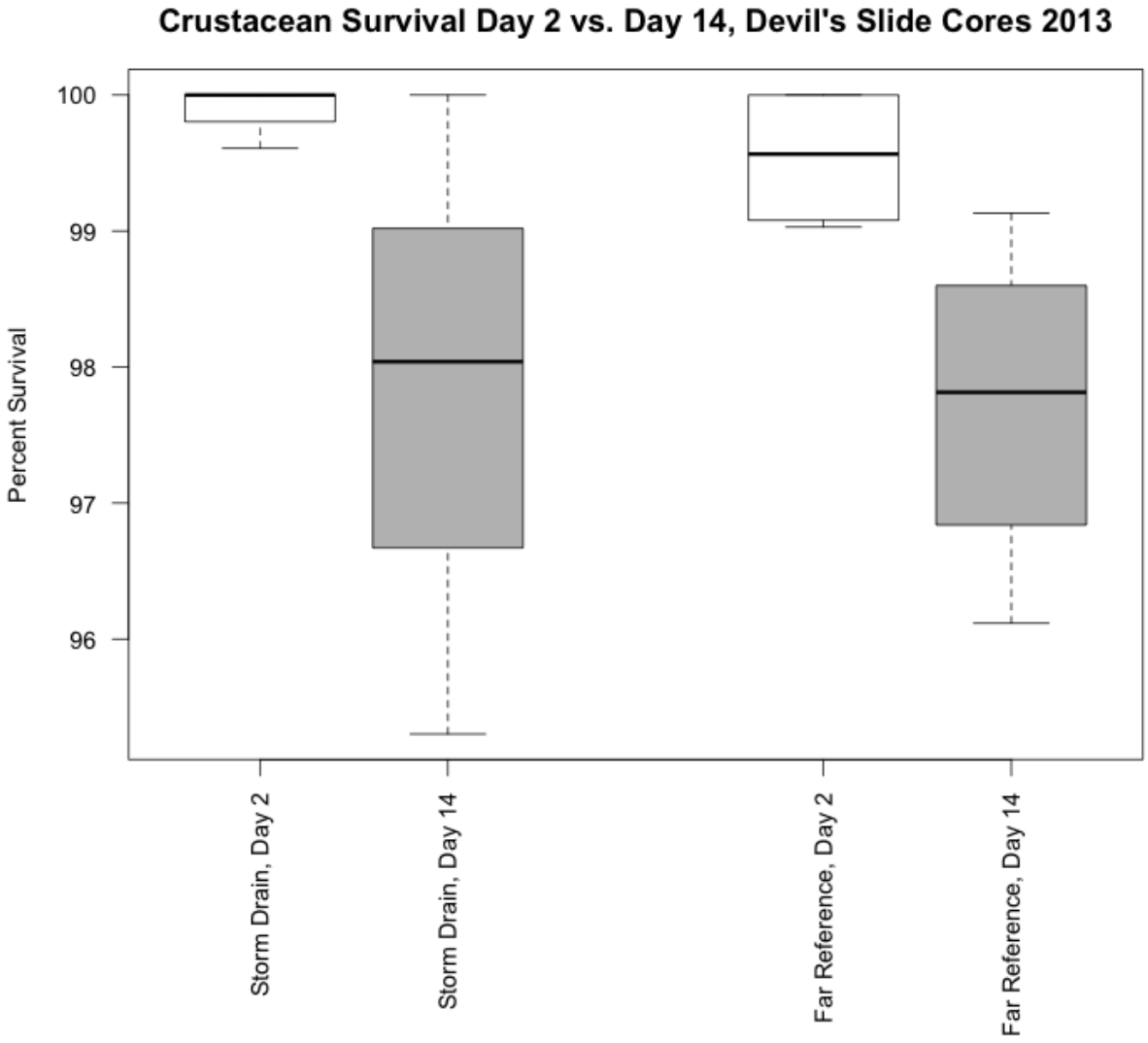


Figure 1.14: Box plot of crustacean percent survival (Devil's Slide cores) at 2 and 14 days post-exposure, 2013 field study.

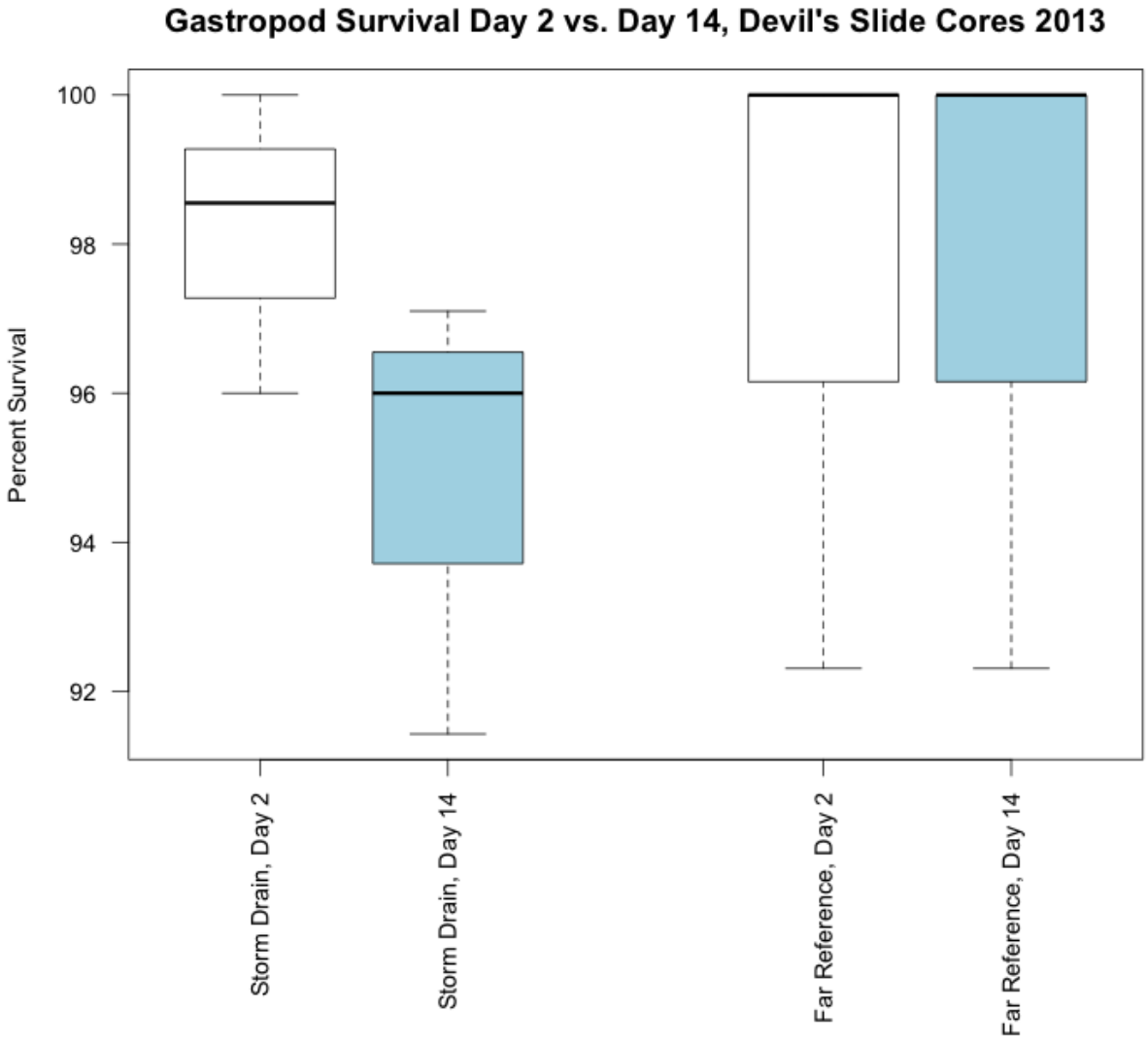


Figure 1.15: Box plot of gastropod percent survival (Devil's Slide cores) at 2 and 14 days post-exposure, 2013 field study.

1.7 RESULTS: Laboratory Study 2013- Immediate and Latent Mortality

1.7a Dike Rock Cores

Again, only crustaceans met the minimum abundance requirement for analysis (3 individuals/core). Mean survival was lowest in freshwater and stormwater treatments (Figure 1.16). Data were arcsine transformed and ANOVA yielded significant results, $F(3,16) = 6.35$, $p = 0.0048$*.

A Tukey HSD post-hoc comparison test showed that crustacean survival was significantly different between the following treatments: Brined Stormwater – Freshwater, $p = 0.0039$*, 95% CI [0.0986, 0.5434]; Stormwater – Freshwater, $p = 0.0234$*, 95% CI [0.029, 0.47]

At 14 days post-treatment, mean survival for crustaceans was still lowest in freshwater and stormwater treatments. (Figure 1.16); however, the ANOVA suggested differences at $p < 0.10$, but did were not significant at $p < 0.05$, $F(3,16)$: 2.512, $p = 0.096$.

1.7b Devil's Slide cores

Crustaceans and gastropods met the minimum abundance for inclusion in analysis and both groups showed significant differences in survival between treatments (Figure 1.17-1.18). These data were arcsine transformed to satisfy all assumptions of ANOVA before analysis. Crustaceans: $F(3,16) = 7.645$, $p = 0.0022$*; Gastropods $F(3,15) = 9.65$, $p = 0.0009$*.

Tukey HSD post-hoc comparisons showed that crustacean survival was significantly different ($p < 0.05$) between those exposed to the following treatments: Freshwater – Clean Saltwater; Stormwater – Clean Saltwater; and, Brined Stormwater – Freshwater. Gastropod survival varied significantly between Stormwater – Clean Saltwater, and Stormwater – Brined Stormwater (Table 1.3).

At 14 days post-treatment, an ANOVA revealed that crustacean and gastropod survival still differed significantly between treatments (Figure 1.17-1.18), Crustaceans: $F(3,16) = 8.66$, $p = 0.0012$*; Gastropods $F(3,15) = 9.67$, $p = 0.0008$*.

Tukey HSD post-hoc comparisons showed that crustacean survival was still significantly different between those exposed to Freshwater – Clean Seawater, Stormwater – Clean Saltwater, and, Brined Stormwater – Freshwater. Gastropod survival still varied significantly between Stormwater – Clean Saltwater, and Stormwater – Brined Stormwater (Table 1.4).

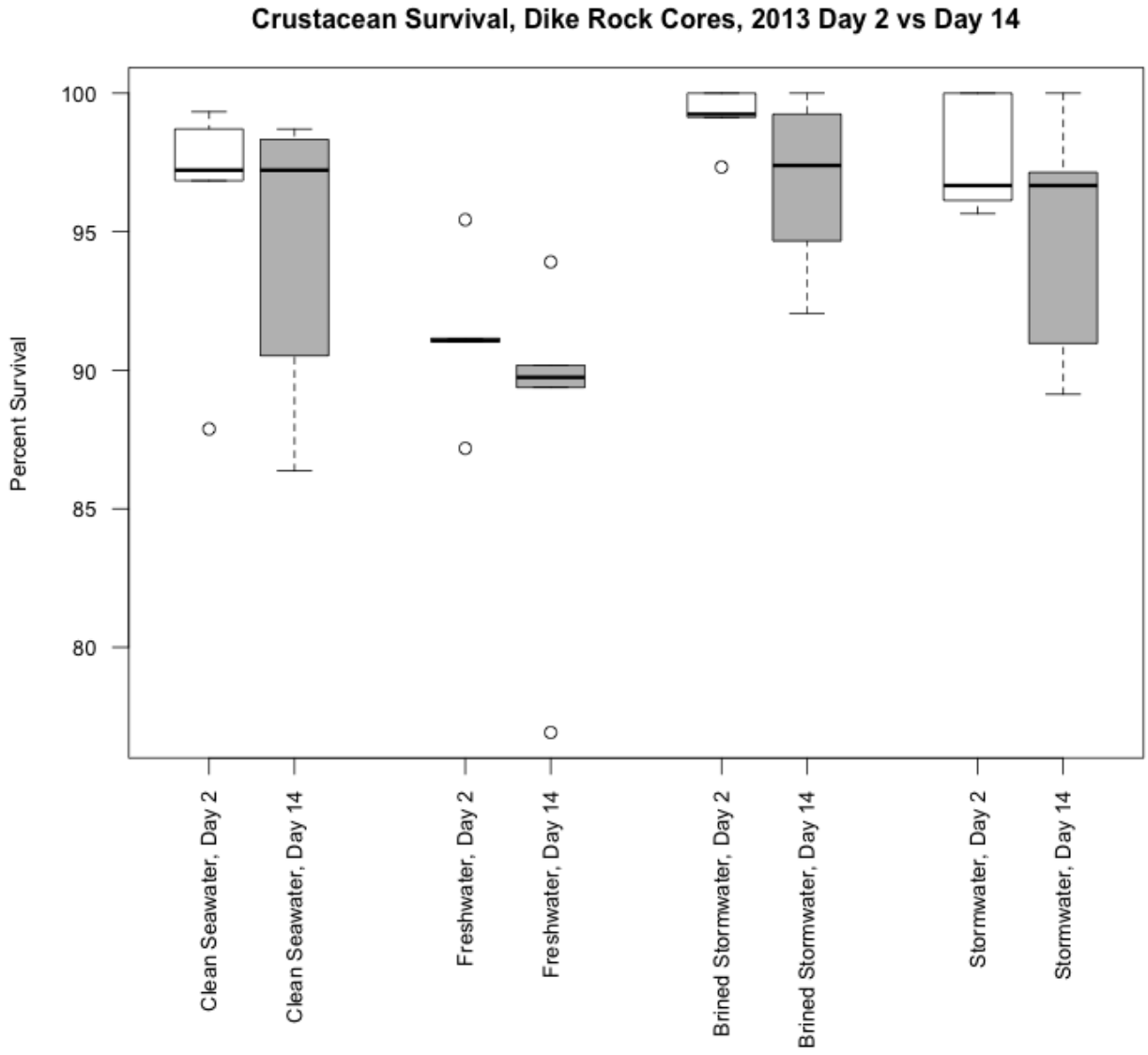


Figure 1.16: Box plot of crustacean percent survival (Dike Rock cores) 2 and 4 days post-treatment, 2013 laboratory study.

Table 1.3: Tukey HSD *p*-values, and CI 95% lower and upper bounds for the 2013 laboratory study, Devil's Slide 2013, Day 2. **P*-values <0.05 emboldened.

Treatment Comparison	Taxonomic Group	95% CI		*P* value
		Lower	Upper	
Freshwater - Clean Saltwater	Crustaceans	-0.85	-0.12	*0.0071
	Gastropods	-0.74	0.030	0.075
Stormwater - Clean Saltwater	Crustaceans	-0.75	-0.025	*0.034
	Gastropods	-1.0010	-0.23	*0.0016
Brined Stormwater - Freshwater	Crustaceans	0.096	0.82	*0.011
	Gastropods	-0.052	0.76	0.098
Stormwater - Brined Stormwater	Crustaceans	-.072	0.46	0.052
	Gastropods	-1.025	-0.21	*0.0028

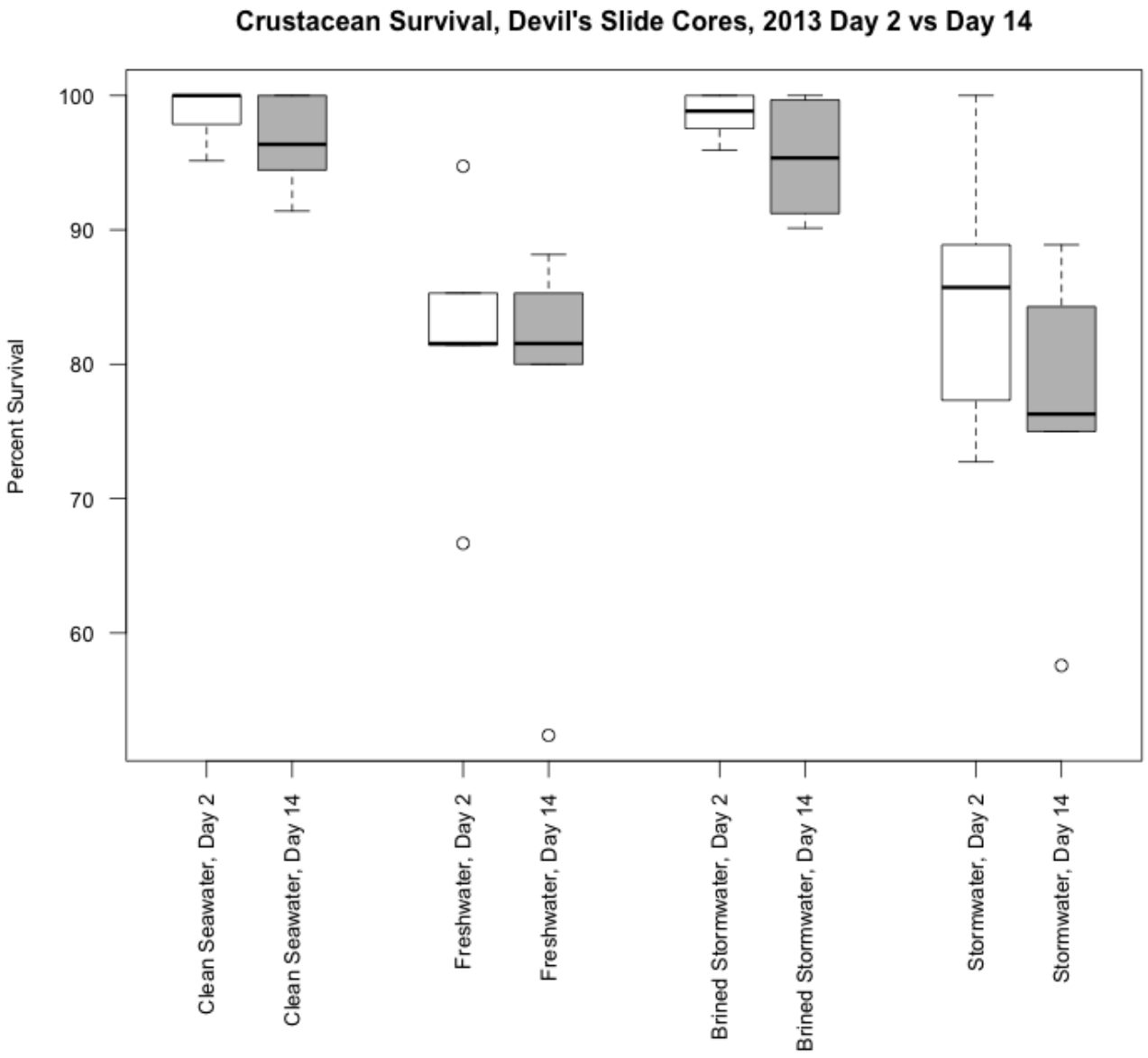


Figure 1.17: Box plot of crustacean percent survival (Devil's Slide cores) 2 and 14 days post-treatment, 2013 laboratory study.

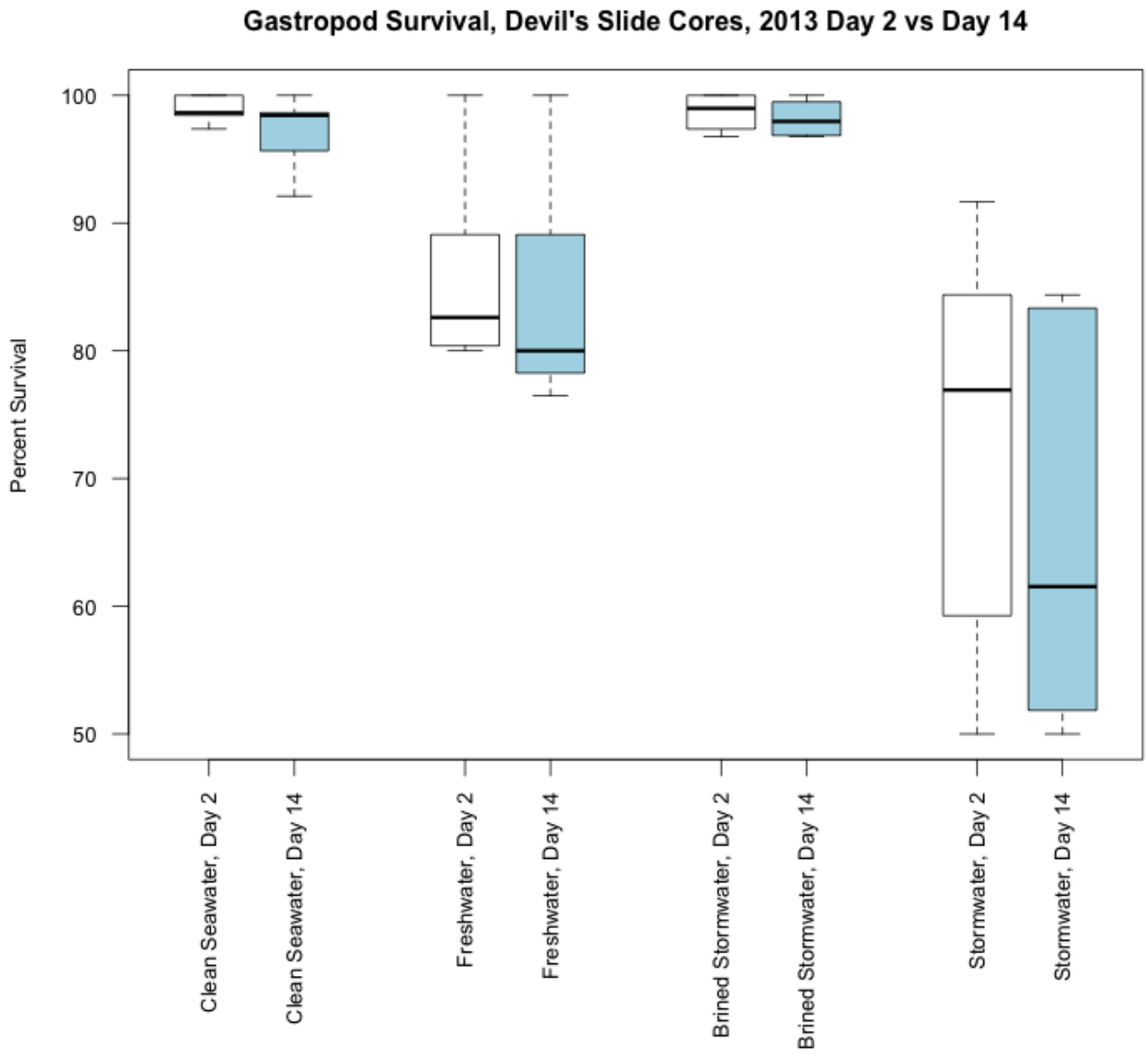


Figure 1.18: Box plot of gastropod percent survival (Devil's Slide cores) 2 and 14 days post-treatment, 2013 laboratory study.

Table 1.4: Tukey post-hoc test results, CI 95% lower and upper bounds, and *p*-values (P<0.05 emboldened) for the 2013 laboratory study, Devil's Slide 2013, Day 14.

Treatment Comparison	Taxonomic Group	95% CI		*P* value
		Lower	Upper	
Freshwater - Clean Saltwater	Crustaceans	-0.82	-0.10	*0.0095
Stormwater - Clean Saltwater	Crustaceans	-0.84	-0.13	*0.0067
	Gastropods	1.011	-0.23	*0.0019
Brined Stormwater - Freshwater	Crustaceans	0.057	0.77	*0.0203
Stormwater - Brined Stormwater	Crustaceans	-0.79	-0.078	0.0521
	Gastropods	-1.081	-0.25	*0.0028

1.8 DISCUSSION

Results from this study showed reduced survivorship for meiofauna that had been exposed to freshwater or effluent (freshwater plus contaminants); however, these results were not statistically consistent between the two storm events used in this study. That is, while meiofaunal survival was reduced in the shallowest tidepools (Field Study 2012) and in freshwater or effluent treatments (Laboratory Studies 2012 and 2013), only those results from the laboratory components in 2012 and 2013 were statistically significant ($p < 0.05$). There are several factors that could have contributed to the mixed results reported here, including variability in the volume and concentration of toxins within effluent between storms.

The amount of precipitation experienced during the two storms varied noticeably. In 2012, approximately 0.58 inches of rain fell within 24 hours, with 0.46 inches falling while the tide was out (MLLW = -0.43ft). By contrast, only 0.26 inches of rain fell within 24 hours during the 2013 storm, with just 0.14inches falling while the tide was out (MLLW = -1.35ft). Considering this, the exposure to effluent (and freshwater directly from rainfall itself) was minimal in the 2013 storm as compared with the event in 2012 and the differing exposure likely impacted the resultant meiofaunal survival as seen in the field components in the study. That is, although neither of the storms resulted in significant differences in meiofaunal survival between exposure sites, overall survival was lower for crustaceans and gastropods during the 2012 storm (Storm Drain: mean survival = 82.93%; Far Reference: mean survival = 87.94%) as compared with 2013 (Storm Drain: mean survival = 98.64%; Far Reference: mean survival = 98.36%). In addition to the variability in effluent volume between storms, the composition of the effluent may have differed significantly.

Concentrations of toxins within effluent have been shown to vary over short time scales (Katznelson et al. 1995) and may be influenced by the amount of time elapsed since previous rainfall has occurred. For instance, the 2012 storm had been preceded by substantial rainfall (0.66in/ 24 hours) over a month before, while the 2013 storm followed a storm event (0.83in/ 24 hours) just 14 days before (Montgomery Field Data). Therefore, it is feasible that there were higher concentrations of toxins contained within the 2012 effluent as more time had passed between storms, allowing more substances such as pesticides, metals from brake dust and housing by-products to accumulate.

Results also varied between taxonomic groups. While some of this variation may be attributable to differences in number of replicates used and the varying number of individuals per replicate, it is important to recognize that effluent can be differentially toxic to different taxa. Previous studies have shown that intertidal invertebrates are able to cope with often-extreme fluctuations in environmental conditions such as salinity, but they do have taxon specific limits (Brand 1984, Berger and Kharazova 1997, Burton 1979, Farmer 1979, Neuparth et al. 2002). For instance, Berger and Kharazova (1997) demonstrated that some shelled marine gastropods respond to abnormal salinity through hermitization (complete closing of the mantel cavity) and can survive in freshwater much longer than other animals that cannot close themselves off from ambient conditions. It would be interesting to examine whether specific toxins (and at what concentrations) present in urban storm effluent may hinder the ability of some gastropods to hermitize (perhaps through decreased sensitivity to changing conditions). Furthermore, invertebrates accumulate, detoxify, and excrete metals as needed for physiological processes, and this can differ between types of invertebrates, and even within subspecies (Depledge and Rainbow 1990, Rainbow 2007). Thus, deleterious, sublethal and lethal effects could vary greatly for meiofauna.

Finally, considering that the statistically significant results were based on laboratory studies, rather than from field studies, the toxins contained in the effluent for these two particular storm events were likely not responsible for the decreases in survival observed. That is, the effluent used in the laboratory studies was obtained during a period commonly referred to as "first flush" (Metcalf 1916), in which runoff during the early part of a storm is more concentrated (with whatever it picks up on its way along impervious surfaces) than effluent occurring later on in a storm. Thus, if toxic effects were not clearly observed in the laboratory where meiofauna were exposed to "first flush" conditions, one could presume that meiofauna in the field would not exhibit toxic effects either, especially as the rain event continued and the volume of freshwater entering the system (through the drain and also directly from the rainfall itself) increased, further diluting the toxin concentration. There were, however, noteworthy decreases in survival for meiofauna exposed to effluent and freshwater treatments and so it is apparent that a reduction in salinity does impact survival.

In summary, it is clear that prolonged exposure to effluent had negative impacts on the survival of bivalves, crustaceans, and gastropods for the two storms included in the study. However, as the results presented here suggest that freshwater exposure alone appears responsible for the decreased survival observed, these negative impacts may be independent of the toxins in the effluent for these two particular storm events.

STUDY 2: EFFECTS OF TRAMPLING ON MEIOFAUNAL ABUNDANCE

2.1 BACKGROUND

Tide-pooling in the rocky intertidal is a popular recreational and educational activity; however, mechanical disturbances such as crushing from foot traffic, turning over rocks, and removal of macrofauna have been shown to negatively impact biological communities (Povey and Keough 1991, Beauchamp and Gowing 1982, Keough and Quinn 1998, Brown and Taylor 1999, Schiel and Taylor 1999, Smith and Murray 2005). Studies have shown even the inconspicuous organisms (meiofauna) that inhabit intertidal turf (algal matrix consisting of anchor and epiphytic species) are impacted by trampling. For instance, Huff (2011) showed that trampling of turf communities decreased diversity and abundance of meiofauna. Another important factor in the abundance of meiofauna is the positive interaction between meiofauna and the algal turf itself. By providing protection against predation and desiccation during low tides, algal turf expands the realized niches of local meiofauna (Bruno et al 2003) and their abundance has been shown to increase with increasing algal biomass (Gibbons and Griffith 1986). Moreover, a reduction in turf that consequently reduces meiofauna could ultimately impinge upon nutrient flow and water-filtering services, influencing the overall health of the ecosystem. Another anthropogenic stress that may affect turf and meiofauna is periodic exposure to urban effluent through storm drains. While intermediate levels of disturbance can result in a healthier intertidal ecosystem (Connell 1978, Paine 1969), too much stress may push a system too hard (Rickets et al. 1985). The purpose of this study was to evaluate effects of trampling on micro-invertebrate abundance and depth of algal turf within and between sites with and without the additional stress of periodic exposure to urban effluent.

2.2 METHODS

2.2a Study Sites

Devil's Slide (DS)- tide pools located in ASBS 29. This site receives very little foot traffic due to its location (see Study 4 of this report) and also receives periodic input from a large storm drain (storm drain 186). (Figure 2.1)

Cabrillo Zone 3 (CZ3)- this is a remote site located >25km to the South of DS (at the Cabrillo National Monument on Point Loma). This site is closed to the public so it receives negligible foot traffic and does not receive inputs from storm drains. (Figure 2.1)

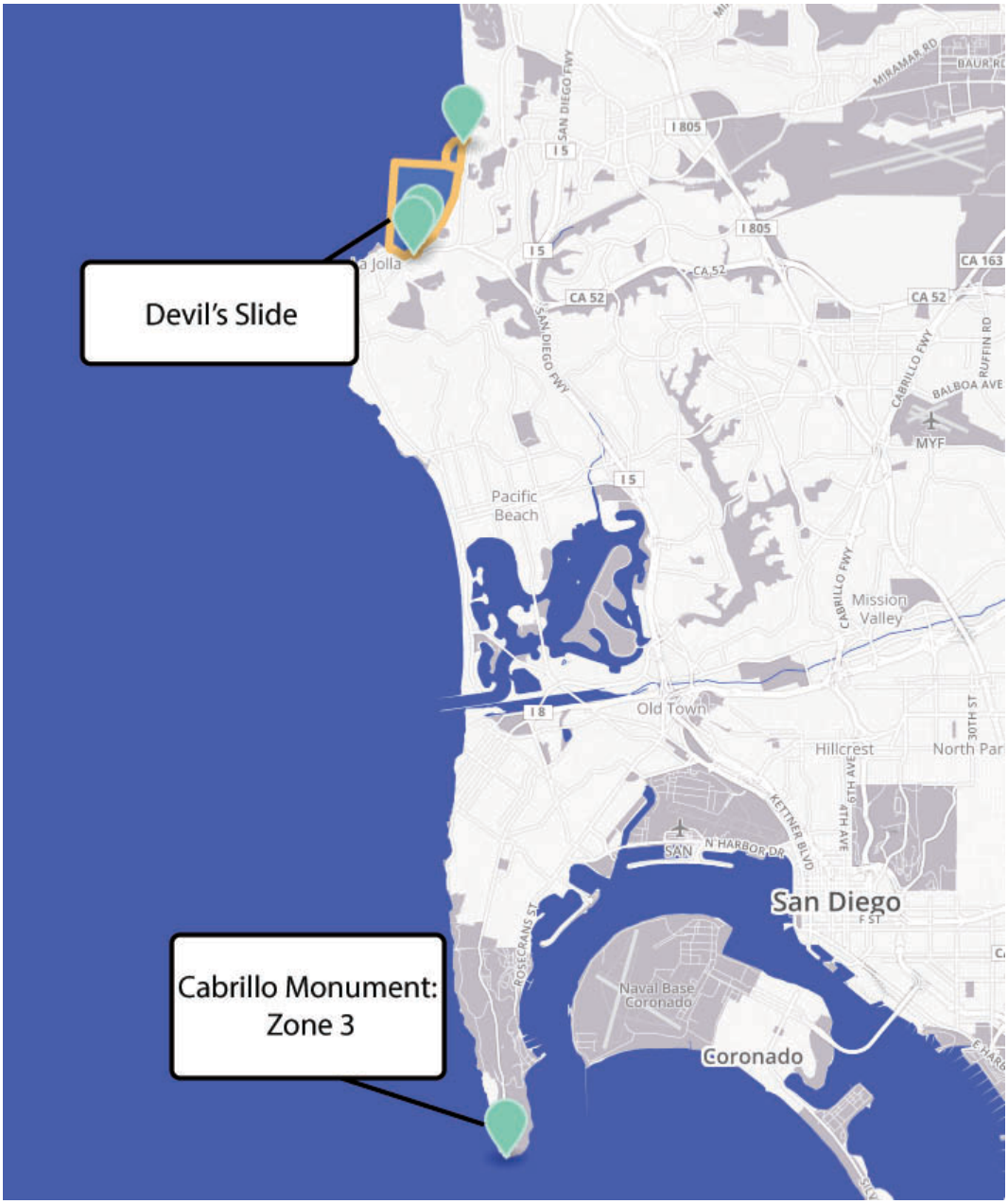


Figure 2.1: Map of Study Sites, Devil's Slide (ASBS 29) and Cabrillo Zone 3.

2.2b Experimental Trampling and Core Collection

Ten permanent plots (each measuring 0.25m by 0.75m) were established in the mid-intertidal of both DS and CZ3 (twenty total plots) and trampling occurred in half (five) of the plots for one year. Cores and turf depth within plots were collected before experimental trampling began (0 months) and at 3, 6, 10 (cores could not be collected at 9 months due to insufficient low tides), and 12 months post-trampling initiation. Core selection was determined using a retractable grid and a random number generator to ensure that no two areas within a plot were ever sampled twice (Figure 2.2). All measurements were collected again at 3 and 6 months after trampling ceased to assess recovery of trampled plots. Using a 1-inch-diameter, open-ended core and a metal scraping device, turf samples were collected, placed in containers, preserved in 70% ethanol, and transported to the Dayton Laboratory at Scripps Institution of Oceanography in La Jolla until they could be processed. Prior to content scraping, turf depth was measured at three random points within a core using a calibrated spike. The experimental design was adapted from Tonya Huff's work in 2006, but rather than trampling plots during every daytime low tide (< -0.5ft) as was done in her study, the frequency of trampling in this study aimed to mimic visitation trends as shown by Huff's video analysis of visitor frequency within turf sites (2006). In her study, Huff found that visitation peaked during the weekends and was heaviest in the afternoon. Thus, to simulate this pattern of visitation, plots were trampled on each weekend day having sufficiently-low (<0.0ft) daytime tide. Plots were trampled up to 4 times (Figure 2.3) each month (excluding April and June-September as there were no sufficiently-low tides occurring during daylight hours).

2.2c Data Analysis

Meiofaunal abundance and core depths were compared between Trampled plots and Control plots within Devil's Slide and Cabrillo Zone 3 study sites. Analyses were performed for each taxonomic class; however, bivalves were not included in analysis of Cabrillo Zone 3 cores, as they were too rare to consider. Welch's T tests were used to determine whether mean abundance and turf depth differed significantly between treatments.

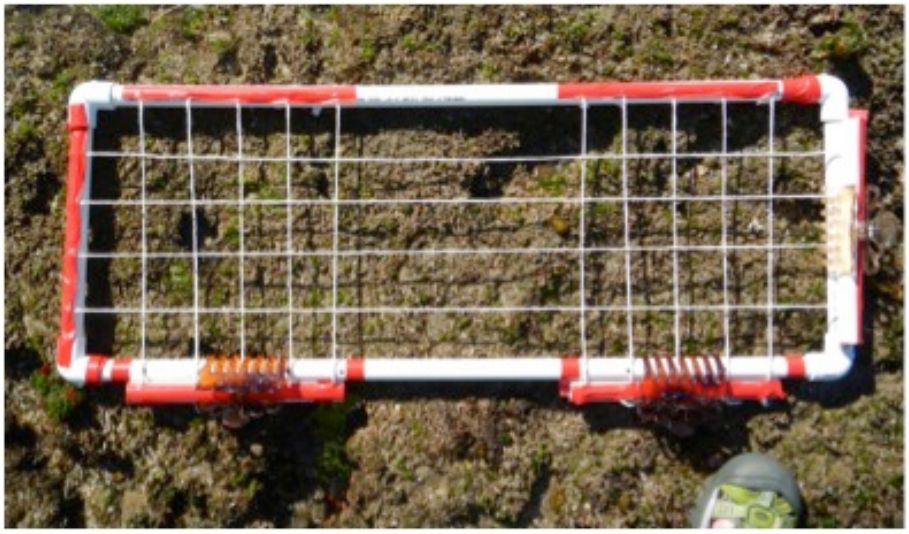


Figure 2.2: Trample plot with retractable grid overlay.

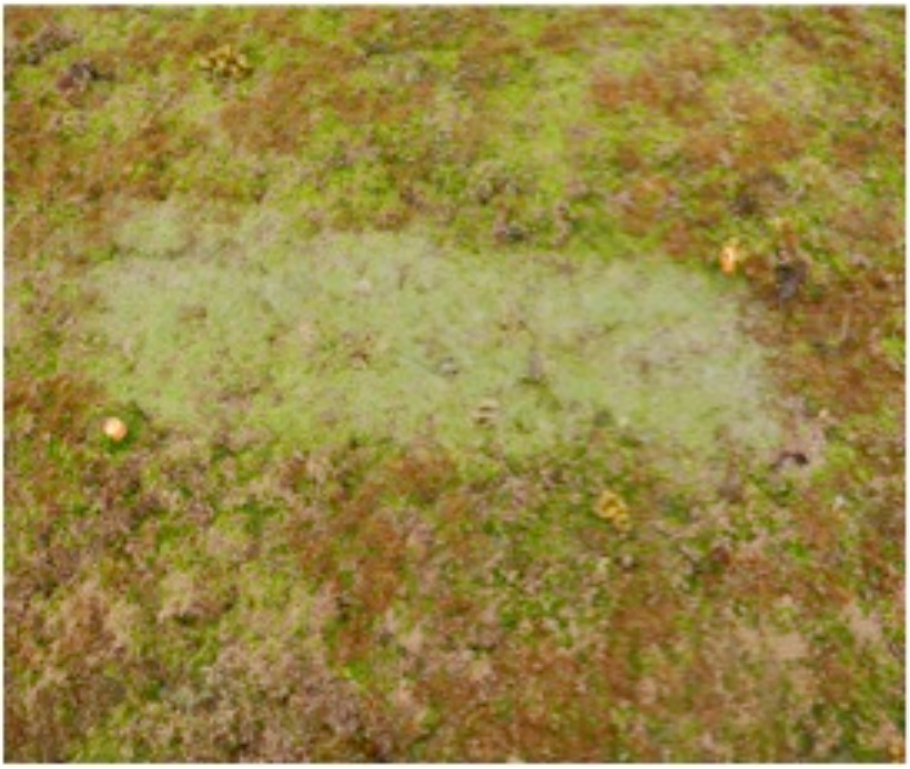


Figure 2.3: Freshly-trampled plot.

2.3 RESULTS: Devil's Slide (ASBS 29)

Results from Welch's T tests showed there were no significant differences in abundance of gastropods, or polychaetes between Trample and Control Plots prior to implementation of experimental trampling; however, there were significantly fewer bivalves in Control Plots (Figure 2.4-2.6 and Table 2.1-2.2).

At 3 months post-trampling (11 days total trampling/3 month period), abundance was significantly lower in Trample Plots for all taxonomic groups except polychaetes (Figure 2.4-2.6 and Table 2.1-2.2). Turf depth was also significantly lower in Trampled Plots (mean depth = 0.13in) as compared to Control Plots (mean depth = 0.39in): $t(22.49) = 5.23$, $p = <<0.05$ (Figure 2.7).

At 6 months post-trampling (14 days total trampling/6 month period; 3 days trampled since previous sampling period), abundance was only significantly lower in Trample Plots for gastropods (mostly *Amphithalamus tenuis*), but not for bivalves or polychaetes Figure 2.4-2.6 and Table 2.1-2.2). Turf depth was significantly lower in Trampled Plots (mean depth = 0.34in) as compared to Control Plots (mean depth = 0.52in): $t(24.64) = 3.63$, $p = <0.0013$ (Figure 2.7).

At 10 months post-trampling (14 days total trampling/10 month period; 0 days trampled since previous sampling period), there were no significant differences in meiofaunal abundance between Trample and Control Plots (Figure 2.4-2.6 and Table 2.1-2.2) and turf depth did not differ significantly between Trampled Plots (mean depth = 0.50in) and Control Plots (mean depth = 0.48in): $t(15.42) = 0.30$, $p = 0.77$ (Figure 2.7).

At 12 months post-trampling (22 days total trampling/12 month period; 8 days trampled since previous sampling period), abundance was significantly lower in Trample Plots for all taxonomic groups (Figure 2.4-2.6 and Table 2.1-2.2). Turf depth did not differ significantly between Trampled Plots (mean depth = 0.20in) and Control Plots (mean depth = 0.28in): $t(21.66) = 1.24$, $p = 0.23$ (Figure 2.7).

At 15 months post-trampling (3 months recovery/ 0 days trampled since previous sampling period), gastropod abundance was significantly lower in Trampled Plots (Figure 2.4-

2.6 and Table 2.1-2.2). Turf depth did not differ significantly between Trampled Plots (mean depth = 0.25in) and Control Plots (mean depth = 0.21in): t (20.33) = 0.72, p = 0.48 (Figure 2.7).

At 18 months post-trampling (6 months recovery/ 0 days trampled since previous sampling period), meiofaunal abundance did not differ significantly between plot types (Figure 2.4-2.6 and Table 2.1-2.2). Turf depth did not differ significantly between Trampled Plots (mean depth = 0.37in) and Control Plots (mean depth = 0.49in): t (15.71) = 1.63, p = 0.12 (Figure 2.7).

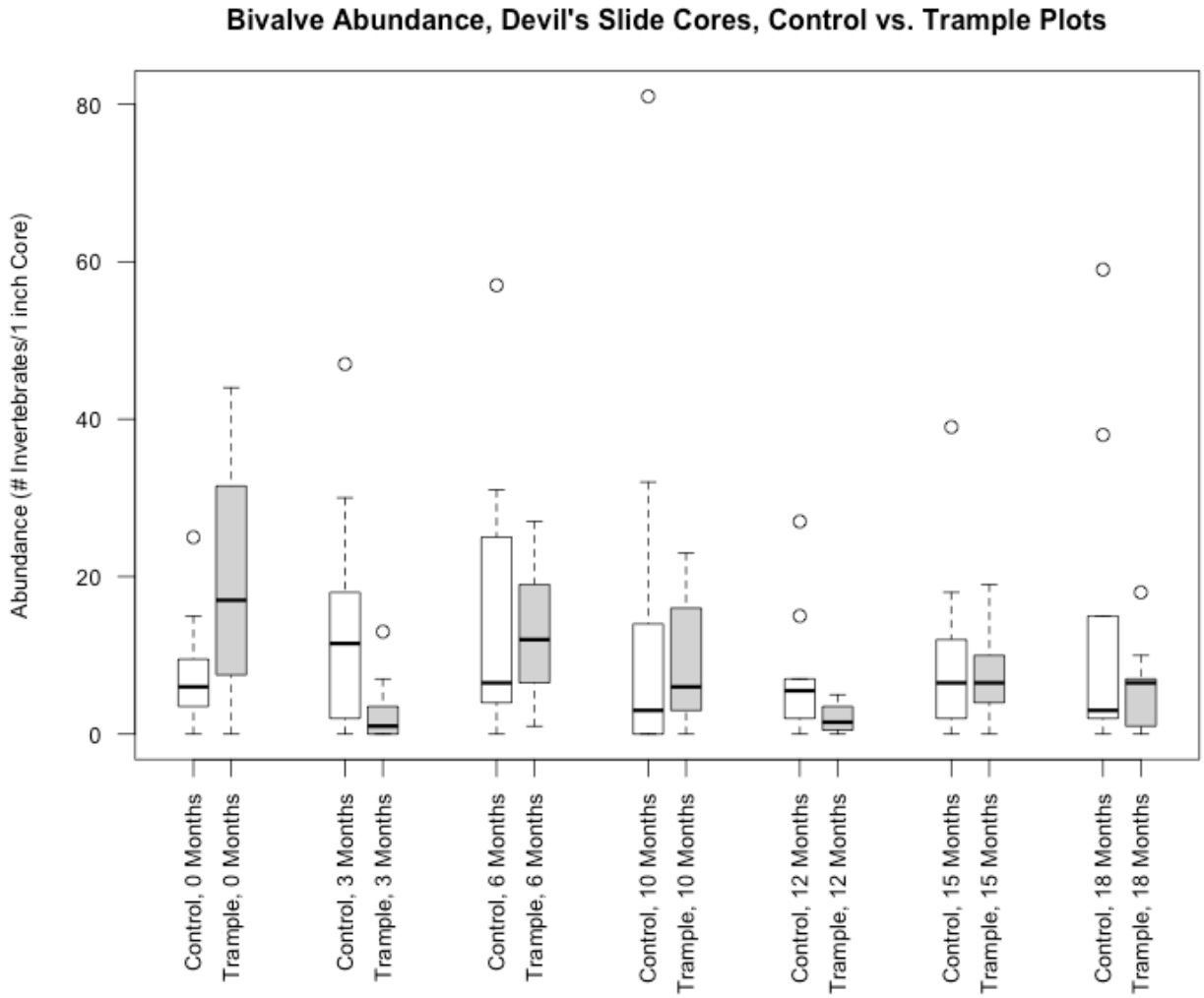


Figure 2.4: Abundance of bivalves during each sampling period, Control and Trample Plots, Devil's Slide (ASBS 29).

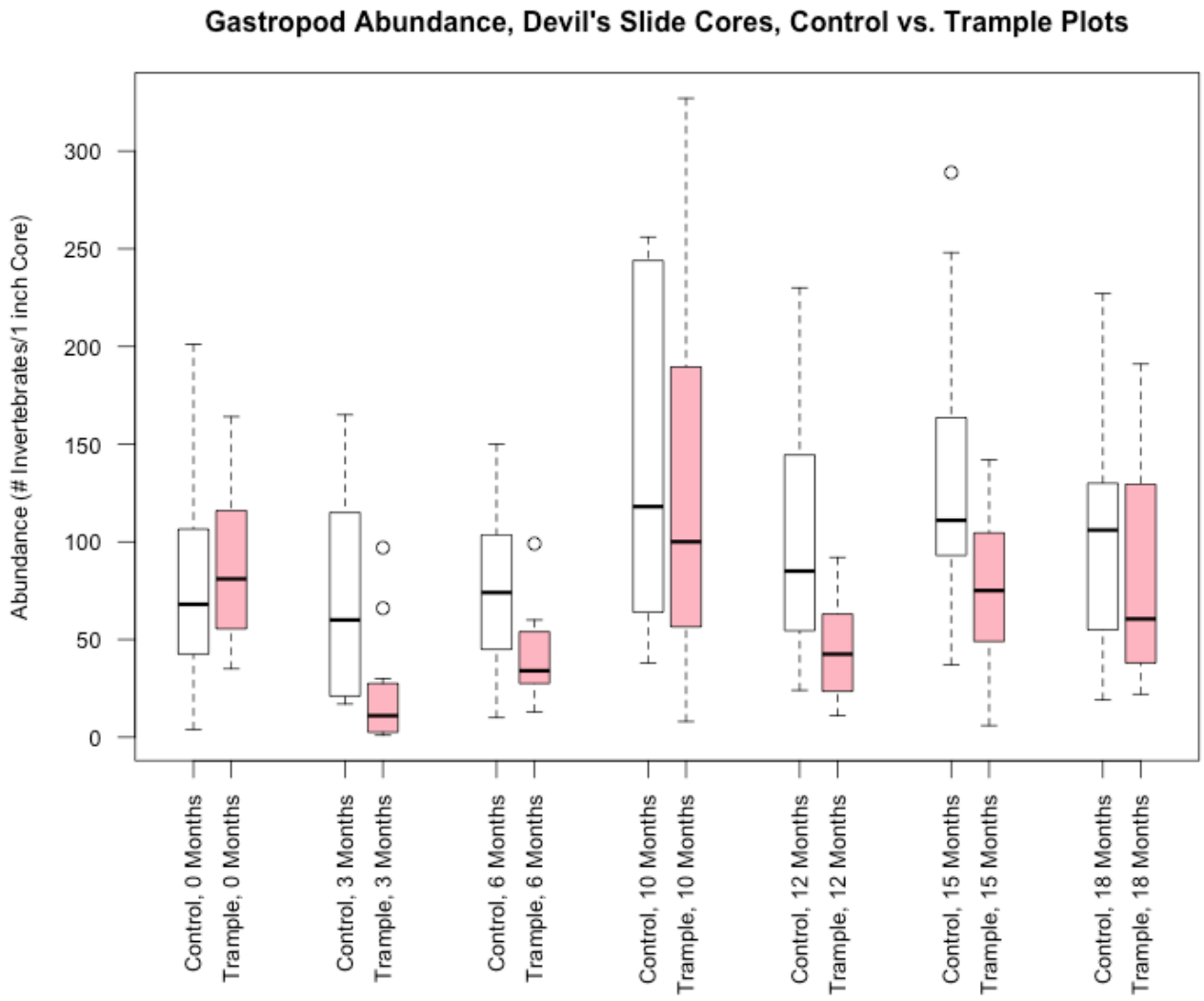


Figure 2.5: Abundance of gastropods during each sampling period, Control and Trample Plots, Devil's Slide (ASBS 29).

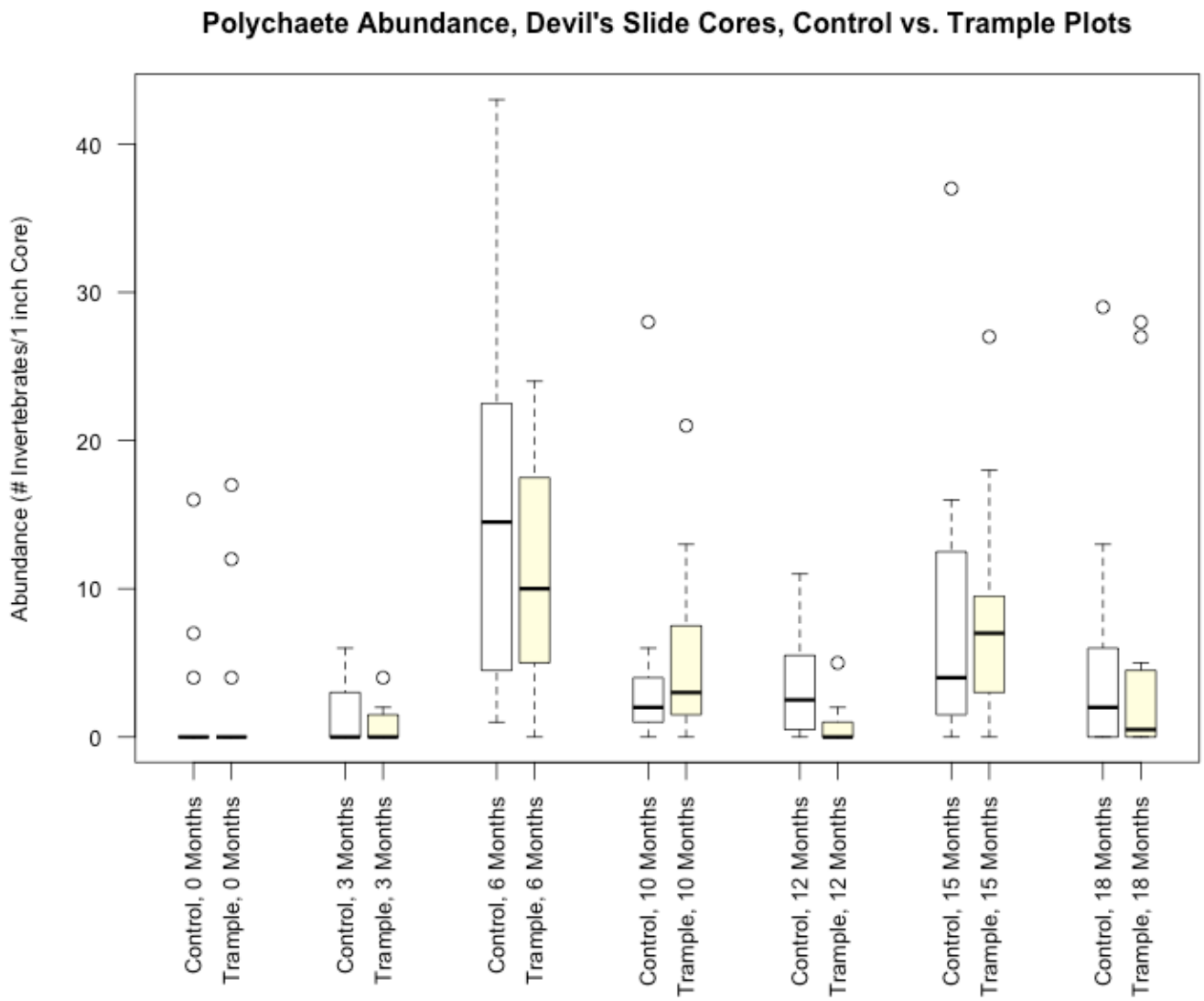


Figure 2.6: Abundance of polychaetes during each sampling period, Control and Trample Plots, Devil's Slide (ASBS 29).

Table 2.1: Welch's T-test results, Devil's Slide, Sampling Months 0-6.

Sampling Month (# Days Trampling Occurred)	Meiofauna Class	Plot Type	Summary Data/ T test results					
			Mean Abundance (#individuals/1in core)	df	t	95% CI		p-value *Significant Results
						Lower	Upper	
0 Months (Pre-trampling initiation)	Bivalves	Trample	19.60	19.39	-2.97	-20.90	-3.64	**0.0077***
		Control	7.33					
	Gastropods	Trample	87.07	24.64	-0.30	-44.062	32.86	0.77
		Control	81.45					
	Polychaetes	Trample	2.20	27.230	-0.228	-4.0047	3.21	0.87
		Control	1.80					
3 Months (11 days trampling since previous sampling)	Bivalves	Trample	2.60	14.90	2.963	3.033	18.62	**0.0097***
		Control	13.43					
	Gastropods	Trample	20.67	18.93	3.284	19.13	20.67	**0.0039***
		Control	73.43					
	Polychaetes	Trample	0.87	19.45	1.047	-0.70	2.11	0.31
		Control	1.57					
6 Months (3 days trampling since previous sampling)	Bivalves	Trample	13.13	15.91	0.377	-9.42	13.49	0.72
		Control	15.17					
	Gastropods	Trample	40.33	16.07	2.553	5.68	61.15	**0.021***
		Control	73.75					
	Polychaetes	Trample	11.13	18.07	0.946	-4.82	12.72	0.36
		Control	15.08					

Table 2.2: Welch's T-test results, Devil's Slide, Sampling Months 10-18.

Sampling Month (# Days Trampling Occurred)	Meiofauna Class	Plot Type	Summary Data/ T test results					
			Mean Abundance (#individuals/1in core)	df	t	95% CI		p-value *Significant Results
						Lower	Upper	
10 Months (0 days trampling since previous sampling)	Bivalves	Trample	9.73	9.24	0.580	-15.52	26.29	0.58
		Control	15.11					
	Gastropods	Trample	128.46	17.94	0.243	-79.67	100.54	0.81
		Control	138.89					
	Polychaetes	Trample	5.64	14.30	-0.181	-8.17	6.90	0.86
		Control	5.00					
12 Months (8 days trampling since previous sampling)	Bivalves	Trample	6.92	12.37	2.221	-15.52	26.29	**0.046***
		Control	2.00					
	Gastropods	Trample	45.08	14.32	3.014	17.97	106.023	**0.0091***
		Control	107.08					
	Polychaetes	Trample	0.83	14.13	2.313	0.20	5.30	**0.036***
		Control	3.583					
Recovery Period: 3 Months	Bivalves	Trample	7.583	16.45	0.573	-5.38	9.38	0.57
		Control	9.58					
	Gastropods	Trample	74.17	17.25	2.417	7.56	110.61	**0.027***
		Control	133.25					
	Polychaetes	Trample	8.083	20.21	0.0889	-7.48	8.15	0.93
		Control	8.41					

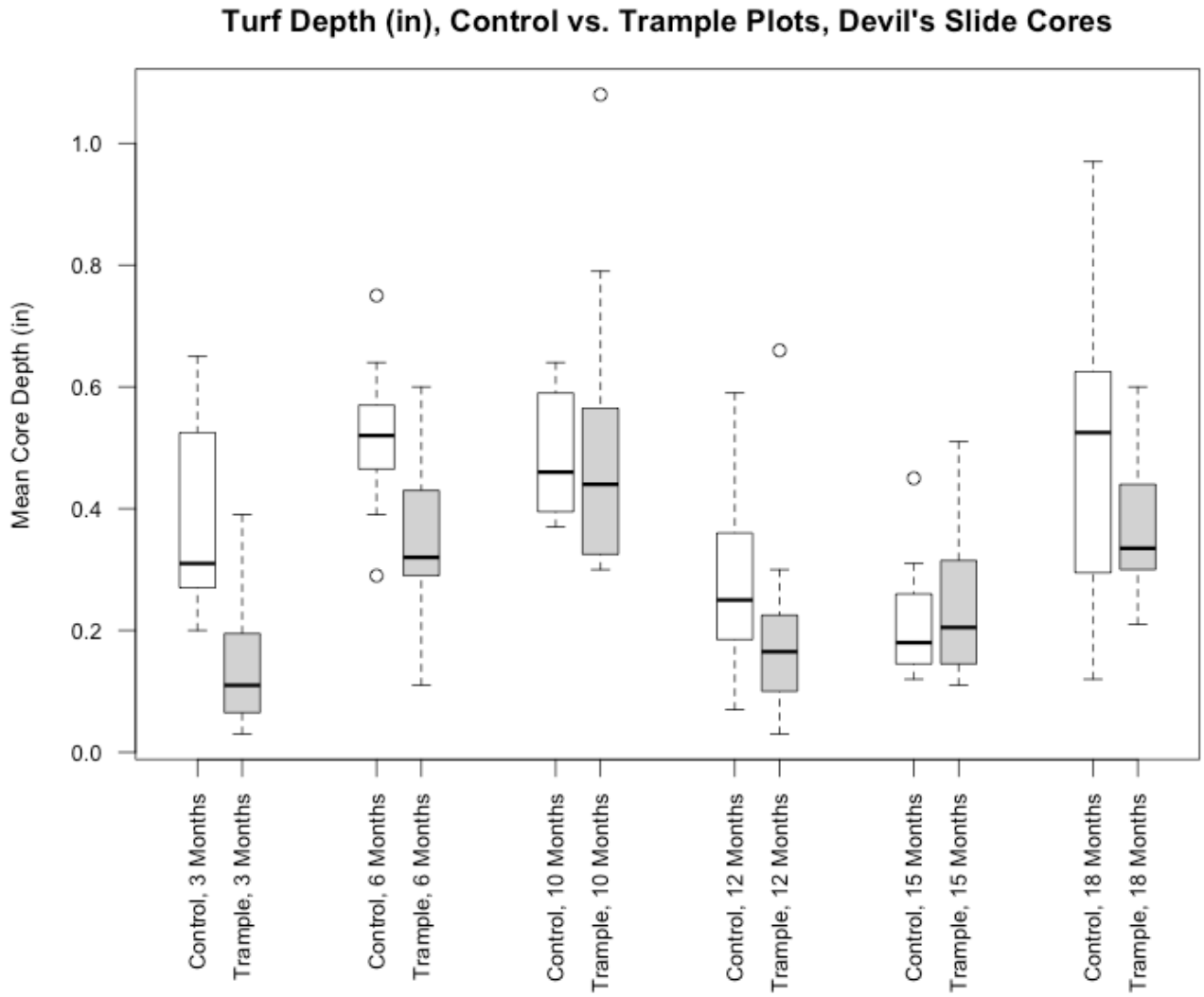


Figure 2.7: Mean Turf Depth (inches) over course of study, Trample versus Control Plots, Devil's Slide (ASBS 29).

2.3 RESULTS: Cabrillo Zone 3 (Reference Site Outside ASBS 29)

Results from Welch's T tests showed there were no significant differences in abundance of bivalves, gastropods, or polychaetes between Trample and Control Plots prior to implementation of experimental trampling (Figure 2.8-2.9 and Table 2.3-2.4).

At 3 months post-trampling (11 days total trampling/3 month period), abundance was significantly lower in Trample Plots for gastropods, but not for polychaetes (Figure 2.8-2.9 and Table 2.3-2.4). Turf depth was significantly lower in Trampled Plots (mean depth = 0.32in) as compared to Control Plots (mean depth = 0.65in): $t(25.62) = 4.20$, $p = <<0.05$ (Figure 2.10).

At 6 months post-trampling (14 days total trampling/6 month period; 3 days trampled since previous sampling period), meiofaunal abundance did not differ significantly between plot types (Figure 2.8-2.9 and Table 2.3-2.4). However, turf depth was significantly lower in Trampled Plots (mean depth = 0.39in) as compared to Control Plots (mean depth = 0.66in): $t(26.69) = 3.22$, $p = <<0.05$ (Figure 2.10).

At 10 months post-trampling (14 days total trampling/10 month period; 0 days trampling since previous sampling period), there were no significant differences in abundance of gastropod or polychaetes between Trample and Control Plots (Figure 2.8-2.9 and Table 2.3-2.4). Likewise, turf depth did not differ significantly between Trampled Plots (mean depth = 0.83in) and Control Plots (mean depth = 1.07in): $t(26.32) = 1.48$, $p = 0.15$ (Figure 2.10).

At 12 months post-trampling (22 days total trampling/6 month period), gastropod and polychaete abundance did not differ significantly between plot types (Figure 2.8-2.9 and Table 2.3-2.4). Turf depth was not recorded for this sampling period due to insufficient time to collect the measurements on that occasion.

At 15 months post-trampling (3 month recovery/ 0 days trampling since previous sampling period), abundance was still lower in Trampled Plots, but Welch's T tests did not yield significant results (Figure 2.8-2.9 and Table 2.3-2.4). Turf depth was significantly different between Trampled Plots (mean depth = 0.32in) and Control Plots (mean depth = 0.50in): $t(19.72) = 2.62$, $p = 0.012$ (Figure 2.10).

At 18 months post-trampling (3 month recovery/ 0 days trampled), abundance was still lower in Trampled Plots, but T tests did not yield significant results (Figure 2.8-2.9 and Table 2.3-2.4). Turf depth did not differ significantly between Trample Plots (mean depth = 0.55in) and Control Plots (mean depth = 0.50in): t (25.5) = 0.58, p = 0.57 (Figure 2.10).

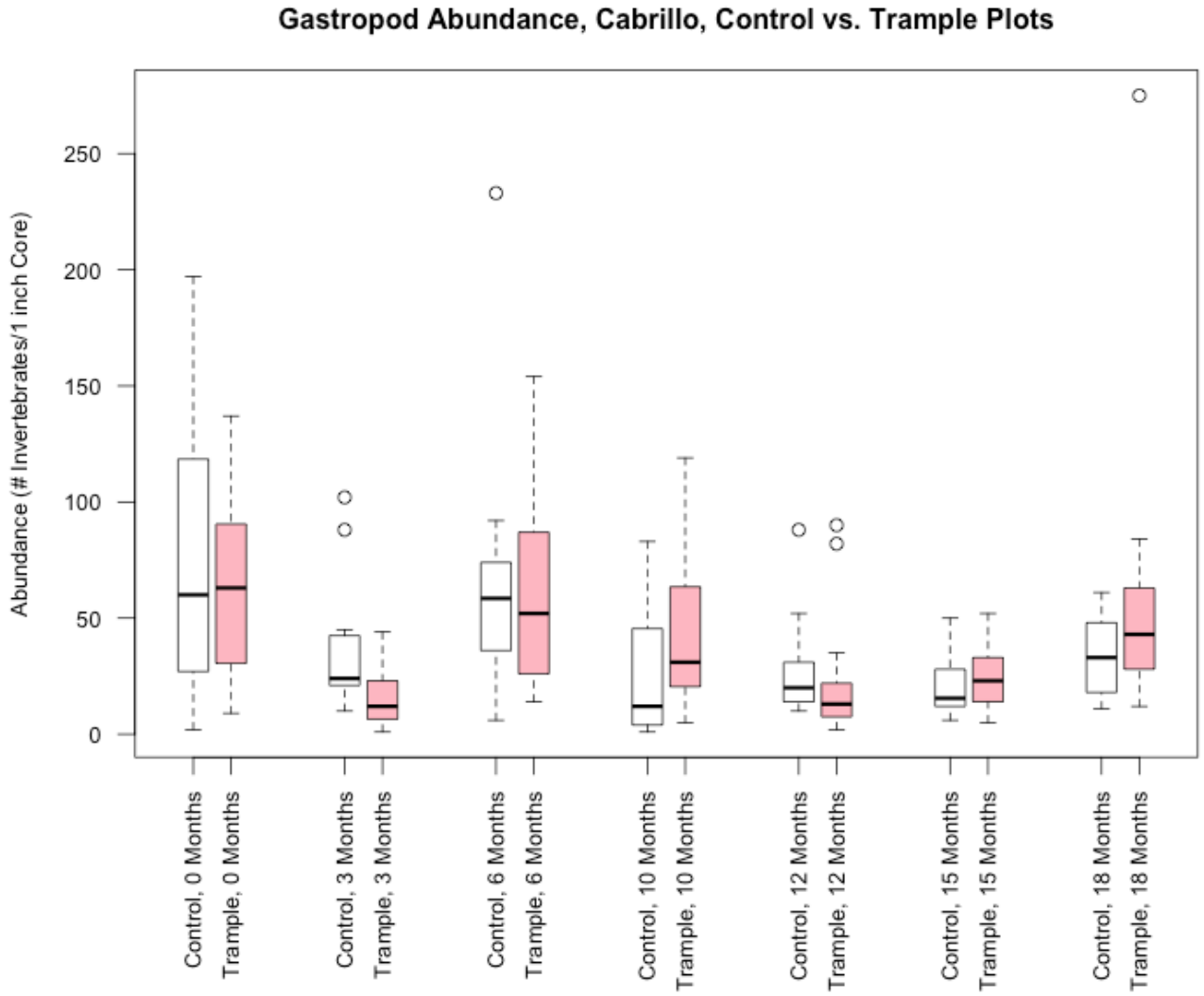


Figure 2.8: Abundance of gastropods during each sampling period, Control and Trample Plots, Cabrillo Zone 3.

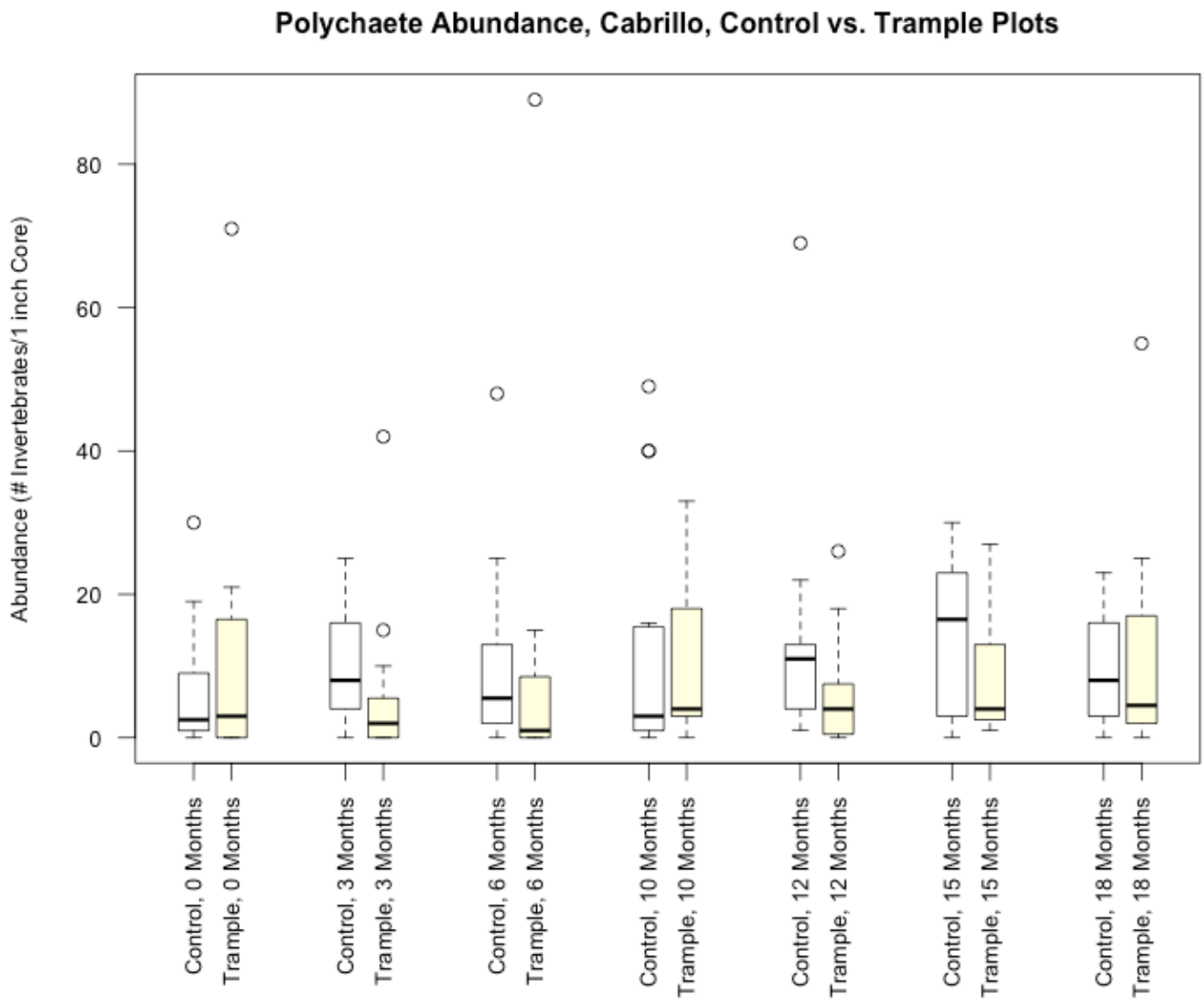


Figure 2.9: Abundance of polychaetes during each sampling period, Control and Trample Plots, Cabrillo Zone 3.

Table 2.3: Welch's T-test results, Meiofaunal Abundance, Cabrillo Zone 3, Months 0-10.

Sampling Month (# Days Trampling Occurred)	Meiofauna Class	Plot Type	Summary Data/ T test results					
			Mean Abundance (#individuals/1in core)	df	t	95% CI		p-value *Significant Results
						Lower	Upper	
0 Months (Pre-trampling initiation)								
	Gastropods	Trample	65.33	25.82	0.48	-27.19	48.85	0.63
		Control	73.67					
	Polychaetes	Trample	10.73	19.81	-0.93	-15.76	6.03	0.36
		Control	5.87					
3 Months (11 days trampling since previous sampling)								
	Gastropods	Trample	16.8	21.66	2.33	2.01	34.39	***0.03**
		Control	35.0					
	Polychaetes	Trample	5.74	25.31	1.19	-3.01	11.27	0.24
		Control	9.87					
6 Months (3 days trampling since previous sampling)								
	Gastropods	Trample	64.87	25.49	0.038	-37.66	39.07	0.97
		Control	65.57					
	Polychaetes	Trample	15.27	22.80	0.17	-12.95	15.27	0.87
		Control	10.43					
10 Months (0 days trampling since previous sampling)								
	Gastropods	Trample	45.2	25.48	-1.83	-43.86	2.53	0.078
		Control	24.53					
	Polychaetes	Trample	10.67	24.04	0.39	-8.60	12.60	0.70
		Control	12.67					

Table 2.4: Welch's T-test results, Meiofaunal Abundance, Cabrillo Zone 3, Months 12-18.

Sampling Month (# Days Trampling Occurred)	Meiofauna Class	Plot Type	Summary Data/ T test results					
			Mean Abundance (#individuals/1in core)	df	t	95% CI		p-value *Significant Results
						Lower	Upper	
12 Months (8 days trampling since previous sampling	Gastropods	Trample	22.13	25.93	0.68	-12.88	25.84	0.50
		Control	28.61					
	Polychaetes	Trample	6.27	16.19	1.55	-2.99	19.38	0.14
		Control	14.46					
Recovery Period: 3 Months	Gastropods	Trample	23.63	18.93	-0.52	-16.16	9.67	0.61
		Control	20.40					
	Polychaetes	Trample	8.73	17.52	1.37	-3.11	14.65	0.19
		Control	14.50					
Recovery Period: 6 Months	Gastropods	Trample	58.71	14.76	-1.38	-64.22	13.79	0.188
		Control	33.5					
	Polychaetes	Trample	10.29	18.86	-0.29	-10.61	8.04	0.78
		Control	9.0					

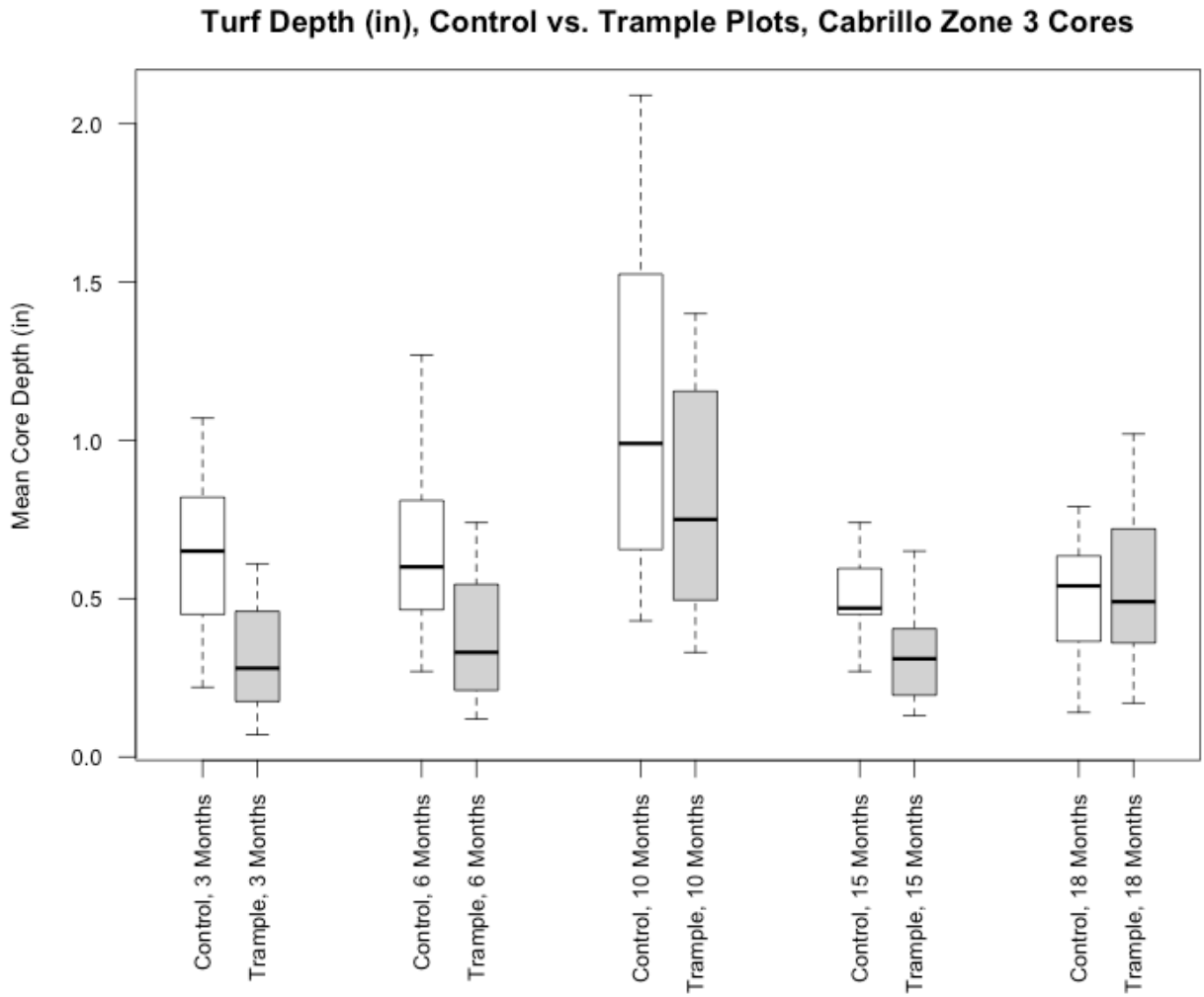


Figure 2.10: Turf Depth (inches) over course of study, Trample versus Control Plots, Cabrillo Zone 3.

2.4 DISCUSSION

Overall, the results presented here indicate that low levels of trampling can negatively impact meiofaunal abundance. That is, even trampling that occurred on just 3 days over a 3-month period was accompanied by a significant decrease in meiofaunal abundance; however, the negative impacts of trampling on meiofaunal abundance was not uniform between taxonomic class or site. Specifically, gastropods appeared most vulnerable to trampling (as compared to bivalves and polychaetes) and the decrease in abundance was more dramatic at Devil's Slide (ASBS 29) as compared with Cabrillo Zone 3. While gastropod abundance declined in Trample Plots at both sites following 11 days of trampling over a 3 month period, abundance was only significantly depressed at Devil's Slide following another 3 days of trampling over a 3 month period. Furthermore, there was a 4-month recovery period (from June - September of 2012, due to a lack of sufficiently low tides (<0.00ft) occurring during daytime hours on weekend days) in the middle of the study and this break from trampling was followed by a rebound in meiofaunal abundance in Trample Plots within both study sites. Once trampling began again, abundance dropped after 8 days of trampling over a three-month period, but this decline was only seen at Devil's Slide. Similarly, once the official recovery period (after 12 months of experimental trampling implementation) began, gastropods at Cabrillo Zone 3 recovered in only 3 months, while full recovery was not seen at Devil's Slide until the 6 month recovery assessment. Thus, meiofauna within trampled patches in Cabrillo Zone 3 appear to have been more resilient (abundance was not as dramatically reduced compared to Devil's Slide) than meiofauna of Devil's Slide. This observed difference in recovery may be partially attributable to the fact that Devil's Slide is periodically exposed to urban storm drain pollution that Cabrillo Zone 3 does not experience; however, there are oceanographic differences between the two areas that may influence recovery as well. For instance, Devil's Slide is a more protected tide pool area as compared to Cabrillo Zone 3 and this can limit recruitment in the area. Ideally, future studies should include a laboratory component, which compares abundance of meiofauna between periodically "polluted" and "non-polluted" treatments.

STUDY 3: MEIOFAUNAL COMMUNITY MONITORING IN SCRIPPS AND LA JOLLA ASBS

3.1 BACKGROUND

Abundance of meiofauna (bivalves, gastropods, and polychaetes) was investigated within four rocky-intertidal sites to investigate whether abundance differs between sites that receive varying degrees of stress from storm drain runoff and trampling. This study examined three sites within the Scripps and La Jolla Shores ASBS and one control site at Cabrillo National Monument (outside of the ASBS) where direct storm water runoff is minimal.

3.2 METHODS

3.2a Study Sites

Three of the four sites used in this study are located within Scripps and La Jolla ASBS (Figure 3.1) and they also vary in types of anthropogenic stress inputs (Table 3.1) as follows:

Dike Rock (DR)- an easily accessible area approximately 500 meters north of Scripps Pier that receives a high volume of visitors and is isolated from large storm drain outfalls (Figure 3.1 and Table 3.1);

The Marine Room (MR)- an easily accessible area that receives a high volume of visitors and is located approximately150 meters south of the Marine Room Restaurant near several small storm drains (Figure 3.1 and Table 3.1);

Devil's Slide (DS)- an area located approximately 400 meters south of Site 2. This site receives very little foot traffic due to its location and also receives input from a large storm drain (storm drain 186) (Figure 3.1 and Table 3.1); and,

Cabrillo Zone 3 (CZ3)- this is a remote site located >25km to the South of Site 3 (at the Cabrillo National Monument on Point Loma). This site is closed to the public so it receives negligible foot traffic and does not receive inputs from storm drains (Figure 3.1 and Table 3.1).

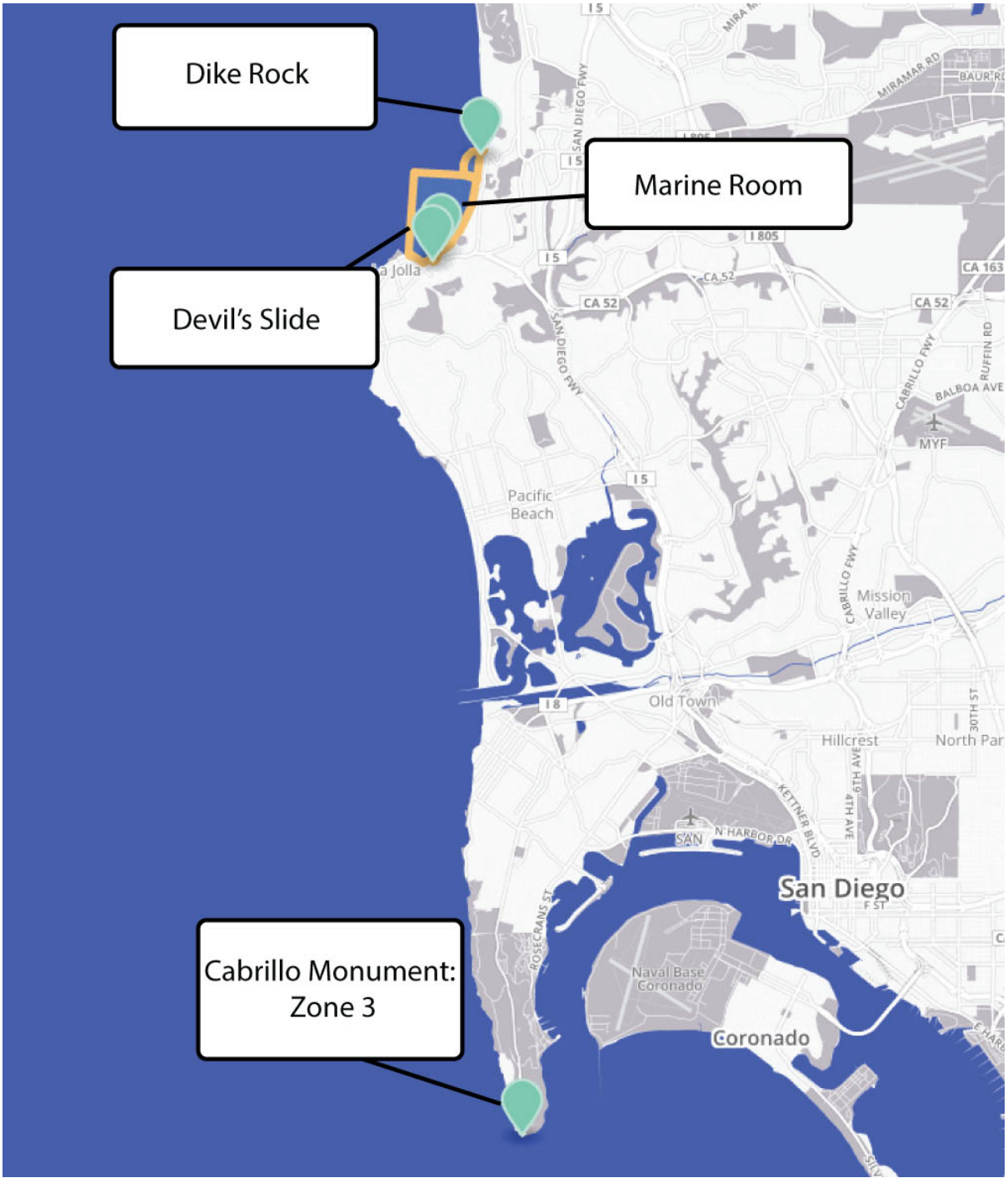


Figure 3.1: Map of 4 Study Sites. Dike Rock is located within ASBS 31 and the Marine Room and Devil's Slide are in ASBS 29.

Table 3.1: Table showing anthropogenic stress exposure for each site.

Study Site	Anthropogenic Stress	
	Human Trampling	Storm drain
Dike Rock (ASBS 31)	X	
Marine Room (ASBS 29)	X	X
Devil's Slide (ASBS 29)		X
Cabrillo Zone 3 (Reference Site)		

3.2b Sample collection

Samples were collected using an open-ended, metal core (1-inch-diameter) that was plunged fully into the turf and removed using a metal scraping device. Before cores were removed, turf depth was measured by placing a calibrated spike into three random spots within the core. Sampling began in December 2011 and occurred monthly (excluding 6 months over the span of the study) through December 2013. Each month, four cores were collected from each site, sealed inside plastic containers, and transported to the Dayton Laboratory at Scripps Institute of Oceanography (SIO) where meiofauna were preserved in 70% ethanol until they could be separated from algae, identified to lowest taxonomic category, and counted.

3.2c Data Analysis

Bivalves, gastropods, and polychaetes were sorted from core samples and the counts of these species were used to assess differences between sites and within sites over time. Mean core depth was also compared between sites.

3.4 RESULTS

Meiofaunal composition and abundance varied greatly between sites and over time (Figures 3.2-3.5). Dike Rock regularly had very few gastropods, while the Marine Room, Devil's Slide, and Cabrillo Zone 3 cores were dominated with them. The most abundant species of gastropod at the Marine room and Devil's Slide were *Amphithalamus tenuis and Amphithalamus inclusis* (Figure 3.6), while Cabrillo Zone 3 was dominated by *Caecum californicum (*Figure 3.7). In total, 42 gastropod species and were found between the four sites (Table 3.2). ANOVA and Tukey HSD results show that mean gastropod abundance was significantly different between all sites [$F(3,301) = 73.66$, $p = <<0.05$; Tukey HSD: $p = <<0.05$ for all site comparisons, excluding Marine Room versus Cabrillo Zone 3, $p = 0.60$) (Figure 3.8)], and that species richness also varied significantly [$F(3,253) = 79.19$, $p = <<0.05$; Tukey HSD: $p = <<0.05$ for all site comparisons] (Figure 3.9).

Bivalves were most abundant at Devil's Slide with the most numerous being *Lasaea sp* [$F(3,301) = 14.05$, $p = <<0.05$; Tukey HSD: $p = <<0.05$ for all site comparisons, excluding the following: Dike Rock – Cabrillo: $p = 0.99$; Marine Room – Cabrillo: $p = 0.95$; Marine Room – Dike Rock: $p = 0.99$) (Figure 3.10-3.11 and Table 3.3)].

Polychaetes were found at all sites, and ANOVA results did not show any significant differences in abundance between sites [$F(3,301) = 2.06$, $p = 0.11$) (Figure 3.12-3.13)].

Overall, total meiofaunal abundance and mean core depth were significantly different between sites over the course of the study [Meiofaunal abundance: $F(3,301) = 65.81$, $p = <<0.05$; Tukey HSD: $p = <<0.05$ for all site comparisons, excluding Cabrillo Zone 3 vs. Marine Room: $p = 0.62$; Mean core depth: $F(3,264) = 54.37$, $p = <<0.05$; Tukey HSD: $p = <<0.05$ for all site comparisons)) (Figure 3.14-3.15)] over the course of the study.

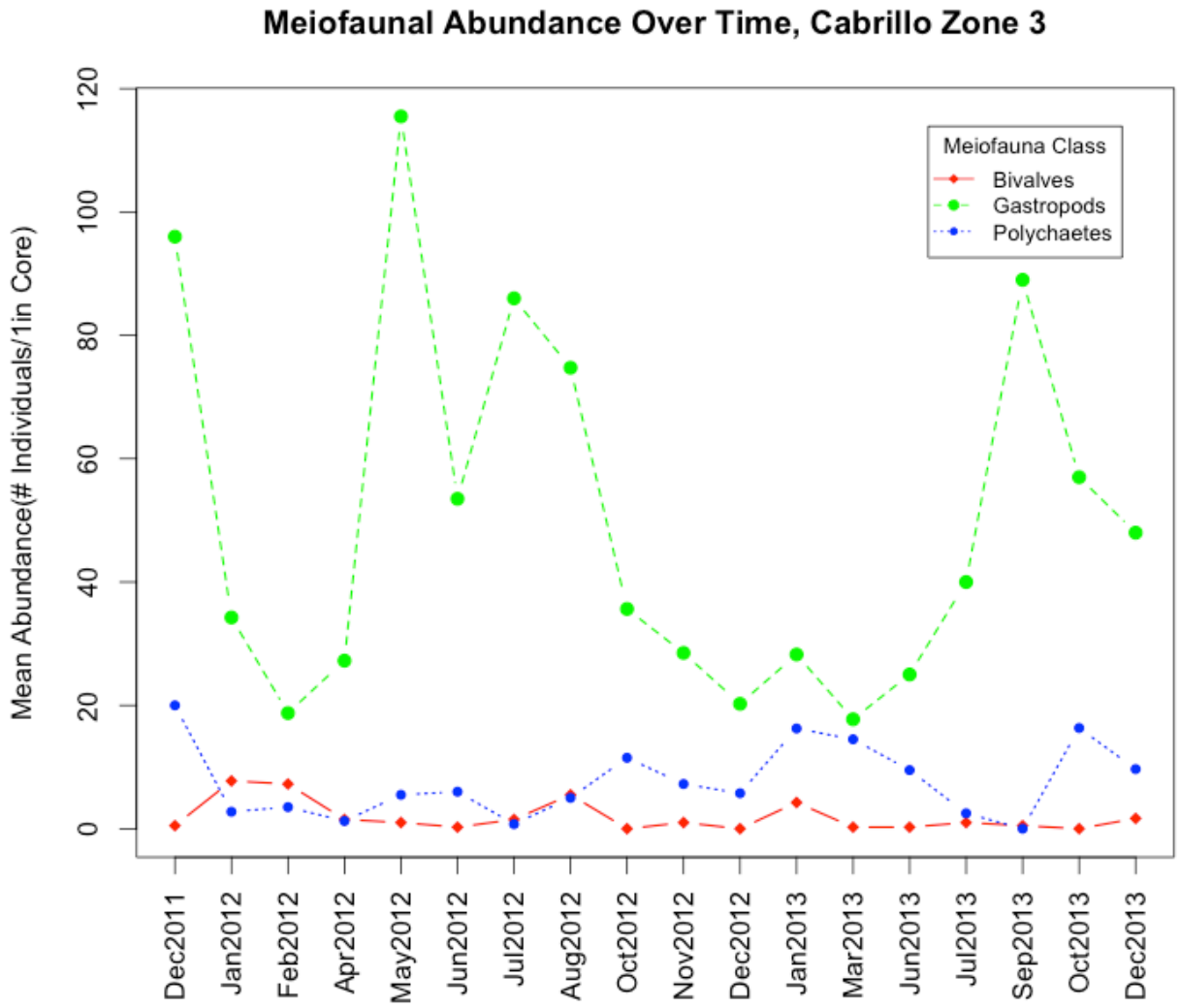


Figure 3.2: Monthly bivalve, gastropod, and polychaete abundance at Cabrillo Zone 3 over the course of the study.

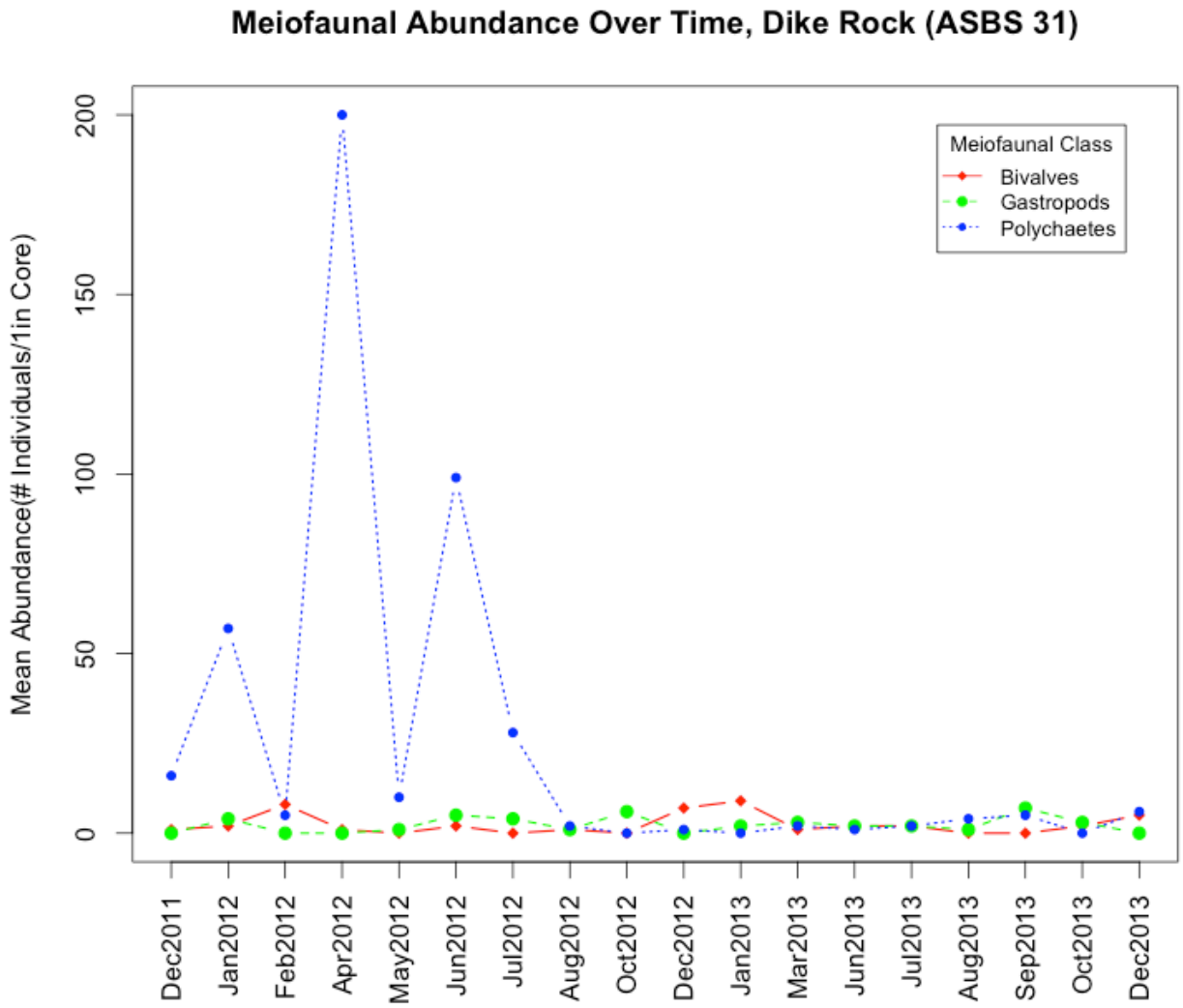


Figure 3.3: Monthly bivalve, gastropod, and polychaete abundance at Dike Rock over the course of the study.

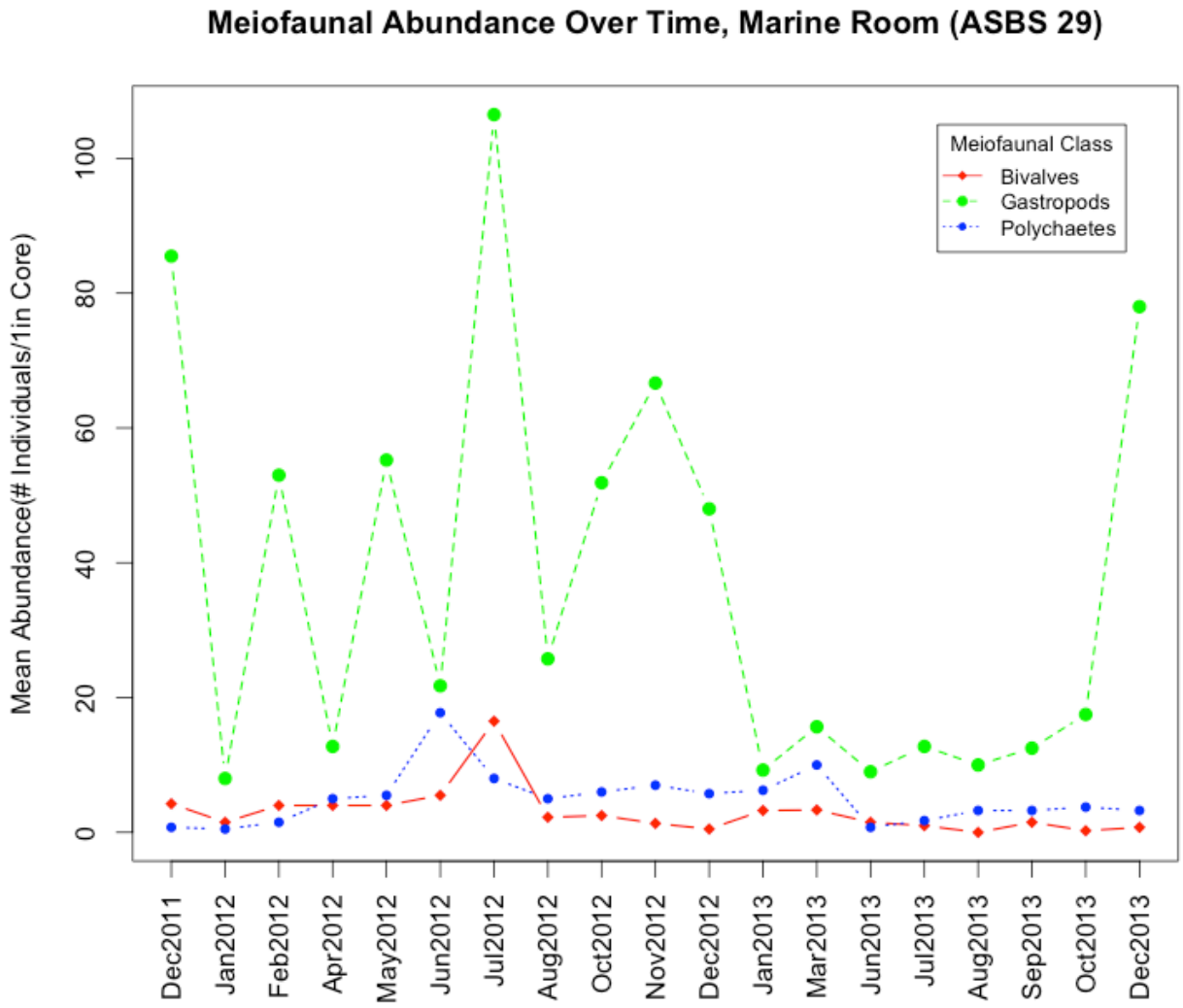


Figure 3.4: Monthly bivalve, gastropod, and polychaete abundance at the Marine Room over the course of the study.

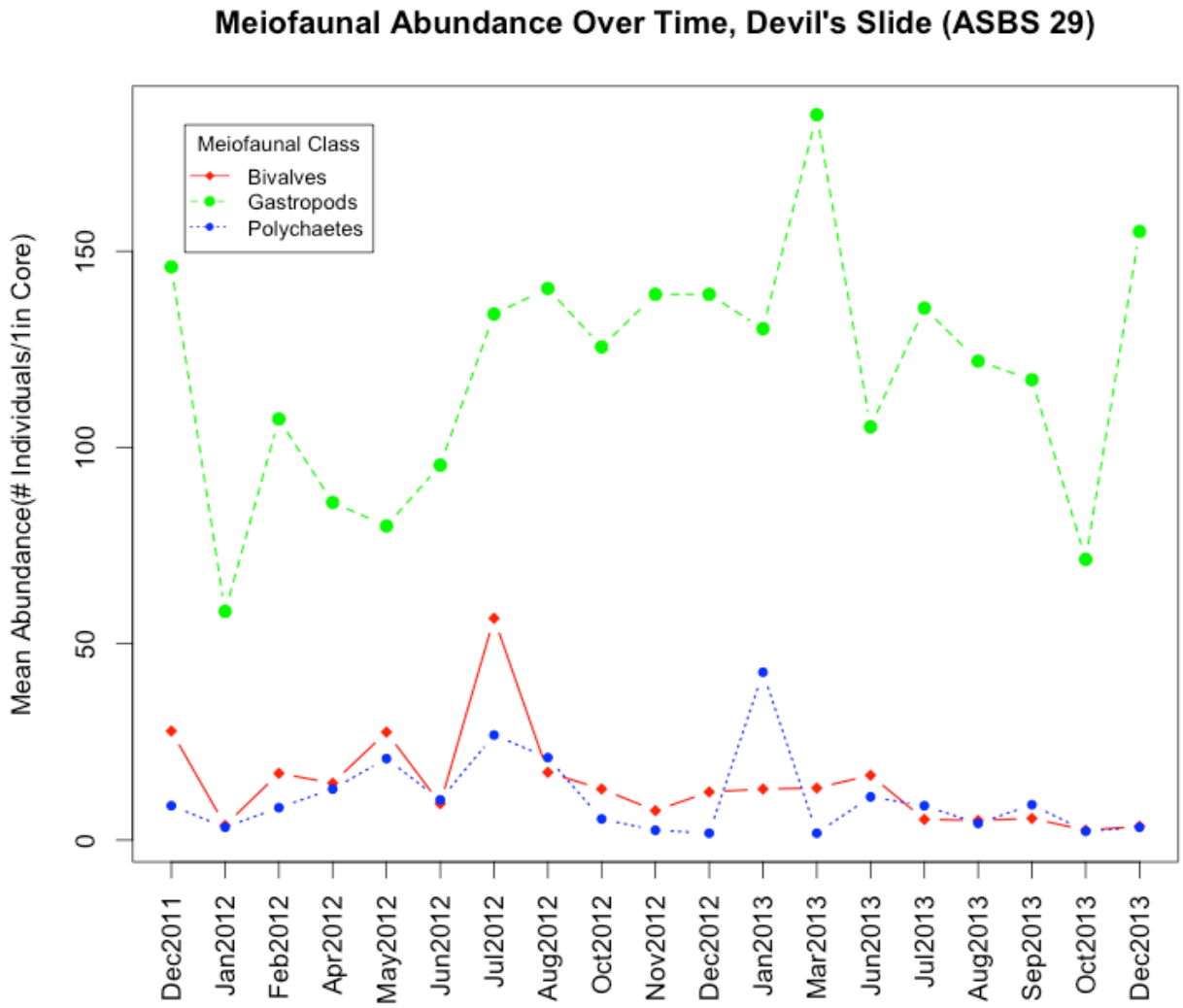


Figure 3.5: Monthly bivalve, gastropod, and polychaete abundance at the Devil's Slide over the course of the study.

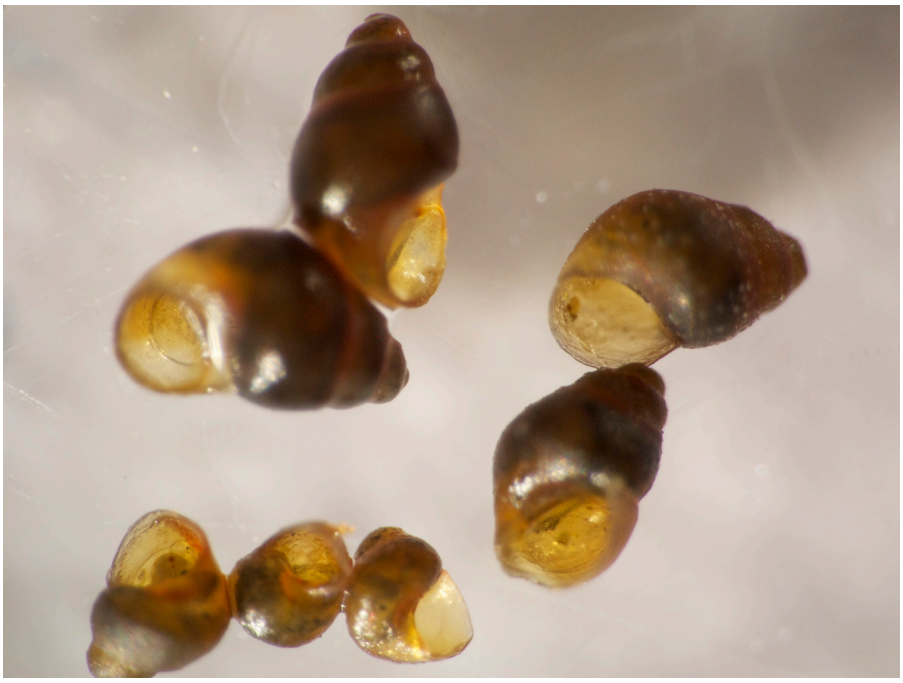


Figure 3.6: *Amphithalamus tenuis* (pictured on the upper left) and *Amphithalamus inclusis* (pictured on the right and lower left) were present at all sites, but were most abundant at the Marine Room and Devil's Slide.



Figure 3.7: *Caecum californicum* was the most abundant gastropod species at Cabrillo Zone 3.

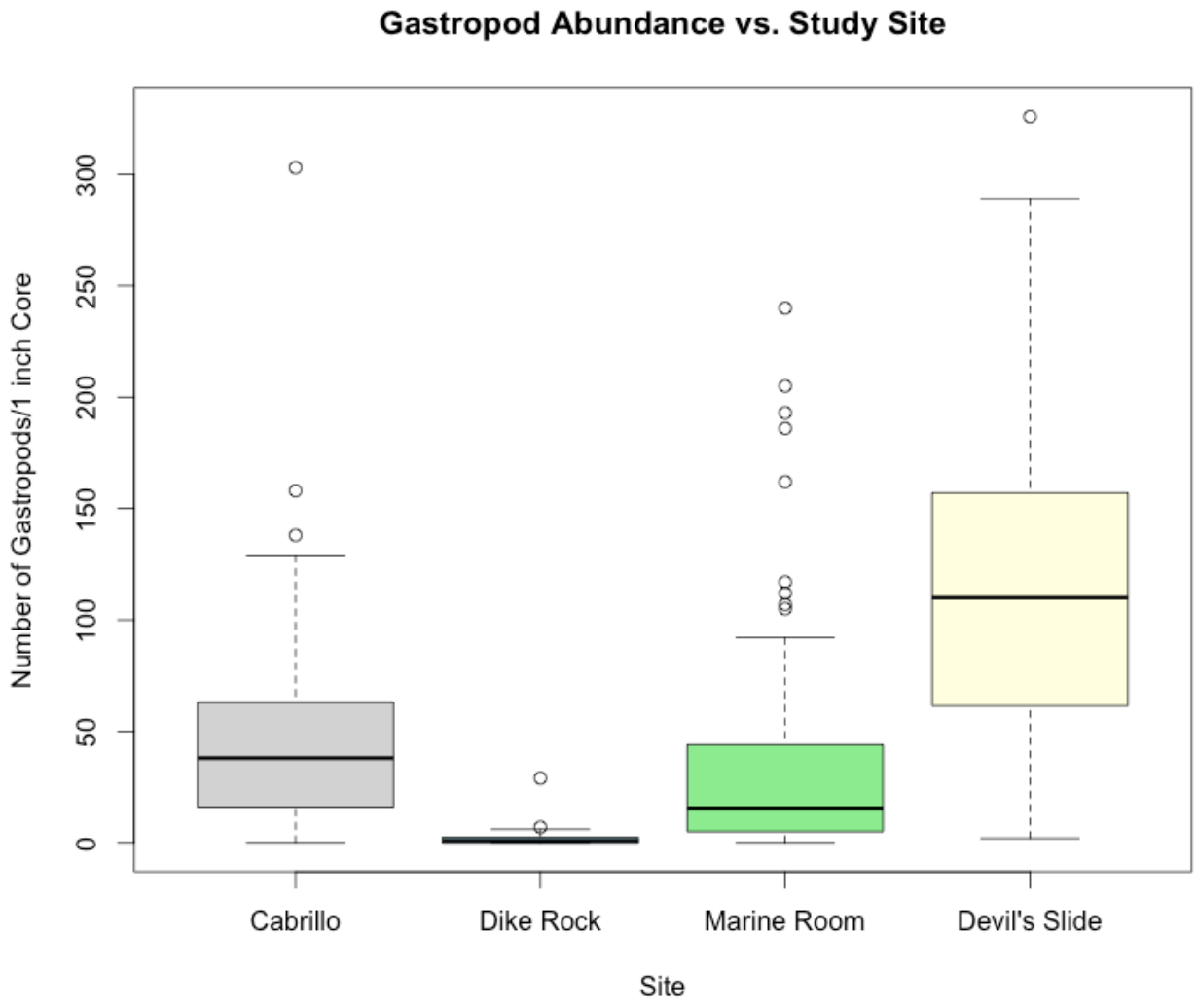


Figure 3.8: Gastropod abundance for all four sites over the course of the study.

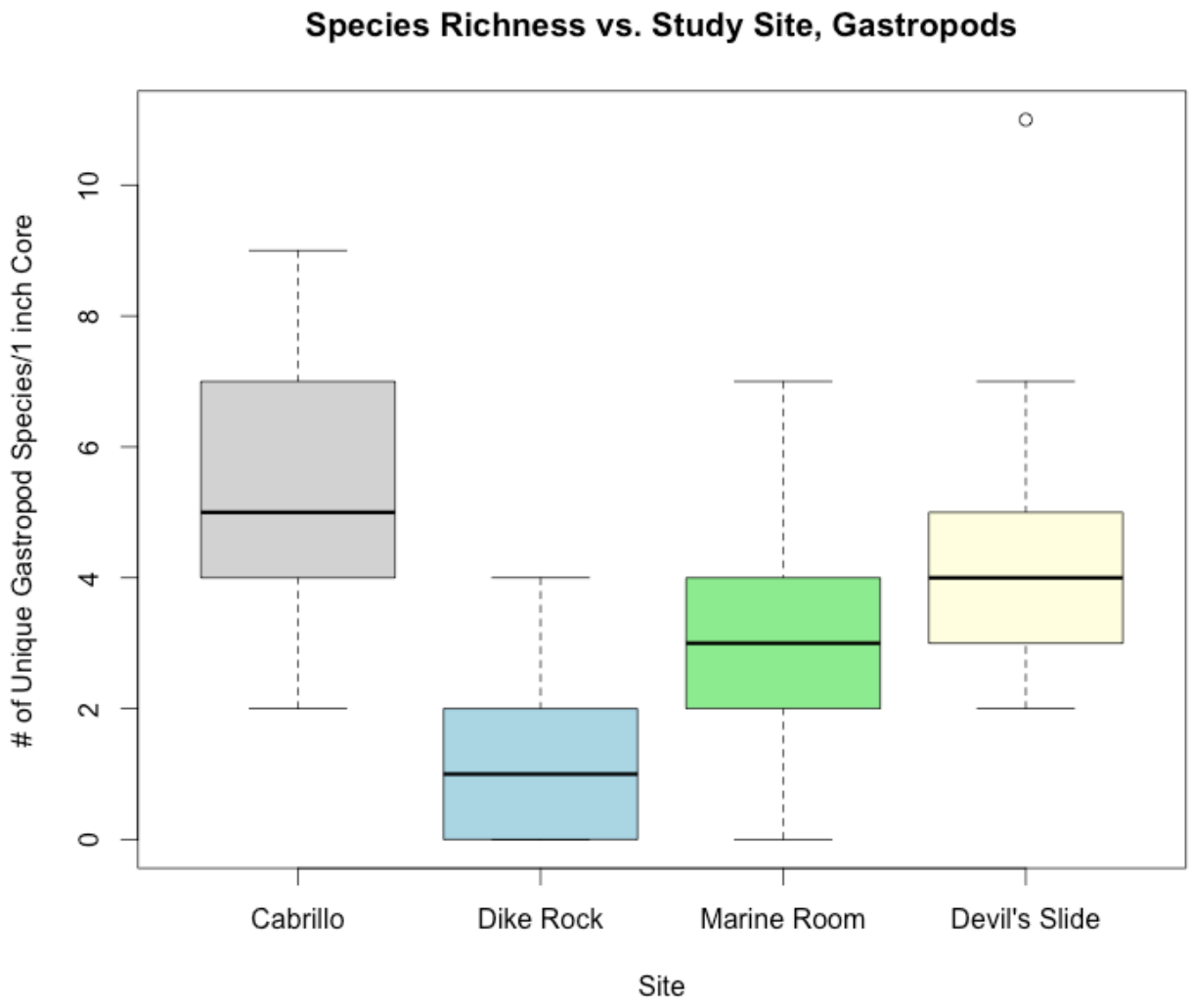


Figure 3.9: Gastropod species richness for all sites over the course of the study.

Table 3.2: List of gastropods present at each site over the course of the study.

Cabrillo Zone 3	Dike Rock	Devil's Slide	Marine Room
Gastropods			
Acetocina harpa *Alvinia sp.* *Amphitalamus tenuis* *Amphithalamus inclusis* *Barleeia californica* *Barleeia sp.* *Bittium sp.* *Caecum californicum* *Chemnitzia sp.* *Epitonium tinctum* *Eulithidium pulloides* *Fartulum occidentale* *Granulina margaritula* *Lacuna sp.* *Oceanabra sp.* *Odostomia nota* *Omalogyra sp.* *Rissoella sp.* *Unknown Gastropod 1* *Unknown Gastropod 2* *Unknown Gastropod 3* *Unknown Gastropod 4* *Unknown Gastropod 5* *Unknown Gastropod 6* *Unknown Gastropod 7*	*Acteocina harpa* *Alia sp. 2* *Amphithalamus inclusis* *Amphithalamus tenuis* *Caecum californicum* *Chemnitzia sp.* *Cysticus jewetti* *Epitonium tinctum* *Eulithidium pulloides* *Fartulum occidentale* *Lacuna sp.* *Littorina sp.* *Omalogyra sp.* *Rissoella sp.* *Unknown Gastropod 1* *Unknown Gastropod 2* *Unknown Gastropod 3* *Unknown Gastropod 4*	*Acteocina harpa* *Alvinia sp.* *Amphithalamus inclusis* *Amphithalamus tenuis* *Barleeia californica* *Barleeia sp.* *Caecum californicum* *Cerithiopsis sp.* *Chemnitzia sp.* *Epitonium tinctum* *Eulithidium pulloides* *Fartulum occidentale* *Graphis (Aclis) shepardiano* *Lacuna sp.* *Odostomia nota* *Odostomia turricula* *Omalogyra sp.* *Rissoella sp.* *Unknown Gastropod 1* *Unknown Gastropod 2* *Unknown Gastropod 3*	*Acetoncina harpa* *Amphithalamus inclusis* *Amphithalamus tenuis* *Barleeia sp.* *Caecum californicum* *Chemnitzia sp.* *Epitonium tinctum* *Eulithidium pulloides* *Granulina margaritula* *Lacuna sp.* *Odostomia turricula* *Omalogyra sp.* *Rissoella sp.* *Unknown Gastropod 1* *Unknown Gastropod 2* *Unknown Gastropod 3* *Unknown Gastropod 4*



Figure 3.10: *Lasaea sp.* was the bivalve most commonly found and abundance was highest at Devil's Slide.

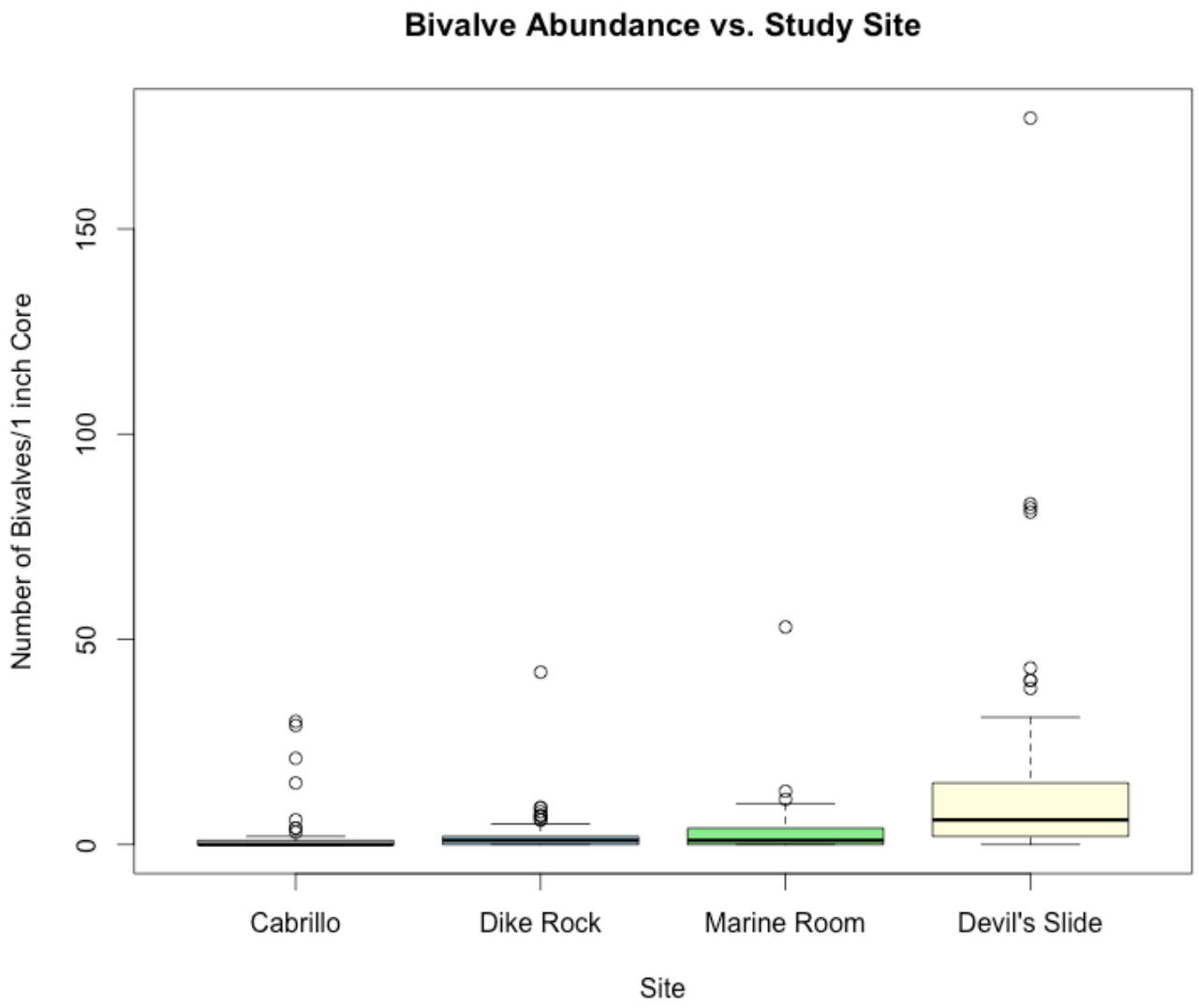


Figure 3.11: Bivalve abundance for all four sites over the course of the study.

Table 3.3: List of bivalves present at each site over the course of the study.

Cabrillo Zone 3	Dike Rock	Devil's Slide	Marine Room
Bivalves			
Hiatella sp. *Lasaea sp.* *Mytilus sp.* *Septifer bifurcatus* *Unknown Bivalve 1* *Unknown Bivalve 2*	*Hiatella sp.* *Lasaea sp.* *Mytilus sp.* *Neolepton subtrigona* *Septifer bifurcatus* *Unknown Bivalve 1* *Unknown Bivalve 2*	*Hiatella sp.* *Lasaea sp.* *Mytilus sp.* *Neolepton subtrigona* *Septifer bifurcatus* *Unknown Bivalve 1* *Unknown Bivalve 2*	*Hiatella sp.* *Lasaea sp.* *Mytilus sp.* *Neolepton subtrigona* *Septifer bifurcatus* *Unknown Bivalve 1*



Figure 3.12: Polychaete common in cores from all sites.

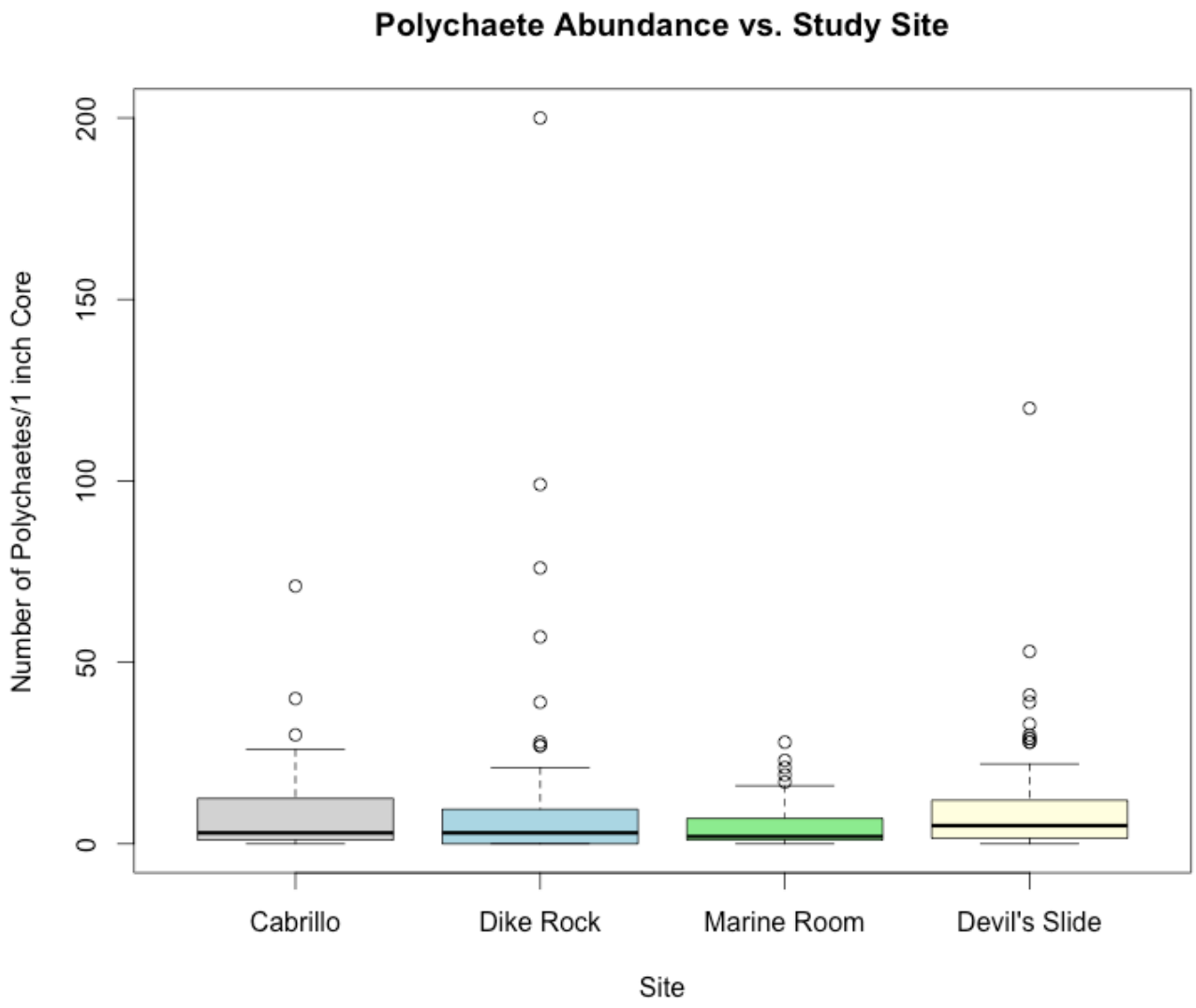


Figure 3.13: Polychaete abundance for all four sites over the course of the study.

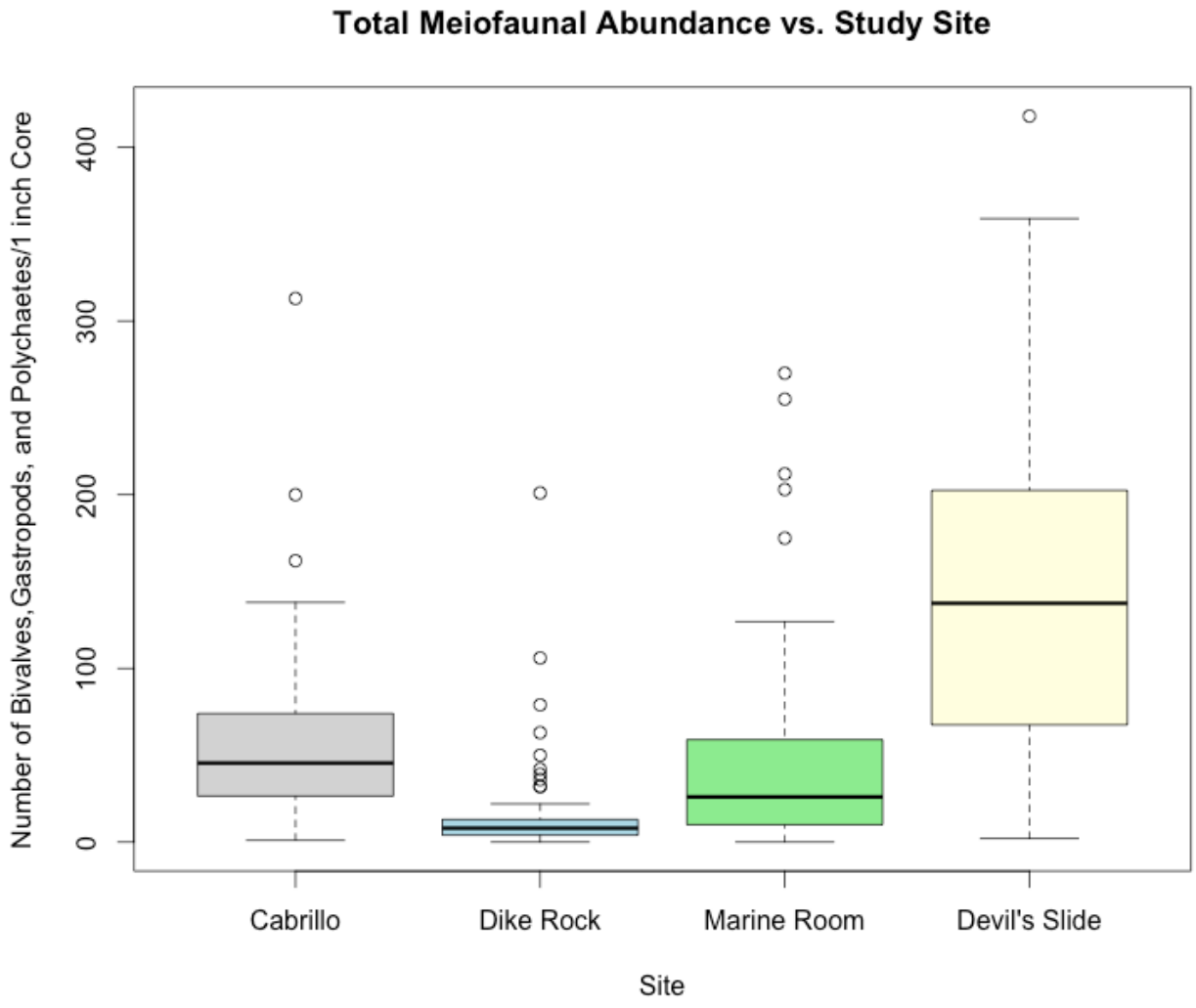


Figure 3.14: Total meiofaunal abundance among the four sites over the course of the study.

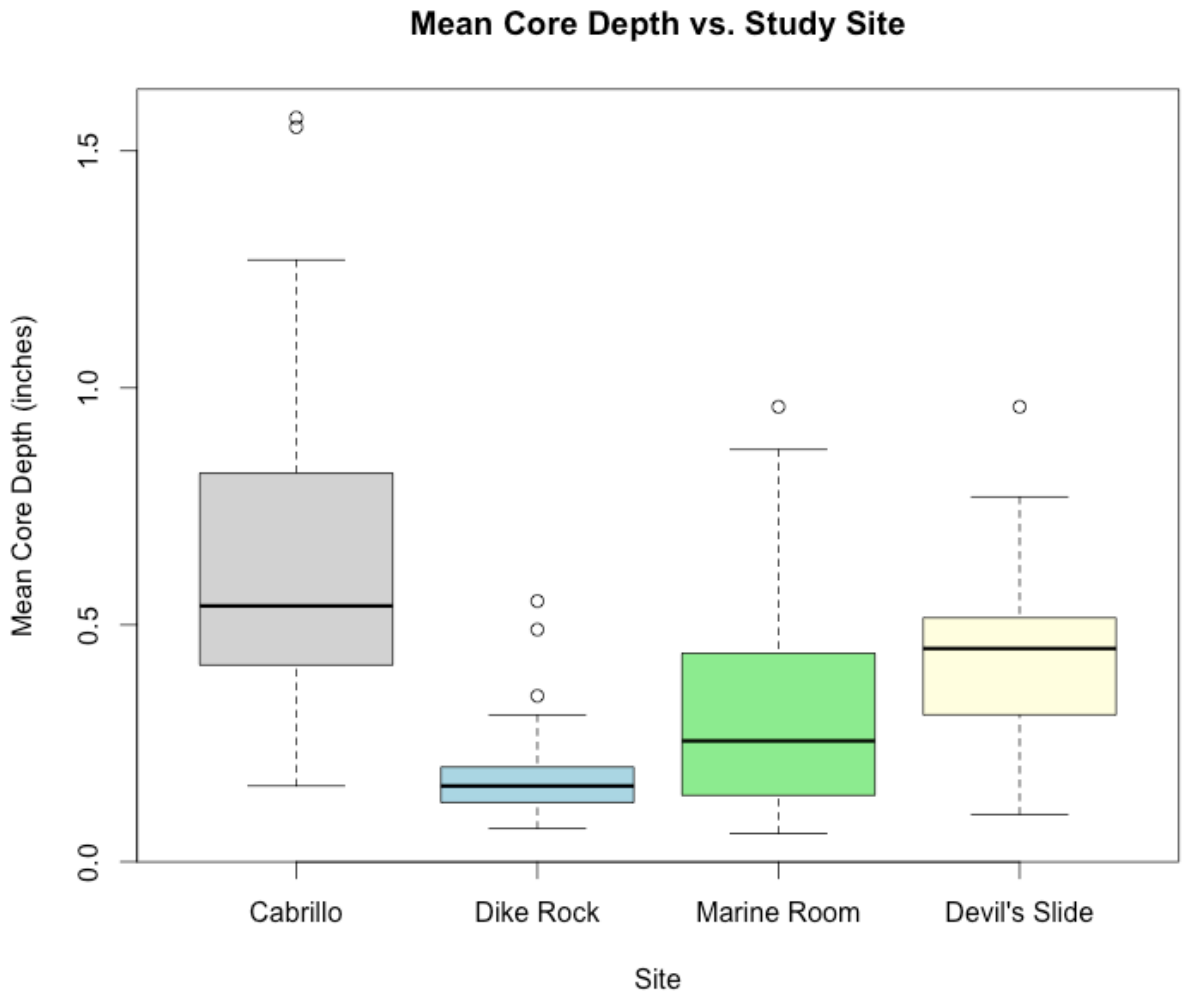


Figure 3.15: Total mean core depth (inches) among the four sites over the course of the study.

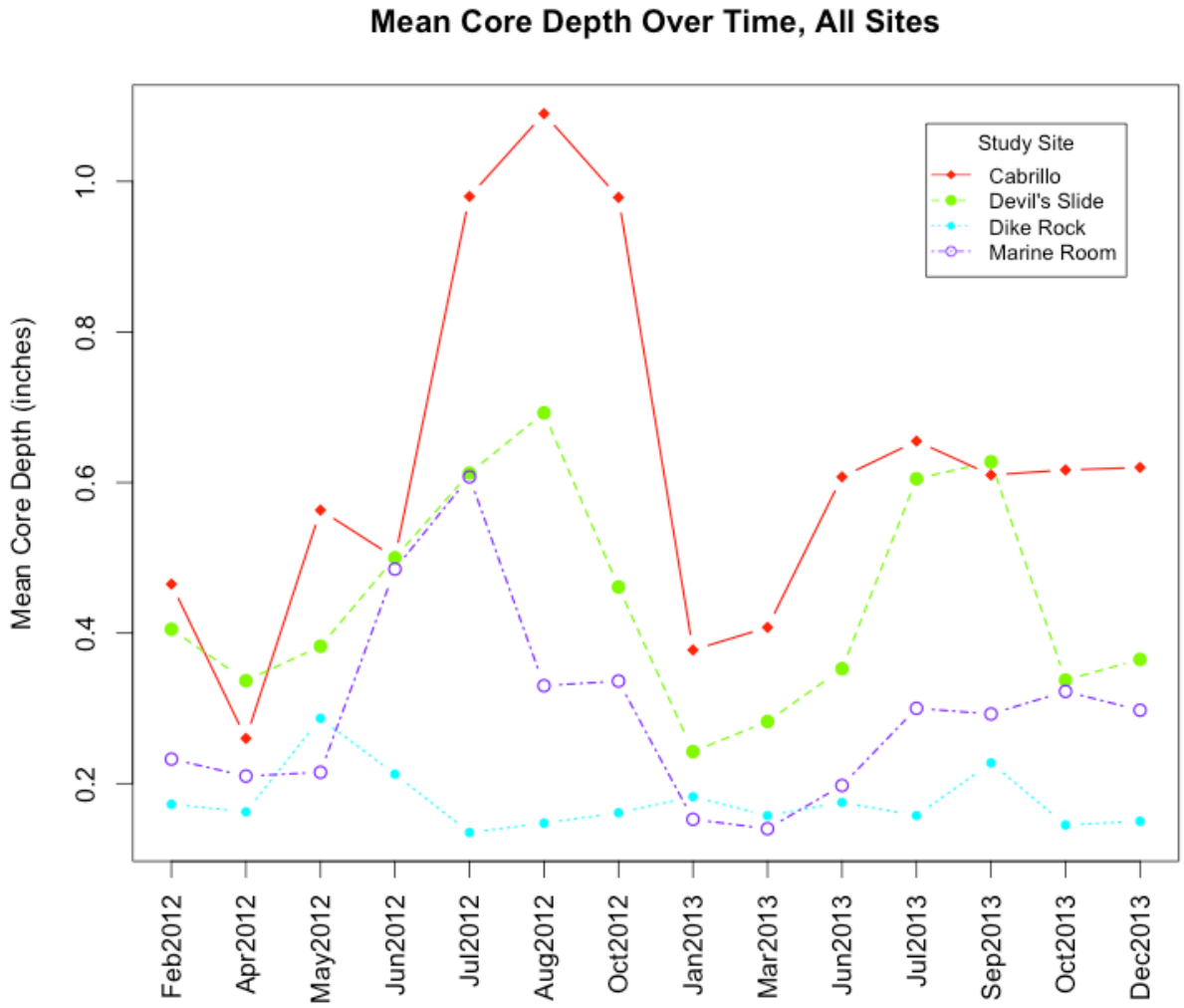


Figure 3.16: Mean core depth (inches) for cores among sites across the course of the study.

3.5 DISCUSSION

Abundance of bivalves, gastropods, and polychaetes varied monthly for all sites suggesting some "seasonality" exists; however, Dike Rock consistently had lower meiofaunal abundance and core depth as compared to the Marine Room, Devil's Slide, and Cabrillo Zone 3 over the two years of monitoring in this study. As seen in Study 2, trampling from tide pool visitation can negatively impact meiofaunal abundance, and most notably, gastropods appear most susceptible to this type of mechanical stress. By extension, it is possible that the low occurrence of gastropods observed at Dike Rock may in part reflect the high levels of trampling that occurs there (see Study 4). Overall, abundance levels correspond well with the level of trampling that occurs at each site. That is, abundance was highest at the least-trampled sites (Cabrillo Zone 3: closed to the public, and Devil's Slide: difficult to reach by foot). Thus, further studies of these communities should consider the amount of trampling stress occurring at any site of study.

STUDY 4: PUBLIC USE OF TIDEPOOLS IN AREAS OF SPECIAL BIOLOGICAL SIGNIFICANCE (ASBS 29 AND 31) IN LA JOLLA, CALIFORNIA.

4.1 BACKGROUND

Rocky intertidal habitats endure a variety of natural stresses such as wave shock, and dramatic changes in temperature and salinity of the water during high and low tides as well as during storm events. Due to their ability to endure these natural stresses, intertidal communities are generally thought to be resilient; however, the addition of anthropogenic stresses to areas near developed areas are many and have been a topic of concern and study for researchers, including exposure to urban pollution via storm drains, erosion from urban development, and human visitation to the areas. Included in the latter stress are activities such as fishing and collection of marine animals and plants, as well as the impacts of mechanical disturbance rock turning and from the foot traffic of humans visiting the areas for recreation and often in educational settings. Stresses posed by public use on the rocky intertidal have been demonstrated in several studies and should therefore be considered in the management of these designated, sensitive areas. For instance, collection of marine organisms for subsistence, hobby, and bait was shown to significantly decrease the size of four gastropod species between open access and areas "protected" from collection (Roy et al. 2003). Furthermore, even without direct removal of organisms, intertidal communities are known to be impacted/decreased through the mechanical stress posed organisms as people walk on them (Povey and Keough 1991, Beauchamp and Gowing 1982, Keough and Quinn 1998, Brown and Taylor 1999, Schiel and Taylor 1999, Smith and Murray 2005). Other studies have shown that even the more inconspicuous organisms inhabiting intertidal turfs can be impacted by trampling. For instance, a recent study showed that trampling of turf communities decreased diversity and abundance of micro-invertebrates (Huff 2011). Declines in these tiny organisms are important to consider as they play important roles in the ecosystem as bacterial grazers (McIntyre 1969), filter-feeders, and prey for higher trophic levels (Bell and Coull 1978, Coull 1990, Gibbons and Griffith 1986).

In this study, human visitation and activities were observed at three intertidal sites within the Scripps ASBS 29 and La Jolla ASBS 31 in La Jolla, California. Previous studies have quantified and described use of publically accessible areas along the California coast and demonstrated that intertidal areas are often heavily visited/used by the public and that even in

"protected areas," collection of marine organisms occurs (Huff 2006, Murray et al. 1999, Garcia and Smith 2012, Ware 2009). The current study focuses on La Jolla and Scripps ASBS in order to specifically address intensity of trampling and collection in these designated sensitive areas. The information presented here may be instructive in the management of public use in ASBS as well as help inform future studies of stresses imposed on rocky intertidal regions by human use.

4.2 METHODS

4.2a Study Sites

The tide pools observed in this study were located in Dike Rock (ASBS 31), the Marine Room and Devil's Slide (ASBS 29) (Figure 4.1).

4.2b Data Collection

To evaluate public use in Scripps ASBS 31, a time-lapse camera was secured to the end of the Scripps Research Pier and set to photograph the intertidal region every 15 minutes. Images were collected from the camera and analyzed from December 23rd 2011 through January 2nd 2013. Visitor frequency per 15-minute interval was collected for 105 days (Dec 23, 2011 – March 24, 2012) and another 136 days were viewed to gather information on behaviors of visitors to the Dike Rock tide pools. Although we were unable to secure a location for a permanent camera within ASBS 29, manual surveys were performed in the two tide pool areas there on 20 days between October 2012 and January 2013. Visitors were counted every 15 minutes and their activities were described. Intensity of use in the two intertidal areas of ASBS 29 (sites divided based on public accessibility) was compared to visitation occurring within ASBS 31 on the same days across the study.

4.2b Data Analysis

For Dike Rock, the total number of unique visitors (unique = not observed during other 15 minute observation periods on the same day) was calculated for each day as well as peak

number of visitors per day. Using ANOVA, these measures were compared to weekday and time of day to look for patterns in public use. A test for correlation by randomization was used to determine whether there was a relationship between the tidal height and number of visitors at the peak visitation time for each day at the Dike Rock tide pools. The test statistic, or correlation coefficient "r", measures the strength and the direction of the association between two numerical variables (Formula: r = (*X-Xmean)(Y-Ymean)/*(*X-Xmean)*^2*) * (Y-Ymean)^2*). The values for r range from -1 to 1. If there is no association between two variables, the r-value will equal 0. A value of -1 shows a strong, negative correlation between two variables and a value of 1 indicates a strong, positive correlation. Descriptions of human activities (presence of educational groups, collections, and illegal fishing) and average length of time visitors spent in the tide pools are also reported here.

For the Marine Room and Devil's Slide tidepools, the total number of unique visitors per observation period (2 hours on average) was compared between sites. Time for day was not used in analyses as the observation periods generally occurred in afternoons for convenience.



Figure 4.1: Map of Study Sites monitored: Dike Rock, Marine Room, and Devil's Slide.

4.3 RESULTS: Dike Rock (ASBS 31)

4.3a Total and Mean Visitation and length of time spent in tidepools.

In the first 105 days observed for this study, there were 2,983 unique visitors ("unique" = only counted once even if appearing in multiple observation periods) to the tide pools at Dike Rock between December 23rd, 2011 and March 24th, 2012 (excluding 5 days in which photographs were not useable and so not included in the analysis). Of those visitors, 402 remained in the tide pools for 30-45 minutes, and another 430 visitors had visits lasting for more than 45 minutes (Figure 4.2).

4.3b Day of Week versus Tide Pool Visitation

ANOVA was used to test for differences in tide pool visitation versus days of the week. While visitation appears lightly elevated on Weekend Days as compared with weekdays (Figure 4.3), ANOVA did not yield significant results: $F(6,112) = 1.80$, $p = 0.11$.

4.3c Tidal Height (ft) versus Tide Pool Visitation

A test for correlation by randomization was used to determine whether there was a relationship between the tidal height and number of visitors at the peak visitation time for each day at the Dike Rock tide pools. In this case, the correlation statistic, $r = -0.44$, suggesting that there is a negative relationship between tidal height and peak number of visitors. A p-value of <0.05 for this test suggests that the negative relationship observed between tidal height and peak number of visitors is significant (Figure 4.4).

4.3d Time of Day versus Tide Pool Visitation

Peak visitation occurred more in the afternoons, but the average number of visitors was not significant between the morning, afternoon, and evening: $F(2,102) = 1.90$, $p = 0.16$ (Figure 4.5).

4.3e Visitor Behaviors Observed

In addition to the first 105 days observed for visitor frequency data, another 136 days were observed to gather information on visitor behavior in the tide pools. Visitors engaged in expected activities including picking up and turning over of rocks, moving seaweed to look for animals, jumping on, kicking and throwing rocks, and walking through the area (surfers and joggers frequently walk through the area). Other behaviors observed included illegal fishing (15 people were observed fishing over the span of 240 days), gathering of large classroom groups (at least 13 large student groups were identified throughout the study), allowing dogs to roam around tide pools (37 dogs were observed over 80 days), and collecting animals in buckets or backpacks.

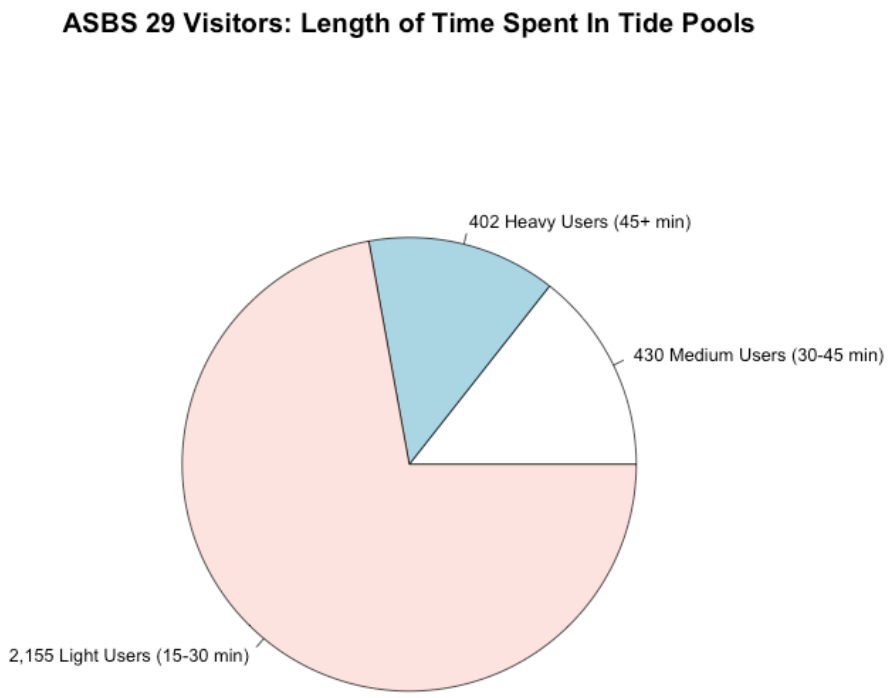


Figure 4.2: Pie Chart of Visitor Length of Time Spent in Tide Pools if Dike Rock (ASBS 29) between December 23, 2011 and March 24th, 2012.

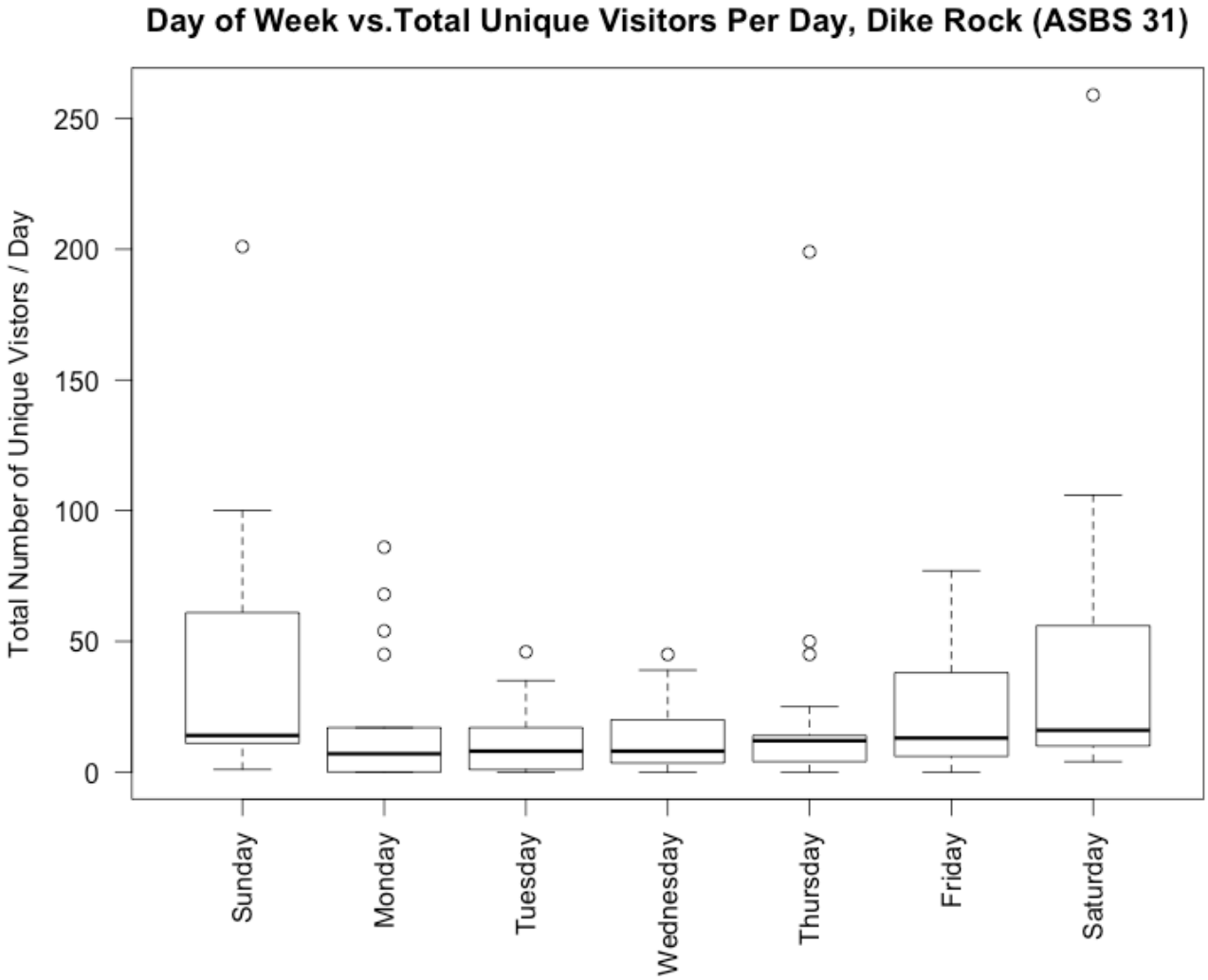


Figure 4.3: Box plot of Total Unique Visitors Per Day versus Day of the Week, December 23, 2011 - March 24, 2012.

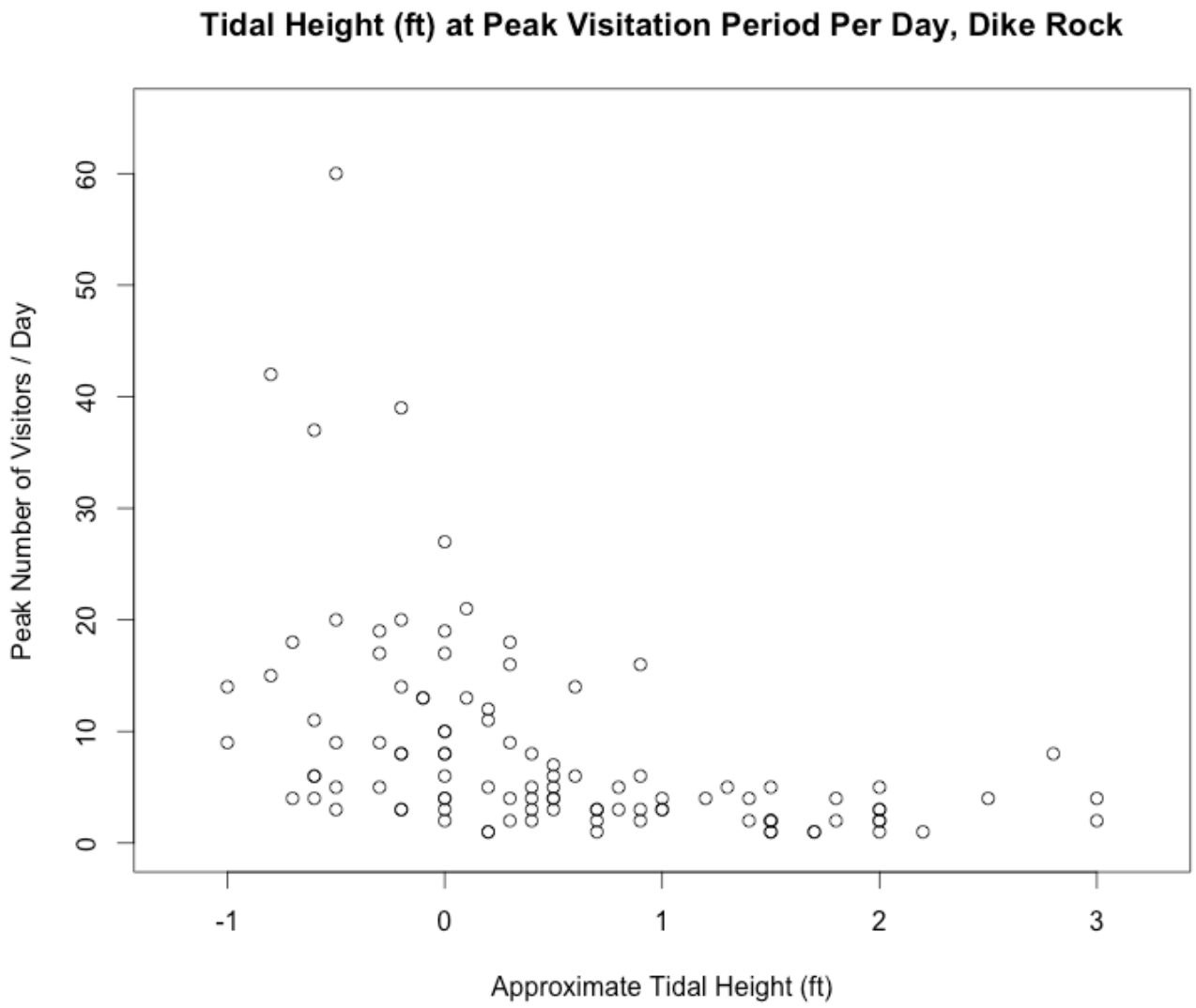


Figure 4.4: Peak Visitation/Day versus Tidal Height during Peak Visitation Time at the Dike Rock Tide Pools (ASBS 31), December 23, 2011 – March 24, 2012.

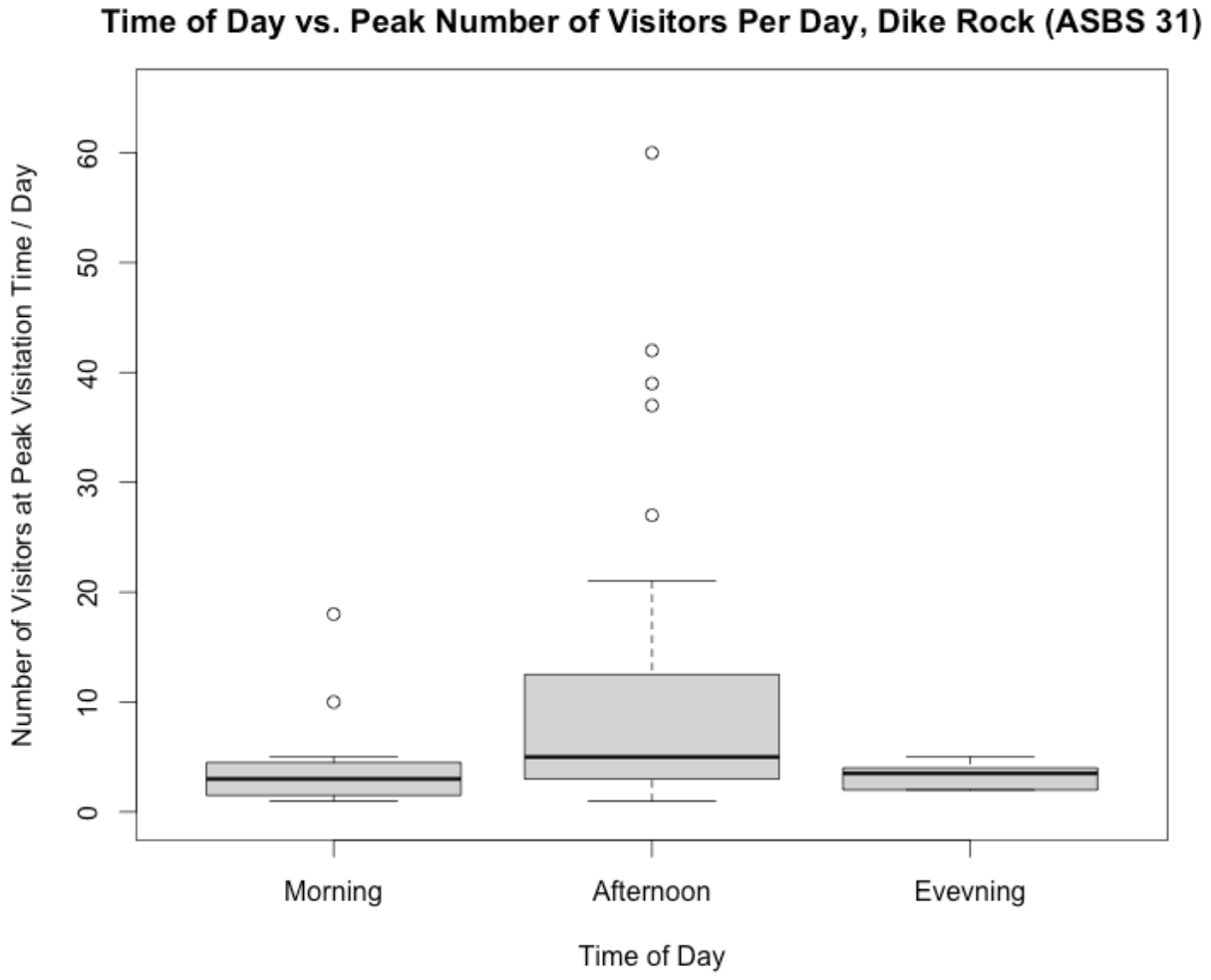


Figure 4.5: Peak Visitation/Day versus Time of Day during Peak Visitation, Dike Rock Tide Pools (ASBS 31).

4.4 RESULTS: Marine Room and Devil's Slide (ASBS 29)

4.4a Visitation at Marine Room versus Devil's Slide

Visitation at the Marine Room tide pools was higher compared to visitation at Devil's Slide (Mean visitors/observation period: MR = 11.68, DS = 2.32. Welch's T test results indicate that this difference is significant: $t(42.05) = -4.61$, $p = <<0.05$. (Figure 4.6).

4.4b Visitor Behaviors Observed

Main activities observed in the tidepools included classroom use (elementary, high school, and undergraduate levels) turning, throwing and kicking of rocks, running, chasing after birds, collection of animals in buckets, illegal poaching of lobsters, abalone, and owl limpets, moving seaweed aside with sticks, and prodding under rocks with sticks.

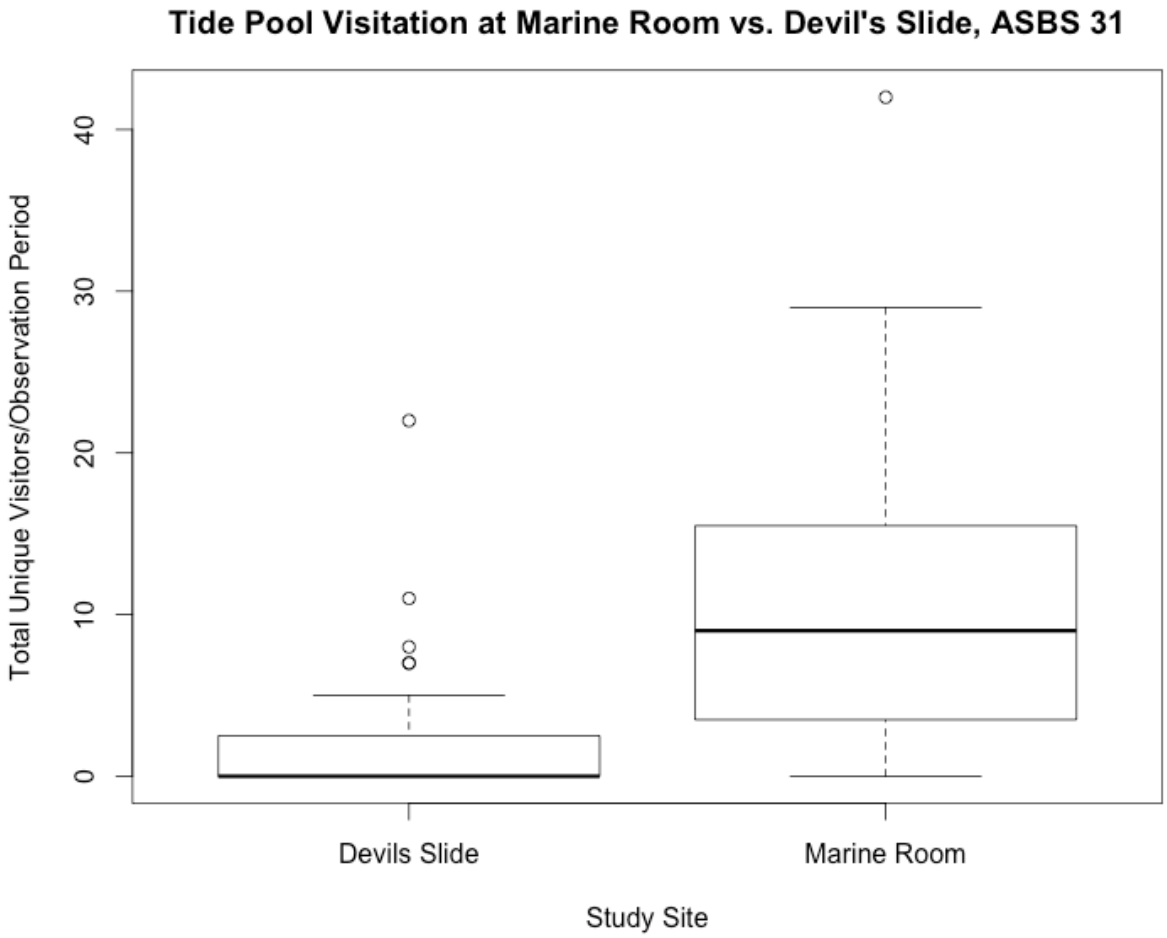


Figure 4.6: Total Number of Unique Visitors per observation period, Marine Room and Devil's Slide.

4.4 DISCUSSION

Visitation occurred in every day of the week and throughout daytime hours. While afternoon visits were more common, the total number of visitors to tidepools was not significantly different between morning, afternoon, and evening. This evenness appears to be influenced by large classroom groups that were frequently present during good low tides, which often occurred in the mornings and on weekdays. Without those large school groups, afternoons were the most popular time to visit tide pools. Of the visitors observed in the first 105 days of observation at Dike Rock, nearly 30% spent at least 30 minutes exploring and moving about (and often more than 45 minutes). Furthermore, individuals that happen to pass through the tide pools but not stop to explore for more than a few moments may not have been counted. Thus, 2,983 visitors is a conservative figure.

Areas of Special Biological Significance are meant to protect sensitive habitat and their biological communities. While dumping is prohibited in these areas, the impacts of human access have yet to be addressed. Trampling and collection studies show that humans can dramatically impact rocky intertidal areas and some degree of management is necessary to curb negative impacts. Over the course of this study, it became clear that having someone present in tide pools that can 1) supervise visitors and report illegal activities, and 2) be a source of knowledge for the public, can change the behavior of visitors. For instance, nearly every time fieldwork was conducted in the presence of visitors, people had questions about tide pools, including macrofauna they found or wanted to find, and science in general and they were very excited to have their questions answered. Tide pool visitors that inquired about the studies presented here appeared to even change how they walked out in the tide pools (they used more care and looked for bare spots to hop on rather than just tromping and twisting around as they had been) once they realized they had been walking on tiny animals they could not see. Out of this, it is possible that one of the simplest tools that could be used to protect these sensitive areas would be making information easily accessible to those that use or visit the areas. It would be instructive to study the impact of having docents present versus not on how humans behave in the tidepools. Furthermore, for those people collecting illegally in protected areas, enforcement needs improvement. For example, with the exception of one incident, every attempt (5 over the course of the study) to contact the Department of Fish and Game was unsuccessful in that no one

ever answered the hot line. It should be noted though that in the one case where the Department was reached, an Officer was sent to investigate and the poachers were intercepted. There is also very little (if any) signage making it clear how to behave properly in tidepools. At a minimum, such signage should be posted near the entry to intertidal areas, clearly indicating how sensitive habitats are and stating fines for illegal collection. Together, educating the public about vulnerability of the habitat, adding the influence of docents on visitor behavior, improving hotline response from the Department of Fish and Game, and adding conspicuous signage regarding rules could be useful in deterring poachers and protecting the sensitive habitat of Scripps and La Jolla ASBS.

REFERENCES

Bell SS, Coull CC. 1978. Field evidence that shrimp predation regulates meiofauna. Oecologia (35): 141-148.

Berger VJ, Kharazova AD. 1997. Mechanisms of salinity adaptations in marine molluscs. Hydrobiologia (121): 115-126.

Beauchamp KA, Gowing MM. 1982. A quantitative assessment of human trampling effects on a rocky intertidal community. Marine Environmental Research (7): 279-293.

Burton RS, Feldman MW, Curtsinger JW. 1979. Population genetics of Tigriopus californicus (Copepoda: Harpacticoida): I. Population structure along the central California coast. Marine Ecocolgy Progress Series (1): 29-39.

Brand LE. 1984. The salinity tolerance of forty-six marine phytoplankton isolates. Estuarine, Coastal, and Shelf Science. (18): 534-556.

Brown PJ, Taylor RB. 1999. Effects of trampling by humans on animals inhabiting coralline algal turf in the rocky intertidal. Journal of Experimental Marine Biology and Ecology (235): 45-53.

Bruno JF, Stachowicz JJ, Bertness MD. 2003. Inclusion of facilitation into ecological theory. Trends in Ecology and Evolution 3(18): 119-125.

Calliari D, Andersone Berg MC, Thor P, Gorokhove E, Tiselius P. 2008. Instantaneous salinity reductions affect the survival and feeding rates of the co-occurring copepods *Acartia tonsa* and *A. clausi Giesbrecht* differently. Journal of Marine Biology and Ecology (362): 18-25.

Chang M, McBroom WM, Beasley SR. 2004. Roofing as a source of nonpoint water pollution. Journal of Environmental Management (73): 307-315.

Coull, BC. 1990. Are members of the meiofauna food for higher tropic levels? Transactions of the American Microscopal Society 3(109): 233-246.

Connell JH. 1978. Diversity in Tropical Rain Forests and Coral Reefs. Science, New Series (199): 1302-1310.

Depledge MH, Rainbow PS. 1990. Models of regulation and accumulation of trace metals in marine invertebrates. Compartive Biochemmical Physiology 1(97C): 1-7.

Dietz ME, Clausen JC. 2008. Stormwater runoff and export changes with development in a traditional and low impact subdivision. Journal of Environmental Management (87): 560-566.

Ebeling AW, Laur LR. 1986. Foraging of surfperches: resource partitioning or individualistic responses? Environmental Biology of Fish. 1-3(16): 123-133.

Farmer L. 1979. Evidence for hyporegulation in the calanoid copepod, *Acartia tonsa*. Comparative Biochemical Physical and Biology (65A): 359-362.

Garcia A, Smith JR. 2003. Factors influencing human visitation of southern California rocky intertidal ecosystems. Ocean and Coastal Management. (74): 44-53.

Gee JM. 1989. An ecological and economic review of meiofauna as food for fish. Zoological Journal of the Linnean Society (96): 243-261.

Gibbons MJ, Griffiths CL. 1986. A comparison of macrofaunal and meiofaunal distribution and standing stock across a rock shore, with an estimate of their productivities. Marine Biology 93(2): 181-188.

Gobel P, Dierkes C, Coldewey WG. 2007. Storm water runoff concentration matrix for urban areas. Journal of Contaminant Hydrology (91): 26-42.

Gosselin LA, Chia F. 1994. Feeding habits of newly hatched juveniles of an intertidal predatory gastropod, Nucella emarginata (Deshayes). Journal of Experimental Marine Biology and Ecology (176): 1-13.

Gosselin LA, Chia F. 1996. Prey selection by inexperienced predators: do early juvenile snails maximize net energy gains on their first attack? Journal of Experimental Marine Biology and Ecology (199): 45-58.

Hall KJ, Anderson BC. 1998. The toxicity and chemical composition of urban stormwater runoff. Canadian Journal of Civil Engineering (15): 98-106.

Huff, TM. 2006. Impacts of human trampling and periodic sand inundation on Southern California intertidal algal turf communities: Implications for conservation and management of rocky shores. Ph.D. dissertation, University of California, San Diego, United States -- California. Retrieved May 10, 2010, from Dissertations & Theses @ University of California. (Publication No. AAT 3222055).

Huff TM. 2011. Effects of human trampling on macro- and meiofauna communities associated with intertidal algal turfs and implications for management of protected areas on rocky shores (Southern California). Marine Ecology 32 (2011) 335–345.

Jartun M, Ottesen RT, Steinnes E, Volden T. 2008. Runoff and particle bound pollutants from urban impervious surfaces studied by analysis of sediments from stormwater traps. Science of the Total Environment (396): 147-163.

Keough MJ, Quinn GP 1998. Effects of periodic disturbances from trampling on rocky intertidal algal beds. Ecological Applications 8(1): 141-161.

Katznelson R, Jewell WT, Anderson SL. 1995. Spatial and temporal variations in toxicity in an urban-runoff treatment marsh. Environmental Toxicology and Chemistry 3(14): 471-482.

Makepeace DK, Smith DW, Stanley SJ. 1995. Urban stormwater quality summary of contaminant data. Critical Reviews in Environmental Science and Technology 2(25): 93-139.

McIntyre AD. 1969. Ecology of marine meiobenthos. Biological Reveiws 2(44): 245-290.

Metcalf L, Eddy H. 1916. American sewerage practice, Disposal of sewage. McGraw-Hill, New York.

Murray SN, Denis TG, Kido JS, Smith JR. 1999. Human Visitation and the Frequency and Potential effects of collecting on rocky intertidal populations in southern California marine reserves. CalCOFI Report (40): 100-106.

Neuparth T, Costa FO, Costa MH. 2002. Effects of Temperature and Salinity on Life History of the Marine Amphipod *Gammarus locusta*. Implications for Ecotoxicological Testing. Ecotoxicology (11): 61-73.

Paine RT, Vadas RL. 1969. The effects of grazing by sea urchins, Strongylocentrotus spp. on benthic algal populations. Limnol. Oceanogr. (14) 710–719.

Pridmore RD, Thrush SF, Cummings VJ, Hewitt JE. 1992. Effects of the Organochlorine Pesticide Technical Chlordane on Intertidal Macrofauna. Marine Pollution Bulleton 2(24): 98-102.

Povey A, Keough MJ. 1991. Effects of Trampling on Plant and Animal Populations on Rocky Shores. Oikos, 3(61): 355-368.

Rainbow PS. 2007. Trace metal bioaccumulation: Models. Metabolic availability and toxicity. Environment International (33): 576- 582.

Ricketts EF, Calvin J, Hedgpeth JW. 1985. Between Pacific Tides. 5th ed. Stanford Univ. Press, Stanford, California.

Roberts DA, Poore GBA, Johnston EL. 2007. MBACI sampling of an episodic disturbance: Stormwater effects on algal epifauna. Marine Environmental Research (64): 514-523.

Roberts DA, Johnston EL, Muller S, Poore GBA. 2008. Field and laboratory simulations of storm water pulses: Behavioral avoidance by marine epifauna. Environmetal Pollution (152): 153-162.

Schiff K, Bay S, Stransky C. 2002. Characterization of stormwater toxicants from an urban watershed to freshwater and marine organisms. Urban Water 3(4): 215-227.

Schueler T. 2000. The Importance of Imperviousness, Article 1 in The Practice of Watershed Protection. Center for Watershed Protection. Ellicott City, MD.

Smith JR, Murray SN. 2005. The Effects of Experimental Bait Collection and Trampling on Mytilus californianus Mussel Beds in Southern California. Marine Biology (147) 699-706.

Thompson RC, Crowe TP and Hawkins SJ. 2002. Rocky intertidal communities: past environmental changes, present status and predictions for the next 25 years. Environmental Conservation 29(2): 168-191.

Walsh CJ. 2000. Urban impacts on the ecology of receiving waters: a framework for assessment, conservation and restoration. Hydrobiologia (431): 107-114.

Watzin MC. 1983. The effects of meiofauna on settling macrofauna: meiofauna may structure macrofaunal communities. Oecologia (59): 163-166.

Weather Forecast & Reports - Long Range & Local [Internet]. c1995-2014. Weather History for San Diego Montgomery, CA: [cited 2014 Feb 04]. Available from: http://www.wunderground.com/history/airport/KMYF/2013/2/1/MonthlyHistory.html

Schueler T. 2000. The Importance of Imperviousness, Article 1 in The Practice of Watershed Protection. Center for Watershed Protection. 1(3): 100-111.

Schiel DR, Taylor DI. 1999. Effects of trampling on rocky intertidal algal assemblage in southern New Zealand. Journal of Experimental Marine Biology and Ecology. (235) 213-235.

Ware R. 2009. Central Orange County Areas of Special Biological Significance Public Use Monitoring Program. Prepared for the City of Newport Beach Public Works.

Worm B, Barbier BB, Beaumont N, Emmett DJ, Folke C, et al. 2006. Impacts of Biodiversity Loss on Ocean Ecosystem Services. Science (314): 787-790.

Yachi S, Loreau M. 1999. Biodiversity and ecosystem productivity in a fluctuating environment: the insurance hypothesis. Proceedings of the National Academy of Science (96): 1463−1468.