An Assessment of Rocky Intertidal Motile Invertebrate Data from Channel Islands National Park: A Project for NPS and MARINe

UCLA Env 180 Senior Practicum

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Executive Summary

Rocky intertidal species are diverse, robust organisms that have adapted to constant environmental fluctuations from both land and sea. As climate change intensifies, it is necessary to study the long-term trends in rocky intertidal motile invertebrate (MI) abundance, which could illustrate the magnitude of climate effects on these organisms. The National Park Service monitoring team provided us an initial dataset of 66 motile invertebrate species from which we narrowed our study focus to 16 core motile species that had counts over 500 over the ten year monitoring period. After synthesizing a literature review and basic summary statistics on the 16 MI species, we narrowed our analysis to two species: *Littorina* and *Tegula funebralis*. We used the statistical program, R, to conduct our multiple linear regression analysis. Our analysis mainly focused on Santa Rosa Island due to its complete dataset and large land area. Climate data analysis was conducted by using average monthly high temperature data and the days over the temperature tolerance threshold for each species to find a correlation with species abundance trends. Our multiple linear regression analysis included the Multivariate ENSO Index (MEI) values, air temperature, and proportion of sessile species and bare rock cover to model plot abundances of species over time. Our regression analysis results indicate a general positive correlation of sessile species and rock coverage with abundance. Unexpectedly, we found a general positive correlation of air temperature and abundance. We also found a general negative correlation of MEI with *Littorina* and *T. funebralis* abundances. Shifting environmental conditions due to climate change could significantly alter MI species abundances and sessile coverage which may modify community structure.

1. Introduction

National Park Service and Multi Agency Rocky Intertidal Network (MARINe), along with their collaborators, requested us to assess the effectiveness of a long-term, large-scale monitoring program designed to collect baseline data on rocky intertidal communities. This monitoring program was proposed to assess resource damage of the communities inhabiting the rocky intertidal zones of the Pacific coast. Specifically, the effectiveness of the Motile Invertebrate (MI) protocol in defining the relative abundance of organisms such as gastropods, crabs and chitons was analyzed. MI data has been collected and used throughout California at universities and other governmental agencies (Channel Islands National Park). Channel Islands National Park also is the pilot study location for this project. A total of 16 core MI species are monitored systematically in the permanently marked plots. The first step in this project was evaluating the data that was collected.

The project objectives were:

- To understand the vulnerability of the motile species to direct and indirect anthropogenic impacts
- To identify abundance trends for motile species
- To assess potential climate impacts

In addition to that, we had the following deliverables:

- Literature review of the relative vulnerability of monitored species/ taxa to climate change and human disturbance

- Summary statistics on the density and size class distribution of each species or taxa by biotic zone
- Statistical analysis of trends in MI density or size classes and the relationships to large-scale climate variations (ENSO)

1.1. Clients

Channel Island National Park (CHIS) and Multi Agency Rocky Intertidal Network (MARINe) collaborated with universities including University of California, Los Angeles, University of California Santa Barbara, University of California Santa Cruz, and California State University, Fullerton.

The rocky intertidal is the area between land and sea. It supports a rich variety of organisms with unique adaptations for living in this environment. Rocky intertidal communities in temperate areas such as California are particularly diverse, and include species such as abalone, mussels, limpets and sea urchins that are harvested by humans.

MARINe monitors the status of rocky intertidal habitat along the west coast of North America. They have conducted monitoring at more than 150 sites over Baja California, Mexico to Alaska over the past 20-30 years. The purpose of the monitoring program is two-fold: to collect baseline data in the event of an oil spill and to better understand the dynamic nature of the rocky intertidal community so it could be properly managed.

Rocky Intertidal Monitoring Program sites generally consist of an array of 15-35 photoplots that are monitored to determine the temporal dynamics of 13 core sedentary species or assemblages (mussels, rockweeds, barnacles etc.). The fixed photoplots are also used to quantify the abundances and sizes of a suite of MI species.

1.2. Monitoring Protocol

Motile invertebrate (MI) monitoring at CHIS was conducted on all five islands: Anacapa, Santa Cruz, San Miguel, Santa Barbara and Santa Rosa, at a total of 22 sites. The monitoring was conducted biannually, in fall and spring. Each site had five fixed plots for each of the biotic zones: *Chthamalus/ Balanus, Endocladia, Silvetia* and *Mytilus*.

Motile invertebrate and sessile species data provided by NPS for this project was collected based on the protocols described in the following two documents: the Rocky Intertidal Communities Monitoring Handbook (Richards and Davis 1988), and Standard Operating Procedure #15 for Motile Invertebrate counts (Whitaker and Richards 2012).

The monitoring is a biannual sampling process of permanent photoquadrats, owl limpets, sea stars and black abalone plots spread out on five islands – Anacapa, Santa Barbara, San Miguel, Santa Cruz and Santa Rosa islands (Figure 1).

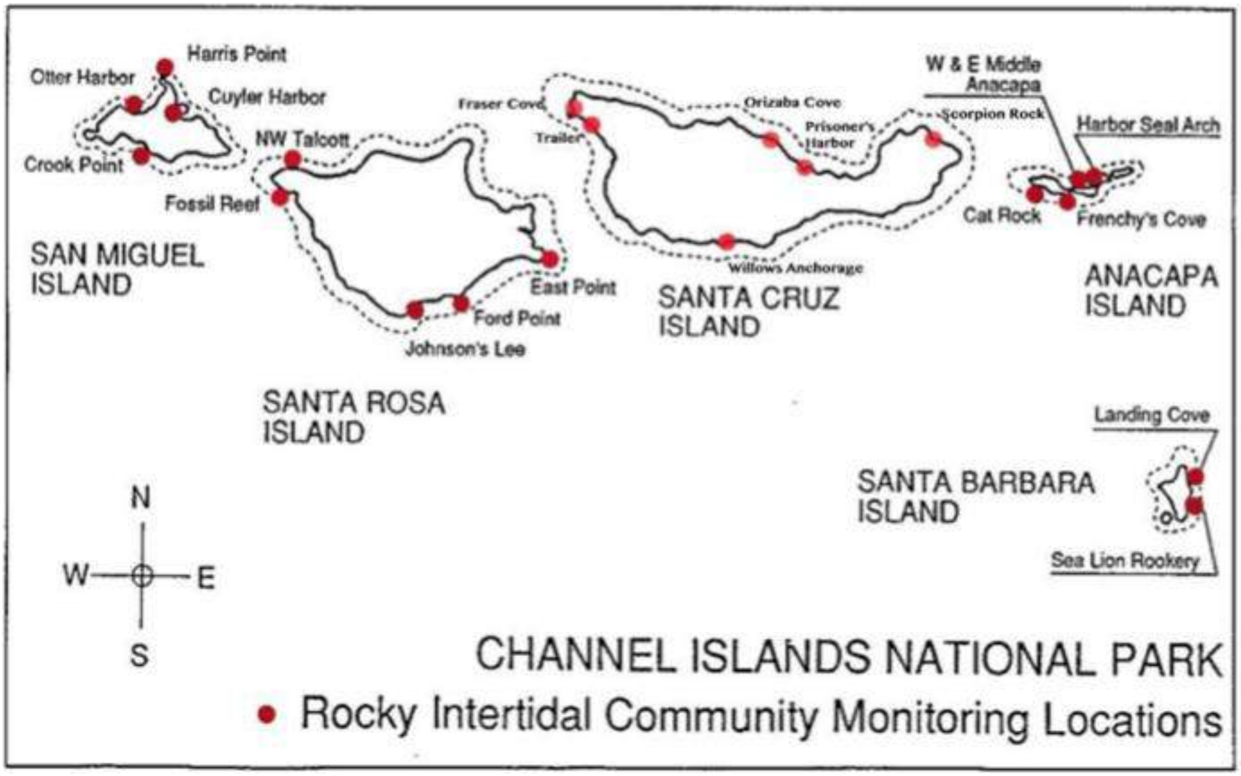


Figure 1. Map of each monitoring site on Channel Islands.

1.3. Importance and Implications

This project contributed to the understanding of recent trends and climatic influences on these motile invertebrates within the rocky intertidal zone. It also includes a discussion of impacts of biotic and abiotic factors and how they affect the motile invertebrates. The study of these species is important because MI is important components of coastal ecosystems including rocky intertidal habitats. They are major consumers and nutrient recycles (Taylor 1998), and contributes to the ecosystem structure. They are active members of predator/prey food webs. Because of their contributions, they influence the dynamics of other taxa like macroalgae (Tegner and Dayton 1987), sessile fauna (Osman et al. 1992) and reef fishes (Holbrook et al. 1997). Even though the abundance of diverse MI can be altered from anthropogenic (trampling, oil spills etc.) (Huff 2011) and non-anthropogenic effects (climate change) (Barry et al. 1995). A healthy MI population is also a reflection of a healthy ecosystem.

Due to time constraint and lack of data available for certain climate metrics, we were unable to analyze all physical and biological impacts on our target species. However, this project includes with recommendations on how the monitoring and analysis should be done, what metrics should be used and what tests should be run.

2. Literature Review Summary

This section contains a summary of our literature review. It includes a description of our research methodology, an overall summary of findings, and detailed information on the two focus species (*Littorina spp* and *Tegula funebralis),* for which we conducted analysis to explore possible climate impacts on abundance (as described later in this report).

The complete review is provided as Appendix D of this report; also included in the Appendix is a spreadsheet summary of the articles, indicating their applicability to each of the 16 core species, various aspects of climate change, and whether the articles relate to studies conducted on Channel Islands or in California.

2.1. Literature Research Methodology

To conduct our literature review, we researched a wide range of topics pertaining to our study of the rocky intertidal. First, we looked for life history information on the motile invertebrate species. We then sought out studies on direct and indirect climate change impacts such as temperature effects, desiccation, ocean acidification, extreme weather events, hypoxia, ENSO effects, wave effects, salinity, range shifts, zonation, food web effects, and food consumption and metabolism. We also looked for information related to human disturbance, including oil spills, trampling, visitation, overturning of rocks, and poaching of our species. We aimed to find literature specific to Channel Islands, but also looked broadly at any rocky intertidal research, both in California and internationally.

We used the following keywords to research climate impacts on our focus species: climate change Channel Islands, heat stress, ocean acidification, rocky intertidal zonation, temperature threshold, desiccation, trophic cascades, habitat shifts, rocky intertidal wave effects, precipitation effects, death by desiccation, mortality, human impacts, predation, sea surface temperatures, ENSO, MEI, salinity, sea level rise, and extreme weather events. Variations of these search terms were used to research a specific organism, for example, "*Littorina* temperature threshold" or "*Tegula funebralis* desiccation".

2.2. Findings

There were a total of 54 papers cited that related to rocky intertidal sites, with 7 of them specific to Channel Islands and 26 related to California. Forty-eight of our 54 papers are related to climate change effects.

Species that were well represented in our study and had the most amount of sources compared to other species include *Lottia digitalis* (10), *Lottia gigantea* (12), *Littorina* (10), and *Tegula funebralis* (7), which are shown in our species source table. Other species that were underrepresented was due to lack of search results or because they were not our two focus species. Of the limpets, *Lottia gigantea* had the most sources available since the other limpet species (*Notoacmea scutum, Notoacmea persona, Fissurela volcano, Lottia pelta, Lottia paradigitalis, Lottia austrodigitalis, Lottia conus, Lottia limatula, Lottia scabra*) are difficult to distinguish in appearance and do not grow as large as *Lottia gigantea*. Most of our sources relating to human poaching are of *Lottia gigantea* due to its larger size which makes it easier to identify and capture. Generally, the limpet species excluding *Lottia gigantea* had sparse background information. Both *Littorina* and *Tegula funebralis* had adequate sources regarding temperature effects, natural history, and desiccation. There were no articles on habitat shifts or extreme weather events for both *Littorina* and *Tegula funebralis*. In general, habitat shifts and extreme weather events did not yield many research results. More research is needed overall for all species relating to extreme weather events, salinity, range shifts, ENSO effects, ocean acidification, and invasive species.

2.3. Overview

According to our literature review, Channel Islands' motile invertebrates can experience variable responses to continually rising human population and climate change. Human disturbance effects include predation, collection, trampling, rock overturning, litter and oil spills, and invasive species. Human predation can lead to significant reductions in species populations as rocky intertidal species are sought after for sale and consumption (Erlandson et al. 2011; Sagarin et al. 2006; Jacobson and Emerson 1971). Collection can alter the community structure of the species' habitat due to the asymmetrical selection of desirable larger individuals rather than undesirable smaller individuals (Smith et al. 2008; Kingsford et al. 1991). Thus, the community is left with only smaller individuals that may not be able to reproduce and lower abundances of harvested species will occur (Smith et al. 2008). Species can be damaged or accidentally removed via trampling and dislodgment as humans walk along the rocky intertidal zone (Huff 2011). The frequent overturning of rocks by humans does not allow for fauna or flora to settle and grow on rocks (Addessi 1994). In addition, pollution entering the ocean from storm drains can harm species metabolism (Gosselin and Chia 1995). Oil from spills can adhere to animals and rock which can greatly affect their survival and habitat availability (Nicholson 1972). Invasive species compete for resources with native rocky intertidal species and can greatly reduce the accessibility of resources (Vitoųsek et al. 1997).

Climate change can induce physical, chemical, and biological changes in the rocky intertidal. Increasing air and sea surface temperatures can cause desiccation and heat stress that can lead to animals shifting their habitat to avoid the onslaught of high temperatures. Even death can occur if temperatures surpass species' temperature tolerance maximum threshold (Tepler et al. 2011; Tomanek and Somero 1999; Gosselin and Chia 1995; Evans 1951; Walther et al. 2002). Long exposure time under high temperatures can cause an animal to dry out. Reproductive ability can be disturbed by abnormal temperature and population size can decrease (Fernandez et al. 2006; Yee and Murray 2004). Since many rocky intertidal species depend on one another either for food or other means, a loss of one species can cause trophic cascades that can be detrimental to dependent species (Yee and Murray 2004; McLean 1962; Blanchette et al. 2009; Jackson 2008). Reduction of dissolved oxygen in the sea can lead to halted respiration and calcification (Palmer 1992; Maeda-Martinez 1985; Cancino et al. 2003). Ocean acidification affects species with calcium carbonate shells the most because acidic waters can dissolve the shells of organisms which can leave them very vulnerable to predators (Byrne and Przeslawski 2013). Rising sea level can eventually cover once exposed rock; those organisms that dwell on these rocks are now susceptible to being inundated for most of the time when previously they experienced periods of no water coverage (Galbraith et al. 2002). The ocean's salinity can fluctuate and can cause stress to organisms that are not well adapted to offset these changes (Moran and Tullis 1980; Willason 1981). Precipitation and extreme weather events can increase the occurrence of stronger, more frequent storms and flooding (Dettinger 2011; Bromirski et al. 2003; Scavia et al. 2002). Stronger waves can gather small projectiles of rock and pebbles that can damage or kill organisms when waves are thrown against the shore (Shanks and Wright 1986). Rocky intertidal species are also susceptible to fluctuating warm and cold waters that are characteristic of El Niño Southern Oscillation (Federov and Philander 2000).

For more a more detailed research of our study species, please see Appendix D.

2.3.1. *Littorina* Literature Summary

Littorina is a genus of small sea snails also known as periwinkles. As the climate warms, *Littorina* can be exposed to various physical and biological stressors that include heat stress, wave effects, trophic cascades, and ocean acidification. Our literature review findings focused mainly on the genus *Littorina*, but some findings were specifically focused on species, such as *Littorina littorea*. Information on *Littorina* physiological responses to high air temperatures was limited. Thus, the only citation we could find was in a report produced by Cashmore and Burton (2009) for a fisheries business in Scotland, in which they state that *Littorina* have "a wide tolerance to temperature, which is greater in air than in water, with heat coma occurring after prolonged exposure to air temperatures greater than 32°C and death occurring at 42°C". The report also provided three related citations: Fretter and Graham, 1962; Arnold, 1972; and Rosenberg and Rosenberg, 1973. Unfortunately, due to the publication dates and specific journals, we were unable to obtain copies of these papers to review firsthand. However, because of the lack of information from any other sources, we chose to use 32°C as the temperature threshold for our quantitative climate analysis.

Littorina is a robust group of snails that have developed a high tolerance to extended periods of high temperature. According to Jackson (2008), *Littorina* has behaviorally adapted to desiccation, gravitating towards damp crevices or aggregating together to reduce moisture loss. They can survive for several hours during prolonged air exposure by creating a dried mucus seal around their shell to counter evaporation (Jackson 2008). Most *Littorina* are adapted to live in the upper intertidal zone because of their ability to breathe air and withstand extreme high temperatures (Castro and Huber 2013).

The strength and momentum generated by waves can have direct impacts on intertidal species zonation and abundance. In an observation on wave effects in Santa Barbara Island, Seapy and Littler (1978) reported that increases in wave exposure will cause dislodging of individual species which can reduce the population size. Jackson (2008) stated that as a response to escape dislocation from waves, *Littorina* forgo their optimal grazing areas. This study concluded that a lowered growth rate occurred due to reduced food access and availability.

Moreover, the mutual interaction of *Littorina* with other sessile species may lead to changes in abundance of both species. *Littorina* species are epifaunal and thus depend on substratum for survival (Jackson 2008). *Littorina* also mainly graze on algae; a reduction in food availability could reduce growth rates and reproductivity of *Littorina* (Jackson 2008). The presence of algae and barnacles in the same zone inhabited by *Littorina* introduces a trophic cascade of indirect and direct effects on species density. As explained in a study on the tidal area of Wadden Sea, Buschbaum (2000) found that a positive effect occurs for barnacles as the grazing activity of *Littorina* suppresses algal growth, thus increasing barnacle cover. Subsequently, the increase in barnacle cover negatively affects *Littorina* survival as they compete for space and resources. During grazing activity, *Littorina* may accidentally dislodge and consume barnacle larvae, decreasing survival rate of newly-settled barnacles. Researchers also conducted cage experiments in which they discovered a strong negative correlation between *Littorina* and barnacle abundance. Nonetheless, fluctuations in *Littorina* density and their grazing behavior are key factors for the variation in barnacle cover in the rocky intertidal area.

Based off the information that we have gathered in our literature findings, we hypothesize that variations in substratum percent cover due to climate change could potentially result in changes to *Littorina* abundance.

As greenhouse gases continue to increase in the atmosphere, the oceans have, in response, absorbed more CO_2 from the atmosphere. While acting as a “carbon sink,” the ocean experiences lower pH levels, leading to ocean acidification. In Bibby et al.’s (2007) experiment on *Littorina*, the researchers discovered how ocean acidification disrupted *Lottorina’s* defense against predators. *Littorina* were grown and observed over the course of 15 days under normal and low pH conditions. When *Littorina* detect a chemical equivalent to predator (crab) cue used for the experiment, they adapted to produce thicker shells in response. At low pH (high acidity), these natural defenses were interrupted and *Littorina* were unable to form thicker shells due to the reduced availability of calcium carbonate ions in water. Researchers suspect that shell thinning causes *Littorina* to become more vulnerable to predation and are easily crushed by crabs’ pinchers, though more research is required to fully assess these implications. To compensate for their heightened susceptibility to predation, *Littorina* increased their avoidance behaviors to defend themselves against predation, which was measured by the amount of time spent above or at the surface level in trials. However, increasing avoidance behaviors when exposed to predator cues and living in a high stress environment meant that *Littorina* spent less time on other important activities such as feeding and foraging (Bibby et al. 2007). To conclude, ocean acidification indirectly affects *Littorina* by weakening their defense mechanism against predators, thereby potentially reducing their population if preyed upon.

With review of the biological characteristics, *Littorina* appears to be highly tolerant to increased temperatures, developing the necessary defense mechanisms to prevent death by desiccation, but are still facing various challenges from climate change. Since they tend to reside in the upper intertidal level, we hypothesize that *Littorina* will likely be more affected by air temperatures than by water temperatures, as they are not often in contact with seawater. *Littorina* are also involved in a trophic cascade with other sessile species; this mutual interaction may reveal correlations between *Littorina* and sessile population abundance. Physical characteristics of the island such as wave effects and ocean acidification could potentially cause reductions in population.

2.3.2. *Tegula funebrails* Literature Summary

Tegula funebralis, or more commonly known as the black turban snail, is a small snail species that inhabits the mid to low intertidal zone of rocky shores. The snail is a macroalgae grazer and feeds primarily on kelp and seaweed that covers the rocks that the snail attaches to (Yee and Murray 2004).

T. funebralis lives in a relatively high zone of the rocky intertidal and is therefore often exposed to ambient air temperatures without protection from water. According to Tepler et al. (2011), it has an optimal body temperature of 21°C but will die from heart failure if temperatures reach below 3°C or above 39.4°C. Tomanek and Somero (1999) found that *T. funebralis* begin to express heat-shock proteins, an indicator of the onset of thermal stress, at 27°C. This can potentially have adverse effects on species abundance. The temperature threshold of 27°C was chosen as the baseline temperature of our climate analysis to correlate temperature with changes in species abundance.

Another focus of our statistical analysis was based on the percent coverage of sessile species of the rocky intertidal. *T. funebralis* inhabits the upper to mid regions of the rocky intertidal, and are mainly found in the rockweed zone, in particular within *Silvetia*. *Tegula funebralis* are algae grazers (Yee and Murray 2004) and Blanchette et al. (2009) also found that high abundances of macroalgae correspond with high abundances of herbivores that graze on them.

3. Methods

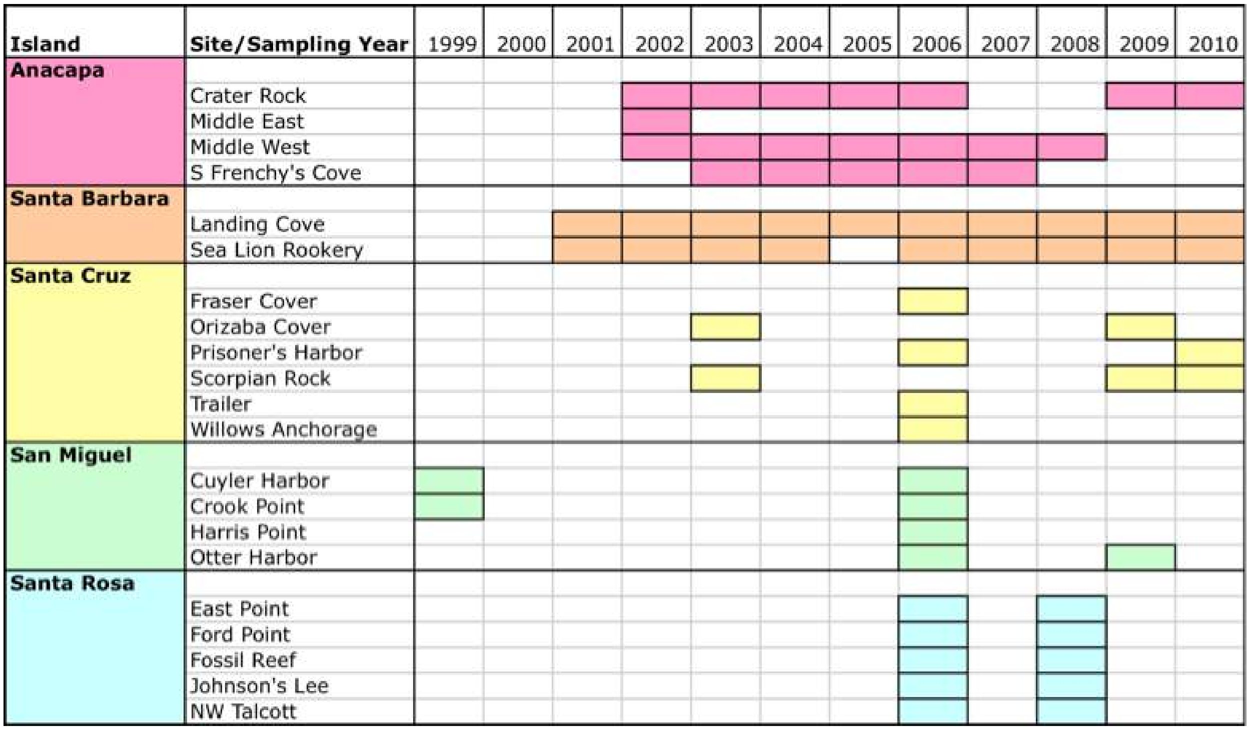
Our methods discussion covers the following steps:

- Initial Data Review
- Initial Species Selection
- Biotic Zones
- Sampling Season
- Selected Species for Regression Analysis
- Island Specific Focus
- Sessile Coverage Covariate
- Temperature Covariates
- Data Analysis for Species of Focus

3.1. Initial Data Review

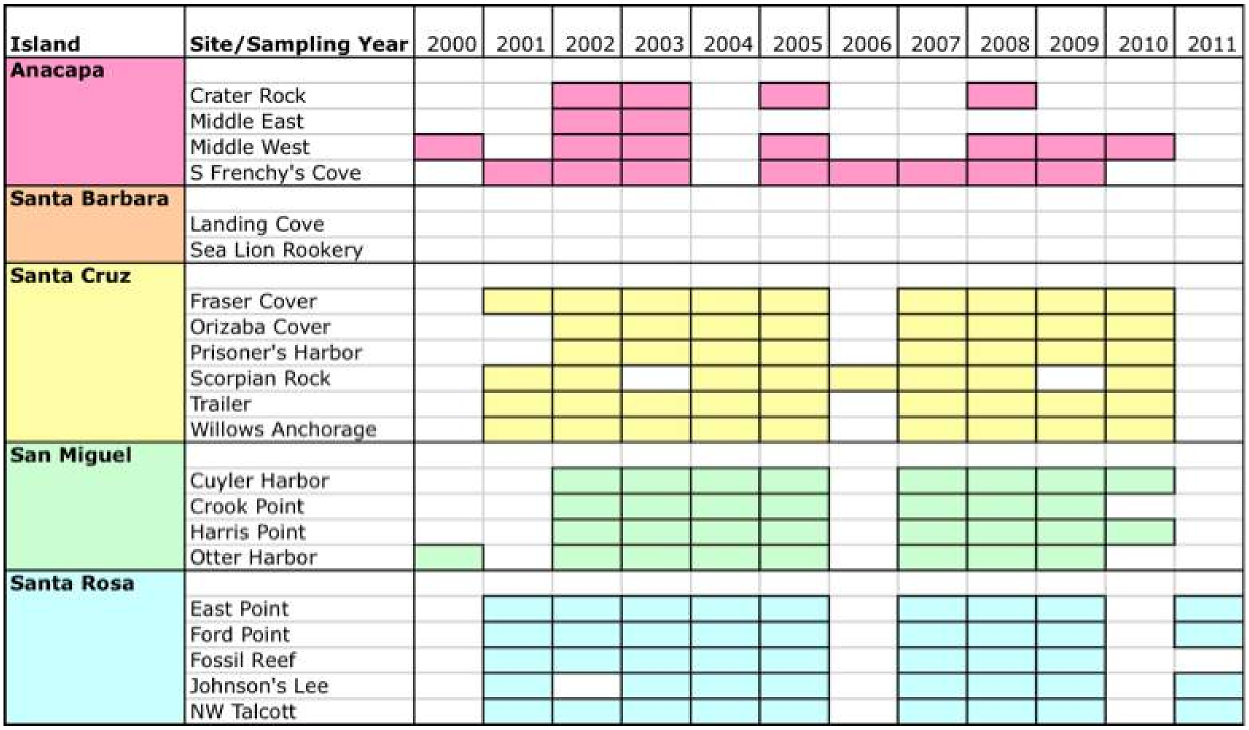
The National Park Service and MARINe provided our team with abundance data for 66 motile invertebrate (MI) species across a 10-year sampling period identified by biotic zone, plot ID, monitoring site, and island (see earlier discussion in Section 1.2 for details of the sampling design). The data was provided as two Excel spreadsheets: the first (CINP_motiles_1999) contained data from fall 1999 to spring 2006; the second (CINP_motiles_2010) contained data from spring 2006 to spring 2011. We were also given two groups of Excel spreadsheets that contained size data for these MI species over the same sampling period; however, after initial review, we determined that we would only be able to analyze the abundance data given the time allotted for this project. Our first step was to combine the two datasets for input to R Studio and chart when sample collection occurred to best track MI abundances. The following tables charts this sample collection, with Table 1 plotting the Fall season collections per site and Table 2 charting the Spring seasonal collection per site across the five Channel Islands.

Table 1. Summary of fall sample collections across Channel Island Site, where highlighted cells indicate years when sampling occurred for that site.



Island	Site/Sampling Year	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Anacapa													
	Crater Rock				■	■	■	■	■			■	■
	Middle East				■								
	Middle West				■	■	■	■	■	■	■		
	S Frenchy's Cove					■	■	■	■	■			
Santa Barbara													
	Landing Cove			■	■	■	■	■	■	■	■	■	■
	Sea Lion Rookery			■	■	■	■		■	■	■	■	■
Santa Cruz													
	Fraser Cover								■				
	Orizaba Cover					■						■	
	Prisoner's Harbor								■				■
	Scorpian Rock					■						■	■
	Trailer								■				
	Willows Anchorage								■				
San Miguel													
	Cuyler Harbor	■							■				
	Crook Point	■							■				
	Harris Point								■				
	Otter Harbor								■			■	
Santa Rosa													
	East Point								■		■		
	Ford Point								■		■		
	Fossil Reef								■		■		
	Johnson's Lee								■		■		
	NW Talcott								■		■		

Table 2. Summary of spring sample collections across Channel Islands sites.



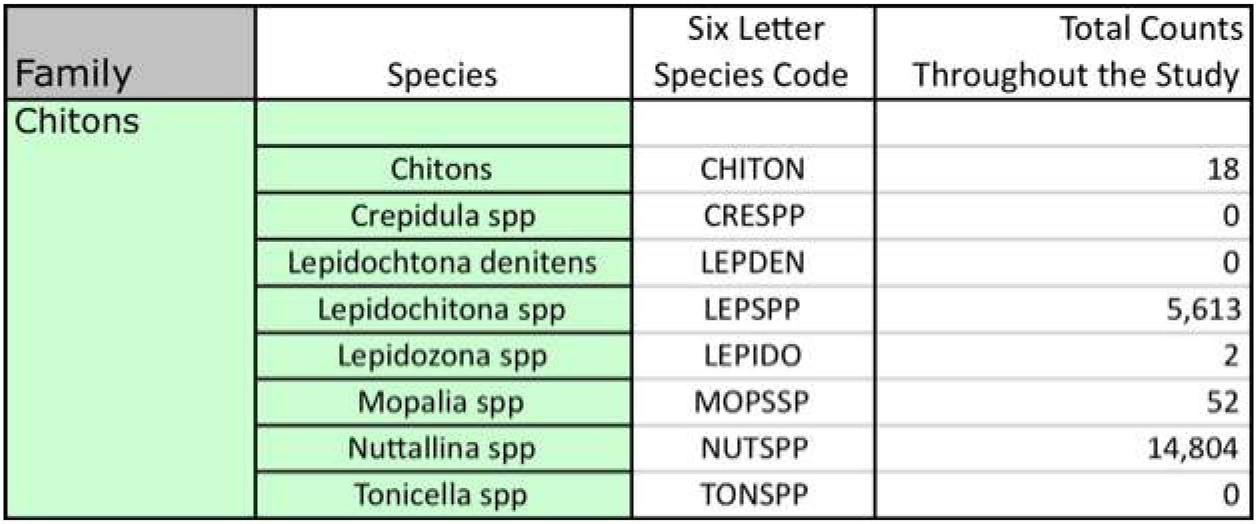
Island	Site/Sampling Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Anacapa													
	Crater Rock			■	■		■			■			
	Middle East			■	■								
	Middle West	■		■	■		■			■	■	■	
	S Frenchy's Cove		■	■	■		■	■	■	■	■		
Santa Barbara													
	Landing Cove												
	Sea Lion Rookery												
Santa Cruz													
	Fraser Cover		■	■	■	■	■		■	■	■	■	
	Orizaba Cover			■	■	■	■		■	■	■	■	
	Prisoner's Harbor			■	■	■	■		■	■	■	■	
	Scorpian Rock		■	■		■	■	■	■	■		■	
	Trailer		■	■	■	■	■		■	■	■	■	
	Willows Anchorage		■	■	■	■	■		■	■	■	■	
San Miguel													
	Cuyler Harbor			■	■	■	■		■	■	■	■	
	Crook Point			■	■	■	■		■	■	■		
	Harris Point			■	■	■	■		■	■	■	■	
	Otter Harbor	■		■	■	■	■		■	■	■		
Santa Rosa													
	East Point		■	■	■	■	■		■	■	■		■
	Ford Point		■	■	■	■	■		■	■	■		■
	Fossil Reef		■	■	■	■	■		■	■	■		
	Johnson's Lee		■		■	■	■		■	■	■		■
	NW Talcott		■	■	■	■	■		■	■	■		■

One of our first objectives was to separate null values found within the dataset when sample collection did not occur for the site from the abundances that did not have any abundance counts. As seen in Table 1 and 2, there was no MI monitoring data for the site Anacapa Middle East (ANME) after Spring 2003. We therefore removed the site from our dataset to reflect for the discontinued collection found on that portion of the island. Within the remaining sites, there were occasional missing values for specific species. We worked with our client, Stephen Whitaker, to determine if these represented times when no monitoring was conducted for that species (due perhaps to field time constraints), or if monitoring was conducted but the count was actually zero. For other null values more intermittent across each site and island, we temporarily added zeroes in place of the periods and “NA” values written within the data so that R would not produce error messages in the output. Non-integer symbols create problems for R if left in a dataset because the program cannot perform mathematical commands, for example, trying to sum all of the counts across one particular island. We eliminated these non-integer values so that our entire dataset could remain readable in R. The zero values that included unsampled dates were not eliminated until our final analysis of our selected MI species in order to keep the column lengths equal to one another, which if not maintained, would mean R would not display the full results as intended.

Once we imported our data to R, we created subsets of the data by dividing each species counts by time so as to analyze the individual species density as indicators of their overall population health within the intertidal zones. We then subdivided each species down to the site level and then by biotic zone grouping to account for where the majority of each MI species resides.

3.2. Initial Species Selection

Table 3. Summary of all motile invertebrate species abundances within the datasets.

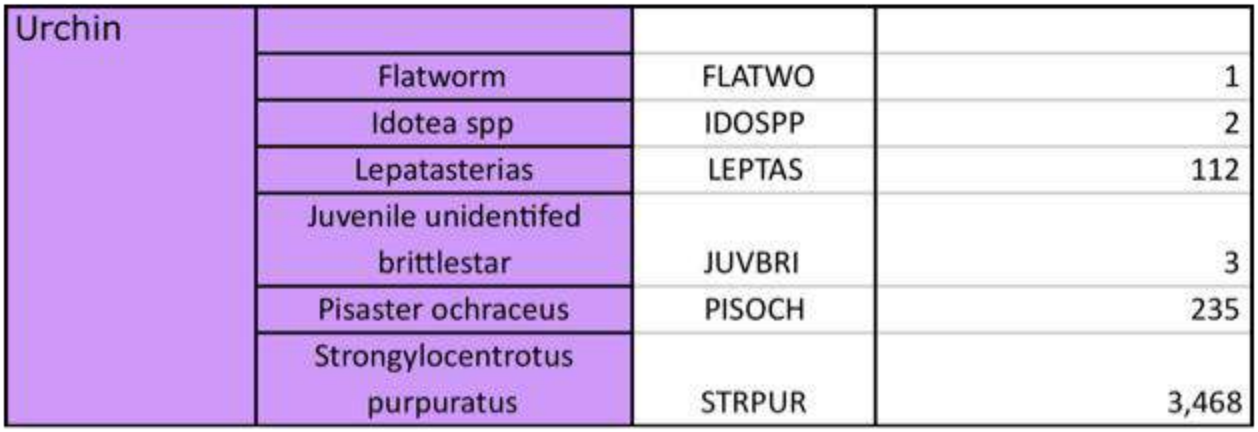


Family	Species	Six Letter Species Code	Total Counts Throughout the Study
Chitons			
	Chitons	CHITON	18
	Crepidula spp	CRESPP	0
	Lepidochtona denitens	LEPDEN	0
	Lepidochitona spp	LEPSPP	5,613
	Lepidozona spp	LEPIDO	2
	Mopalia spp	MOPSSP	52
	Nuttallina spp	NUTSPP	14,804
	Tonicella spp	TONSPP	0

Crabs			
	Hemigrapsus oregenesis	HEMORE	0
	Hemigrapsus nudus	HEMNUD	0
	Hermit crabs	HERMIT	0
	Pachygrapsus crassipes and Hemigrapsus nudus recruits	HEMPAC	0
	Pachygraspus Crassipes	PACCRA	6,437
	Pachycheles spp	PACSPP	0
	Pagurus beringanus	PAGBER	0
	Pagurus granosimanus	PAGGRA	0
	Pagurus hirsutiusculus	PGAHIR	241
	Pagurus samuelis	PAGSAM	59
	Pagurus spp	PAGSPP	2,815
	Petrolisthes spp	PETSPP	8
	Pugettia spp	PUGSPP	17

Limpets			
	Fissurella volcano	FISVOL	2,553
	Small Limpets (< 5 mm)	LSMALS	181,158
	Medium Limpets (5 -15 mm)	LMDALL	284,876
	Large Limpets (> 15 mm)	LIMPLG	6,361
	Unsized Limpets	LIMUNS	40,400
	Lottia gigantea	LOTGIG	4,094

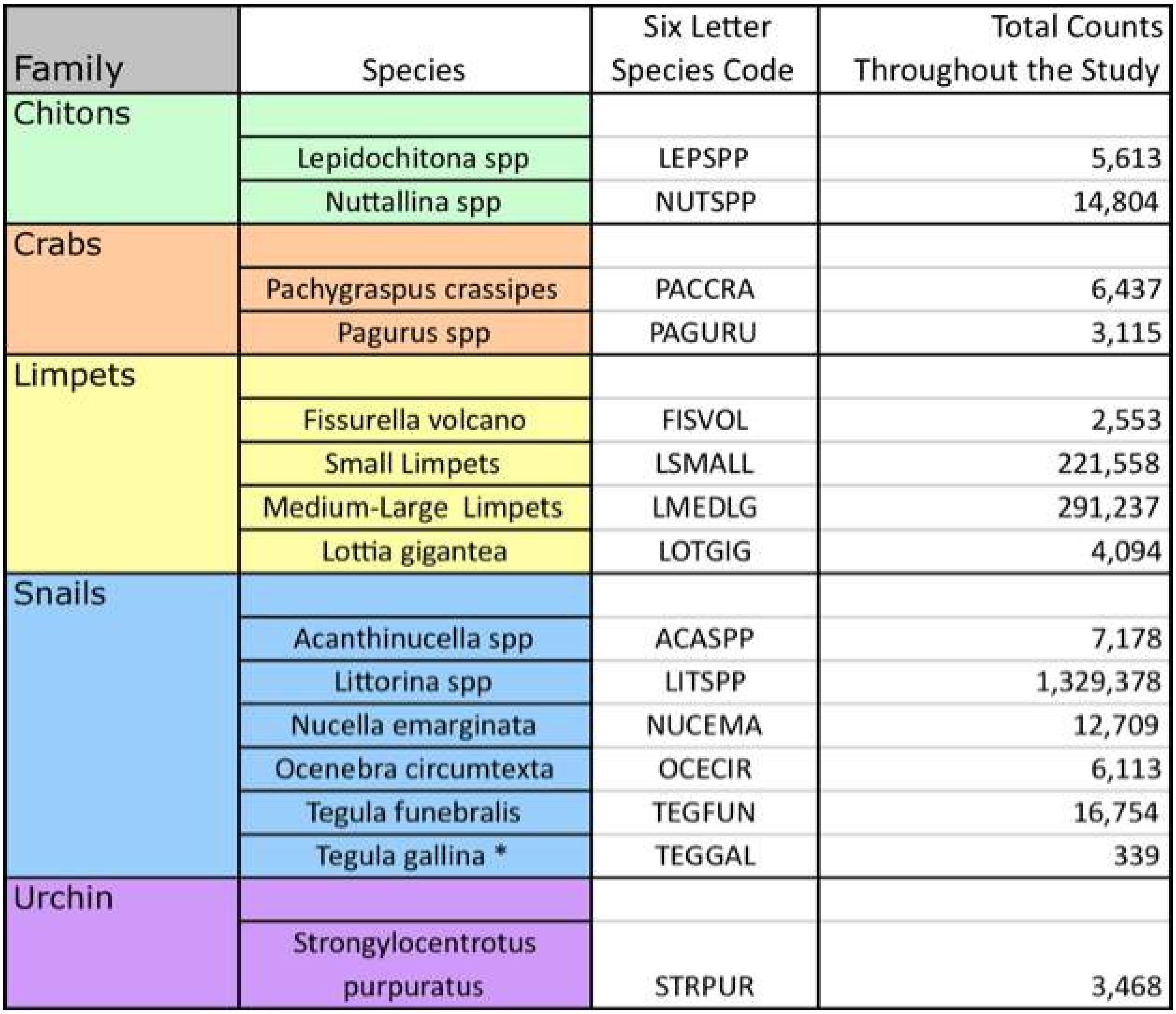
Snails			
	Acanthinucella spp	ACASPP	7,178
	Alia spp	ALISPP	2
	Amphissa spp	AMPSPP	137
	Aplusia californica	APLCAL	2
	Bittium spp	BITSPP	2
	Calliostoma spp	CALSPP	2
	Ceratostoma nuttalli	CERNUT	83
	Conus californicus	CONCAL	1
	Epitonium tinctum	EPITIN	88
	Haliotis cracherodii	HALCRA	8
	Homalopoma spp	HOMSPP	54
	Kelletia kelletii	KELKEL	0
	Littorina spp	LITSPP	1,329,378
	Lirabuccinum dirum	LIRDIR	0
	Macron lividus	MACLIV	0
	Norrisia norrisi	NORNOR	2
	Nucella canaliculata	NUCCAN	0
	Nucella emarginata	NUCEMA	12,709
	Nucella lamellosa	NUCLAM	3
	Nucella spp	NUCSPP	8
	Ocenebra circumtexta	OCECIR	6,113
	Ocenbra poulsoni	OCEPOU	0
	Ocenebra spp	OCESPP	39
	Onchidella borealis	ONCBOR	1
	Opalia spp	OPASPP	0
	Tegula aureotincta	TEGAUR	0
	Tegula brunnea	TEGBRU	0
	Tegula eiseni	TEGEIS	4
	Tegula funebralis	TEGFUN	16,754
	Tegula gallina *	TEGGAL	339



Urchin			
	Flatworm	FLATWO	1
	Idotea spp	IDOSPP	2
	Lepatasterias	LEPTAS	112
	Juvenile unidentifed brittlestar	JUVBRI	3
	Pisaster ochraceus	PISOCH	235
	Strongylocentrotus purpuratus	STRPUR	3,468

From a starting pool of sixty-six motile invertebrate species (Table 3), we narrowed our initial focus to species that had more than 500 counts over the ten-year period of the dataset. By setting our cutoff to 500, we aimed to ensure we would have sufficient samples to reflect any long-term trends that might be present in the data. This resulted in fifteen groups of "core" MI species that met this criteria (Table 4): *the Acanthinucella snails, Fissurella volcano limpets, Small Limpets, Medium to Large Limpets, Lepidochitona species, Lottia gigantea limpets, the Nuttallina species, Pachygrapsus crassipes, Pagurus species, Nucella emarginata, Nuttallina species, Ocenebra circumtexta, Stronglyocentrotus purpuratus, Tegula funebralis and Tegula gallina*. Although counts of Tegula gallina were less than 500, we include the species at this stage, based on its prevalence in southern, warmer waters, and the possibility that its appearance in certain years might indicate changing climate conditions in these rocky intertidal habitats.

Table 4. "Core" Motile Invertebrates with total counts above 500 for the study period



Family	Species	Six Letter Species Code	Total Counts Throughout the Study
Chitons			
	Lepidochitona spp	LEPSPP	5,613
	Nuttallina spp	NUTSPP	14,804
Crabs			
	Pachygraspus crassipes	PACCRA	6,437
	Pagurus spp	PAGURU	3,115
Limpets			
	Fissurella volcano	FISVOL	2,553
	Small Limpets	LSMALL	221,558
	Medium-Large Limpets	LMEDLG	291,237
	Lottia gigantea	LOTGIG	4,094
Snails			
	Acanthinucella spp	ACASPP	7,178
	Littorina spp	LITSPP	1,329,378
	Nucella emarginata	NUCEMA	12,709
	Ocenebra circumtexta	OCECIR	6,113
	Tegula funebralis	TEGFUN	16,754
	Tegula gallina *	TEGGAL	339
Urchin			
	Strongylocentrotus purpuratus	STRPUR	3,468

* T gallina is an exception to the 500-count cut-off because of its appearance potentially indicating warmer waters around Channel Islands.

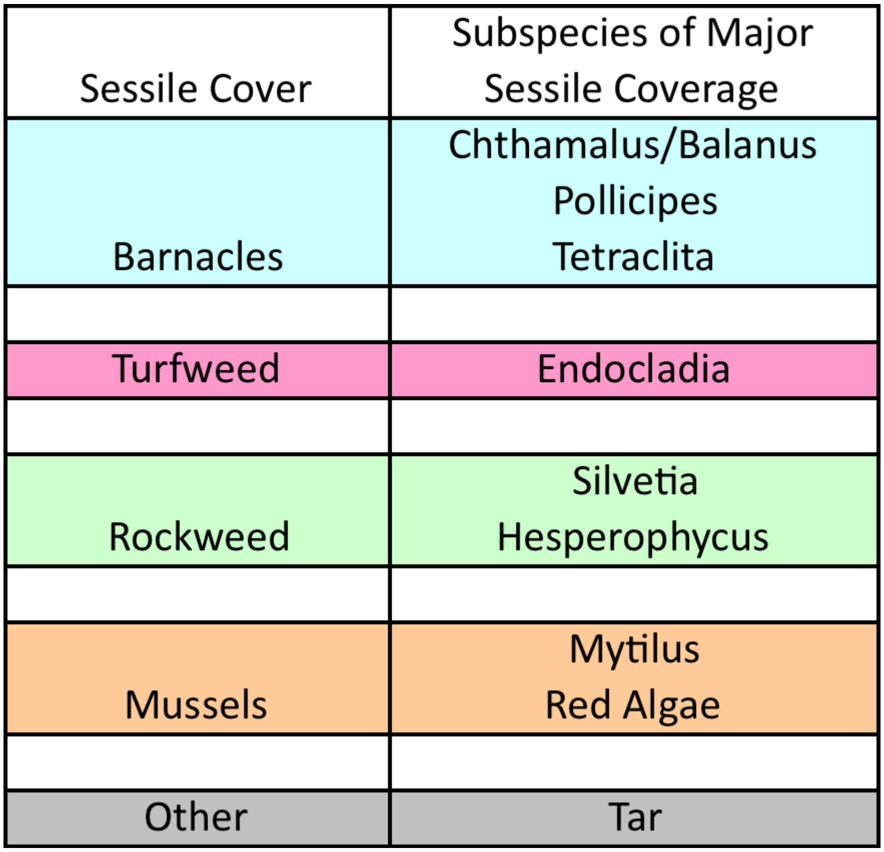
This list reflects some combinations of species due to biological similarities. For example, the original data set contained four categories of limpet species within the dataset: limpets with no size information, small limpets below 5 mm in length, medium limpets from 5 to 15 mm, and large limpets above 15 mm. However, there was inconsistency across sampling events with respect to the level of classification detail. For example, from 1999 to 2002, small and medium limpets were not separately categorized but were grouped with the un-sized limpets. After consultation with our client, Stephen Whitaker, and with UCLA Professor Richard Ambrose, we chose to use two categories: small limpets, and medium-to-large limpets. The small limpets contain abundance data from the un-sized limpets and small limpets, while the medium and large are combined for all sampling years. This decision accounts for our assumption that small limpets reflect the early stages of recruitment for this genus and the medium to large limpets are older individuals that have grown since the previous sampling measurement.

The *Lepidochitona* species and the *Pagurus* species were the two remaining groups that needed editing within the dataset. The *Lepidochitona* group had two different naming conventions presented in the dataset. From 1999 to 2006, the *Lepidochitona* species could be found under the label *Lepidochitona hartwegii*. From 2006 on, however, the species was labeled under its broader classification of *Lepidochitona*. Our dataset analysis combines these two labels under one group to account for the dataset naming convention. Under advisement of our supporting faculty advisor, Dr. Richard Ambrose, we also combined each of the *Pagurus* hermit crabs under one common grouping as it is difficult out in the field to distinguish each small crab from another.

3.3. Biotic Zones

Our next step was to look at the biotic substrate associated with each plot for the 15 species. MI species are found in one of nine different plot types associated with a specific biotic zone/substrate (for details, refer to earlier discussion of the sampling design). The biotic zones denoted by the NPS plots are shown in Table 5:

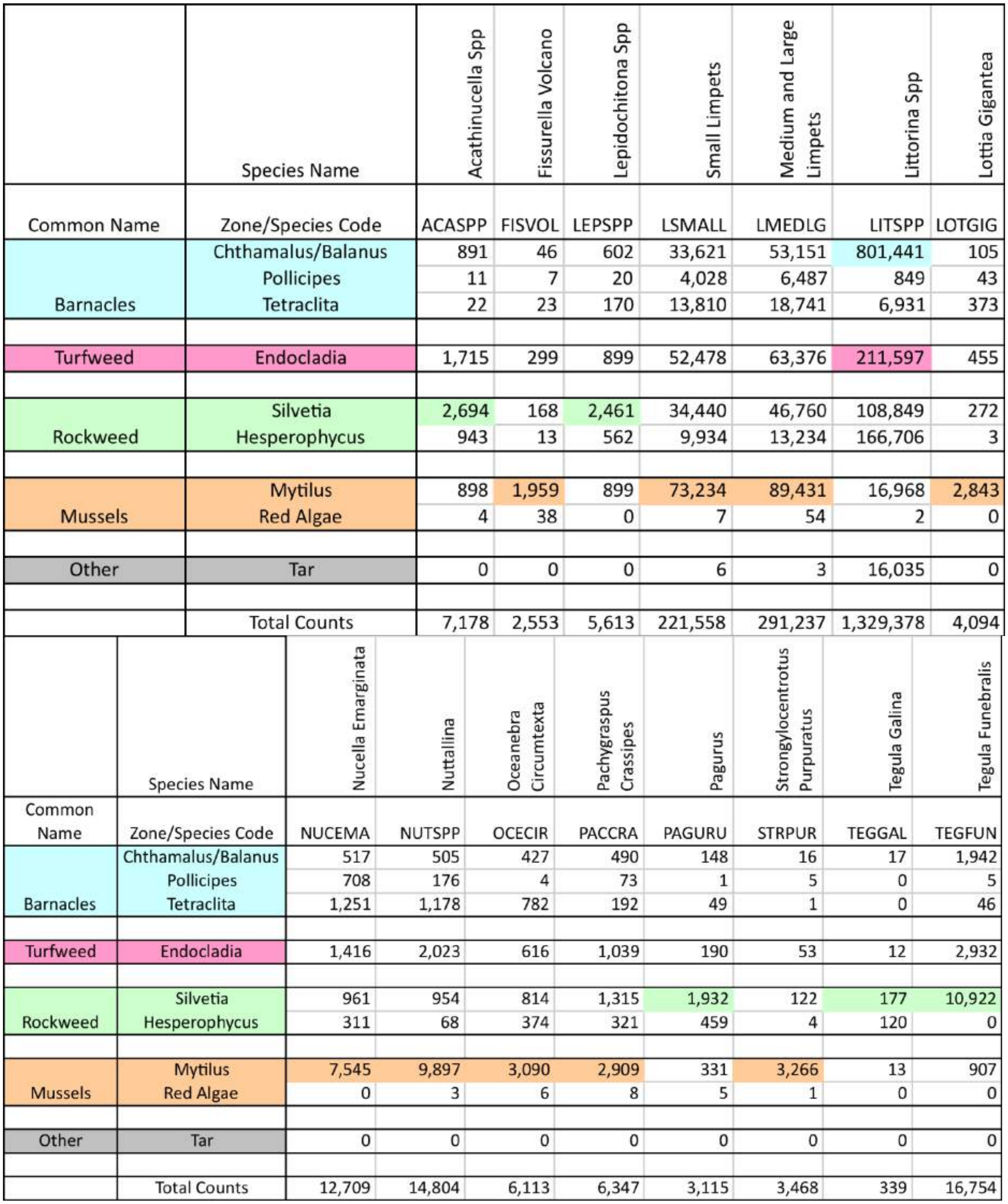
Table 5. Chart of biotic zones category and each subspecies within them.



Sessile Cover	Subspecies of Major Sessile Coverage
Barnacles	Chthamalus/Balanus Pollicipes Tetraclita
Turfweed	Endocladia
Rockweed	Silvetia Hesperophycus
Mussels	Mytilus Red Algae
Other	Tar

We broke the abundance counts down to the substrate level to show densities of the MI species by biotic zone. The following table (Table 6) summarizes the overall biotic zone distribution for each MI species:

Table 6. Distribution of species by biotic zone.



	Species Name	Acathinucella Spp	Fissurella Volcano	Lepidochitona Spp	Small Limpets	Medium and Large Limpets	Littorina Spp	Lottia Gigantea
Common Name	Zone/Species Code	ACASPP	FISVOL	LEPSPP	LSMALL	LMEDLG	LITSPP	LOTGIG
Barnacles	Chthamalus/Balanus	891	46	602	33,621	53,151	801,441	105
	Pollicipes	11	7	20	4,028	6,487	849	43
	Tetraclita	22	23	170	13,810	18,741	6,931	373
Turfweed	Endocladia	1,715	299	899	52,478	63,376	211,597	455
Rockweed	Silvetia	2,694	168	2,461	34,440	46,760	108,849	272
	Hesperophycus	943	13	562	9,934	13,234	166,706	3
Mussels	Mytilus	898	1,959	899	73,234	89,431	16,968	2,843
	Red Algae	4	38	0	7	54	2	0
Other	Tar	0	0	0	6	3	16,035	0
	Total Counts	7,178	2,553	5,613	221,558	291,237	1,329,378	4,094

	Species Name	Nucella Emarginata	Nuttallina	Oceanebra Circumtexta	Pachygraspus Crassipes	Pagurus	Strongylocentrotus Purpuratus	Tegula Galina	Tegula Funebralis
Common Name	Zone/Species Code	NUCEMA	NUTSPP	OCECIR	PACCRA	PAGURU	STRPUR	TEGGAL	TEGFUN
Barnacles	Chthamalus/Balanus	517	505	427	490	148	16	17	1,942
	Pollicipes	708	176	4	73	1	5	0	5
	Tetraclita	1,251	1,178	782	192	49	1	0	46
Turfweed	Endocladia	1,416	2,023	616	1,039	190	53	12	2,932
Rockweed	Silvetia	961	954	814	1,315	1,932	122	177	10,922
	Hesperophycus	311	68	374	321	459	4	120	0
Mussels	Mytilus	7,545	9,897	3,090	2,909	331	3,266	13	907
	Red Algae	0	3	6	8	5	1	0	0
Other	Tar	0	0	0	0	0	0	0	0
	Total Counts	12,709	14,804	6,113	6,347	3,115	3,468	339	16,754

Based upon the abundance distribution above, we identified each species' preferred habitat based on total summed counts. Highlighted in Table 6 is each MI species' principal biotic zone, and we used this data to determine which portions of the rocky intertidal each species could be found. We plotted the distribution of each core species across the various biotic zones. We also used this information to focus our climate impact analysis, described later in this section.

3.4. Sampling Season

Our next step was to divide the data by sampling season in order to control for the different external factors that might affect MI species abundance during different times of year. Abundance during spring and fall sampling periods may be influenced by different weather conditions. For example, summer high temperatures may be a primary influence on fall abundance counts whereas spring abundance may be more strongly related to storm activity and wave impact. Similarly, we determined it was important to look at species abundance at the island level due to differences in air and water temperatures or tidal influence across the five islands.

Once we subdivided the data in this manner, we plotted abundances over the study period for each of the 15 species by summing the species across both sampling seasons and then by their preferred biotic zone coverage in their most abundant season. These charts (Appendix A.1) show the variability and potential trends for our 15 selected MI species during the ten-year sampling period. For more in-depth analysis of how climatic factors or habitat change might be affecting MI species, we narrowed down our focus further to two species of interest, *Littorina spp* and *Tegula funebralis*.

3.5. Selected MI Species for Regression Analysis

Our high-level analysis and summary of the abundance data, combined with our literature review and consultation with Stephen Whitaker and Dr. Richard Ambrose, led us to narrow our focus to two invertebrates. For these selected species, we performed our statistical analysis considering external factors such as sample location, mean climate, and biotic zone shifts. Our first species of interest was the *Littorina* snail group because it is the most abundant of all the MI species. The *Littorina* category had well over 1.3 million total counts over all the sampling period, with the 76% of the data occurring within the *Chthamalus* and *Endocladia* biotic zones (Figure 2).

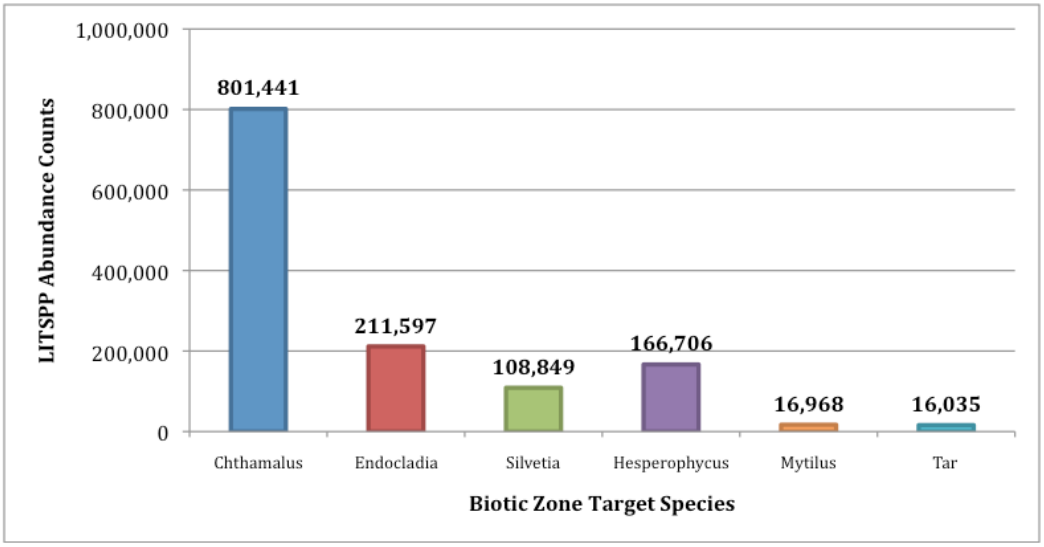


Figure 2. *Littorina* Species counts per biotic zone across the Channel Islands in the dataset

Limpets, though abundant with nearly 300,000 counts in our two size categories, were not included for further analysis due to the difficulty in classifying these species, as previously explained. Our suggestions for organizing the data helped account for null values as the categorization changed for *Littorina* species, but we were not confident in performing analysis on small and the medium to large limpets since we had altered the data.

To contrast our first selected species of *Littorina*, we decided to focus on the *Tegula funebralis* snails. While the *Littorina* snails mainly dwell within the upper portions of the rocky intertidal, *Tegula funebralis* dwell in the lower to middle zones or tide pools (Figure 2) and are more likely to be immersed during high tide. In addition, *Tegula funebralis's* primary substrate is the rockweed species *Silvetia*, while the *Littorina* snails mainly reside in the barnacle and turfweed formations. *Tegula* abundances can thus be used to examine how a species affected primarily by water temperature is surviving within the rocky intertidal (See Figure 3 for biotic zone distribution of *Tegula funebralis*).

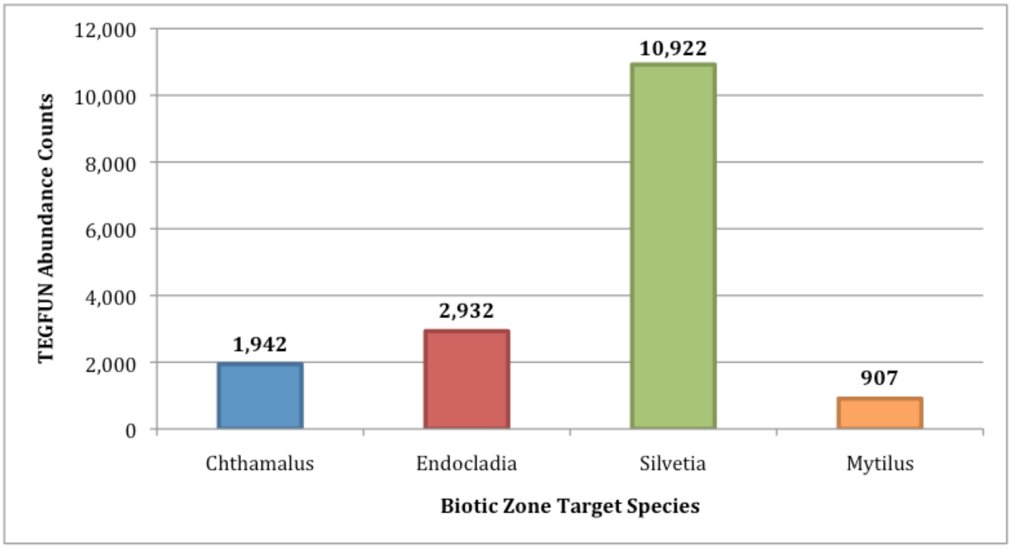


Figure 3. *Tegula funebralis* counts on each biotic zone across the Channel Islands in the dataset

Based on the data showing that the majority of *Littorines* reside in the *Chthamalus* and *Endocladia* zones and that *Tegula* snails reside in the *Silvetia* zone, our density analysis will focus primarily on these invertebrates in their most common living assemblages.

3.6. Island-Specific Focus

With our scope narrowed to two specific MI species, our group established our sampling parameters for analyzing abundance changes with climate. As previously mentioned, we broke down sampling data for all the islands to spring and fall collections so that growth patterns and climatic factors would be kept relatively constant. Our next phase was to determine which island showed the most complete abundance and climate data for MI and over which sampling season this occurs. Of the five Channel Islands, our analysis led us to choose Santa Rosa Island during the spring seasonal sampling.

We chose to focus on the data specific to Santa Rosa Island because of its large size, central location, and we believed it would be most representative. We chose the Spring season because, as seen in Table 1 and 2, Fall samples had fewer collection years that were much more intermittent than Spring collection as a whole. Santa Rosa Island had both complete climate data from its Remote Automated Weather Station (RAWS) as well as data from 2000 to 2011. Compared to other islands, Santa Rosa also had more active sites when sampling occurred. These five sites had two years (2006 and 2010) that went unsampled during our dataset period (see Table 2), but unlike other islands, Santa Rosa had greater incidence of sampling the first initial years of data sampling, and remained fairly constant the rest of the spring collections. This gave us a much more reliable baseline counts of the *Littorina* and *Tegula* species on the island than other islands that didn't have widespread sampling of spring season in 2000.

Seen in below in Tables 7 – 11 are the specific *Littorina* data for Santa Rosa sampling that led to us choosing focusing on Santa Rosa Island. Table 7 and 8 chart *Chthamalus* counts, Table 9 and 10 for *Endocladia* counts, and Table 11 charts when sampling occurred for each site during the spring season. After establishing reliable density data, we explored covariates for our multiple linear regression that might be responsible for any observed abundances of *Littorina* and *Tegula* species.

Table 7. *Littorina* Distribution of Chthamalus on all Channel Islands.

Site ID Code	LITSPP Total Chthamalus Counts	LITSPP Spring Chthamalus Counts	LITSPP Fall Chthamalus Counts	Chthamalus Plot IDs	Number of Chthamalus Plots
ANCR	55,602	23,238	32,364	31 - 33, 35 - 39, 135	9
ANMW	7,315	4,877	2,438	243 - 245, 447 - 451	8
ANSFC	56,025	34,366	21,659	249 - 253	5
SBLC	3,911	0	3,911	315 - 319	5
SBSLR	10,379	0	10,379	345 - 349	5
SCFC	29,801	29,570	231	876 - 880	5
SCOC	60,596	43,235	17,361	851 - 855	5
SCPH	23,795	17,063	6,732	826 - 830	5
SCSR	39,611	26,559	13,052	801 - 805	5
SCTR	41,307	35,608	5,699	911 - 915	5
SCWA	0	0	0	0	0
SMCH	41,168	37,354	3,814	416 - 420	5
SMCP	71,670	58,638	13,032	137, 147 - 149, 495	5
SMHP	44,150	39,926	4,224	440 - 444	5
SMOH	25,514	23,782	1,732	370 - 374	5
SREP	78,303	64,690	13,613	575 - 579	5
SRFP	59,703	49,643	10,060	520 - 524	5
SRFR	48,083	35,685	12,398	605 - 609	5
SRJL	75,106	62,557	12,549	500 - 504	5
SRNWT	29,402	26,442	2,960	560 - 564	5
Sum of Counts	801,441	613,233	188,208		

Table 8. *Littorina* Distribution on Chthamalus in Spring: All Channel Islands.

Sample Year	Anacapa Island	Santa Cruz Island	San Miguel Island	**Santa Rosa Island**	Overall LITSPP Chth Spring Counts
2001	2,944	6,196	~~0~~	**21,772**	30,912
2002	10,992	14,176	14,808	**11,732**	51,708
2003	15,917	15,034	26,921	**27,777**	85,649
2004	~~0~~	10,592	16,484	**29,766**	56,842
2005	10,272	12,673	24,358	**22,870**	70,173
2006	4,310	15,225	~~0~~	**~~0~~**	19,535
2007	1,930	17,970	18,371	**39,314**	77,585
2008	11,997	20,078	20,261	**29,343**	81,679
2009	3,536	19,621	21,750	**31,899**	76,806
2010	583	20,470	16,747	**~~0~~**	37,800
2011	0	0	0	**24,544**	24,544
Overall Sum	62,481	152,035	159,700	**239,017**	613,233

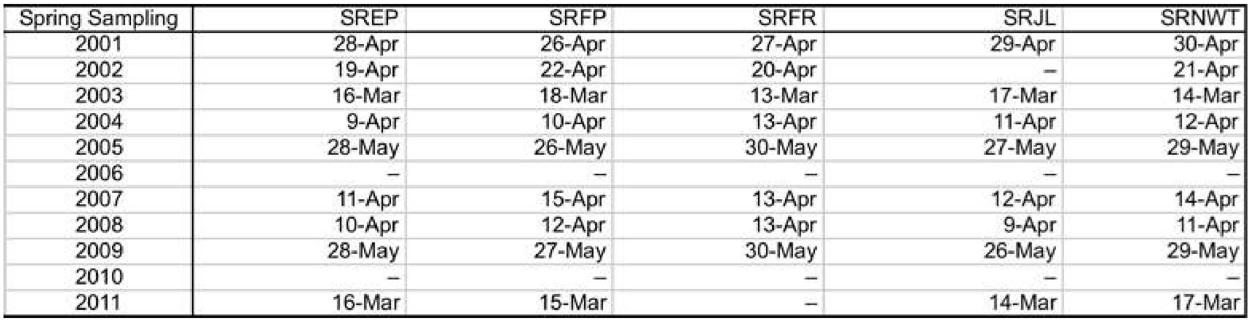
Table 9. *Littorina* Distribution on *Endocladia*.

Site ID Code	LITSPP Total Endocladia Counts	LITSPP Spring Endocladia Counts	LITSPP Fall Endocladia Counts	Endocladia Plot IDs	Number of Endocladia Plots
ANCR	2,641	1,307	1,334	555 - 559	5
ANMW	5,462	3,963	1,499	240 - 242, 457 - 461	8
ANSFC	5,207	3,965	1,242	154, 155, 256 - 258	5
SBLC	–	–	–	–	–
SBSLR	–	–	–	–	–
SCFC	8,950	8,865	85	881 - 885	5
SCOC	0	0	0	–	–
SCPH	23,483	18,383	5,100	831 - 835	5
SCSR	20,270	13,674	6,596	806 - 810	5
SCTR	0	0	0	–	–
SCWA	22,356	20,307	2,049	931 - 935	5
SMCH	5,892	5,655	237	411 - 415	5
SMCP	17,472	15,056	2,416	386 - 390	5
SMHP	8,856	7,639	1,217	431 - 435	5
SMOH	5,428	5,034	394	361 - 364	4
SREP	39,076	29,942	9,134	580 - 584	5
SRFP	9,314	7,613	1,701	525 - 529	5
SRFR	26,289	21,108	5,181	610 - 614	5
SRJL	8,144	6,309	1,835	505 - 509	5
SRNWT	1,827	1,824	3	555 - 559	5
Sum of Counts	210,667	170,644	40,023		

Table 10. *Littorina* Distribution on *Endocladia* in Spring: All Channel Islands

Sample Year	Anacapa Island	Santa Cruz Island	San Miguel Island	**Santa Rosa Island**	Overall LITSPP Endo Spring Counts
2001	0	6,012	~~0~~	**3,860**	9,872
2002	1,605	8,104	3,632	**3,608**	16,949
2003	3,078	1,093	4,322	**4,489**	12,982
2004	0	4,855	4,338	**6,314**	15,507
2005	1,397	5,251	4,315	**7,935**	18,898
2006	562	831	~~0~~	**~~0~~**	1,393
2007	442	8,218	2,628	**11,592**	22,880
2008	578	6,851	6,084	**9,017**	22,530
2009	958	12,334	4,574	**14,010**	31,876
2010	615	7,680	3,491	**~~0~~**	11,786
2011	0	0	~~0~~	**5,971**	5,971
Overall Sum	9,235	61,229	33,384	**66,796**	170,644

Table 11. *Littorina* Distribution on *Endocladia* in Spring: All Channel Islands



Spring Sampling	SREP	SRFP	SRFR	SRJL	SRNWT
2001	28-Apr	26-Apr	27-Apr	29-Apr	30-Apr
2002	19-Apr	22-Apr	20-Apr	–	21-Apr
2003	16-Mar	18-Mar	13-Mar	17-Mar	14-Mar
2004	9-Apr	10-Apr	13-Apr	11-Apr	12-Apr
2005	28-May	26-May	30-May	27-May	29-May
2006	–	–	–	–	–
2007	11-Apr	15-Apr	13-Apr	12-Apr	14-Apr
2008	10-Apr	12-Apr	13-Apr	9-Apr	11-Apr
2009	28-May	27-May	30-May	26-May	29-May
2010	–	–	–	–	–
2011	16-Mar	15-Mar	–	14-Mar	17-Mar

3.7. Sessile Coverage Covariate

Before we could analyze the abundance data for a potential climate influence, we needed to understand if there were other significant covariates. We decided to examine the variability of sessile species coverage within plots. For example, for plots originally designated as "*Chthamalus* plots" or "*Endocladia* plots", what percentage of the plot continued to be covered by that sessile species throughout the study period? We obtained biotic zone coverage data from Lena Lee of the National Park Service, MEDN Inventory & Monitoring Program, and we used this data to track the percentage of target sessile species and percent area of rock cover of designated Plot IDs on Santa Rosa Island. Shifts in the sessile species coverage might be the result of changing environmental conditions or human disturbance. We tracked the major percent living cover, the target substrate, and non-living cover, the percentage of bare rock, to test if our selected MI species were adversely affected when their preferred habitat was no longer in the selected plots. For each plot on the site, we graphed the percent cover of both sessile coverage and rock against the total abundance over time to determine if a visual relationship could be seen. The figures found in the Results Section demonstrate examples of these plots to visually correlate if the change in *Chthamalus* cover tracks the change in total *Littorina* counts.

3.8. Temperature Covariates

After gathering the sessile coverage data, we gathered two temperature metrics to run against our data. The first temperature covariate was the Multivariate El Niño Southern Oscillation Index, whose scores indicate whether the overall Pacific Ocean is experiencing a warmer or colder phase in a given month. A positive MEI value indicates El Niño conditions and warmer conditions in the Pacific, while a negative value indicates a La Niña phase or colder conditions. We used these MEI values to serve as our primary water temperature metric in our regression analysis. We obtained MEI values from the National Oceanic and Atmospheric Administration's MEI index, and Table 12 below highlights the MEI values for each month where our target MI species were sampled on Santa Rosa Island.

Table 12. MEI values for Santa Rosa Spring sampling.

Sampling Year	Santa Rosa Sampling	MEI Value
2001	April 26 - 30	0.185
2002	April 19 - 22	0.778
2003	March 13 - 14, 16 - 18	0.197
2004	April 9 - 13	0.221
2005	May 26 - May 30	0.487
2007	April 11 - 15	0.068
2008	April 9 - 13	-0.942
2009	May 26 - 30	0.960
2011	March 14 - 17	-1.525

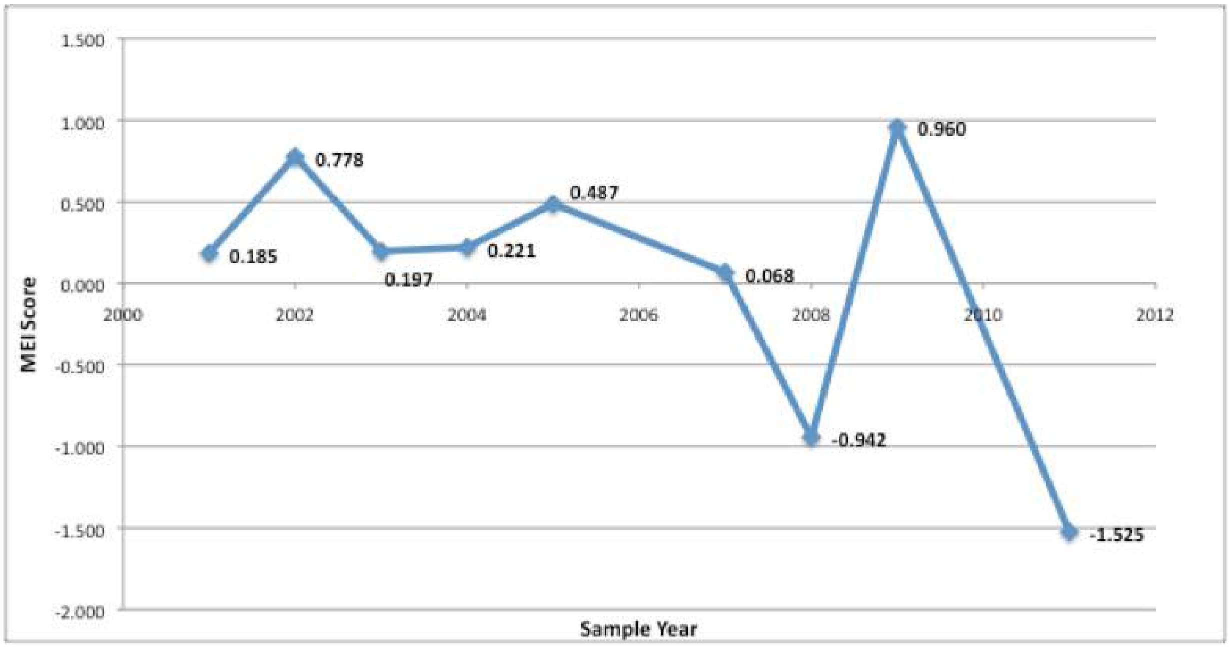


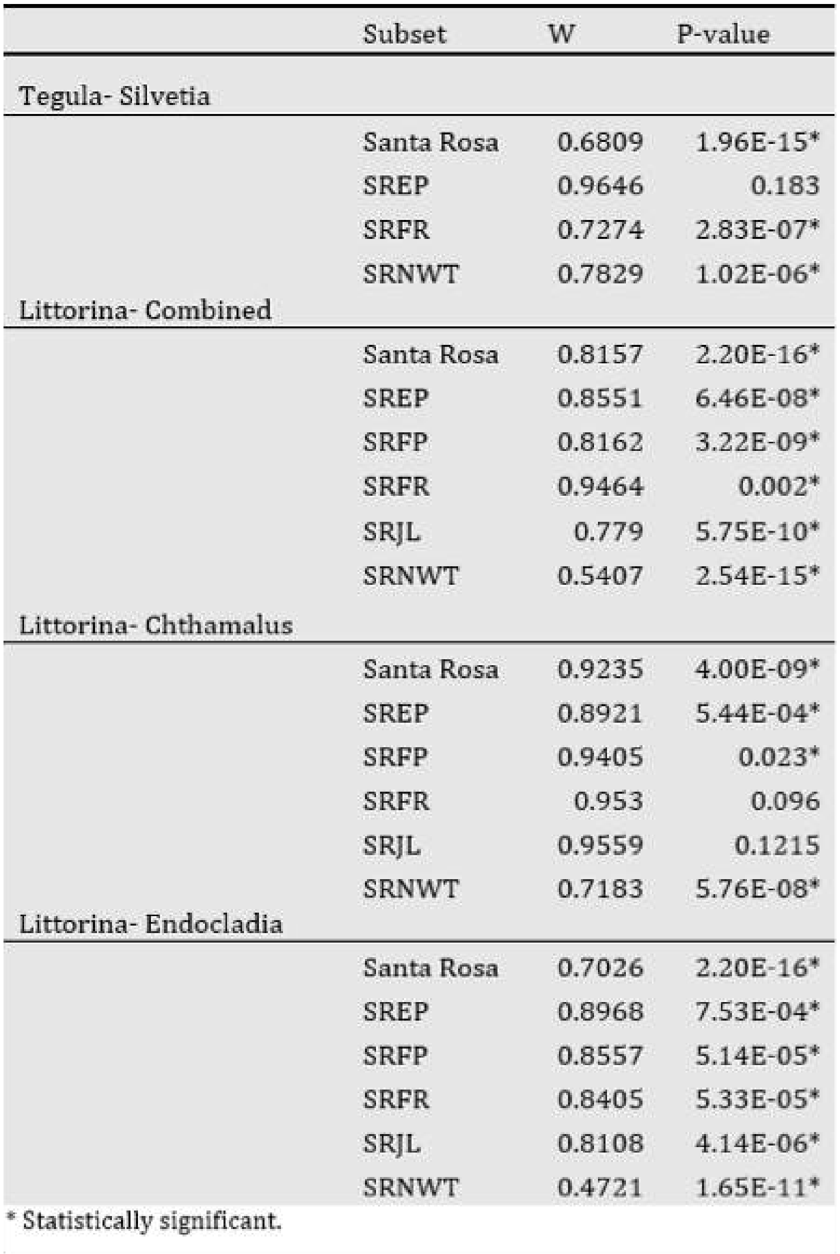
Figure 4. Plot of MEI values for Santa Rosa Spring sampling

Our second temperature covariate was based on the individual temperature thresholds of *Littorina* and *Tegula funebralis* that might cause heat stress within these species. For *Littorina* species, we used a threshold of 32◦C (Cashmore and Burton 1997), and for *Tegula funebralis*, we used a threshold of 27◦ C (Tomanek and Somero 1999). Using the Climate Analyzer tool given to us by the National Park Service, we obtained climate data for Santa Rosa, specifically the daily maximum and minimum temperatures from its Remote Automated Weather Station. We then calculated the number of days exceeding the temperature thresholds for these two MI species in the 12 months prior to each monitoring date. We used this number of days as the air temperature covariate for our multiple linear regression analysis. We hypothesized that a greater number of high temperature days within the prior 12 months would correlate with lower abundance values of *Littorina* and *Tegula funebralis*.

3.9. Data Analysis for Species of Focus

Our next step was to perform multiple linear regressions to examine the influence of climate and sessile species cover on *Littorina* and *Tegula* abundances on Santa Rosa Island. First, we tested for normality within our abundance data using the Shapiro-Wilk test (Table 13) to determine if abundances for our MI species needed to be log transformed before running a linear regression of the data. Next, we inputted our temperature and biotic metrics in tabular form to run the multiple regressions analysis in R Studio for the specific biotic zones for sites and for each individual plot.

Table 13. Site-Level Data Normality (Shapiro-Wilk Test).



	Subset	W	P-value
Tegula- Silvetia			
	Santa Rosa	0.6809	1.96E-15*
	SREP	0.9646	0.183
	SRFR	0.7274	2.83E-07*
	SRNWT	0.7829	1.02E-06*
Littorina- Combined			
	Santa Rosa	0.8157	2.20E-16*
	SREP	0.8551	6.46E-08*
	SRFP	0.8162	3.22E-09*
	SRFR	0.9464	0.002*
	SRJL	0.779	5.75E-10*
	SRNWT	0.5407	2.54E-15*
Littorina- Chthamalus			
	Santa Rosa	0.9235	4.00E-09*
	SREP	0.8921	5.44E-04*
	SRFP	0.9405	0.023*
	SRFR	0.953	0.096
	SRJL	0.9559	0.1215
	SRNWT	0.7183	5.76E-08*
Littorina- Endocladia			
	Santa Rosa	0.7026	2.20E-16*
	SREP	0.8968	7.53E-04*
	SRFP	0.8557	5.14E-05*
	SRFR	0.8405	5.33E-05*
	SRJL	0.8108	4.14E-06*
	SRNWT	0.4721	1.65E-11*

* Statistically significant.

To ensure quality control of our data, both statisticians in the group began with the original data set and independently eliminated incomplete observations, to ensure that none were accidentally deleted or kept. After subdividing the data using R, both statisticians ran the same tests independently to reinforce the results and highlight any discrepancies between their work and to ensure that the tests were run properly and the data input properly. In this manner, we strove to eliminate as much human error as possible. We also have provided the R coding commands and relevant comma separated values files so that future analysis on the abundance datasets can be performed.

4. Results

4.1. Plot Densities for Core MI Species

Shown below in Figures 5 - 7 are example abundance plots for one of our fifteen "core" MI invertebrates, *Nucella emarginata*. The plots shown here show the variability of MI abundances species by charting counts through fall and spring seasons over the entire sampling period of the datasets, and then abundances on the MI preferred biotic substrate. The remaining plots for the other MI species can be found within Appendix A.2.

There are some years, such as 2006, that have a drastic drop in sampled counts, and these results are due to unsampled time points where not all islands or sites recorded data during that time. To denote these unsampled periods, figures have dashed lines between such years where no sampling occurred. The dominant sessile coverage are color coded as follows: *Silvetia* (rockweed) plots are denoted in green, *Mytilus* (mussel) plots in orange, *Endocladia* (turfweed) plots in pink, and *Chthamalus/Balanus* (barnacle) plots in blue.

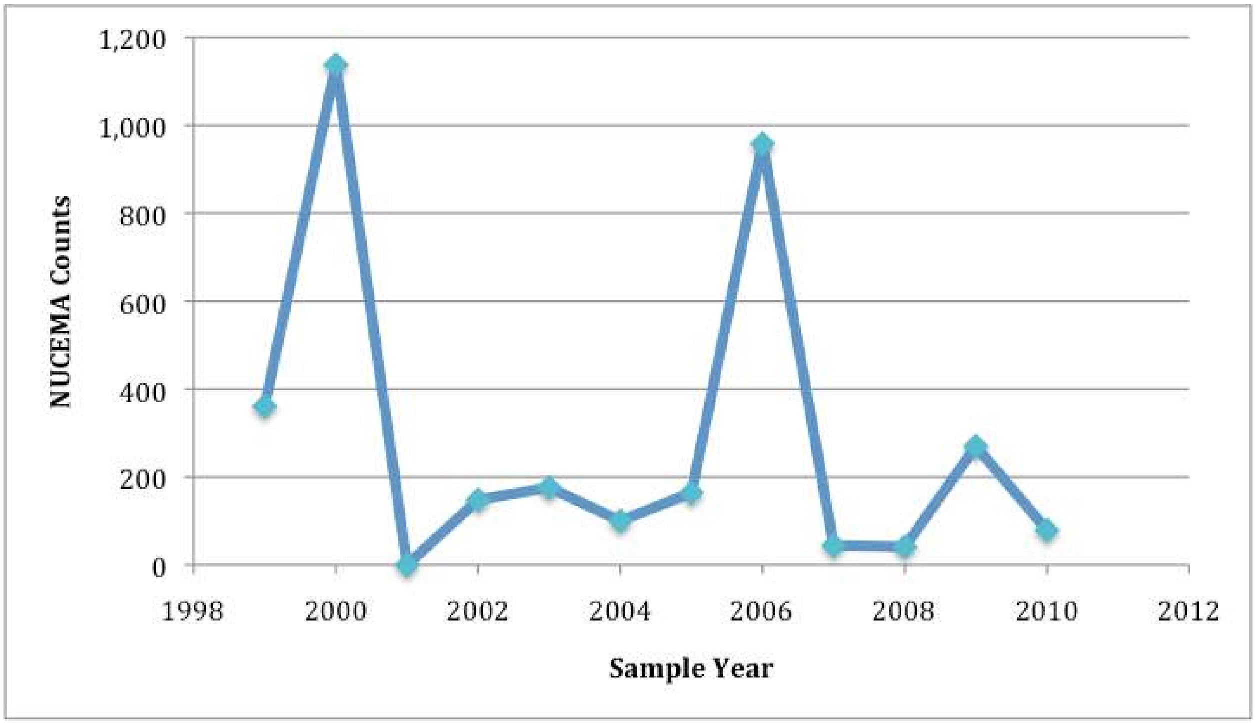


Figure 5. *Nucella emarginata* Fall abundances across Channel Islands.

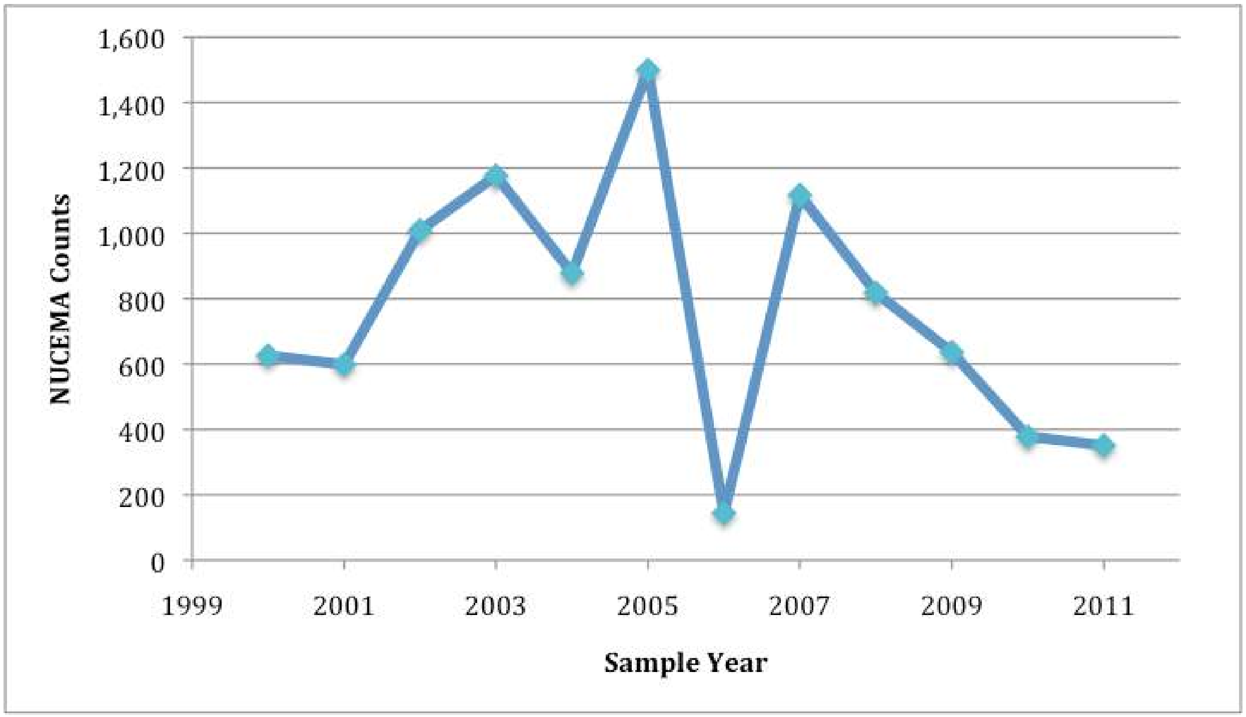


Figure 6. *Nucella emarginata* Spring abundances across Channel Islands.

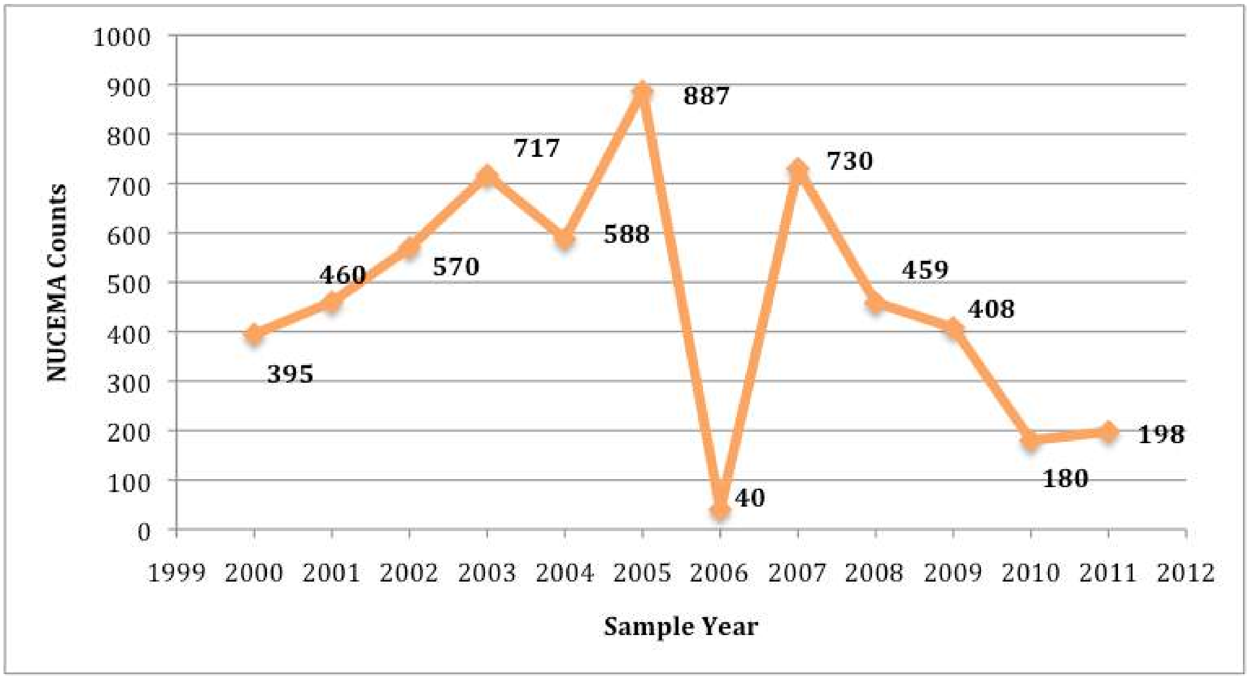


Figure 7. *Nucella emarginata* Spring abundances on *Mytilus* substrates, all Channel Islands.

4.1.1. Abundance versus Cover

Figure 8 displays species abundance versus proportion cover of both sessile and rock coverage in each plot. Green bars represent the proportion of rock cover, blue bars represent the *Chthamalus* cover, purple bars represent *Endocladia* cover, and red bars represent *Silvetia* cover. The red lines represent *Littorina* abundance of the sample taken that year, with yellow lines representing the same for *T. funebralis*. Dotted lines once again represent a gap in sampling for that year. Graphs for each of the 65 plots we analyzed can be found in the appendix, but a few samples are shown below. While the first graphs of plot 524 and 582 show a relatively intact correlation between sessile cover and motile invertebrate abundance, plots 567 and 508 show almost no correlation. Statistical significance is not shown for these graphs, but is included in the linear regression analysis (see appendix).

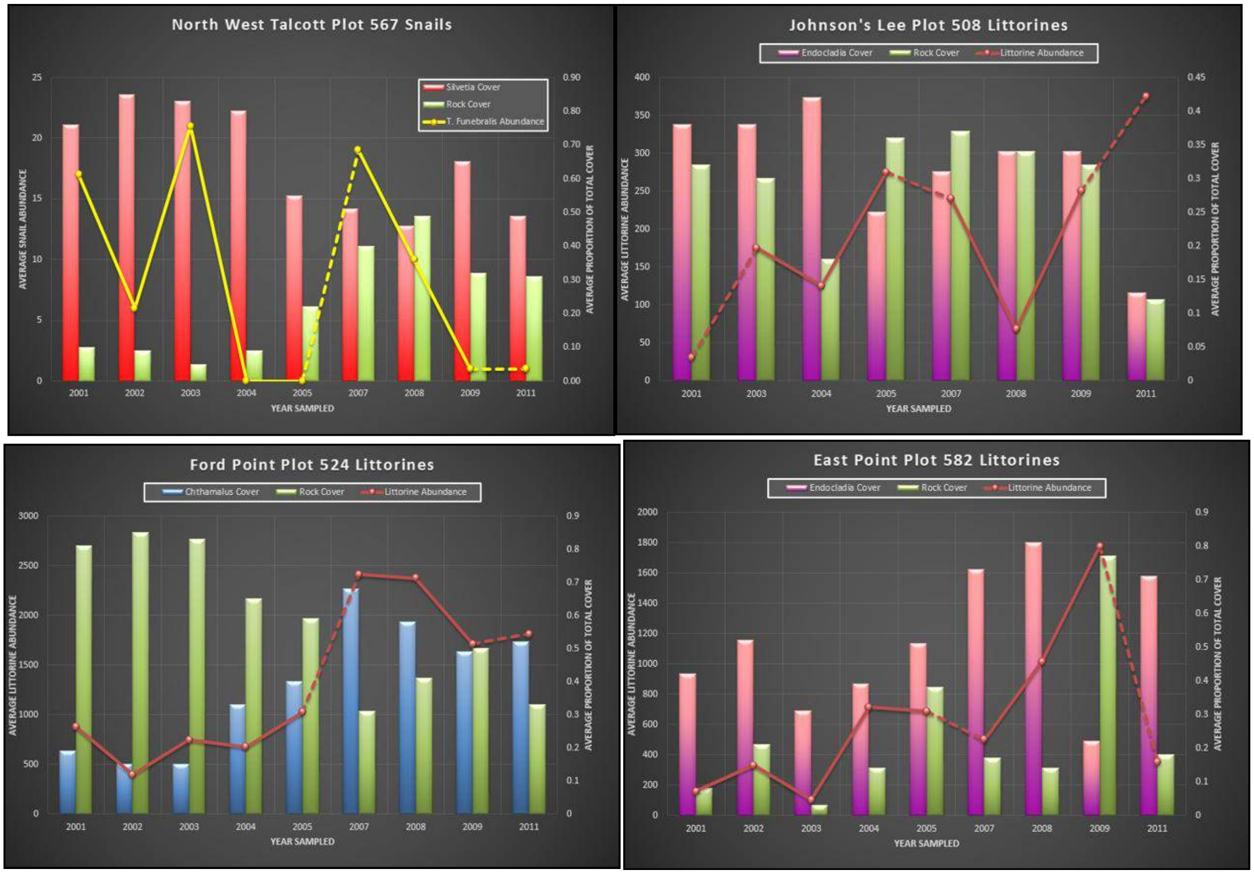


Figure 8. Species abundance versus proportion cover of both sessile and rock cover in select plots.

4.2. Climate Analysis

Climate data was pulled from the climate analyzer from Lena Lee, from the National Park Service. The data included daily and monthly lows and highs for all islands, for multiple types of stations. The stations that we focused on were Remote Automated Weather Station (RAWS) and NPS Manual Stations. We obtained RAWS data for all stations except for San Miguel, which did not have a RAWS station. Instead, we used a NPS Manual Station for this island.

After this data was obtained, we removed all null data. We then compared the differences in temperature across islands by creating two graphs: monthly highs (Figure 9a) and monthly lows (Figure 9b) across all islands.

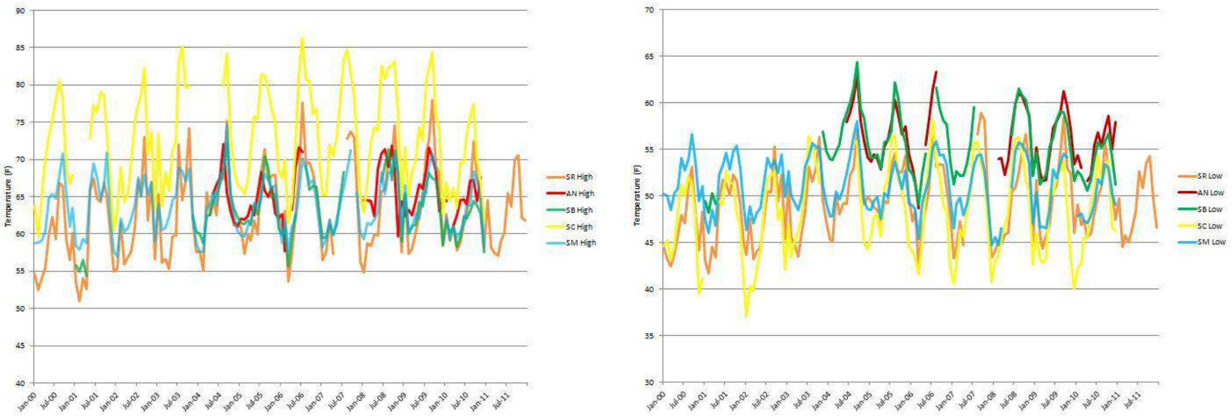


Figure 9. (*a*, *left*) Monthly average high temperatures for all islands from 2000-2011 (*b*, *right*) Monthly average low temperatures for all islands from 2000-2011.

We then focused on Santa Rosa Island data only, since it was the most complete dataset. We found in the literature the temperature thresholds for the different species: 32^0 C for *Littorina* and 27^0 C for *Tegula funebralis*. We then found the number of days over that threshold from the years 2000-2011 for each of the species on Santa Rosa Island (Figure 10a and 10b) and added that to the multiple regression analysis.

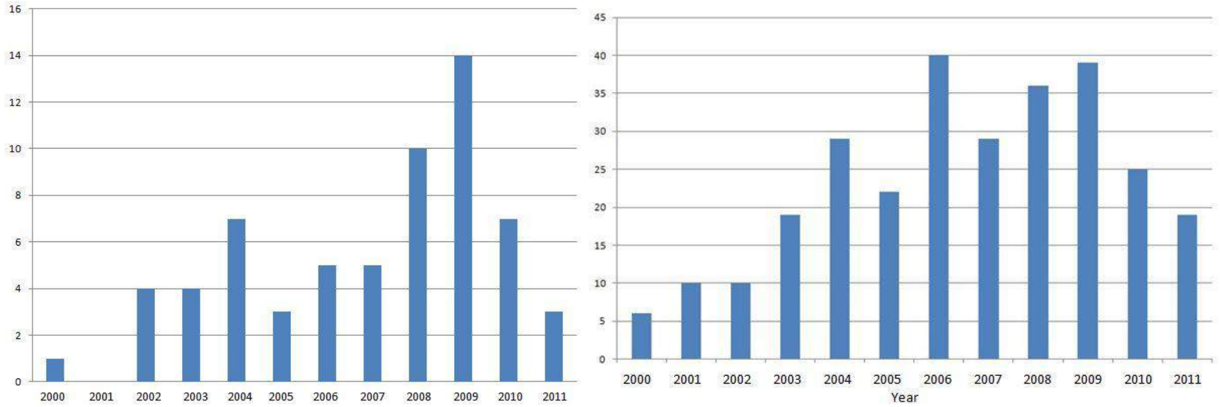


Figure 10. *(a, left)* Days over 32^0 C temperature threshold for *Littorina* on Santa Rosa Island from 2000-2011 and (*b*, *right*) days over 27^0 C temperature threshold for *Tegula funebralis* on Santa Rosa Island from 2000-2011.

4.3. Regression Analysis

Our regression analysis considered the MEI, the air temperature, and the proportion of sessile cover and rock cover to model the individual plot abundances and their changes over time. Results of those that were found to meet the normality assumptions of the linear model are shown in Table 14 (site-level) and Table 15 (plot-level). Statistical significance is denoted by an asterisk. For the R-squared value, it is determined by the *p*-value being below 0.05, as shown in the table. Although each coefficient also had a *p*-value, including those in the table would have made it far too large, but each case where the coefficient's *p*-value is less than 0.05 is also denoted by an asterisk.

For the site-level analysis (Table 14), MEI had two significant coefficients, one of which was positive and one of which was negative. All of the significant air temperature coefficients show a positive correlation with abundance. Significant sessile cover coefficient always display a positive correlation with abundance. Rock cover also followed a similar pattern of almost all positive significance, with one negative significant coefficient of -25.21. Though there were a number of significant R-squared values, only two of them were over 0.5, meaning that the data's variation is not well explained by the model equation.

Below the site-level analysis is the plot-level analysis in Table 15. Though only three plots were found to have significant R-squared values, these three plots displayed high R-squared values, indicating a high level of correlation between the model and the data points for abundance. No significant trends were found between the statistically significant variable coefficients and the abundance.

Table 14. Multiple Linear Regression Analysis- Site Level.

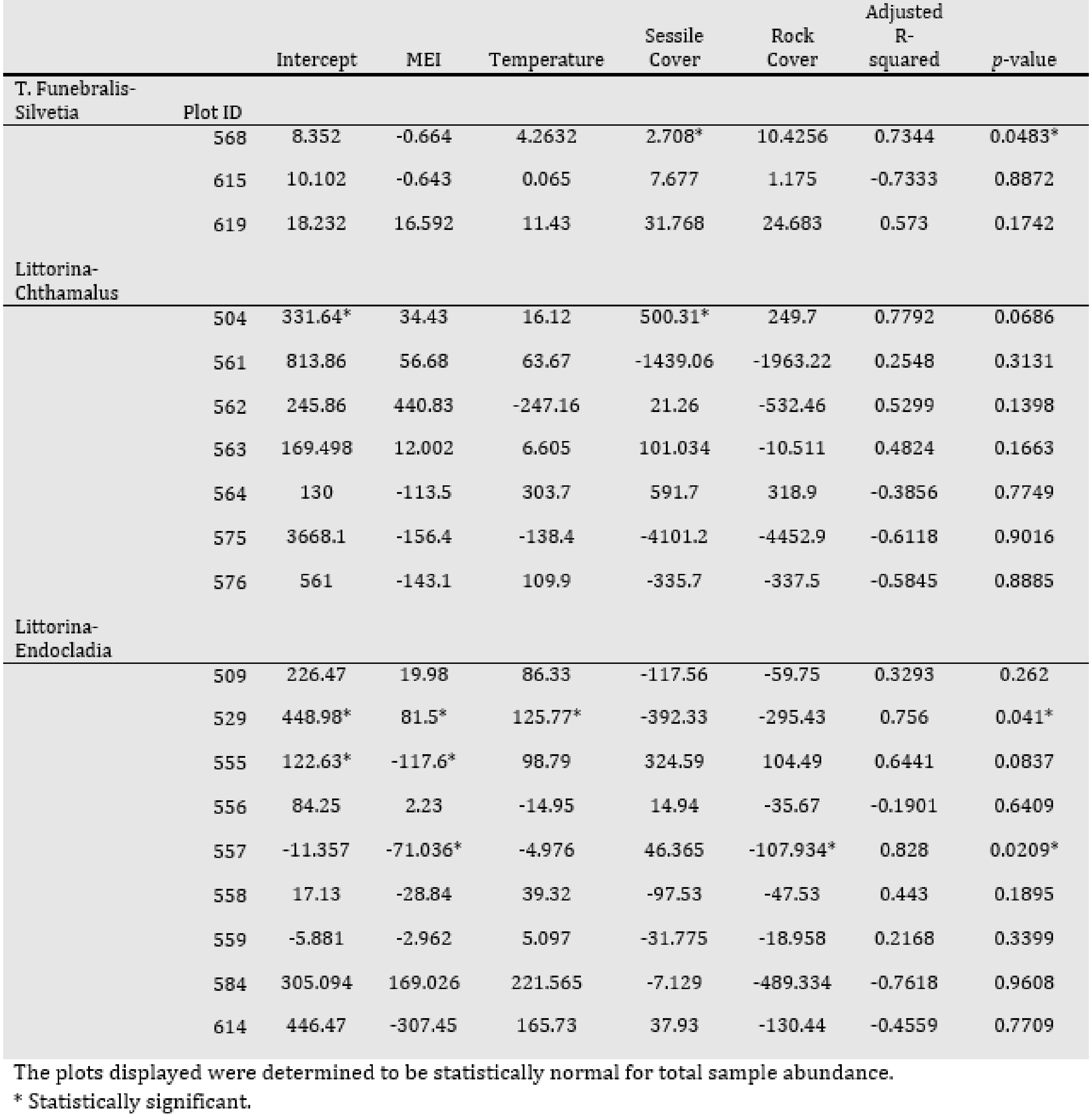
		Intercept	MEI	Temperature	Sessile Cover	Rock Cover	Adjusted R-squared	*p*-value
T. Funebralis-Silvetia								
	Santa Rosa	19.622*	1.642	4.717*	-3.464	-8.423	0.04297	0.04971*
	SREP[b]	24.1659*	-2.404	-0.9291	4.8133	2.2694	-0.04882	0.7445
	SRFR	44.78*	5.115	8.428	24.535*	2.996	0.3214	0.001333*
	SRNWT	2.6841*	-0.773	-1.1662	4.0687	1.5604	0.1433	0.03658*
Littorina-Combined[a]								
	Santa Rosa	720.49*	-36.93	111.26*	308.09*	269.32*	0.1415	2.58E-14*
	SREP	1225.87*	-133.57	89.87	79.76	389.62*	0.21	7.24E-05*
	SRFP	589.06*	-24.5	118.36	279.36*	505.51*	0.2563	6.46E-06*
	SRFR	759.19*	-129.94	105.7*	116.44	151.22*	0.1103	0.01216*
	SRJL	655.3*	-75.24	259.42*	803.98*	370.39*	0.3266	2.95E-07*
	SRNWT	419.81*	-50.06	13.99	325.53*	101.33	0.1849	0.0002488*
Littorina-Chthamalus								
	Santa Rosa	1123.48*	-20.81	108.49	427.6*	117.26*	0.1767	3.98E-09*
	SREP	1526.15*	-41.55	-70.36	359.07*	245.07	0.07763	0.1249
	SRFP	1191.77*	36.15	186.84*	477.18*	219.88	0.2908	0.001248*
	SRFR	920.83*	-164.13	124.44	-134.81	31.95	0.1179	0.07779
	SRJL	1207.7*	88.85	215.18	1026.26*	224.41	0.6117	1.21E-07*
	SRNWT	598.92*	-57.81	25.81	330.45*	157.82	0.09106	0.09851*
Littorina-Endocladia								
	Santa Rosa	314.786*	17.509	114.986*	53.004	-9.103	0.07529	0.000333*
	SREP	949.84*	-89.39	110.92	-15.57	348.63*	0.5087	1.21E-06*
	SRFP	198.482*	47.412*	40.677*	-50.39	1.903	0.1756	0.01877*
	SRFR[b]	591.07*	-59.07	85.52	-21.73	-215.3	0.08334	0.1347
	SRJL[b]	142.747*	-4.729	83.129*	-29.543	11.031	0.3261	0.0004853*
	SRNWT	36.6	-42.06*	12.12	-20.56	-25.21*	0.2618	0.002604*

[a] Combined Chthamalus and Endocladia plots. Sessile cover reflects the proportion of the sessile species for which the plot is named.

[b] These data sets were not found to be parametric, and do not meet the assumptions of the regression analysis.

* Statistically significant.

Table 15. Multiple Linear Regression Analysis- Plot Level.



		Intercept	MEI	Temperature	Sessile Cover	Rock Cover	Adjusted R-squared	*p*-value
T. Funebralis-Silvetia	Plot ID							
	568	8.352	-0.664	4.2632	2.708*	10.4256	0.7344	0.0483*
	615	10.102	-0.643	0.065	7.677	1.175	-0.7333	0.8872
	619	18.232	16.592	11.43	31.768	24.683	0.573	0.1742
Littorina-Chthamalus								
	504	331.64*	34.43	16.12	500.31*	249.7	0.7792	0.0686
	561	813.86	56.68	63.67	-1439.06	-1963.22	0.2548	0.3131
	562	245.86	440.83	-247.16	21.26	-532.46	0.5299	0.1398
	563	169.498	12.002	6.605	101.034	-10.511	0.4824	0.1663
	564	130	-113.5	303.7	591.7	318.9	-0.3856	0.7749
	575	3668.1	-156.4	-138.4	-4101.2	-4452.9	-0.6118	0.9016
	576	561	-143.1	109.9	-335.7	-337.5	-0.5845	0.8885
Littorina-Endocladia								
	509	226.47	19.98	86.33	-117.56	-59.75	0.3293	0.262
	529	448.98*	81.5*	125.77*	-392.33	-295.43	0.756	0.041*
	555	122.63*	-117.6*	98.79	324.59	104.49	0.6441	0.0837
	556	84.25	2.23	-14.95	14.94	-35.67	-0.1901	0.6409
	557	-11.357	-71.036*	-4.976	46.365	-107.934*	0.828	0.0209*
	558	17.13	-28.84	39.32	-97.53	-47.53	0.443	0.1895
	559	-5.881	-2.962	5.097	-31.775	-18.958	0.2168	0.3399
	584	305.094	169.026	221.565	-7.129	-489.334	-0.7618	0.9608
	614	446.47	-307.45	165.73	37.93	-130.44	-0.4559	0.7709

The plots displayed were determined to be statistically normal for total sample abundance.
* Statistically significant.

5. Discussion

5.1. Results Discussion

For our results, we did not expect to find a positive correlation between species count and air temperature. In a similar study done by Schiel et al. (2004), they also found an increase in invertebrate grazers with an increase in temperature. After ten years of induced warming, gastropods specifically showed a positive response to temperature, due to the fact that they can repair thermal damage to proteins (Tomanek and Somero 1999). They also found a decrease in algal cover, which meant that there was more available habitat for these gastropods that prefer areas clear of excess algae (Schiel et al. 2004). Another explanation (that would require further research) is that the increase in temperature affects a common predator of these species more than it affects our focus species. Therefore, these macroinvertebrates are able to reproductively thrive in a habitat with fewer predators.

In regards to biotic zones, we found that *Tegula funebralis* preferred the *Silvetia* zone and the *Littorina* prefered the *Chthamalus* zone. We found a positive correlation between the preferred sessile species cover and the motile species. This confirms that each of these species has a preferred habitat, and that a change in cover of this habitat could affect the motile species abundance.

We did not expect to see any significant trends between species abundance and MEI data, which is what our multiple regression showed. This is due to the fact that ENSO is not a local event for the Channel Islands, and was only a proxy for surface temperature data.

We also did not expect to see a positive correlation between rock cover and our motile species abundance. This may be attributed to the fact that since these areas are not inhabited by a sessile species, it allows them a space with little or no competition for habitat or other resources. Since they are motile species, they perhaps were able to move to an area with more food and resources when necessary, but spend most of their time in an uninhabited area of rock.

5.2. Future Studies

Due to the time constraint and lack of data available for certain climate metrics, we were unable to run statistical tests on all aspects of physical and biological impacts on our target species. Due to the many aspects of ecosystem science, it can be hard to determine the immediate effects of global warming on species abundance. Some of the factors to consider for future direction of this project include, but are not limited to: precipitation, water temperatures, tidal height, salinity, and biotic zone shifts.

In regards to precipitation effects, heavy rainfall events lead to higher turbidity and higher inputs of contaminants into the ocean, causing eutrophication in which organisms are then depleted of oxygen (Wilby et al. 2006; Callaway et al 2012). More research is needed regarding the amount of pollution in Channel Island waters, which can be utilized to observe how pollution before and after rainfall events can affect species abundance. Unfortunately, we were unable to correlate precipitation data to our species abundance due to lack of time and incomplete metrics. Upon further review and advisement under our supporting faculty advisor, Dr. Richard Ambrose, we concluded that observing the relationship between precipitation and tidal height would not be an accurate indication of species abundance as tidal height is highly variable and there were no available data sources on tidal height for our island of interest. Although daily tidal height is available, more data is needed regarding seasonal tidal height fluctuations so that it can be compared over a period of time with the species survival rate, especially during periods of drought, as well as the spatial placement of each plot. Further recommendation for observing tidal height correlation is to run two-way analysis of variance (ANOVA) tests on the effects of wave exposure, tidal height, and the relationship between these two factors on motile species abundance and percent cover of sessile organisms. Additional statistical tests may be run to observe precipitation fluctuations in each season versus the species abundance. Periods of drought may be correlated with higher mortality due to an increase in desiccation events. Perhaps in the near future, a precipitation index for the Channel Islands can be created to assess climate change effects on the rocky intertidal species.

Another factor we neglected was the exact air temperature that the intertidal species are actually exposed to, due to differences in tide. This would correlate hourly temperature data with tide data to observe whether air temperature or water temperature had the greater effect on our intertidal species. For example, one plot may be exposed to low low tides more often than others, and this might affect the species abundance. There might be a sessile cover change on one plot, but another plot with the same plot ID would not. However, we were unable to find reliable hourly air temperature data as well as water temperature data. This information is something that should be taken into consideration when daily air temperature is used as a metric for climate change and global warming.

The amount of precipitation also influences salinity levels in the ocean as the freshening of waters reduces salinity. In contrast, increase in temperatures can cause more rapid evaporation of ocean water, leading to higher salinity. Low salinity has been reported as the cause of mortality for some species as it interferes with metabolic processes. Thus, species can experience salinity stress. Salinity is a physical factor that can influence vertical zonation and is a concern for organisms that are in constant contact with water. Certain species are better adapted to rapid changes in salinity than others. Due to the scope of our research, we did not focus on salinity effects on our target species. In addition, we were unable to obtain salinity data for our specific study site. We recommend further research be conducted on surface salinity to observe seasonal trends in the data in the rocky intertidal zones of the Channel Islands.

Some limitations with sessile coverage analysis included assuming that *Silvetia* coverage is the independent variable and *T. funebralis* abundance is the dependent variable; however, we recognize there is likely a mutual dependence between these species.

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Sincerely,
Kim Bowen, Tom Folker, Rachel Ker, Melissa Grace Klose, Julianne Marshall, Sargam Saraf, and Anna Tram

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(in style of Ecology)

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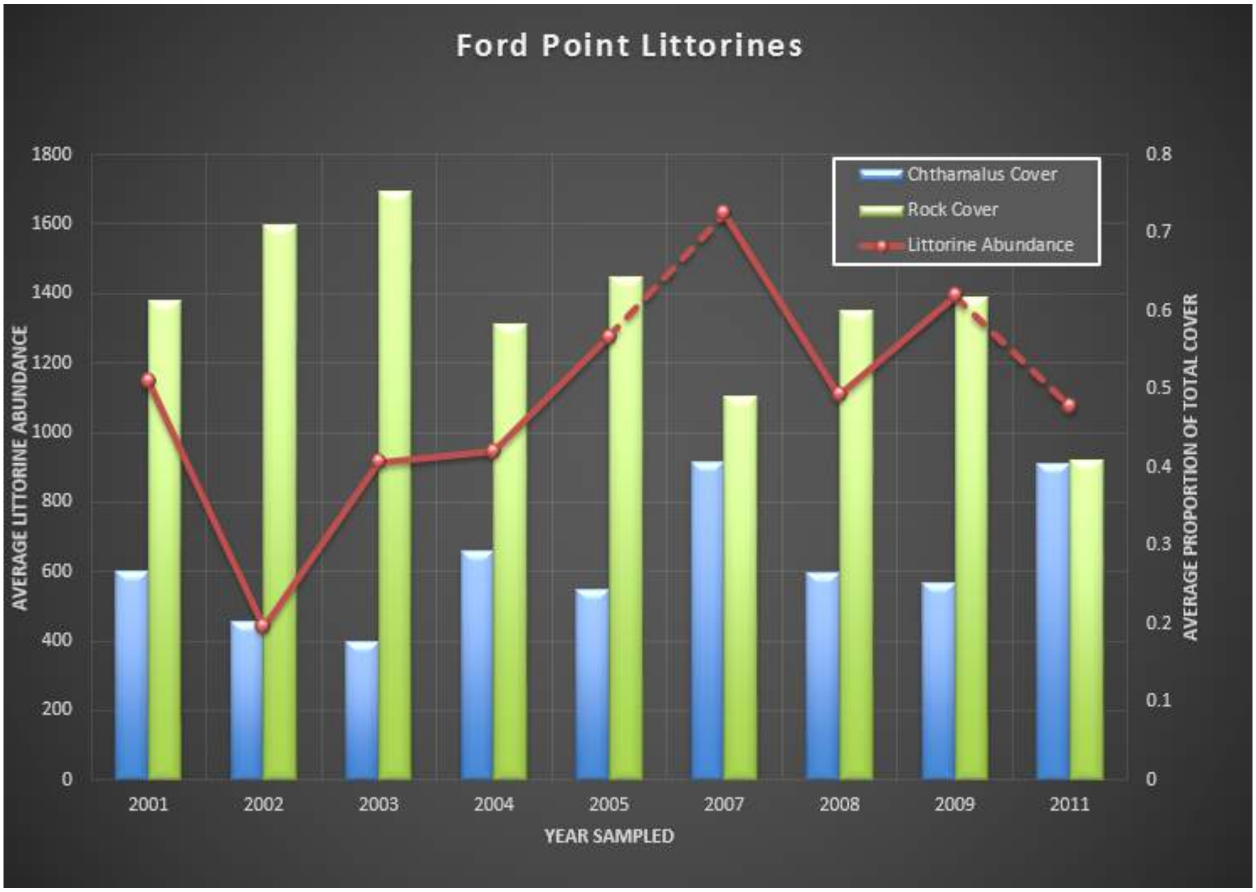
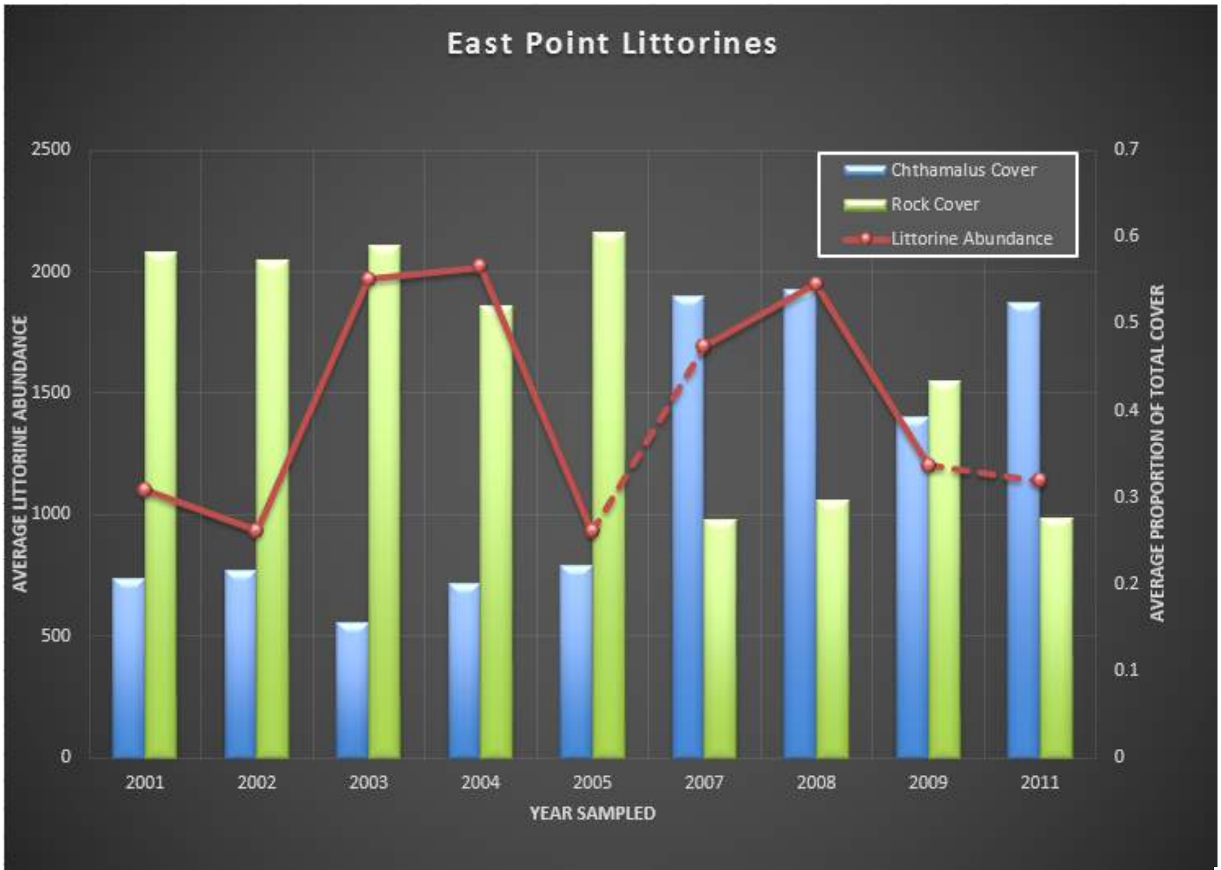
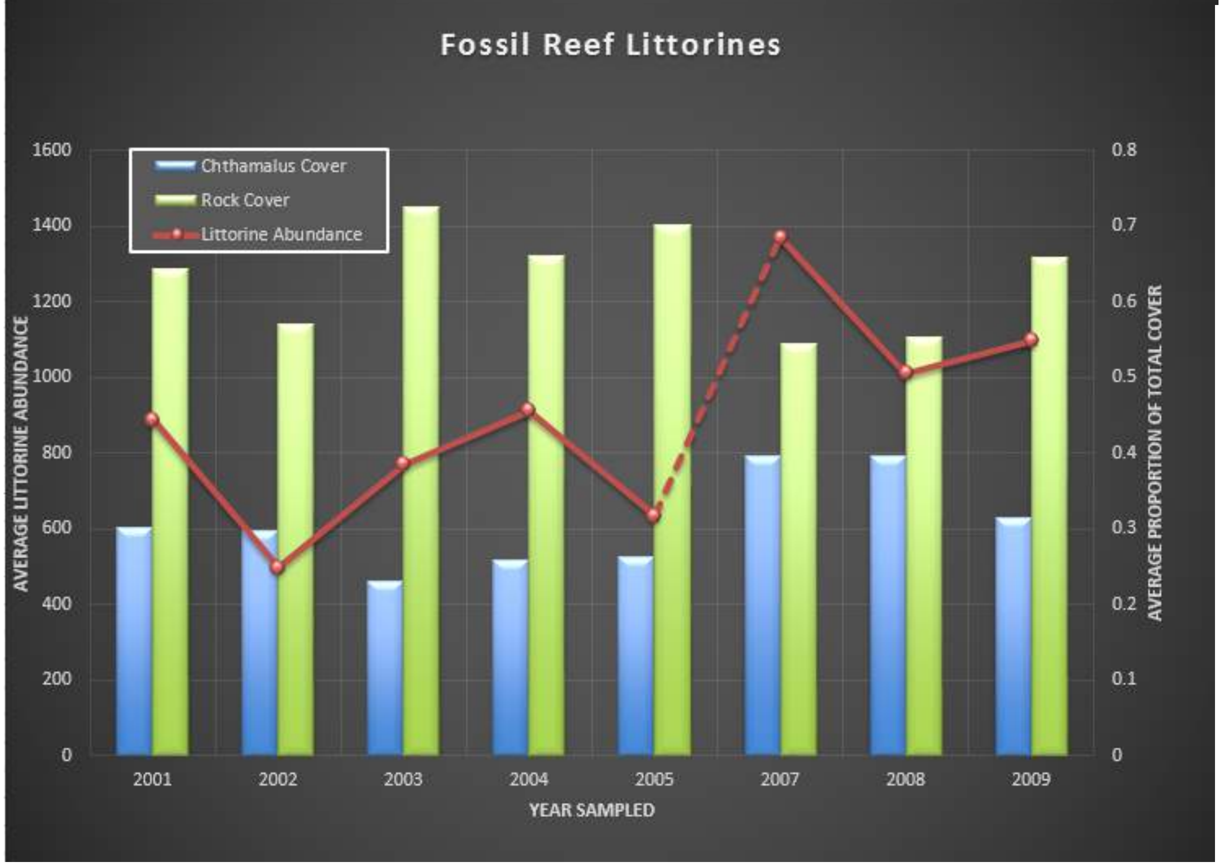
Appendix A Graphs

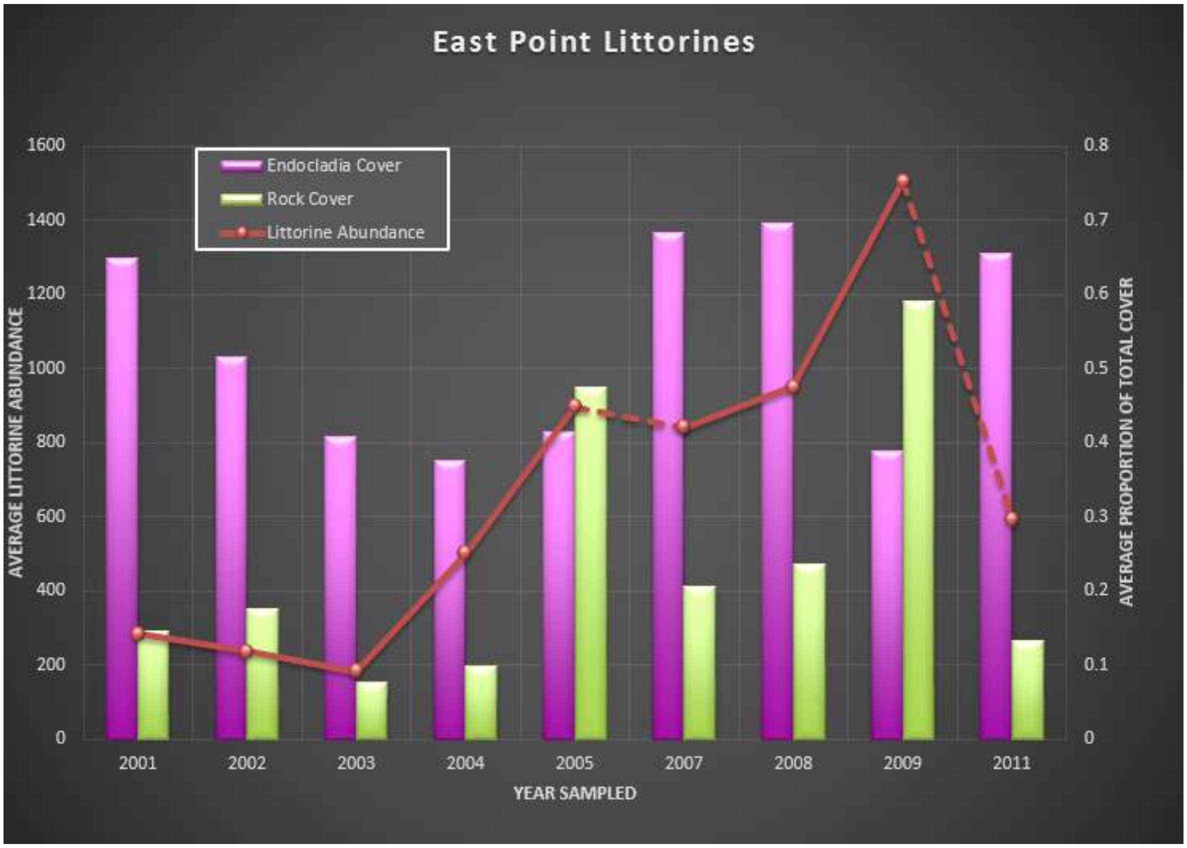
Appendix A.1 Species Abundance versus Sessile Cover

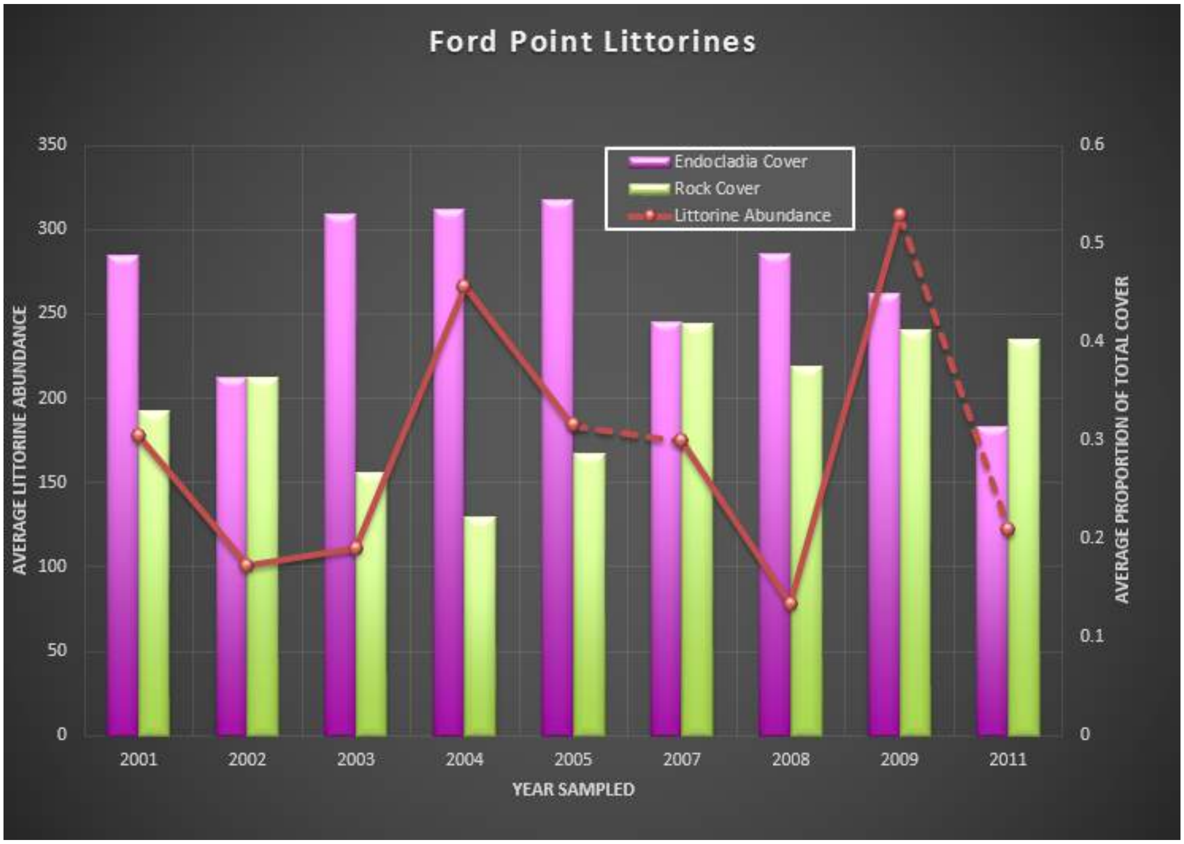
Appendix A.1.1 Littorines Abundance vs. Sessile Cover (by site)

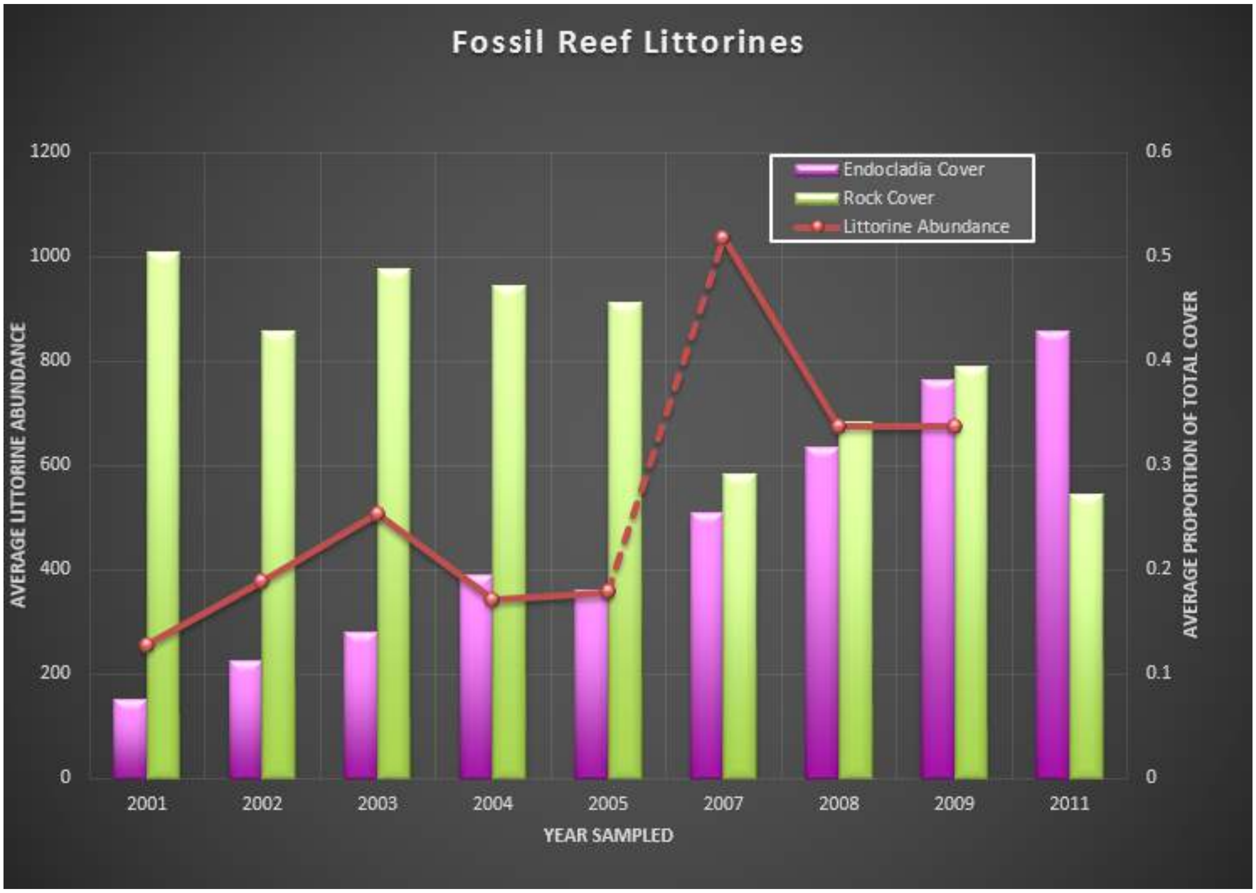



East Point Littorines
Chthamalus Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
0
500
1000
1500
2000
2500
AVERAGE PROPORTION OF TOTAL COVER
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

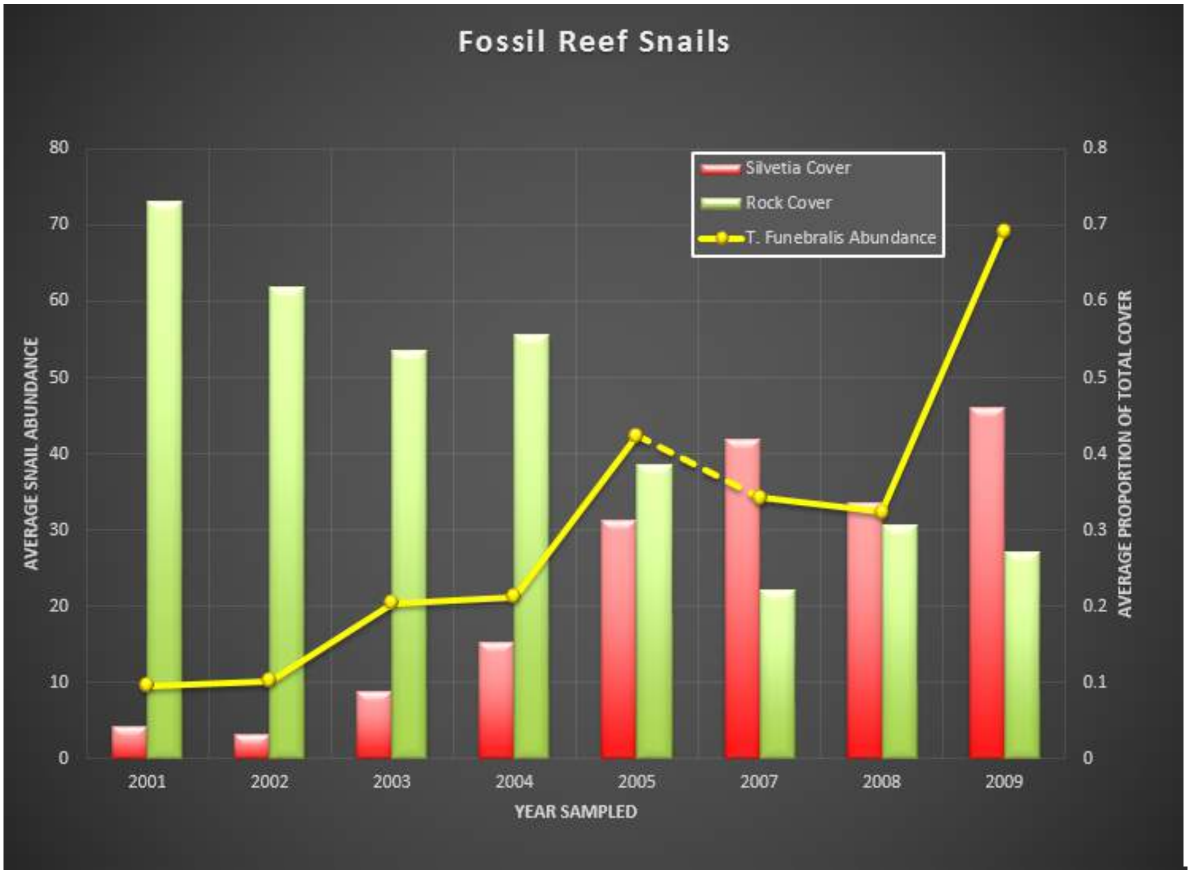

Fossil Reef Littorines
Chthamalus Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
0
200
400
600
800
1000
1200
1400
1600
AVERAGE PROPORTION OF TOTAL COVER
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
2001
2002
2003
2004
2005
2007
2008
2009
YEAR SAMPLED

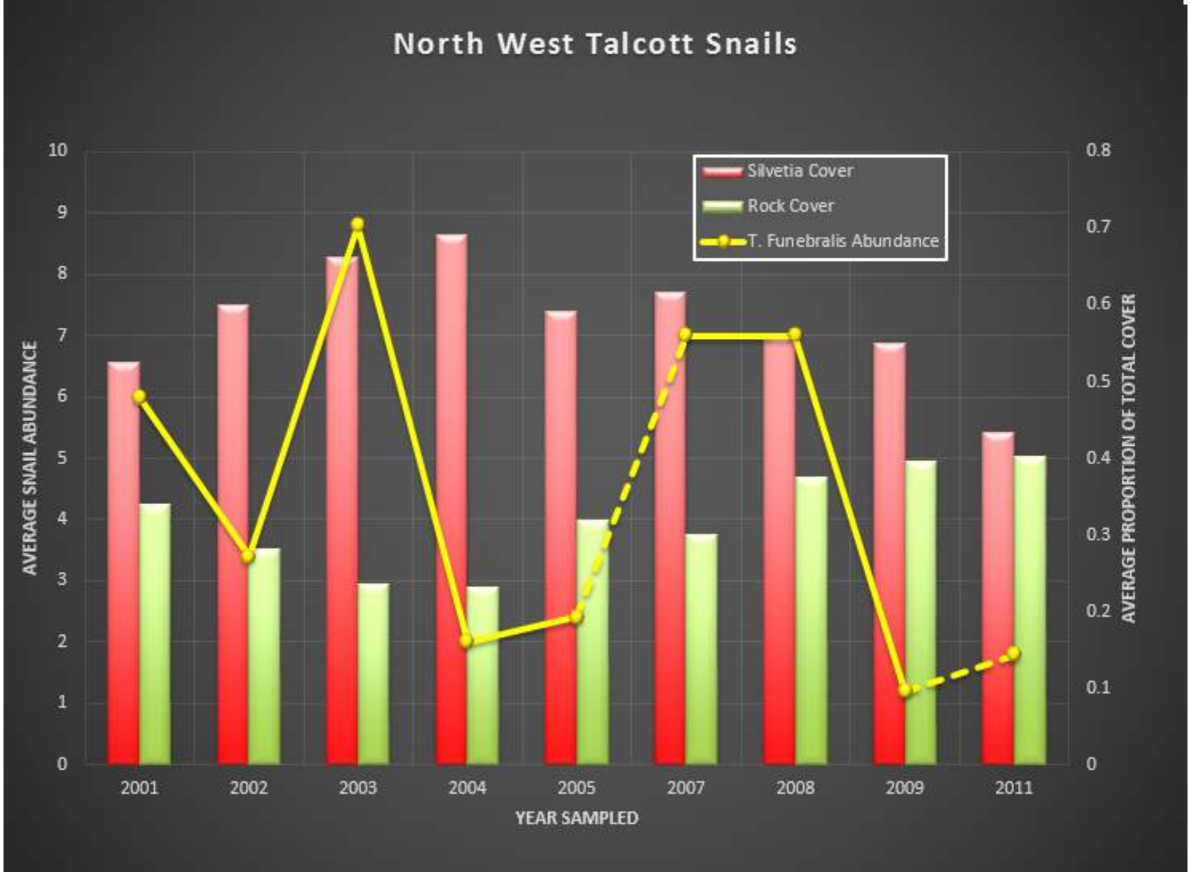

East Point Littorines
Endocladia Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
0
200
400
600
800
1000
1200
1400
1600
AVERAGE PROPORTION OF TOTAL COVER
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED


Ford Point Littorines
Endocladia Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
0
50
100
150
200
250
300
350
AVERAGE PROPORTION OF TOTAL COVER
0
0.1
0.2
0.3
0.4
0.5
0.6
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

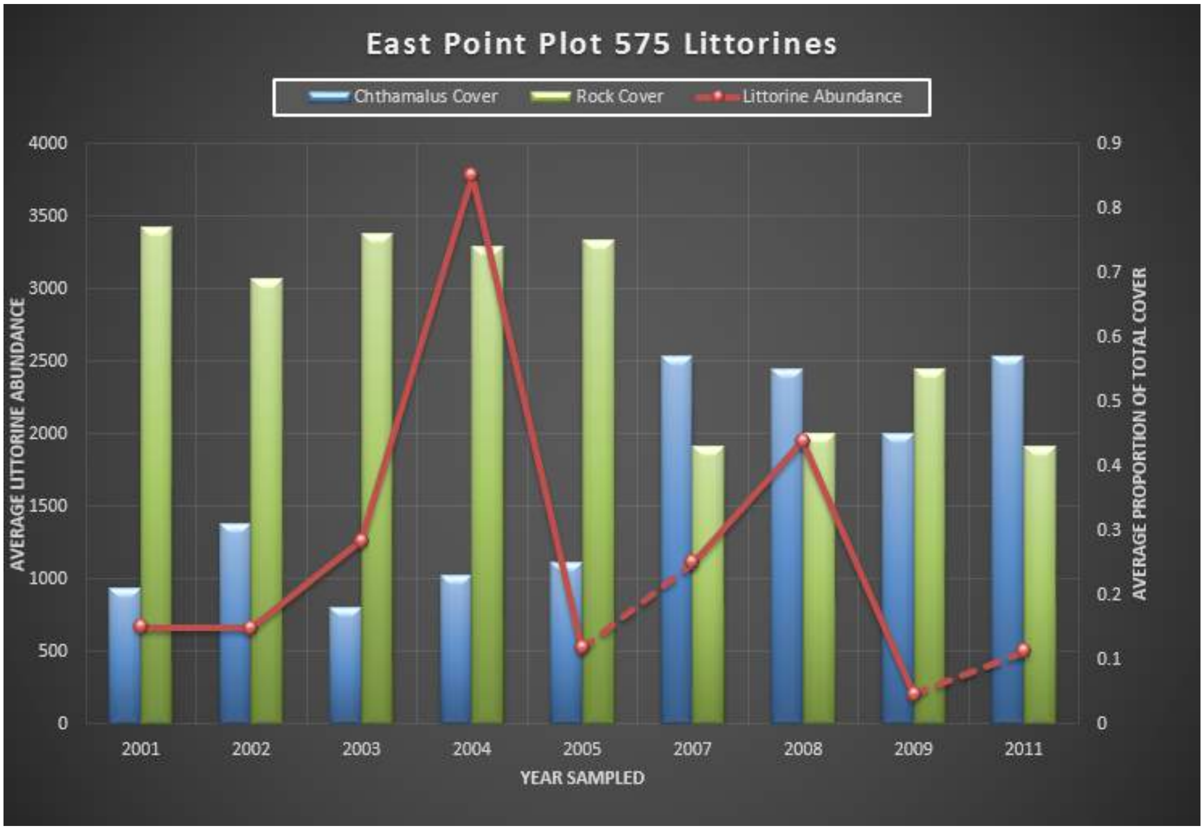

Fossil Reef Littorines
Endocladia Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
AVERAGE PROPORTION OF TOTAL COVER
YEAR SAMPLED
0
200
400
600
800
1000
1200
0
0.1
0.2
0.3
0.4
0.5
0.6
2001
2002
2003
2004
2005
2007
2008
2009
2011

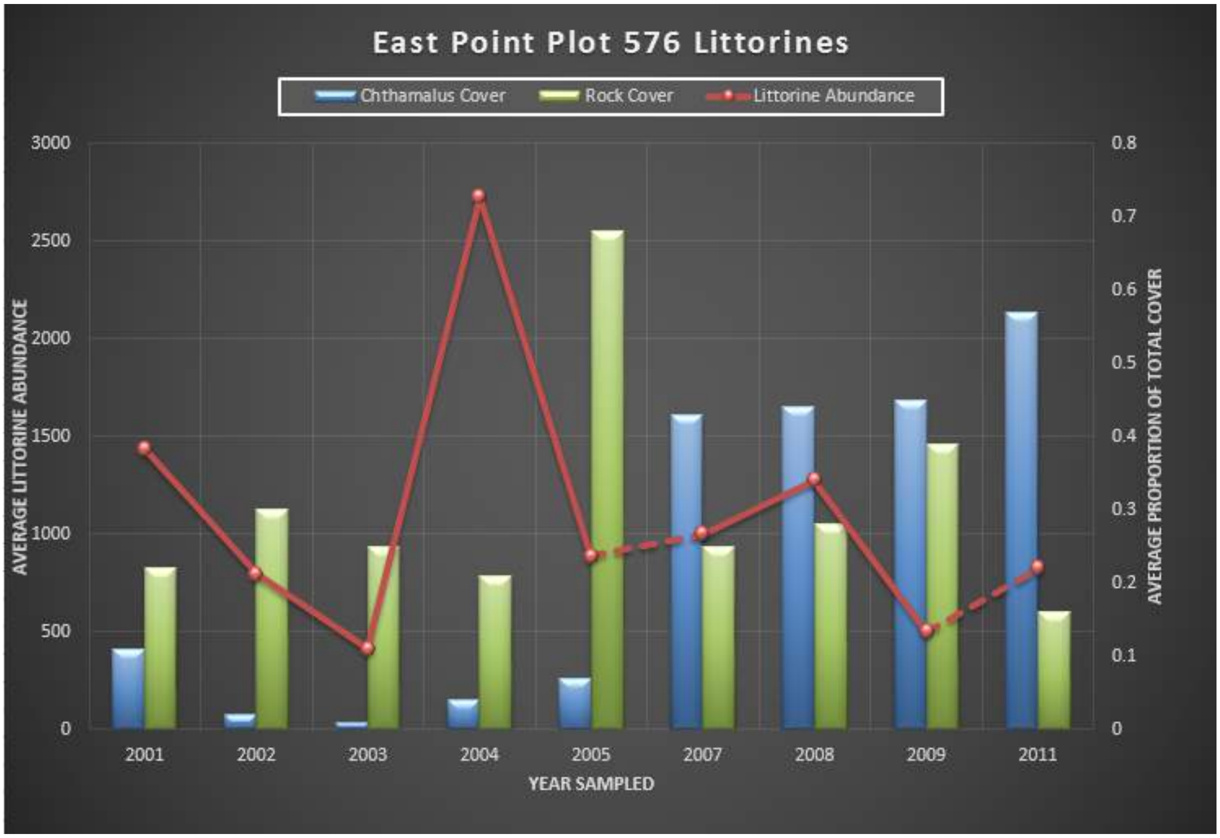
Appendix A.1.2 Tegula Funebralis Abundance vs. Sessile Cover (by site)

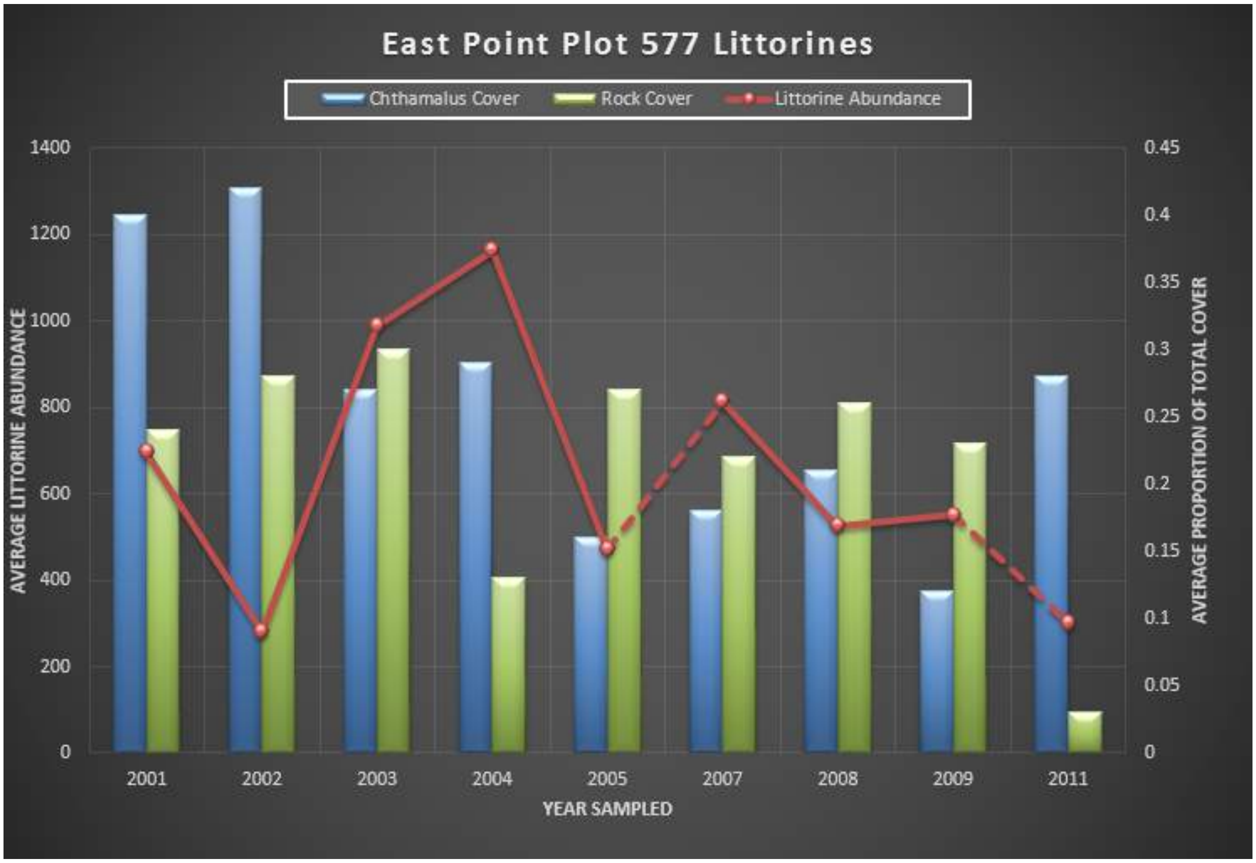

Fossil Reef Snails
Silvetia Cover
Rock Cover
T. Funebralis Abundance
AVERAGE SNAIL ABUNDANCE
AVERAGE PROPORTION OF TOTAL COVER
YEAR SAMPLED
80
70
60
50
40
30
20
10
0
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2001
2002
2003
2004
2005
2007
2008
2009

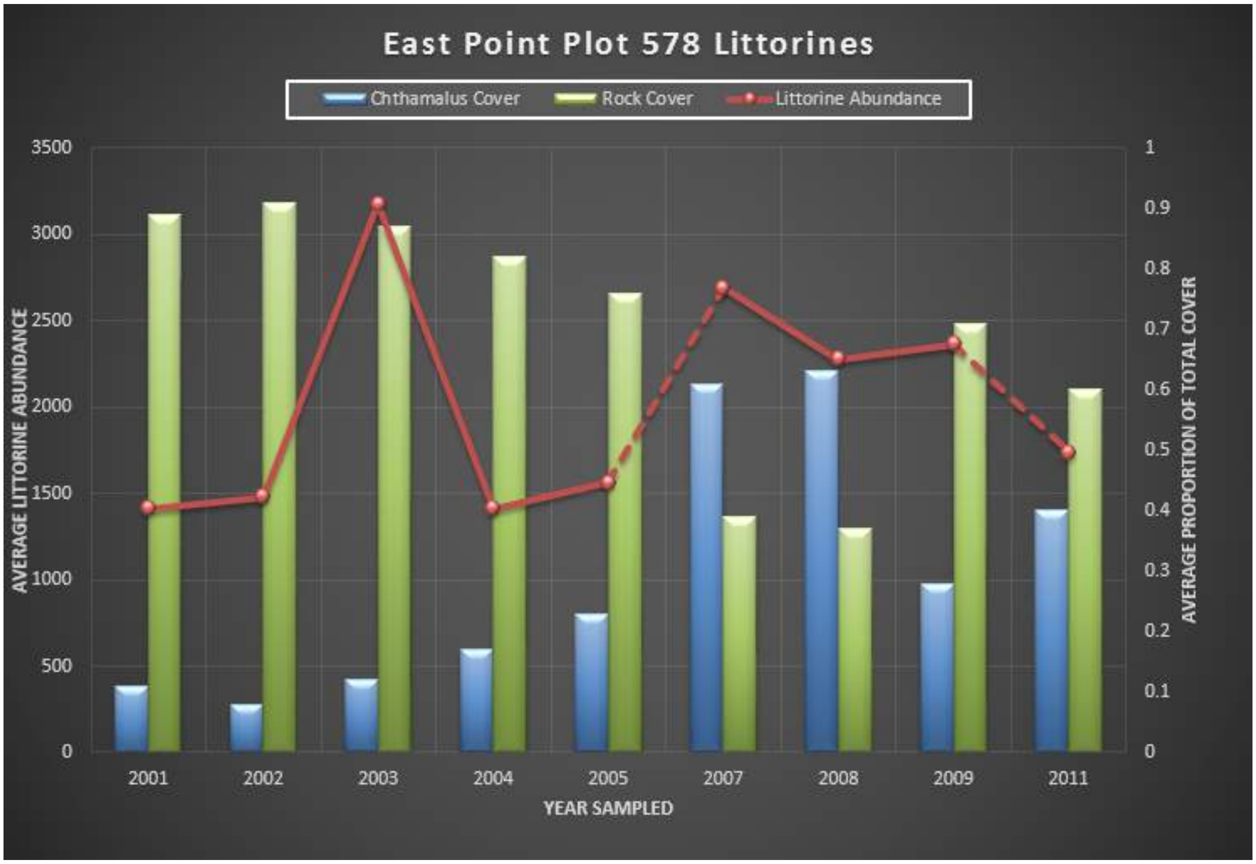

North West Talcott Snails
Silvetia Cover
Rock Cover
T. Funebralis Abundance
AVERAGE SNAIL ABUNDANCE
AVERAGE PROPORTION OF TOTAL COVER
YEAR SAMPLED
10
9
8
7
6
5
4
3
2
1
0
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2001
2002
2003
2004
2005
2007
2008
2009
2011

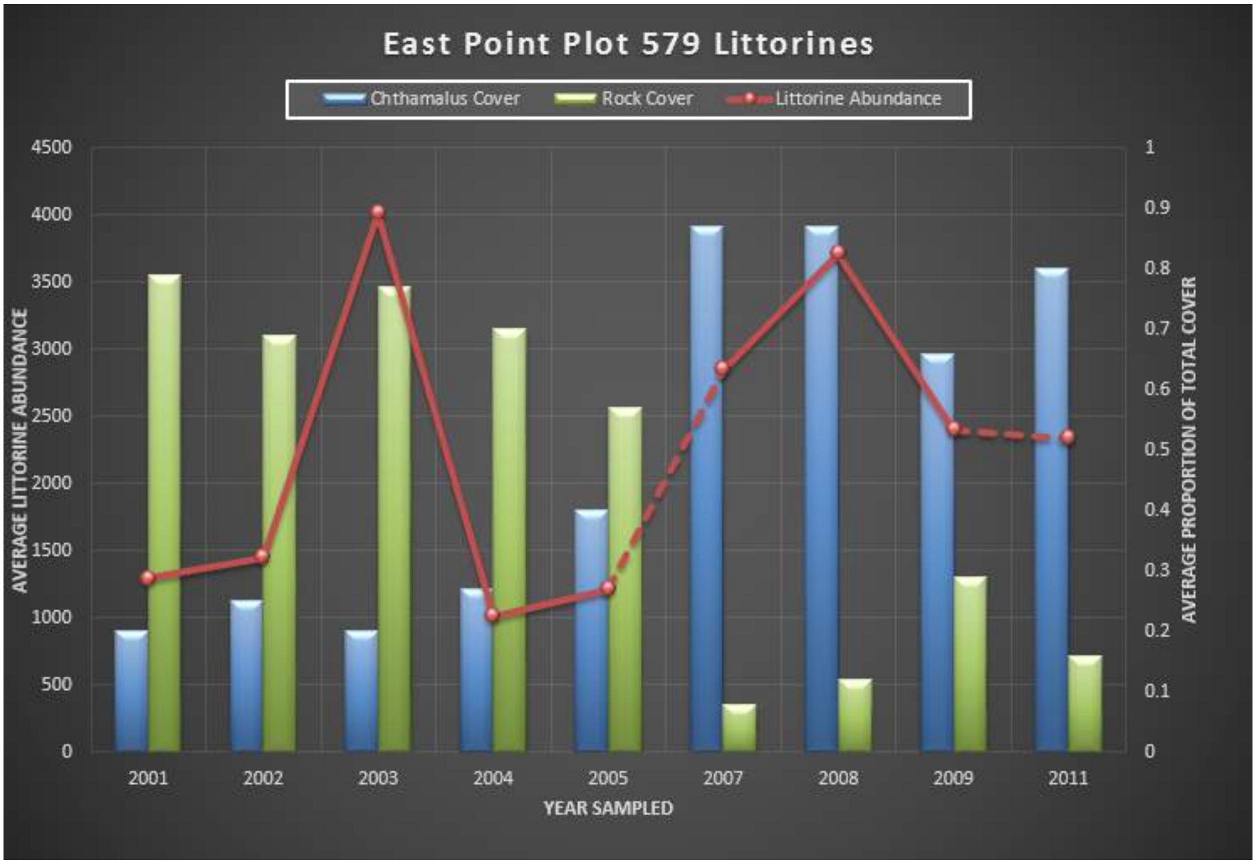
Appendix A.1.3 Littorines Abundance vs. Sessile Cover (by plot)

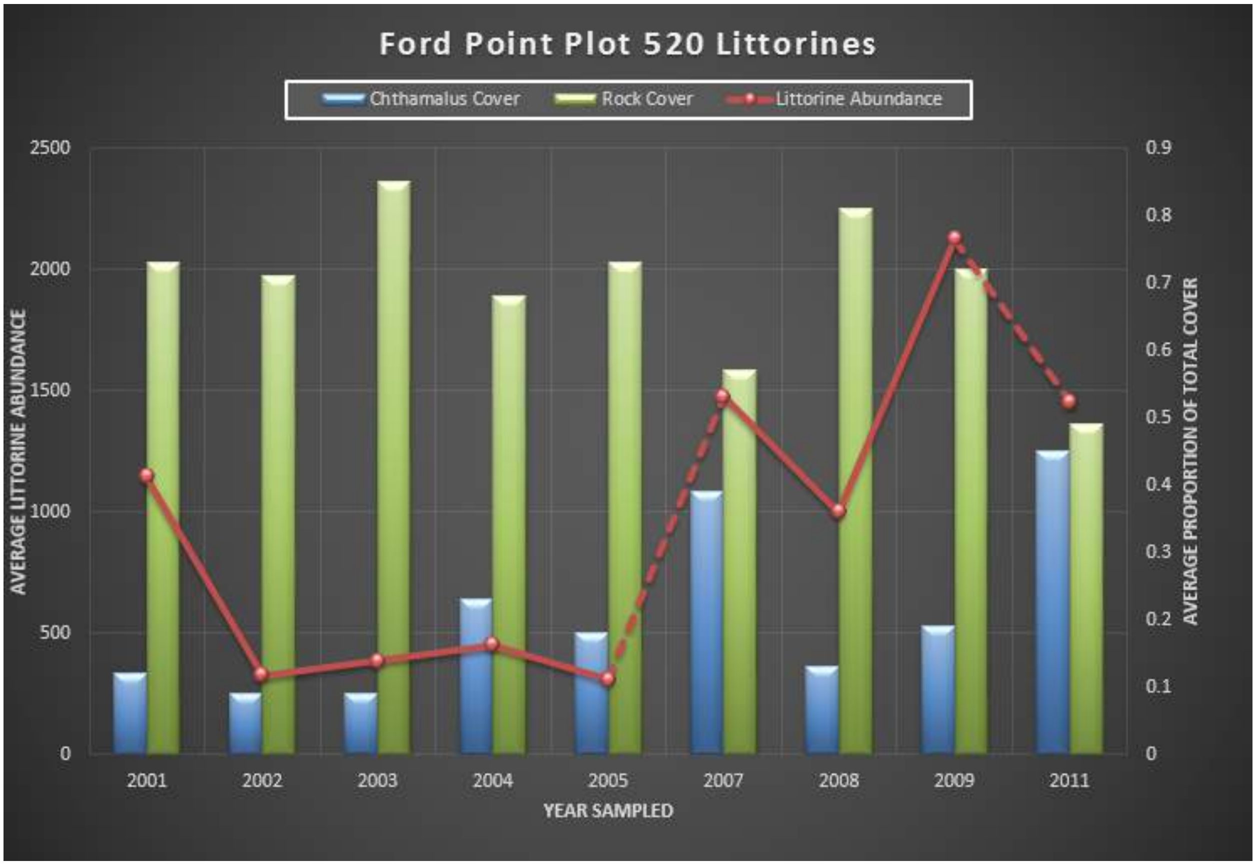


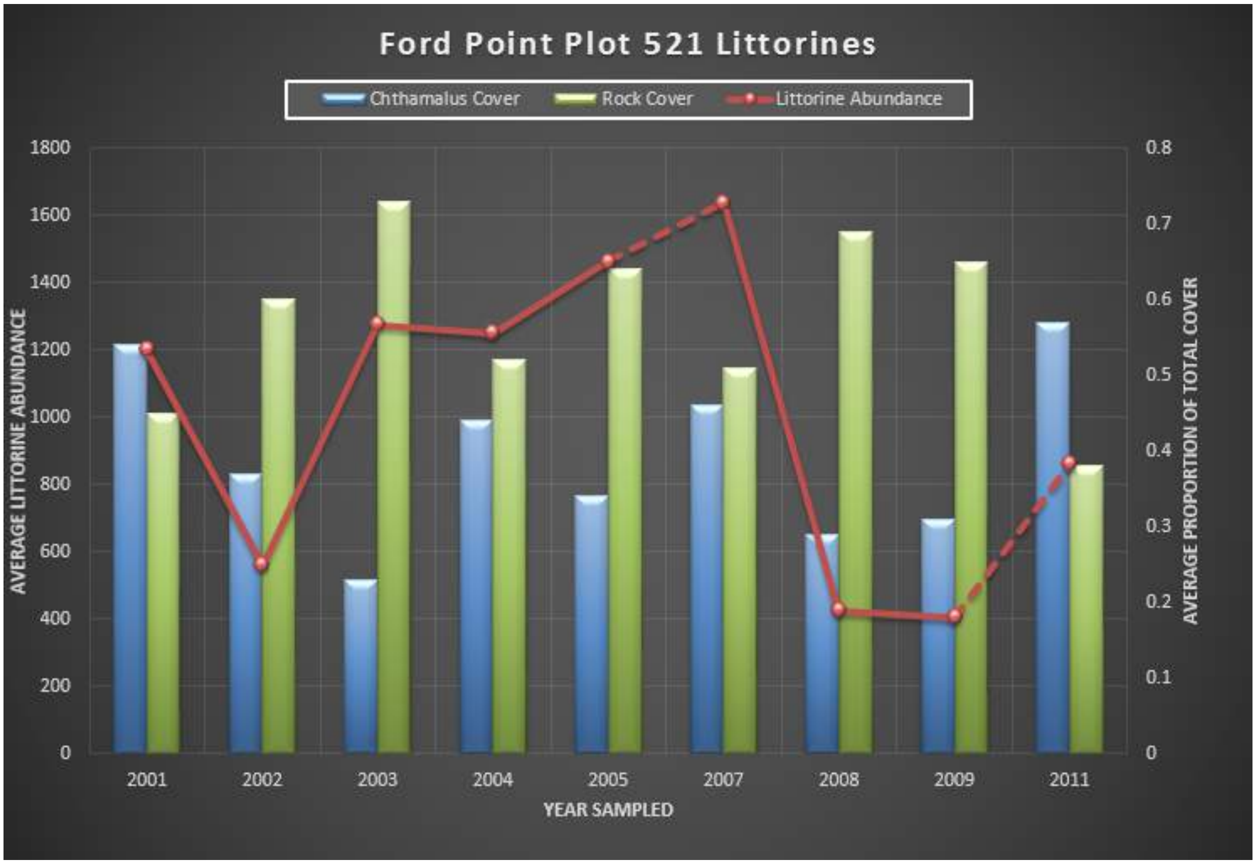


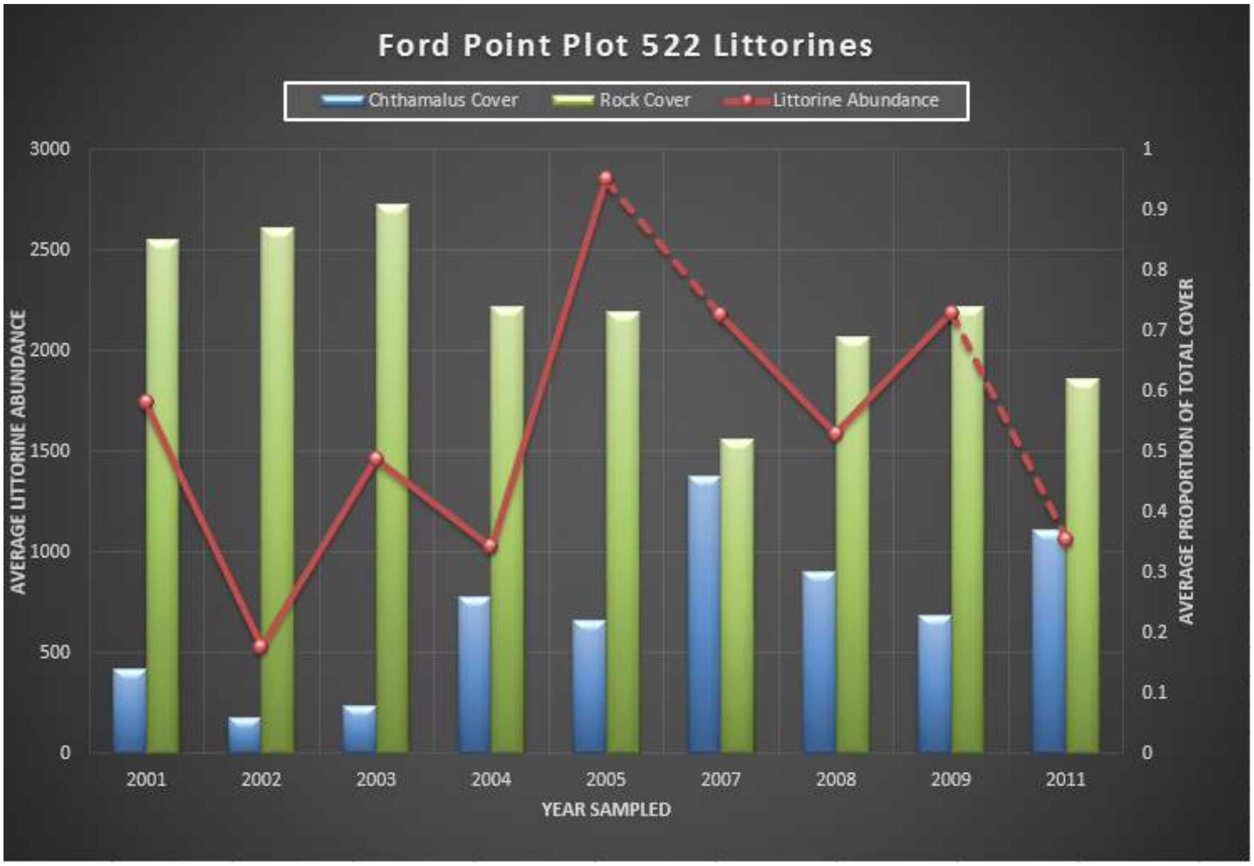

East Point Plot 577 Littorines
Chthamalus Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
1400
1200
1000
800
600
400
200
0
AVERAGE PROPORTION OF TOTAL COVER
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

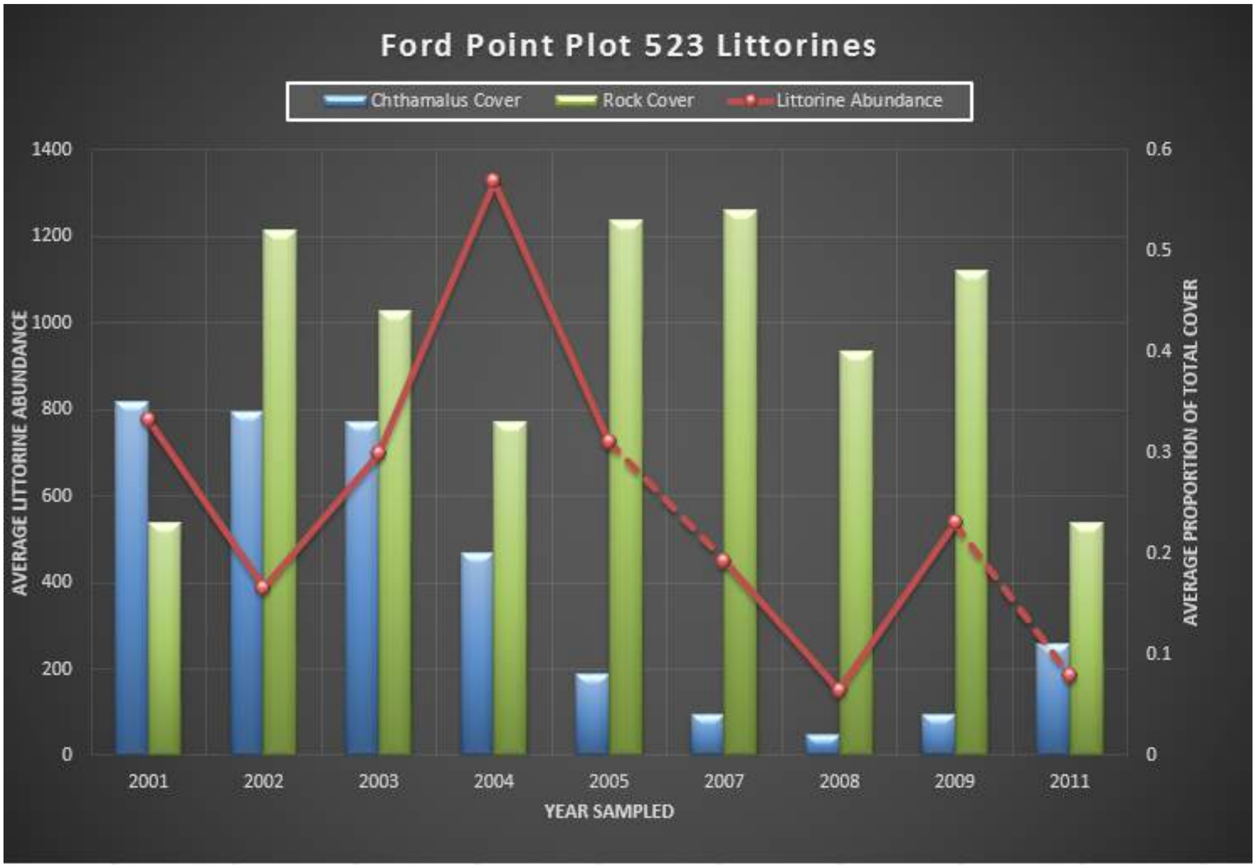

East Point Plot 578 Littorines
Chthamalus Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
3500
3000
2500
2000
1500
1000
500
0
AVERAGE PROPORTION OF TOTAL COVER
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

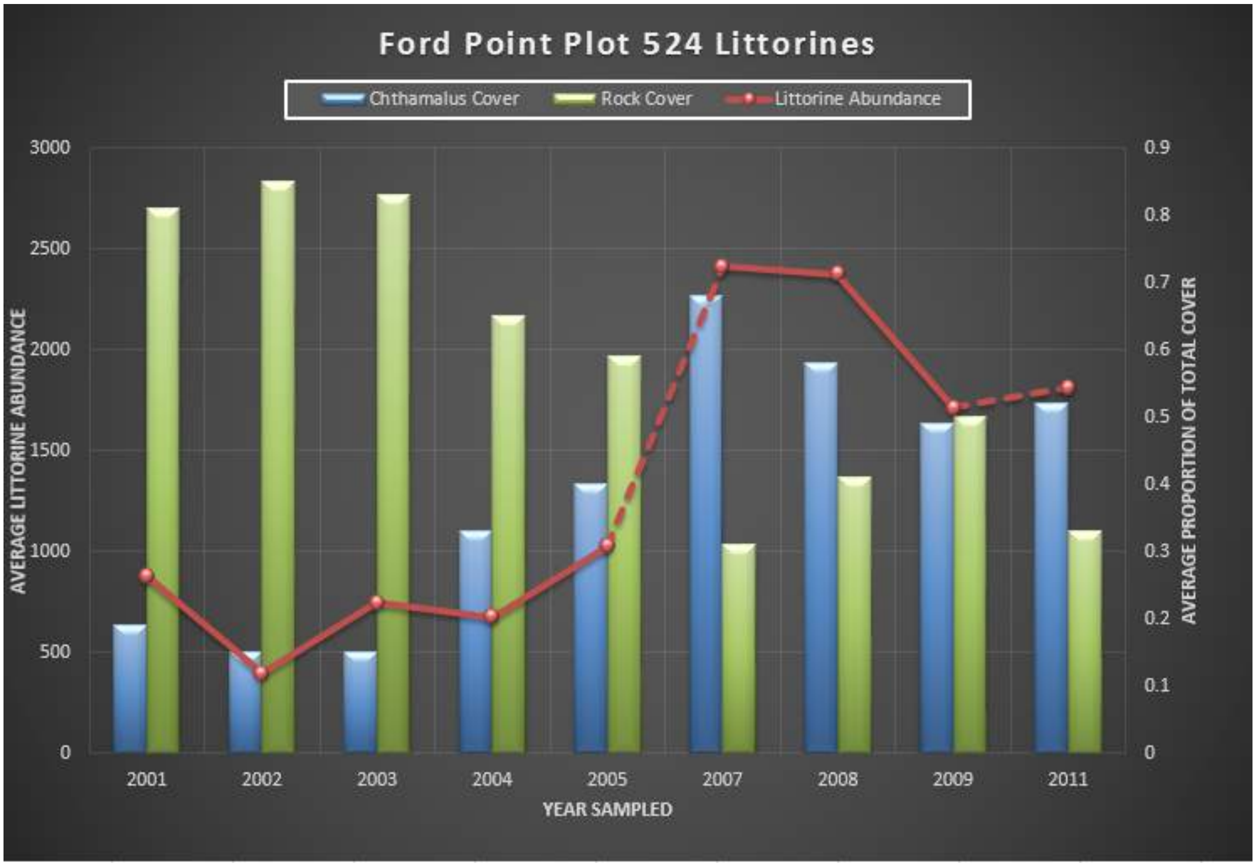

East Point Plot 579 Littorines
Chthamalus Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
0
500
1000
1500
2000
2500
3000
3500
4000
4500
AVERAGE PROPORTION OF TOTAL COVER
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

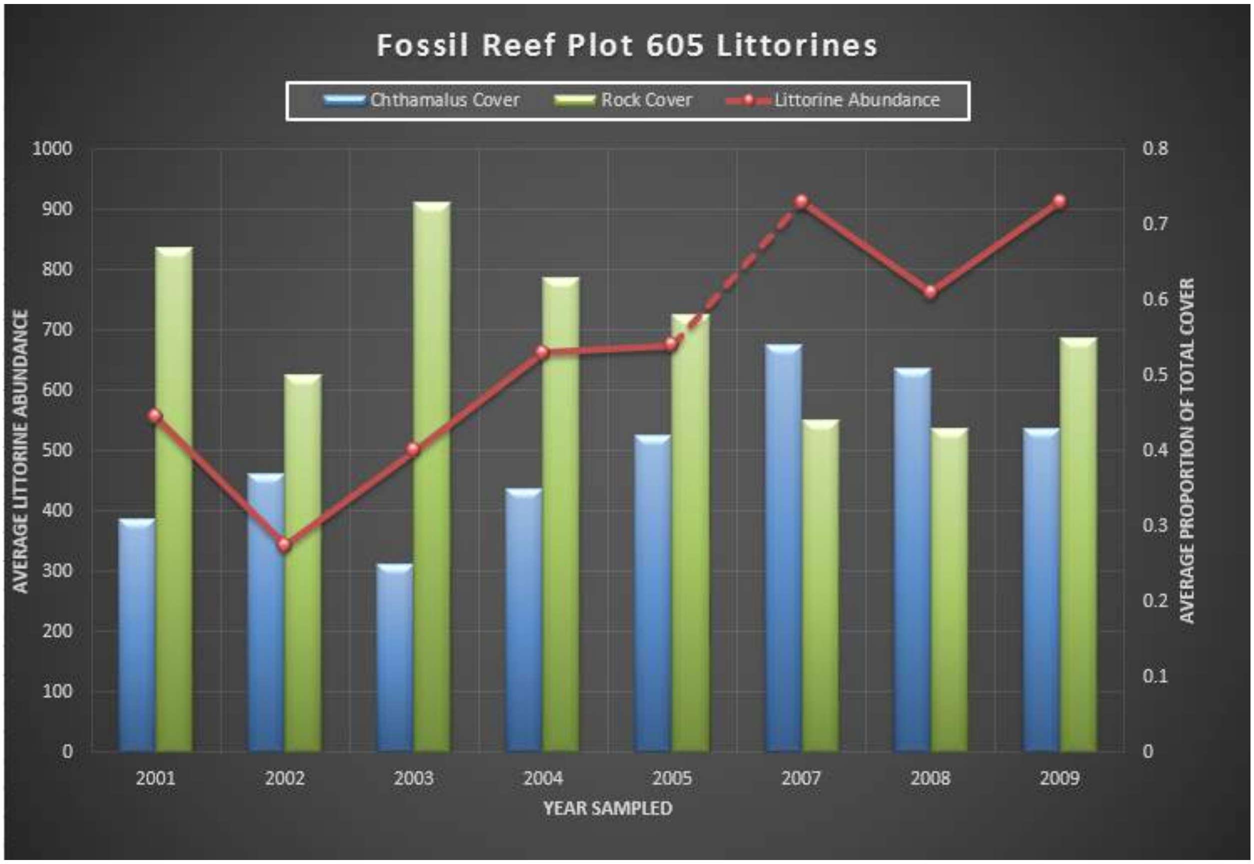

Ford Point Plot 520 Littorines
Chthamalus Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
0
500
1000
1500
2000
2500
AVERAGE PROPORTION OF TOTAL COVER
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

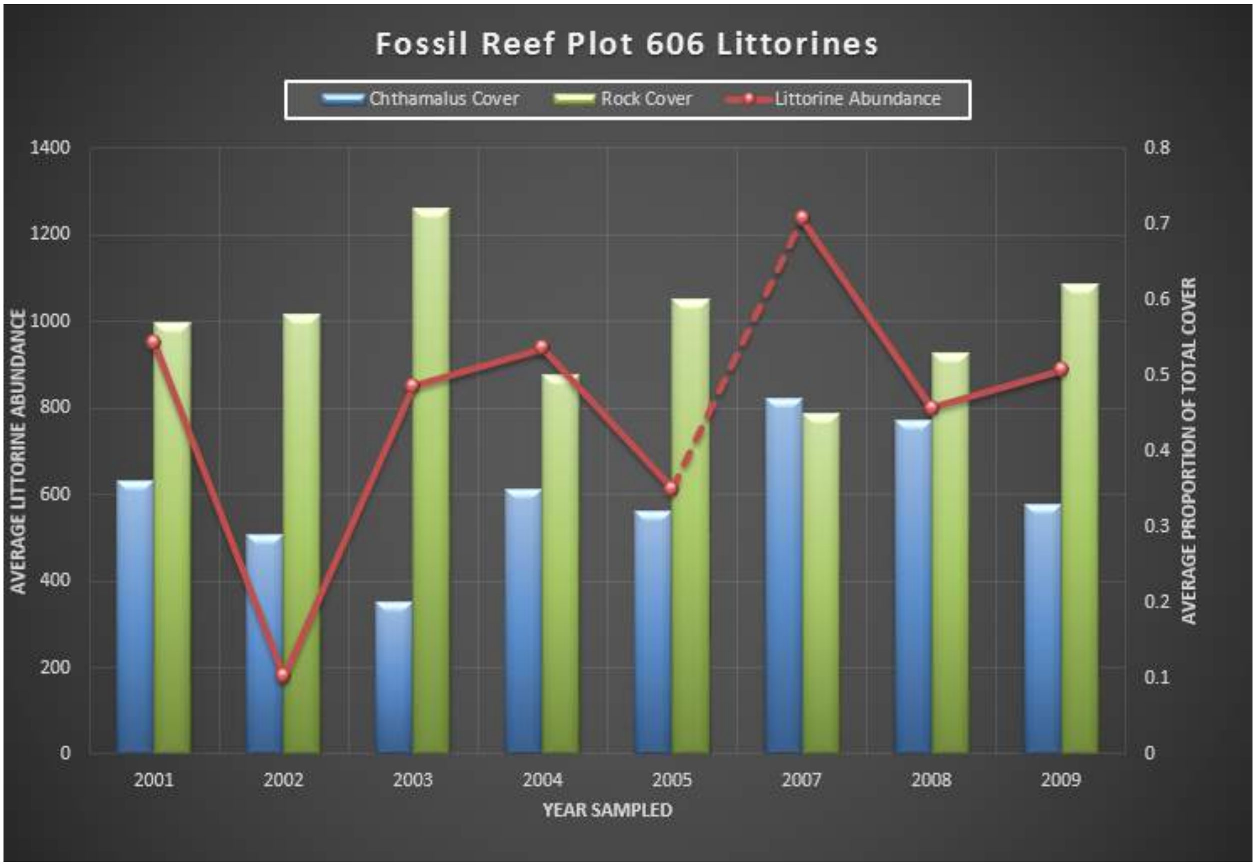

Ford Point Plot 521 Littorines
Chthamalus Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
0
200
400
600
800
1000
1200
1400
1600
1800
AVERAGE PROPORTION OF TOTAL COVER
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

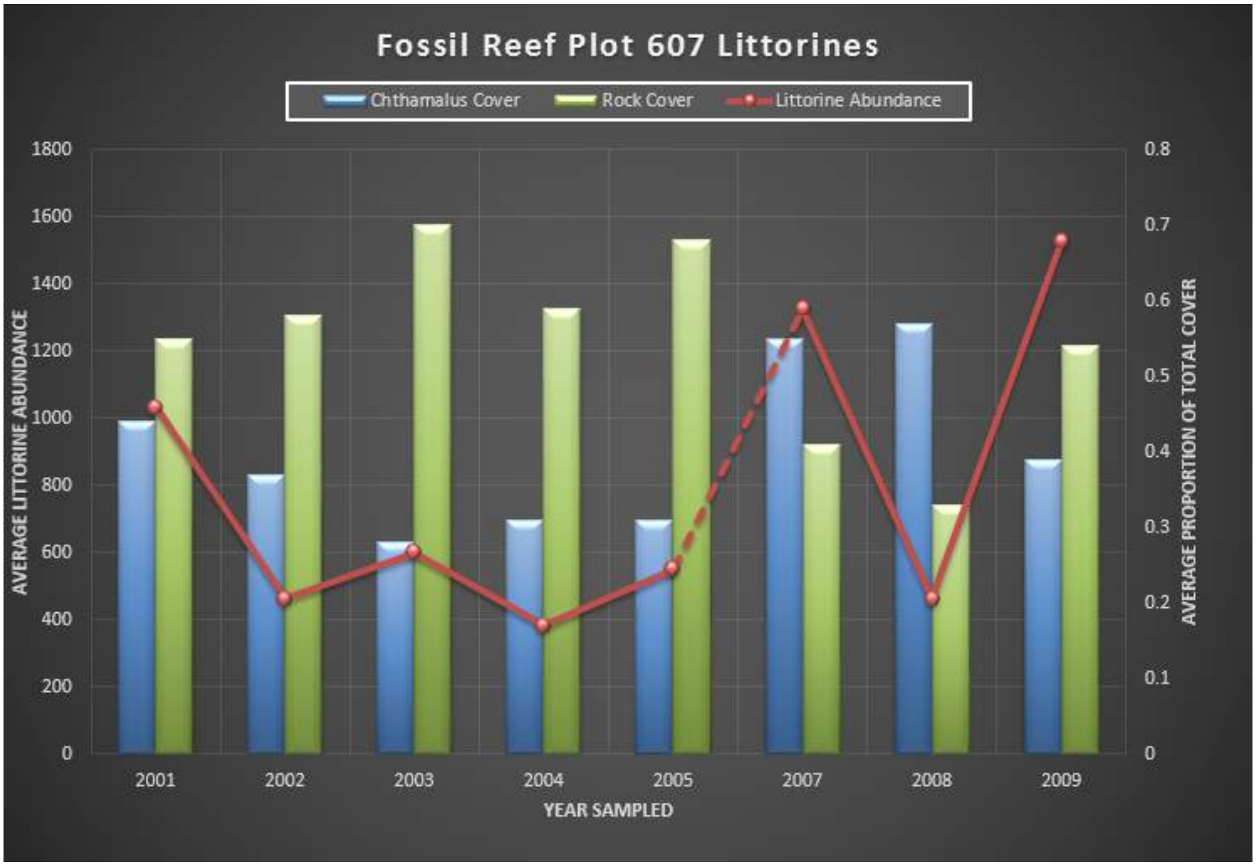

Ford Point Plot 522 Littorines
Chthamalus Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
0
500
1000
1500
2000
2500
3000
AVERAGE PROPORTION OF TOTAL COVER
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

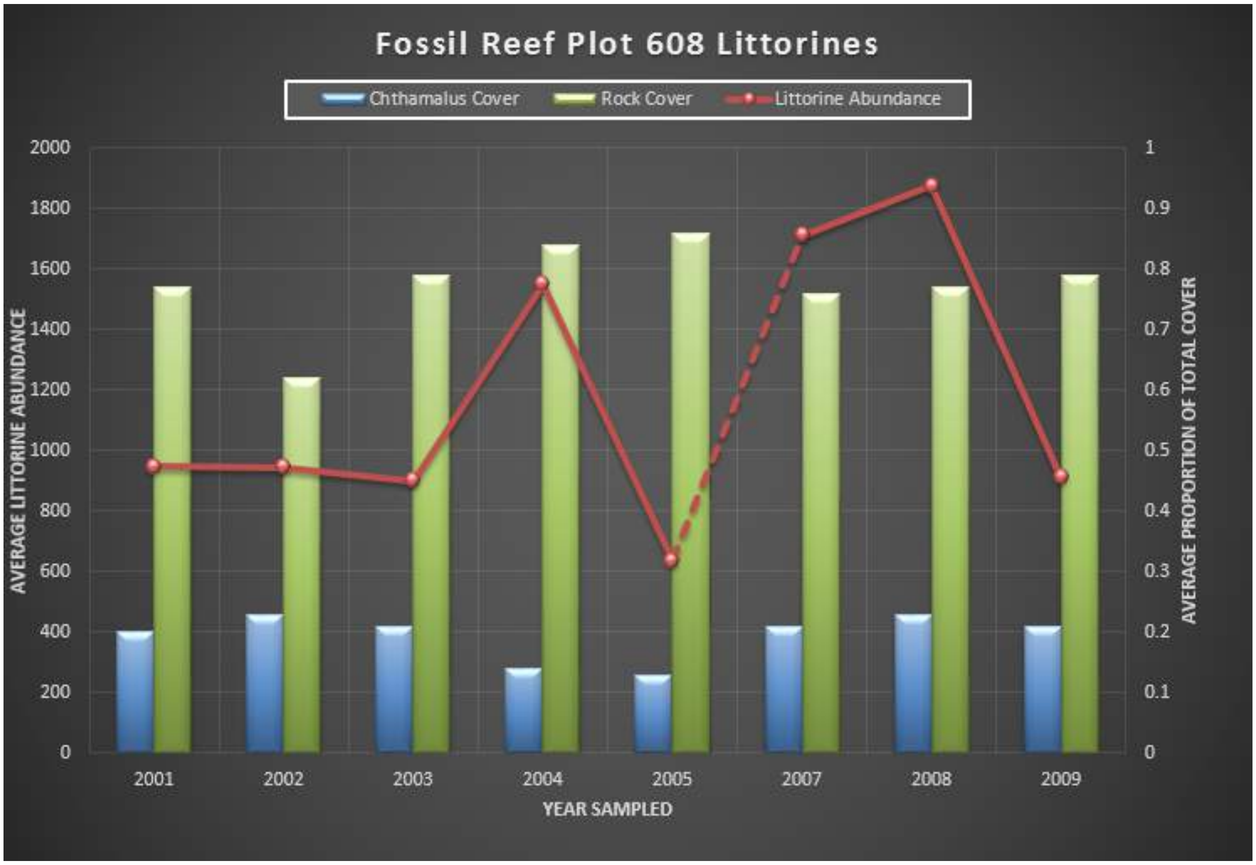

Ford Point Plot 523 Littorines
Chthamalus Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
AVERAGE PROPORTION OF TOTAL COVER
YEAR SAMPLED
0
200
400
600
800
1000
1200
1400
0
0.1
0.2
0.3
0.4
0.5
0.6
2001
2002
2003
2004
2005
2007
2008
2009
2011

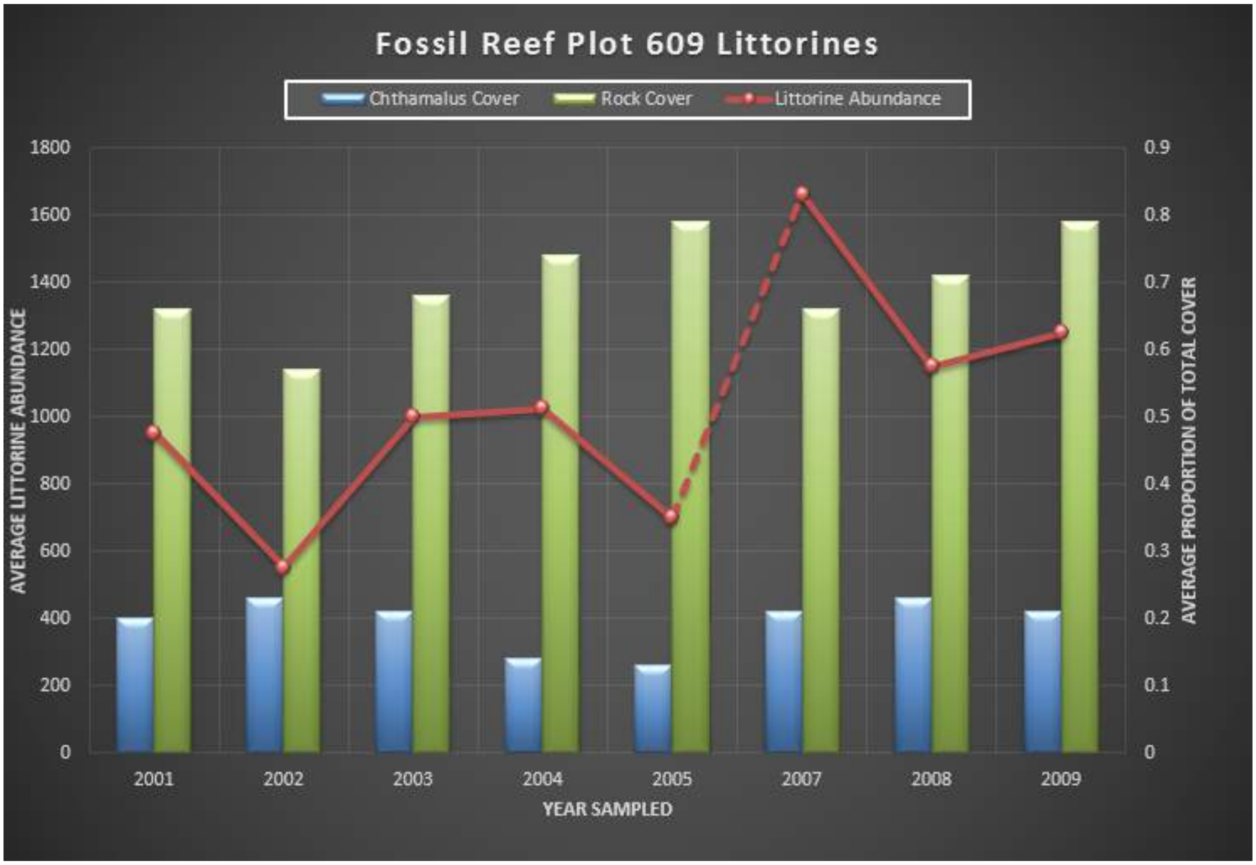

Ford Point Plot 524 Littorines
Chthamalus Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
AVERAGE PROPORTION OF TOTAL COVER
YEAR SAMPLED
0
500
1000
1500
2000
2500
3000
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
2001
2002
2003
2004
2005
2007
2008
2009
2011


Fossil Reef Plot 605 Littorines
Chthamalus Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
1000
900
800
700
600
500
400
300
200
100
0
AVERAGE PROPORTION OF TOTAL COVER
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2001
2002
2003
2004
2005
2007
2008
2009
YEAR SAMPLED

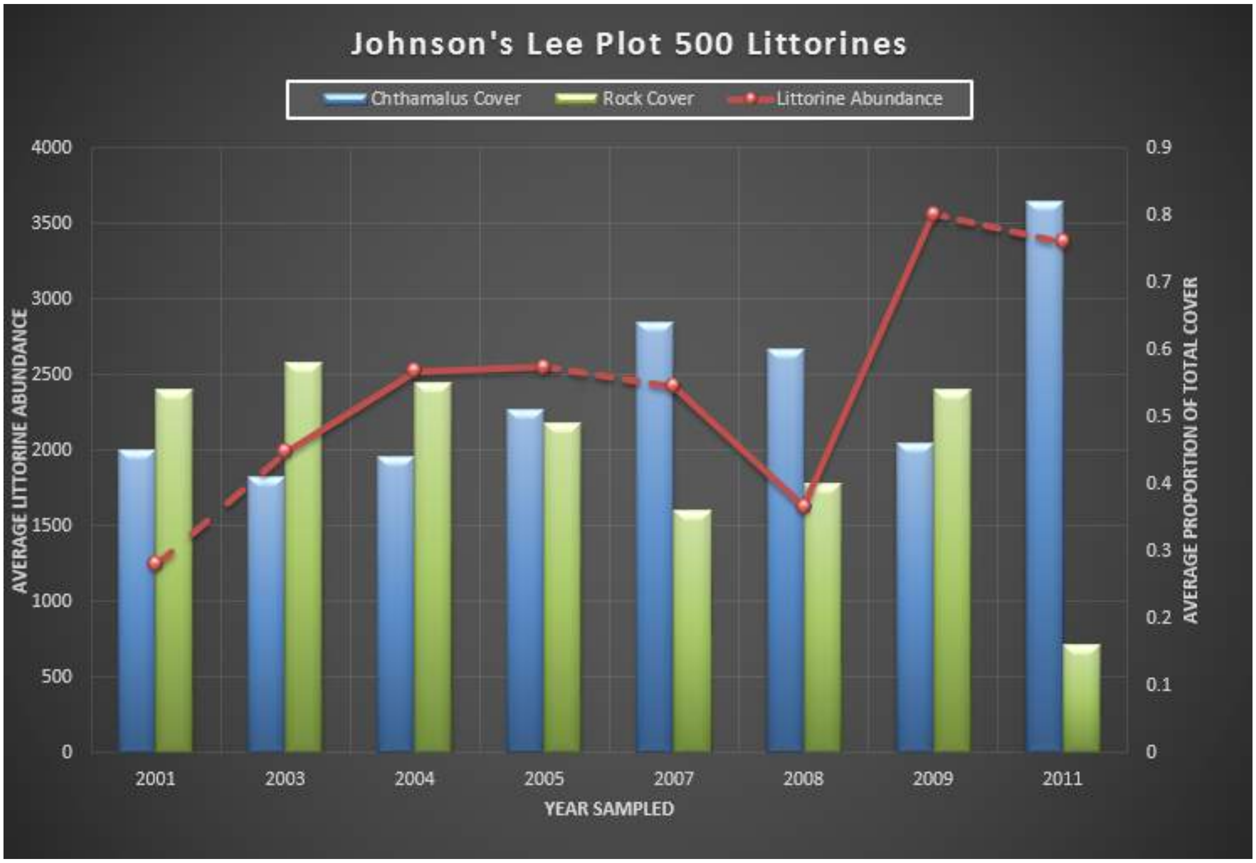

Fossil Reef Plot 606 Littorines
Chthamalus Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
1400
1200
1000
800
600
400
200
0
AVERAGE PROPORTION OF TOTAL COVER
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2001
2002
2003
2004
2005
2007
2008
2009
YEAR SAMPLED


Fossil Reef Plot 607 Littorines
Chthamalus Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
0
200
400
600
800
1000
1200
1400
1600
1800
AVERAGE PROPORTION OF TOTAL COVER
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
2001
2002
2003
2004
2005
2007
2008
2009
YEAR SAMPLED

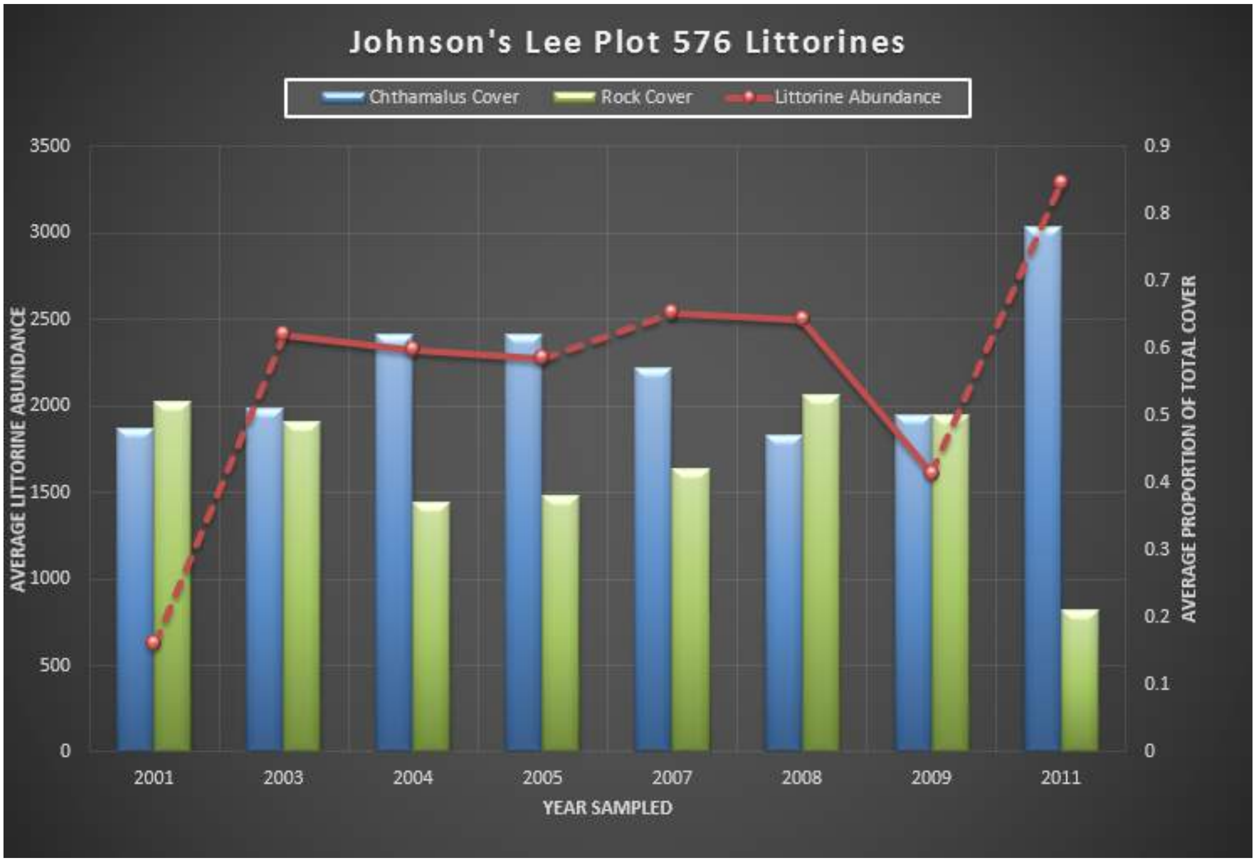

Fossil Reef Plot 608 Littorines
Chthamalus Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
0
200
400
600
800
1000
1200
1400
1600
1800
2000
AVERAGE PROPORTION OF TOTAL COVER
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2001
2002
2003
2004
2005
2007
2008
2009
YEAR SAMPLED



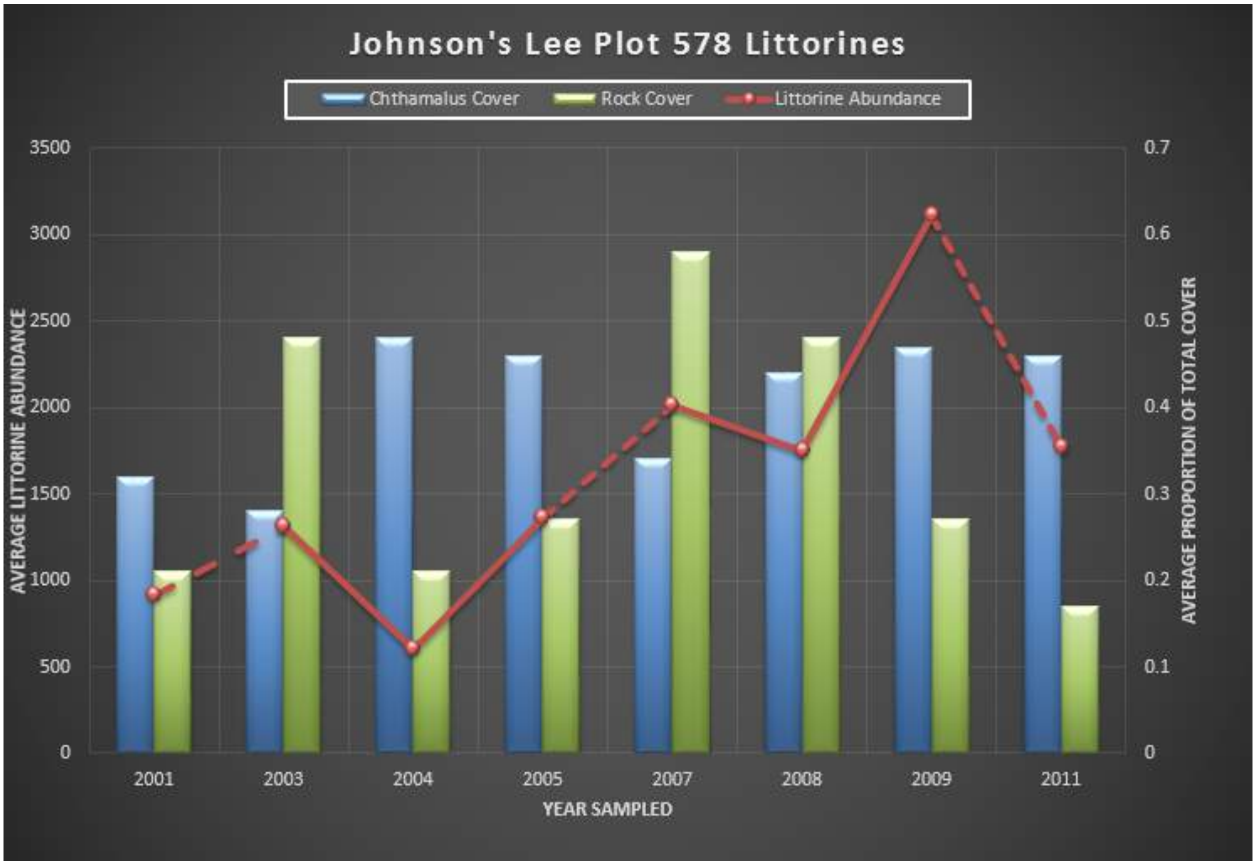
Fossil Reef Plot 609 Littorines
Chthamalus Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
0
200
400
600
800
1000
1200
1400
1600
1800
AVERAGE PROPORTION OF TOTAL COVER
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
2001
2002
2003
2004
2005
2007
2008
2009
YEAR SAMPLED

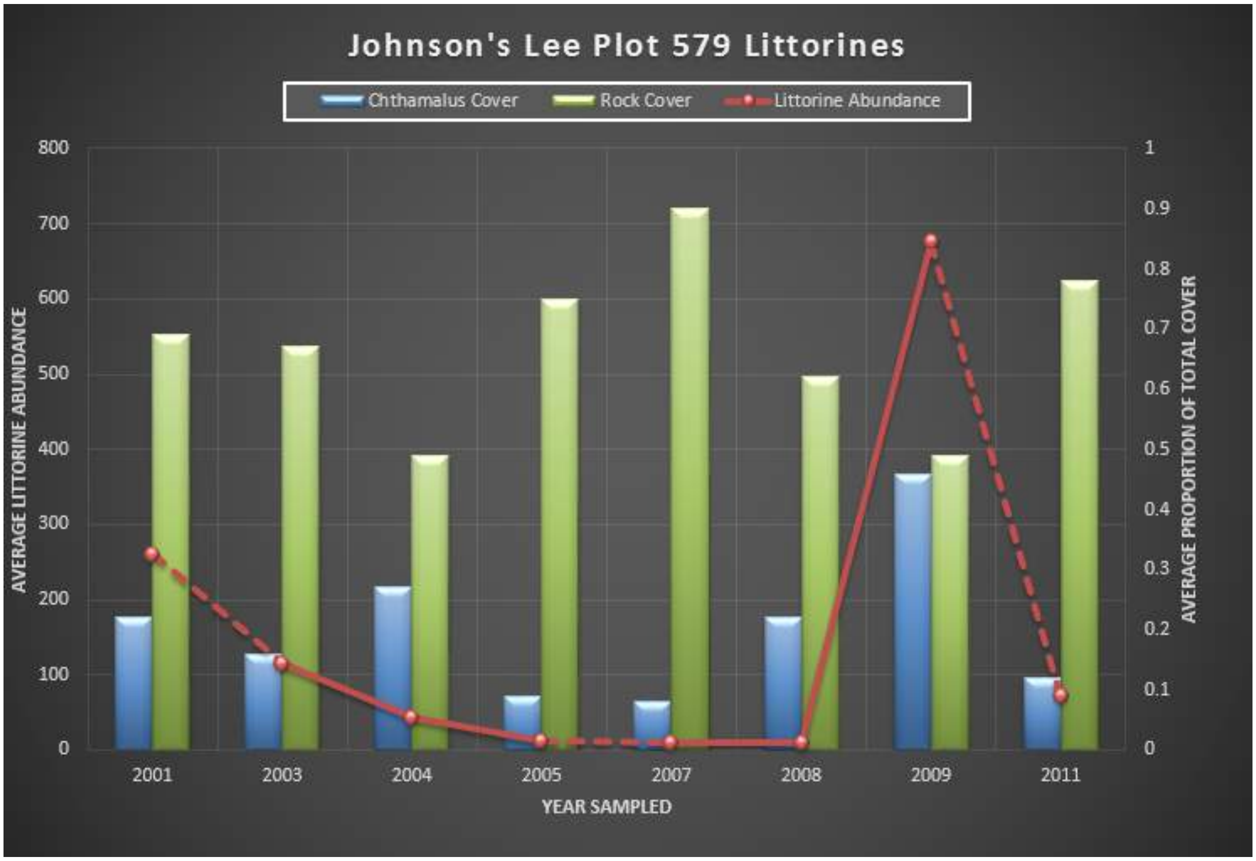


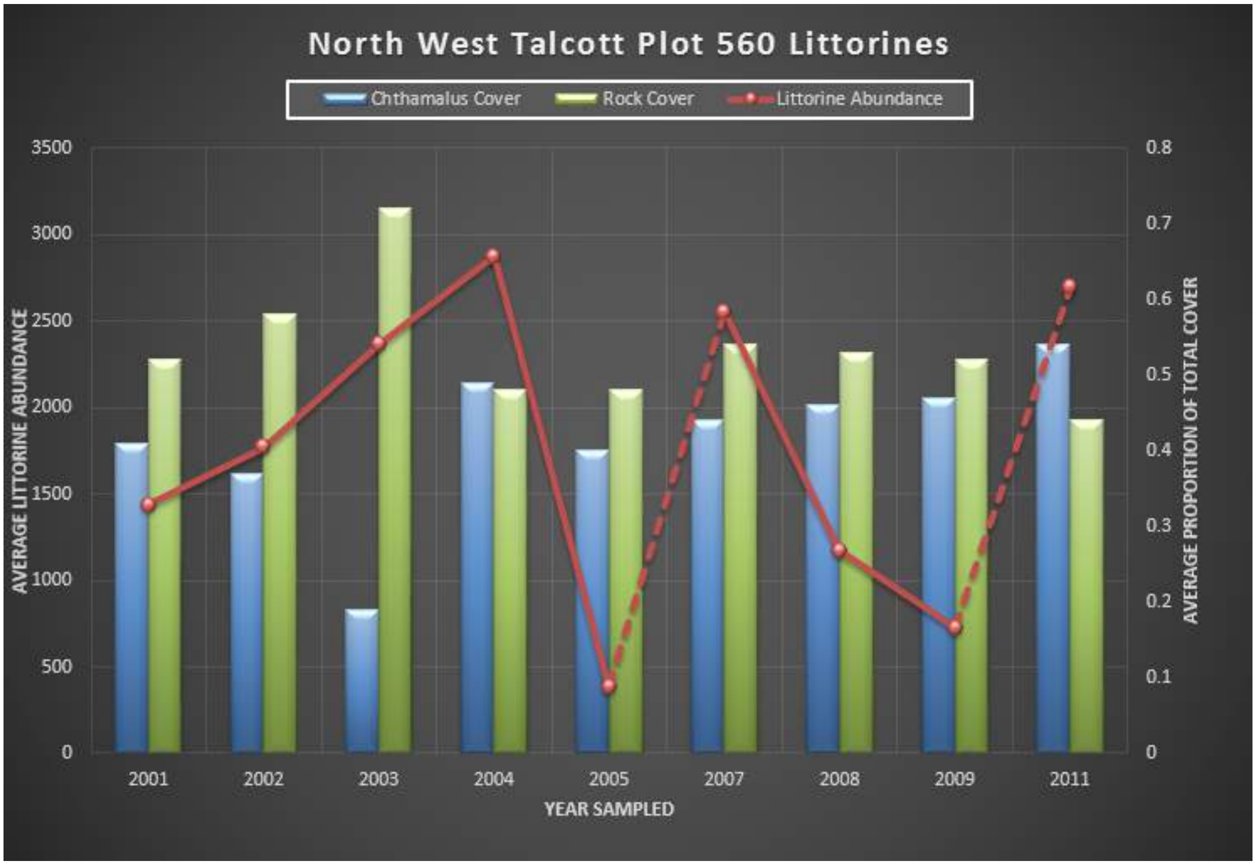
Johnson's Lee Plot 500 Littorines
Chthamalus Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
0
500
1000
1500
2000
2500
3000
3500
4000
AVERAGE PROPORTION OF TOTAL COVER
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
2001
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

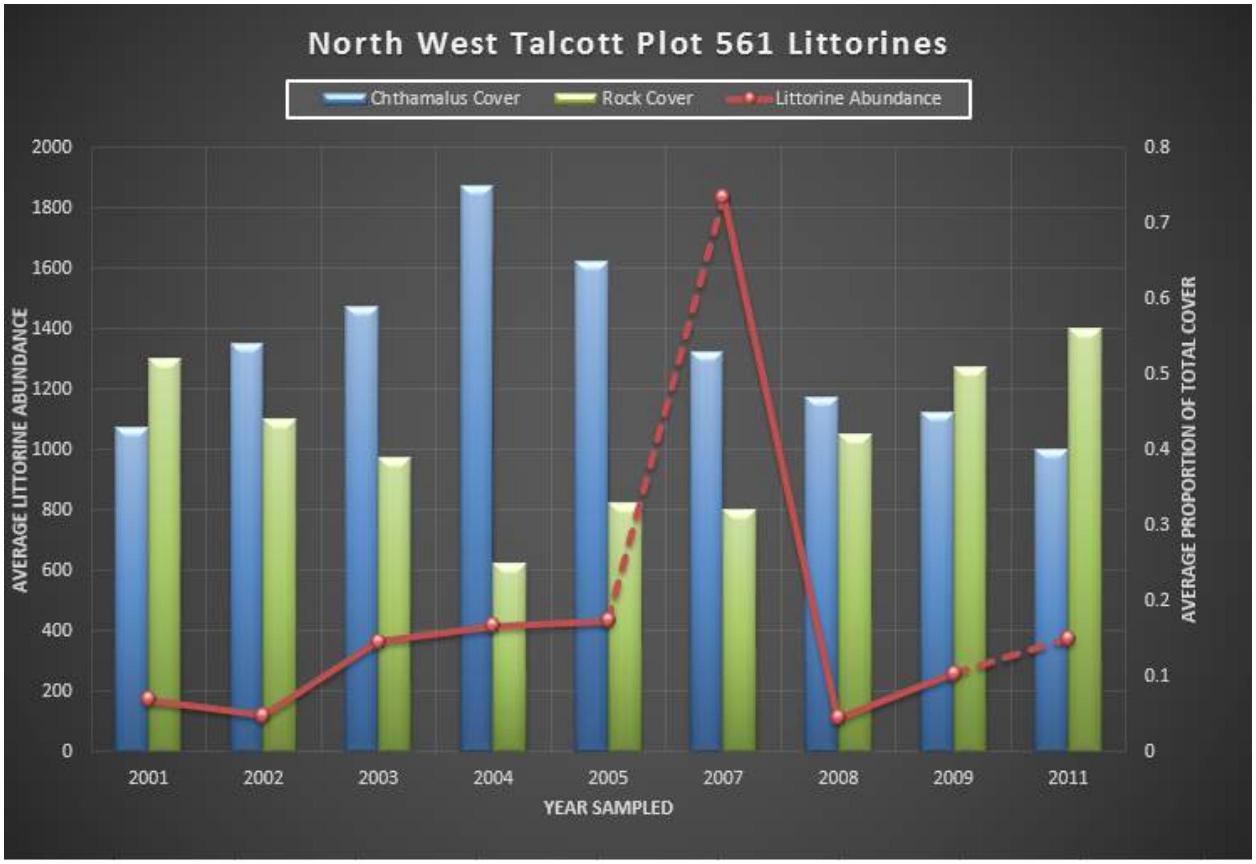

Johnson's Lee Plot 576 Littorines
Chthamalus Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
3500
3000
2500
2000
1500
1000
500
0
AVERAGE PROPORTION OF TOTAL COVER
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2001
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

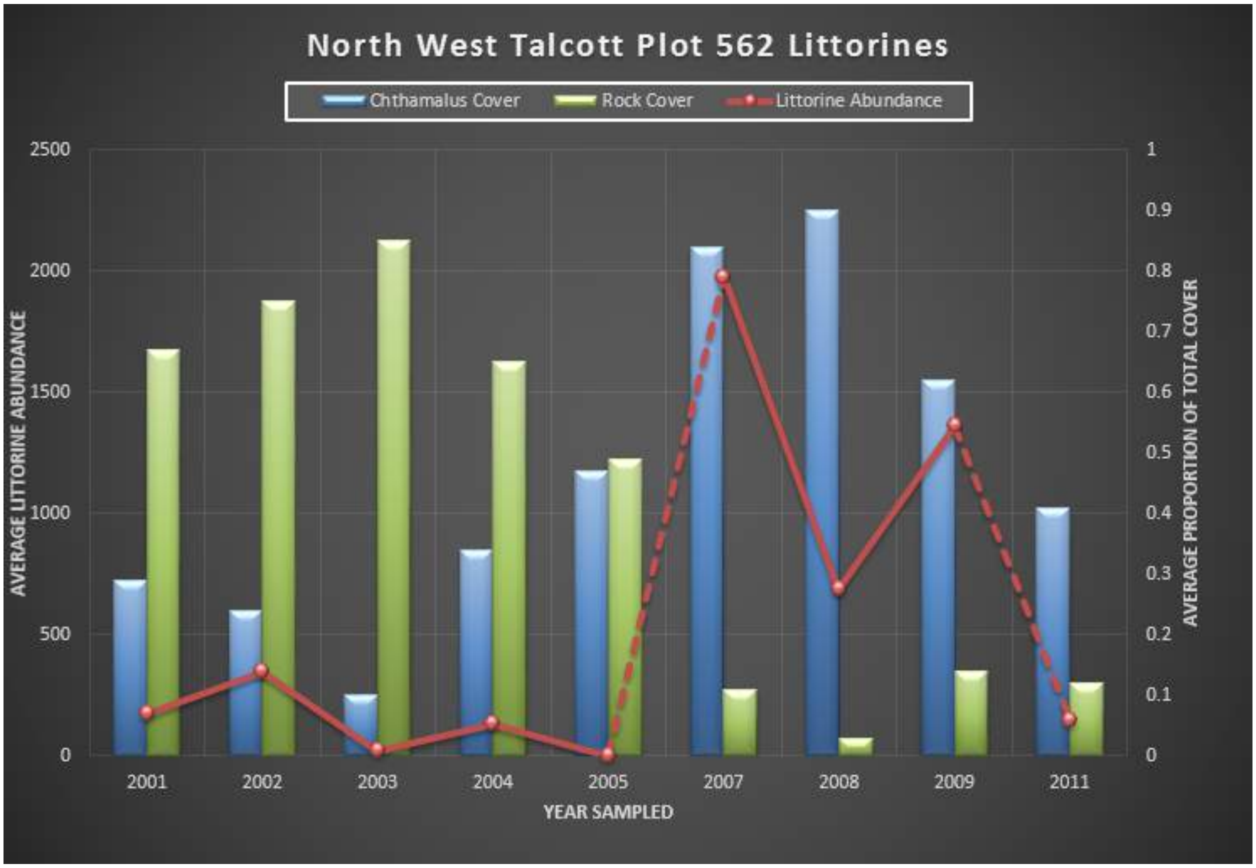

Johnson's Lee Plot 577 Littorines
Chthamalus Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
3000
2500
2000
1500
1000
500
0
AVERAGE PROPORTION OF TOTAL COVER
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2001
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

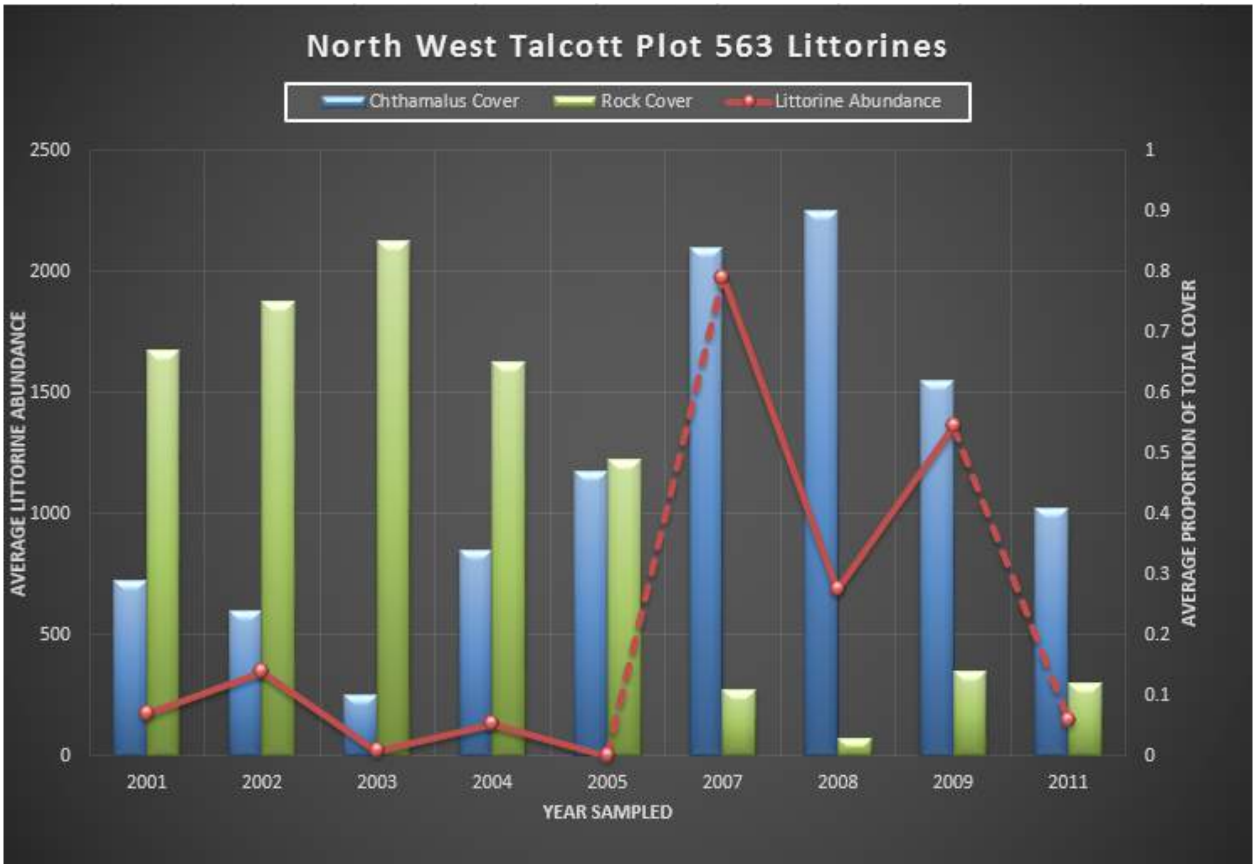

Johnson's Lee Plot 578 Littorines
Chthamalus Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
3500
3000
2500
2000
1500
1000
500
0
AVERAGE PROPORTION OF TOTAL COVER
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2001
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED


Johnson's Lee Plot 579 Littorines
Chthamalus Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
800
700
600
500
400
300
200
100
0
AVERAGE PROPORTION OF TOTAL COVER
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2001
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED


North West Talcott Plot 560 Littorines
Chthamalus Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
3500
3000
2500
2000
1500
1000
500
0
AVERAGE PROPORTION OF TOTAL COVER
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED


North West Talcott Plot 561 Littorines
Chthamalus Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
2000
1800
1600
1400
1200
1000
800
600
400
200
0
AVERAGE PROPORTION OF TOTAL COVER
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED


North West Talcott Plot 562 Littorines
Chthamalus Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
0
500
1000
1500
2000
2500
AVERAGE PROPORTION OF TOTAL COVER
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED


North West Talcott Plot 563 Littorines
Chthamalus Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
0
500
1000
1500
2000
2500
AVERAGE PROPORTION OF TOTAL COVER
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2001
2002
2003
2004
2005
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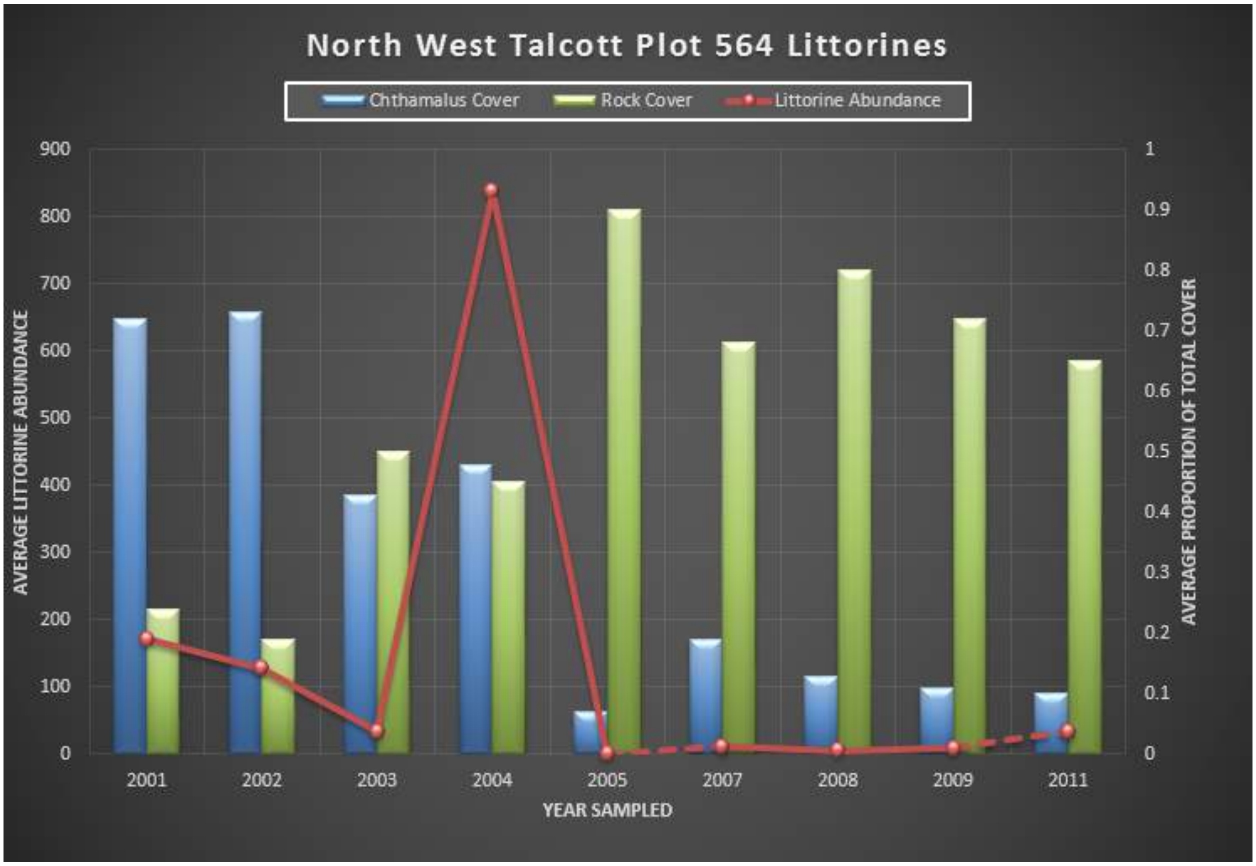
2008
2009
2011
YEAR SAMPLED


North West Talcott Plot 564 Littorines
Chthamalus Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
0
100
200
300
400
500
600
700
800
900
AVERAGE PROPORTION OF TOTAL COVER
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
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2004
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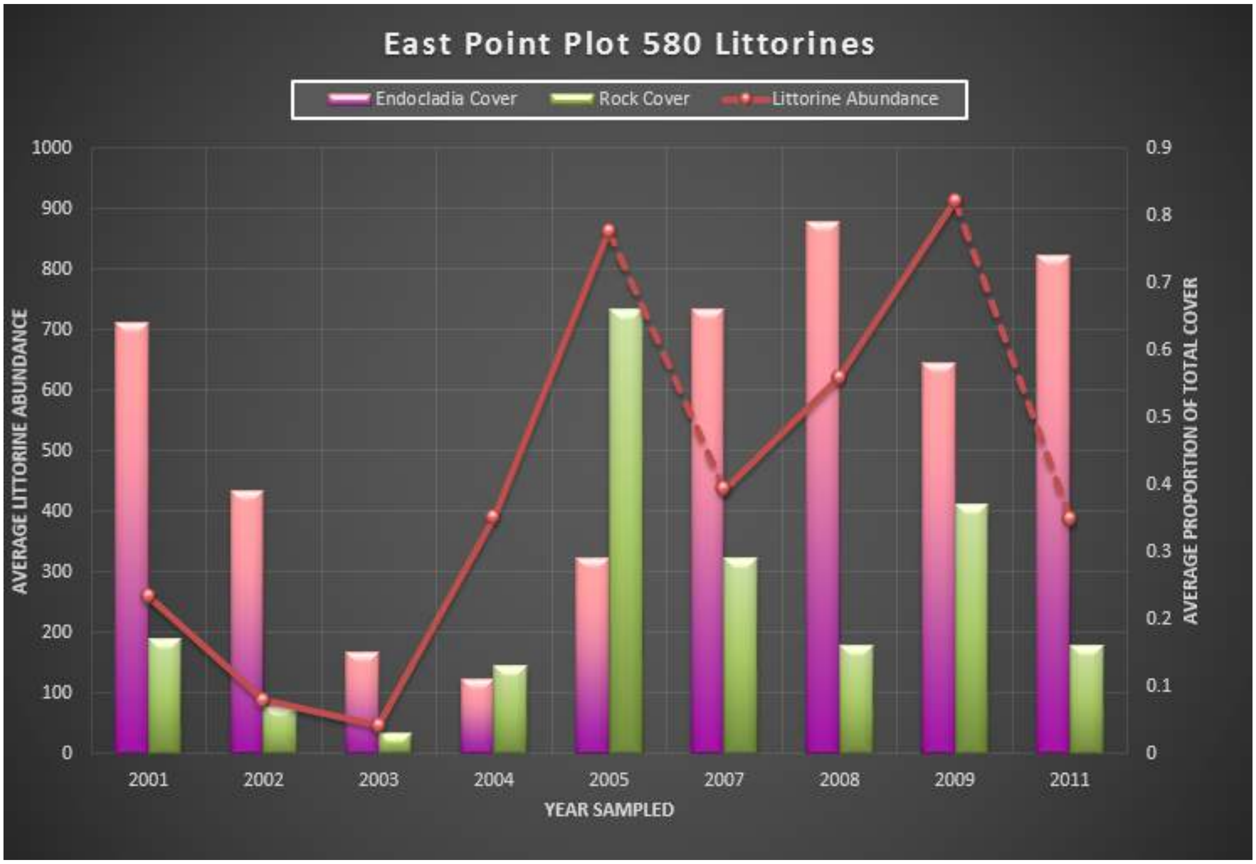
2009
2011
YEAR SAMPLED


East Point Plot 580 Littorines
Endocladia Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
0
100
200
300
400
500
600
700
800
900
1000
AVERAGE PROPORTION OF TOTAL COVER
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
2001
2002
2003
2004
2005
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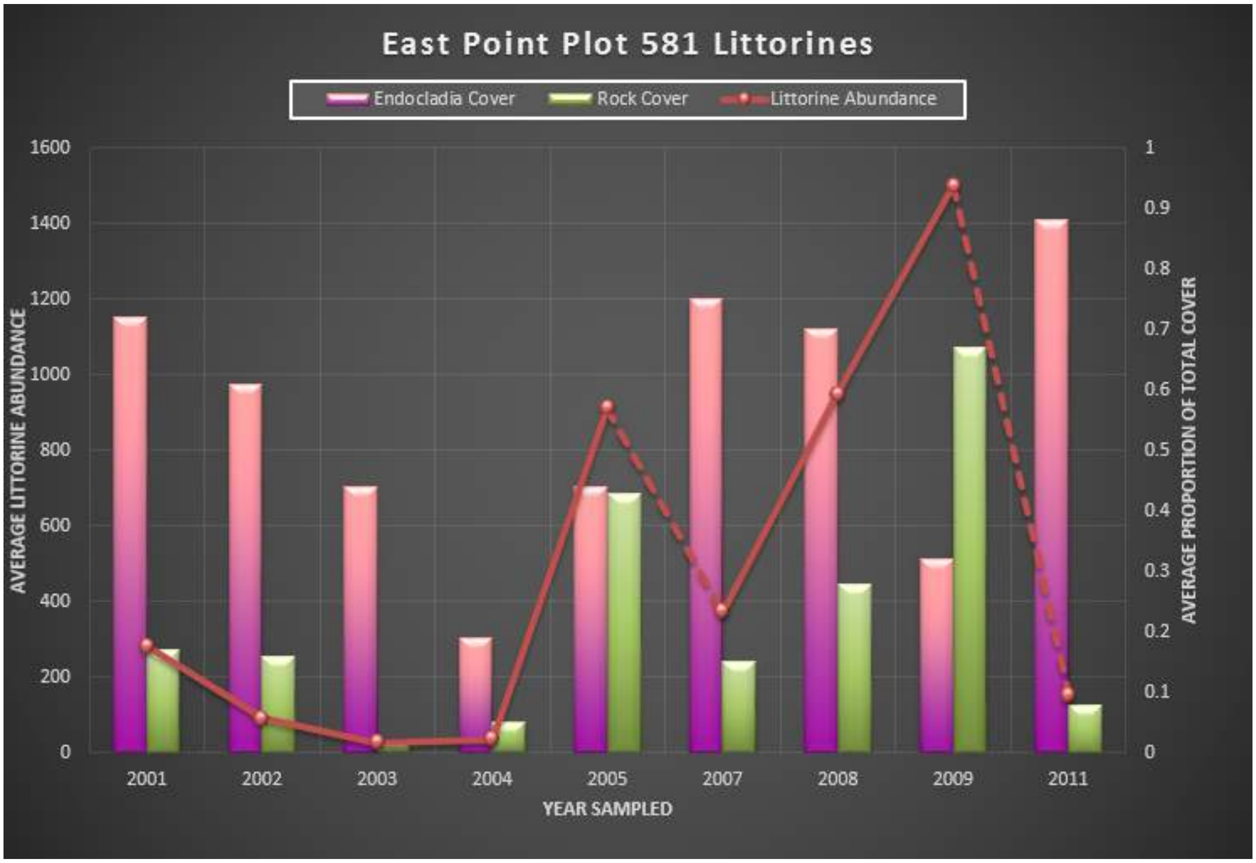
2011
YEAR SAMPLED


East Point Plot 581 Littorines
Endocladia Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
0
200
400
600
800
1000
1200
1400
1600
AVERAGE PROPORTION OF TOTAL COVER
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
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2002
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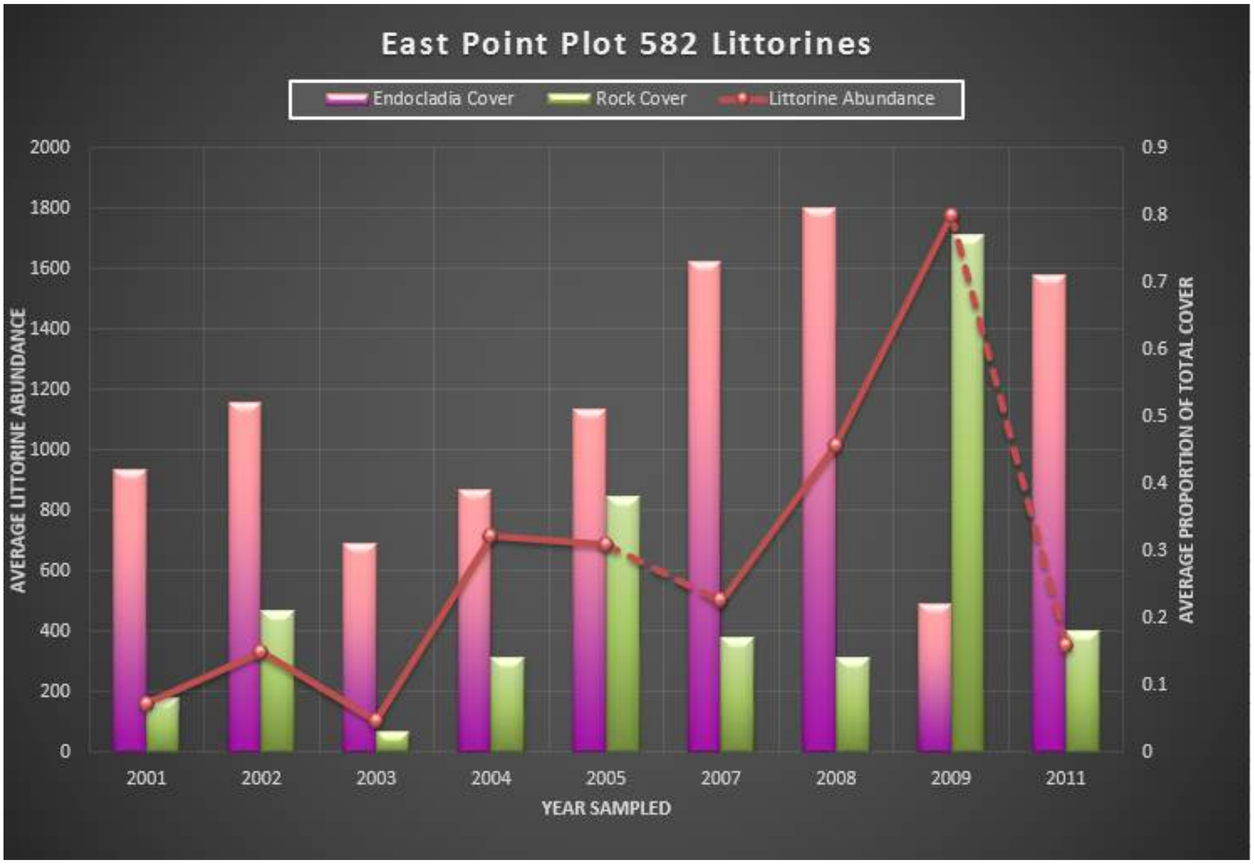
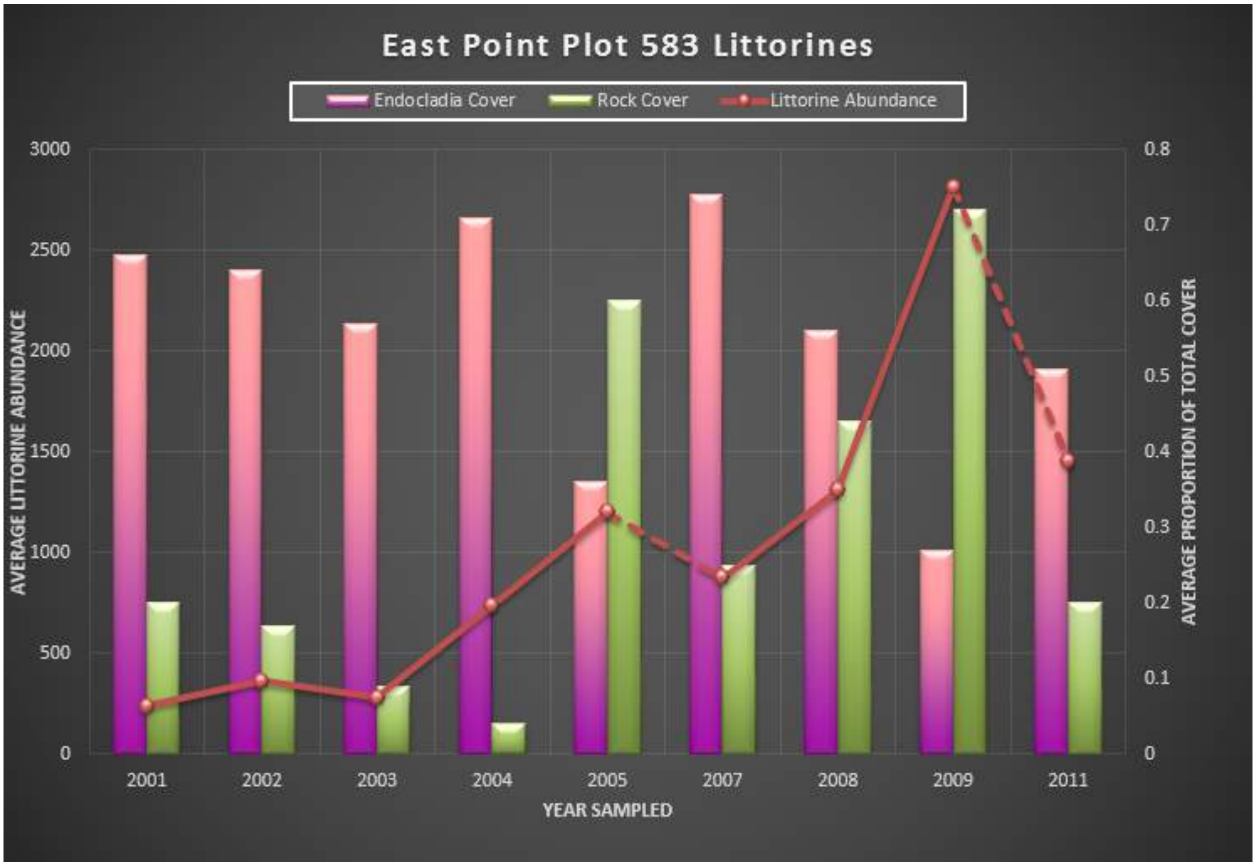
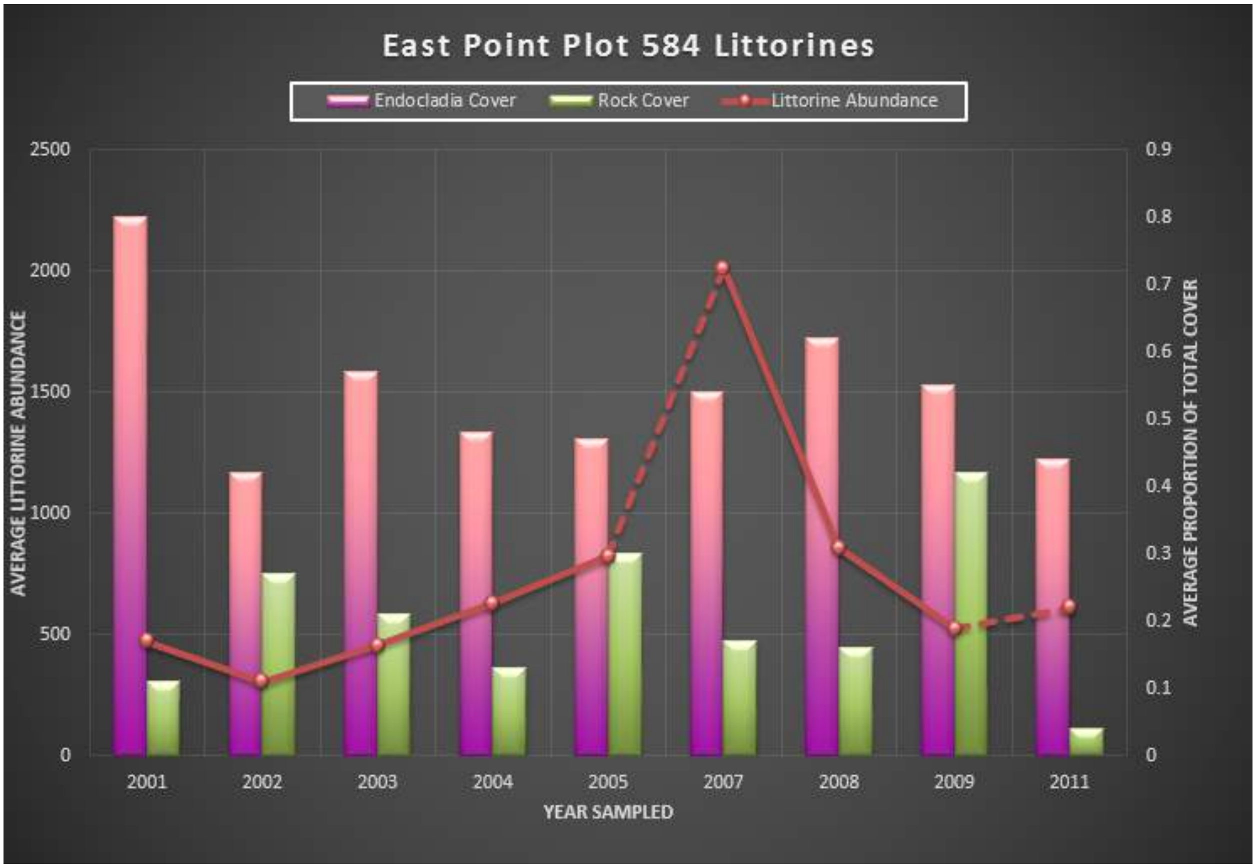
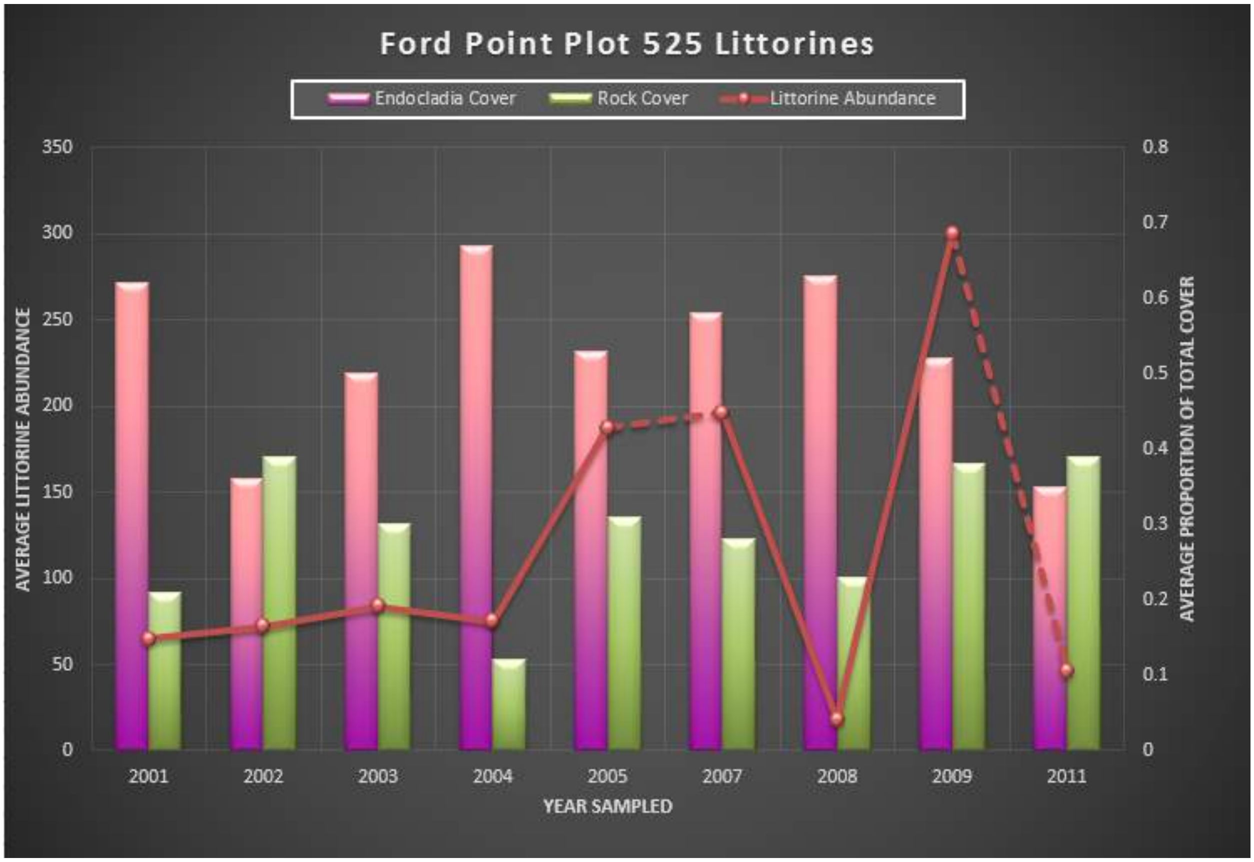
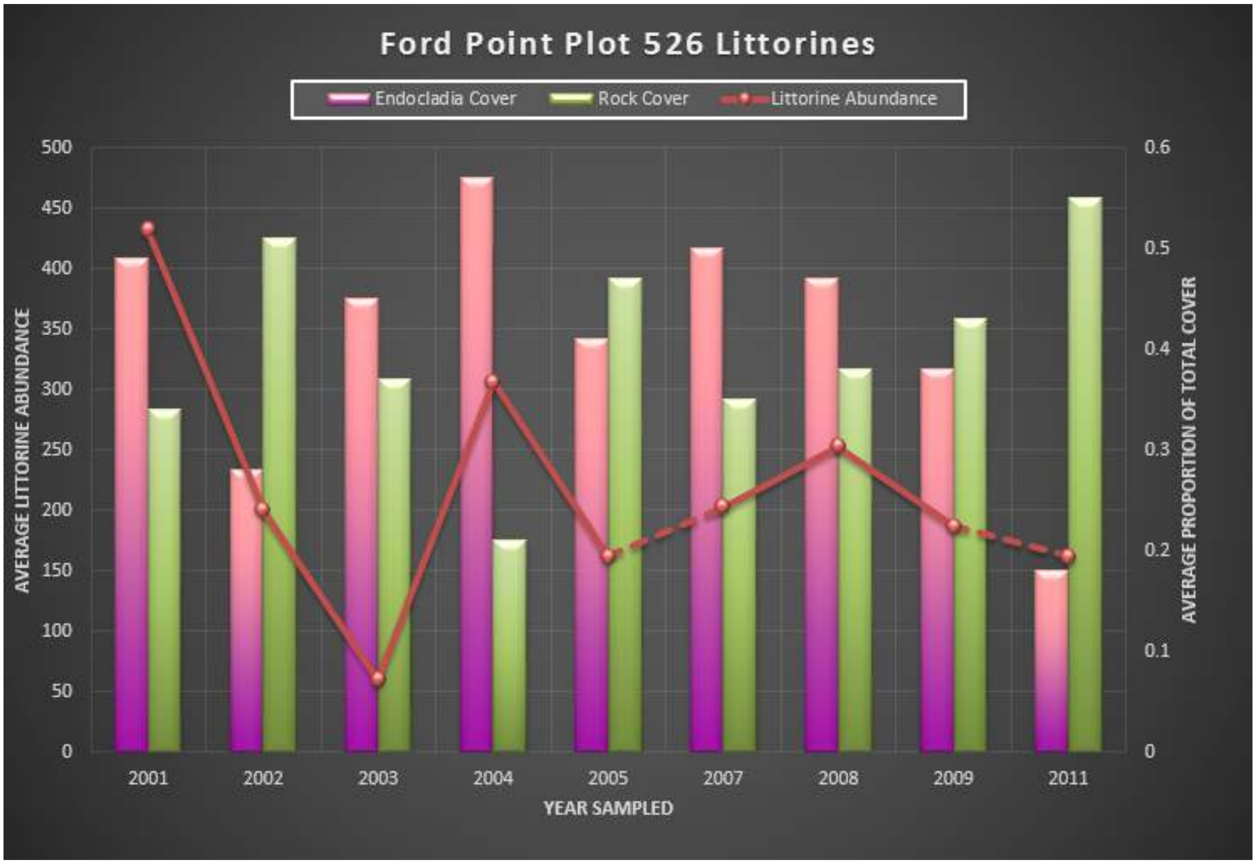
2008
2009
2011
YEAR SAMPLED

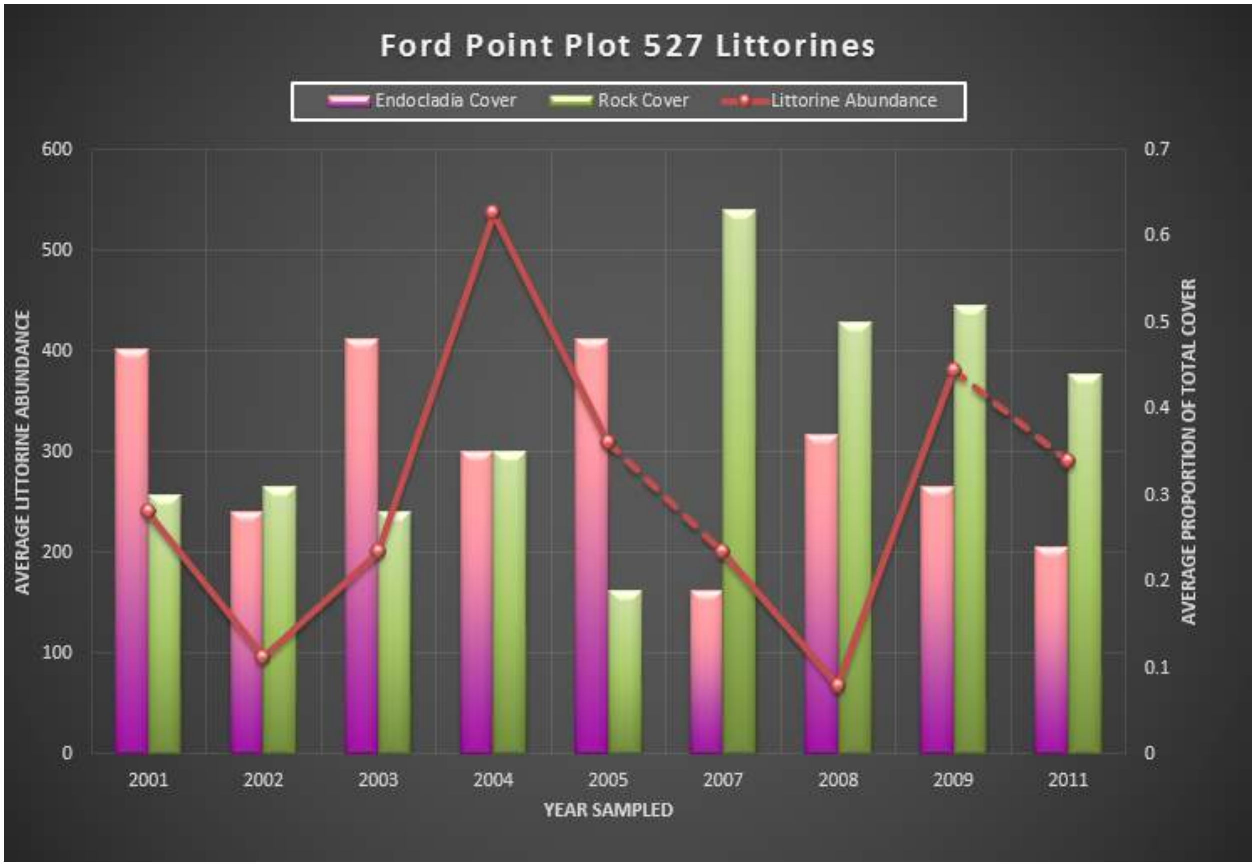

East Point Plot 582 Littorines
Endocladia Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
0
200
400
600
800
1000
1200
1400
1600
1800
2000
AVERAGE PROPORTION OF TOTAL COVER
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

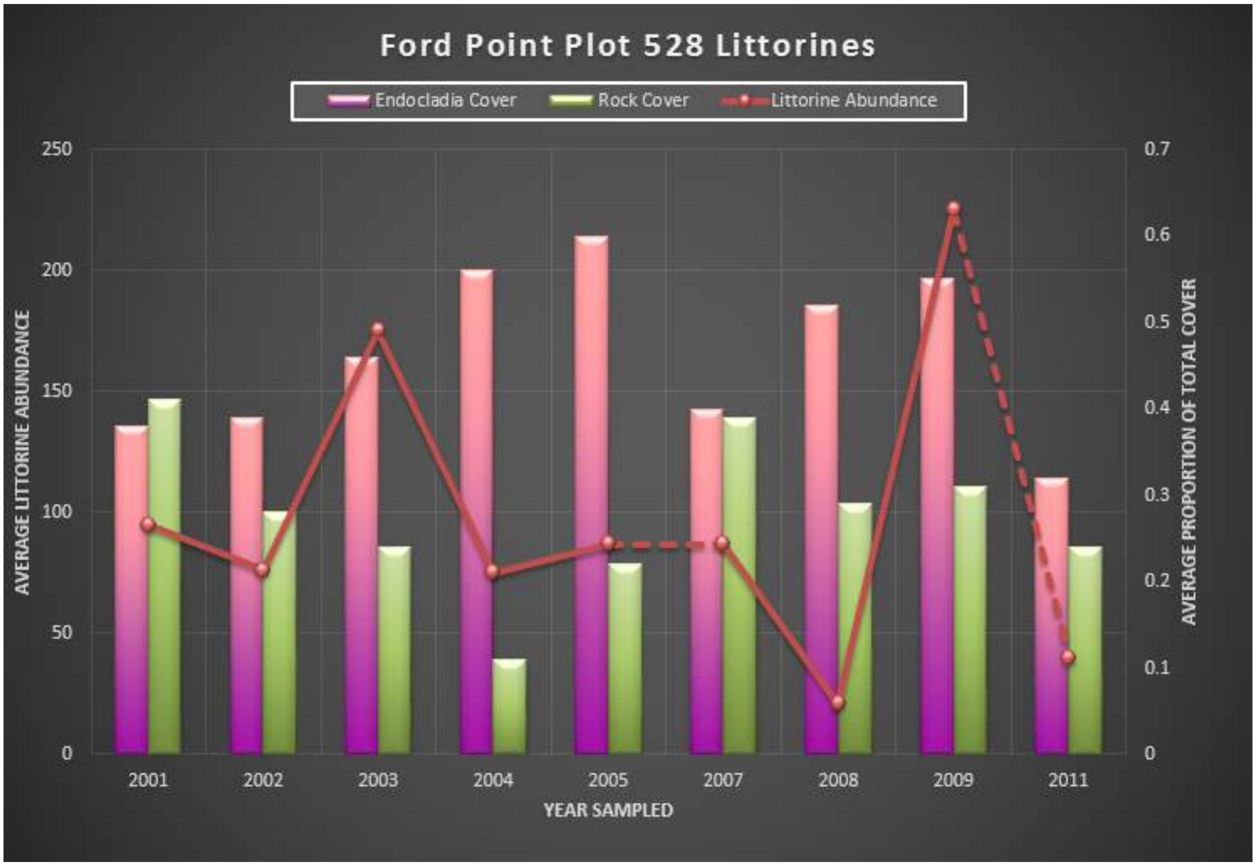

East Point Plot 583 Littorines
Endocladia Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
3000
2500
2000
1500
1000
500
0
AVERAGE PROPORTION OF TOTAL COVER
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

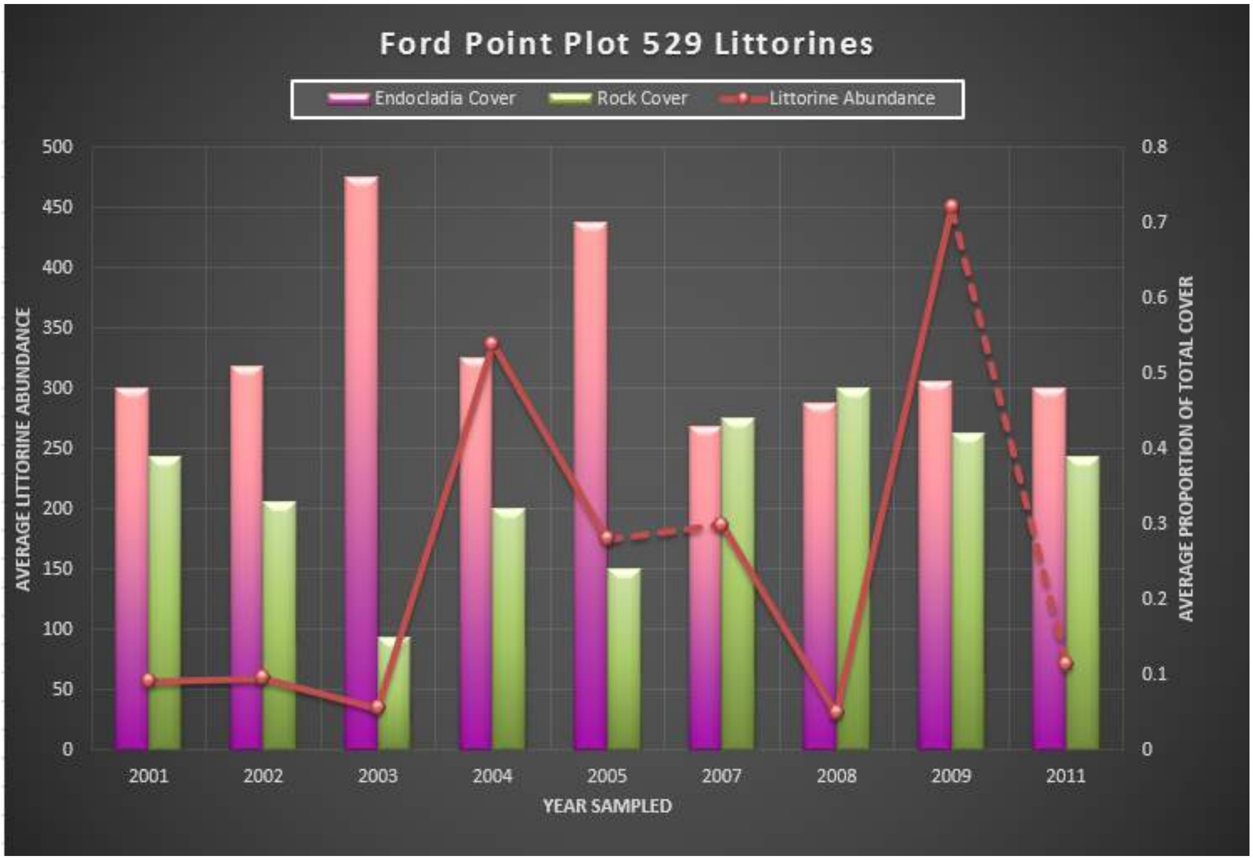

East Point Plot 584 Littorines
Endocladia Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
2500
2000
1500
1000
500
0
AVERAGE PROPORTION OF TOTAL COVER
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

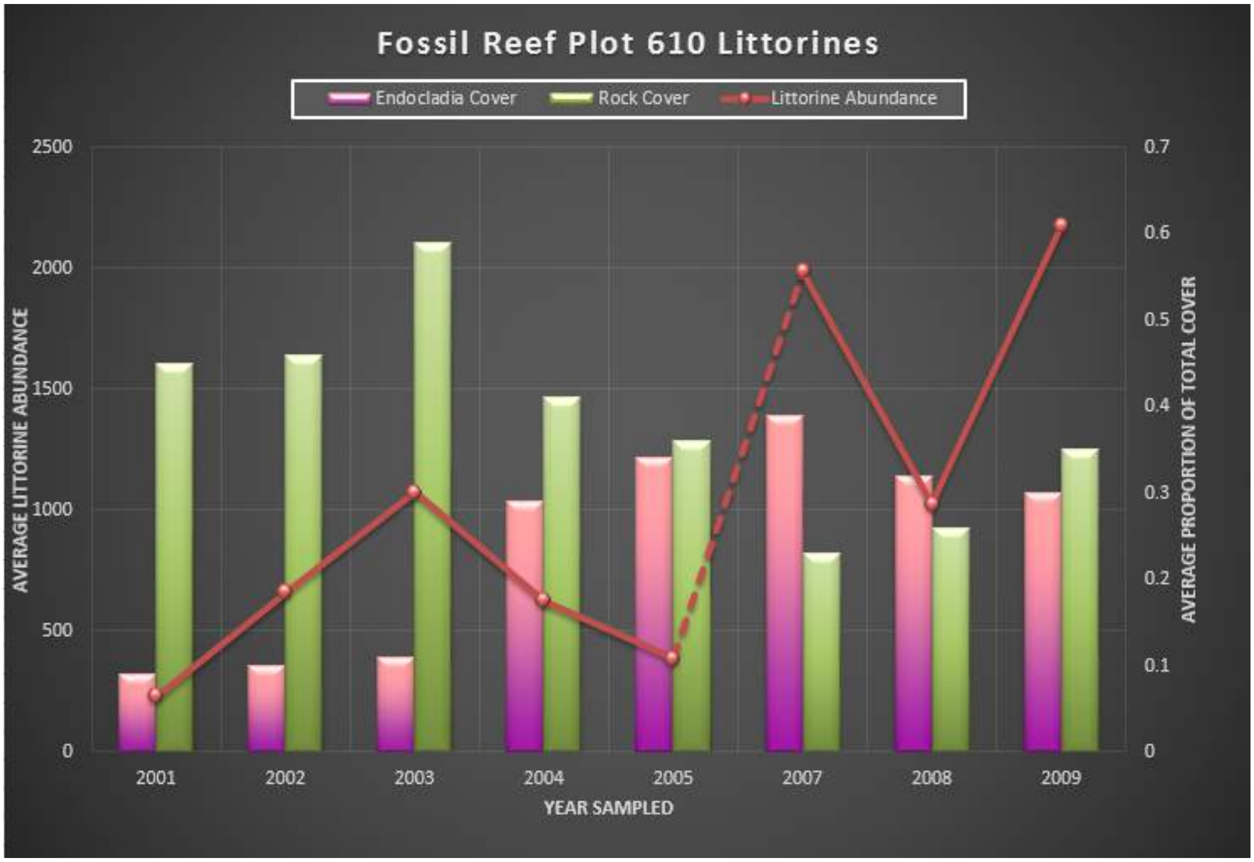

Ford Point Plot 525 Littorines
Endocladia Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
350
300
250
200
150
100
50
0
AVERAGE PROPORTION OF TOTAL COVER
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

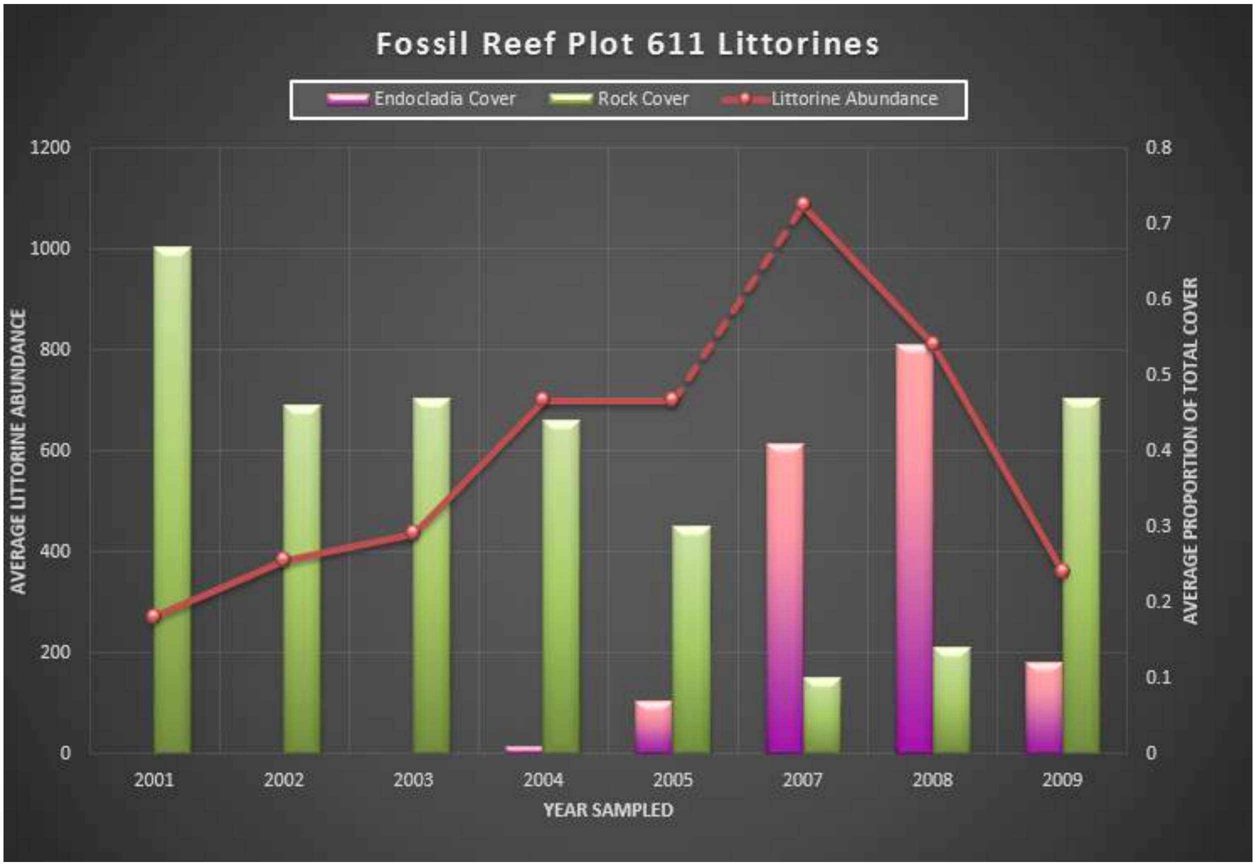

Ford Point Plot 526 Littorines
Endocladia Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
500
450
400
350
300
250
200
150
100
50
0
AVERAGE PROPORTION OF TOTAL COVER
0.6
0.5
0.4
0.3
0.2
0.1
0
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

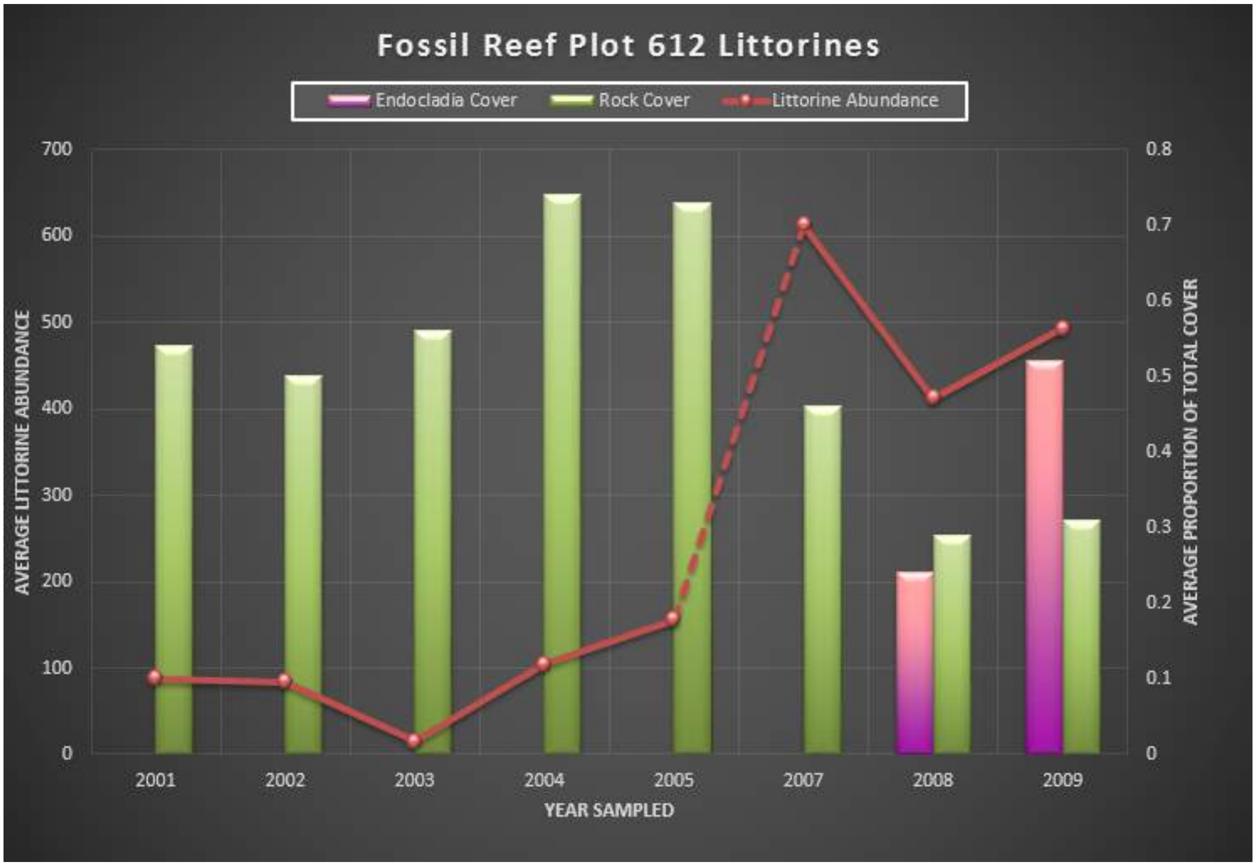

Ford Point Plot 527 Littorines
Endocladia Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
600
500
400
300
200
100
0
AVERAGE PROPORTION OF TOTAL COVER
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

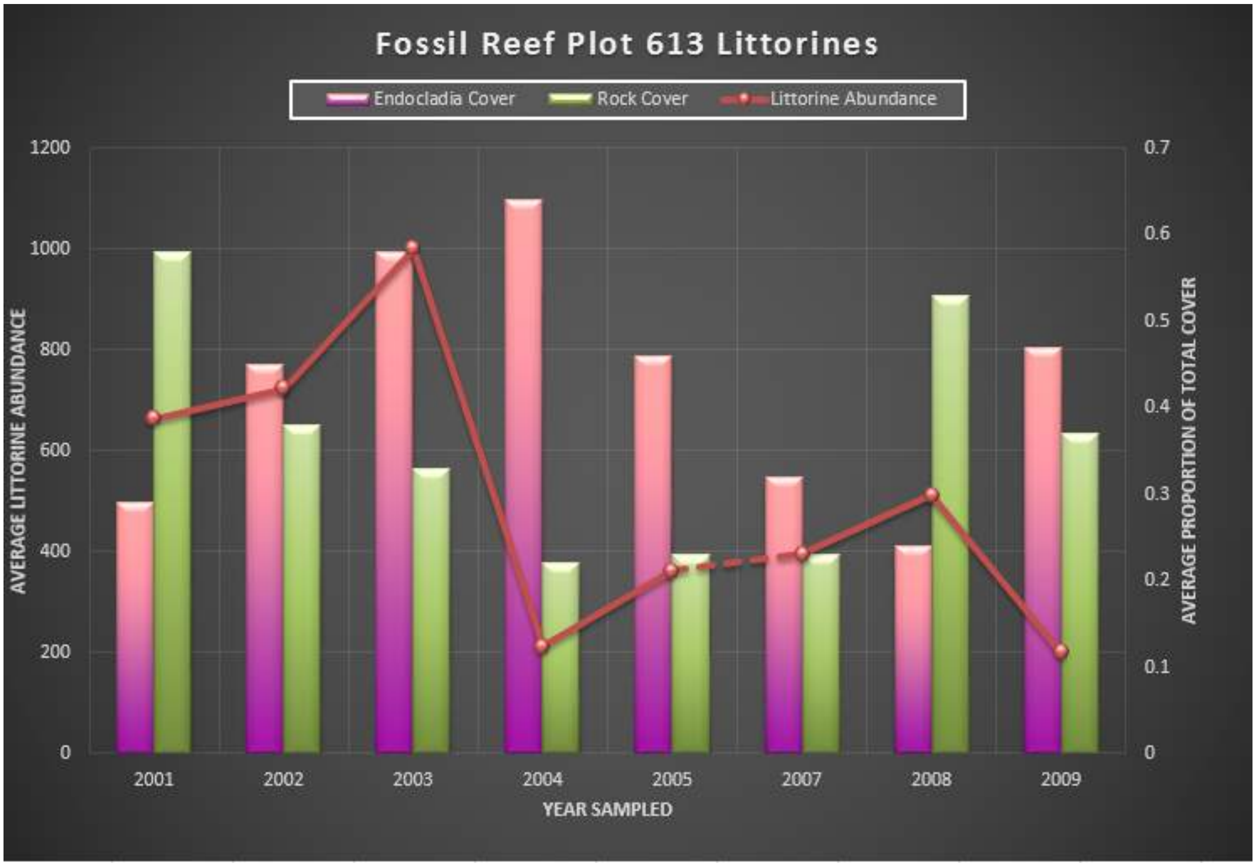

Ford Point Plot 528 Littorines
Endocladia Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
250
200
150
100
50
0
AVERAGE PROPORTION OF TOTAL COVER
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

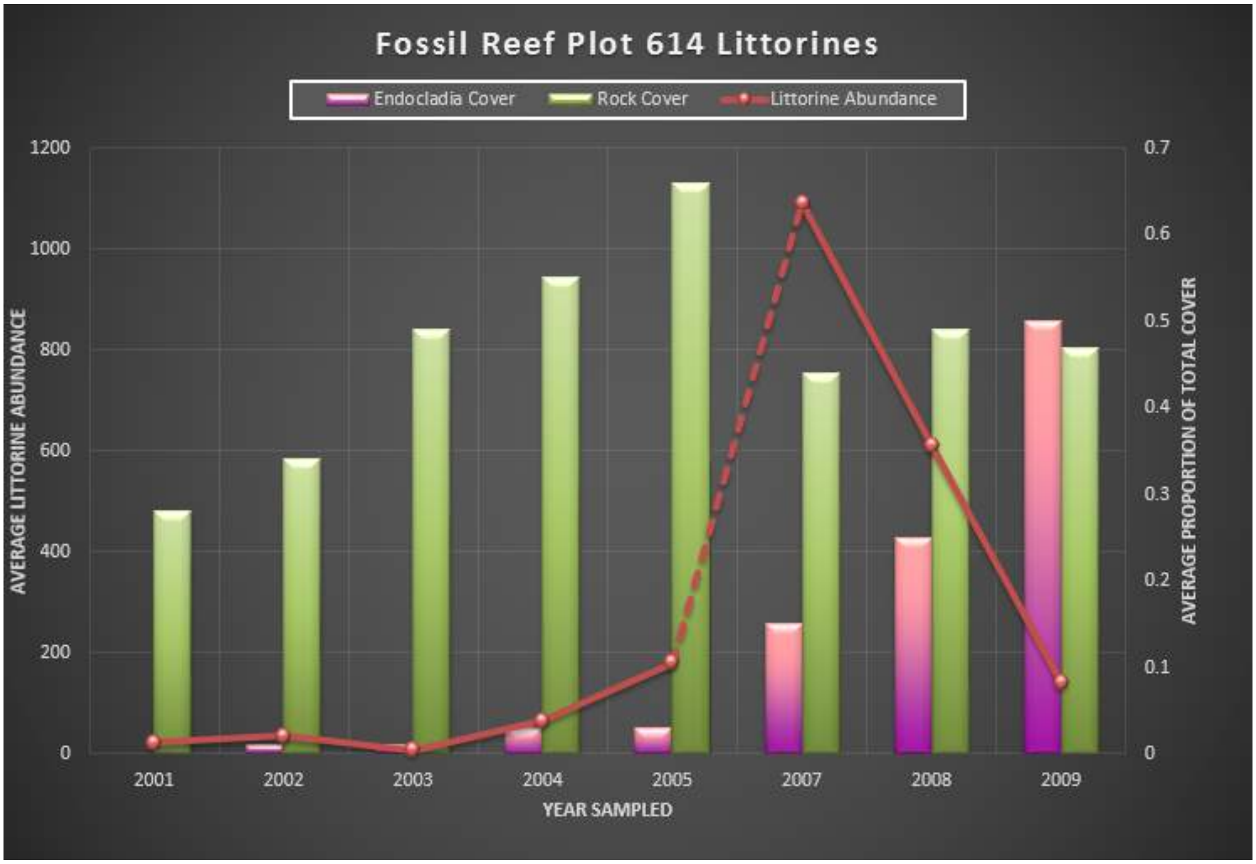

Ford Point Plot 529 Littorines
Endocladia Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
500
450
400
350
300
250
200
150
100
50
0
AVERAGE PROPORTION OF TOTAL COVER
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED


Fossil Reef Plot 610 Littorines
Endocladia Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
2500
2000
1500
1000
500
0
AVERAGE PROPORTION OF TOTAL COVER
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2001
2002
2003
2004
2005
2007
2008
2009
YEAR SAMPLED

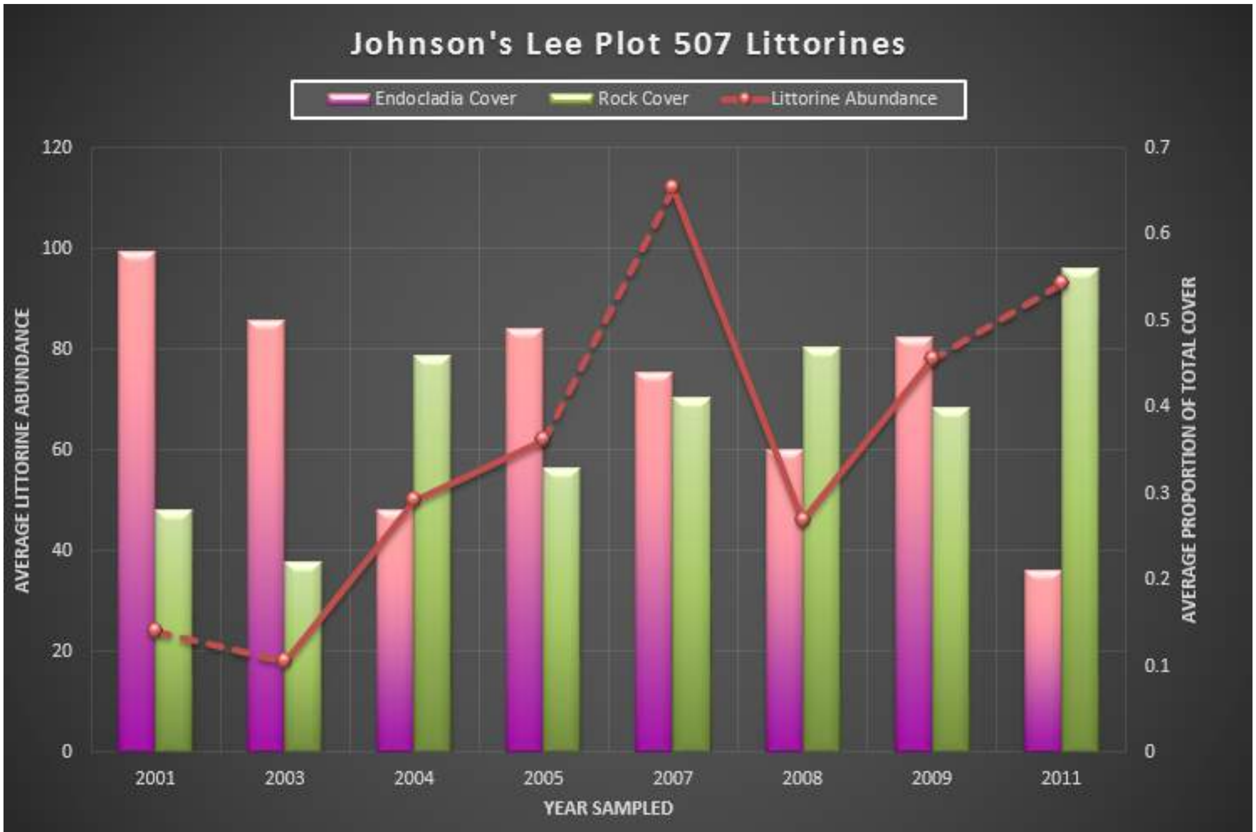

Fossil Reef Plot 611 Littorines
Endocladia Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
1200
1000
800
600
400
200
0
AVERAGE PROPORTION OF TOTAL COVER
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2001
2002
2003
2004
2005
2007
2008
2009
YEAR SAMPLED

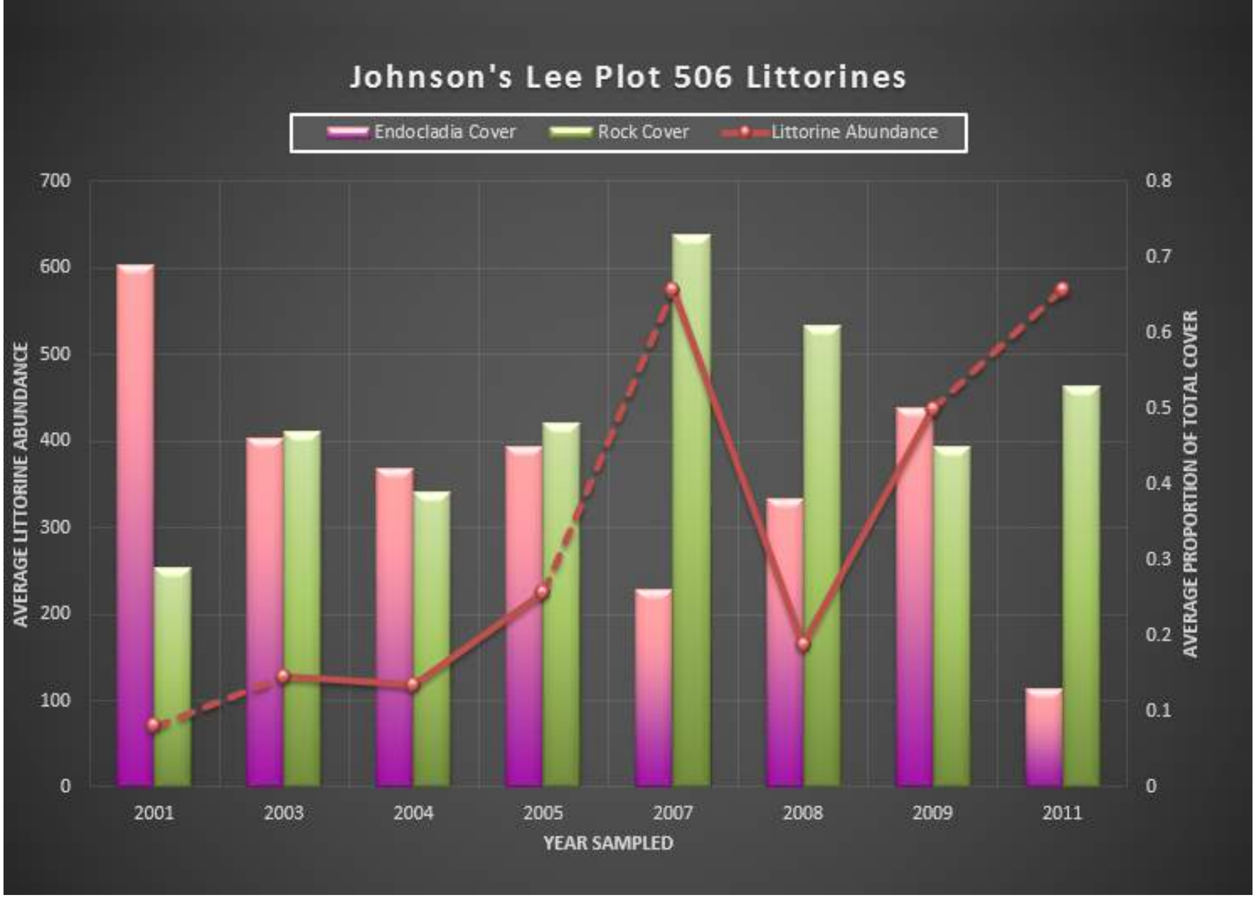

Fossil Reef Plot 612 Littorines
Endocladia Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
700
600
500
400
300
200
100
0
AVERAGE PROPORTION OF TOTAL COVER
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2001
2002
2003
2004
2005
2007
2008
2009
YEAR SAMPLED


Fossil Reef Plot 613 Littorines
Endocladia Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
0
200
400
600
800
1000
1200
AVERAGE PROPORTION OF TOTAL COVER
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
2001
2002
2003
2004
2005
2007
2008
2009
YEAR SAMPLED


Fossil Reef Plot 614 Littorines
Endocladia Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
0
200
400
600
800
1000
1200
AVERAGE PROPORTION OF TOTAL COVER
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
2001
2002
2003
2004
2005
2007
2008
2009
YEAR SAMPLED


Johnson's Lee Plot 505 Littorines
Endocladia Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
350
300
250
200
150
100
50
0
AVERAGE PROPORTION OF TOTAL COVER
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2001
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED


Johnson's Lee Plot 507 Littorines
Endocladia Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
0
20
40
60
80
100
120
AVERAGE PROPORTION OF TOTAL COVER
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
2001
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED


Johnson's Lee Plot 506 Littorines
Endocladia Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
0
100
200
300
400
500
600
700
AVERAGE PROPORTION OF TOTAL COVER
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
2001
2003
2004
2005
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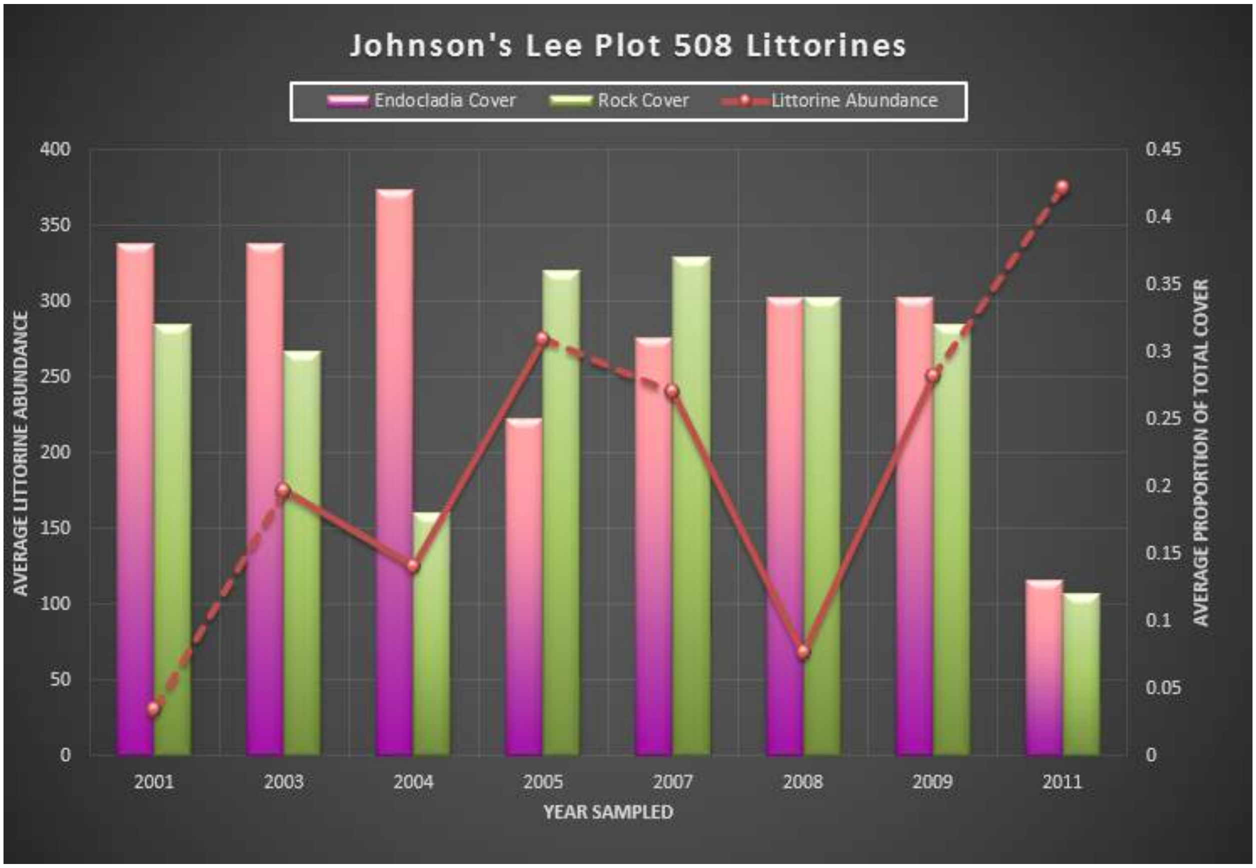
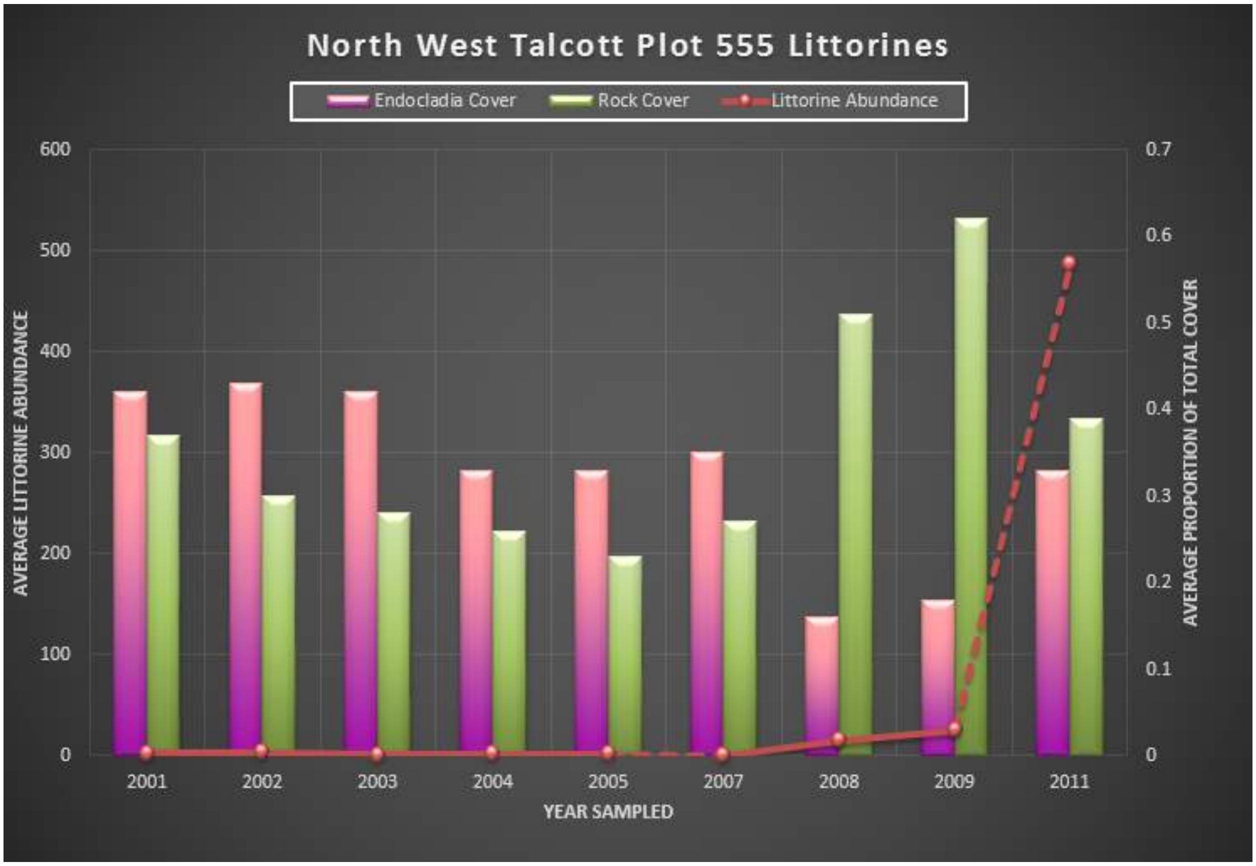
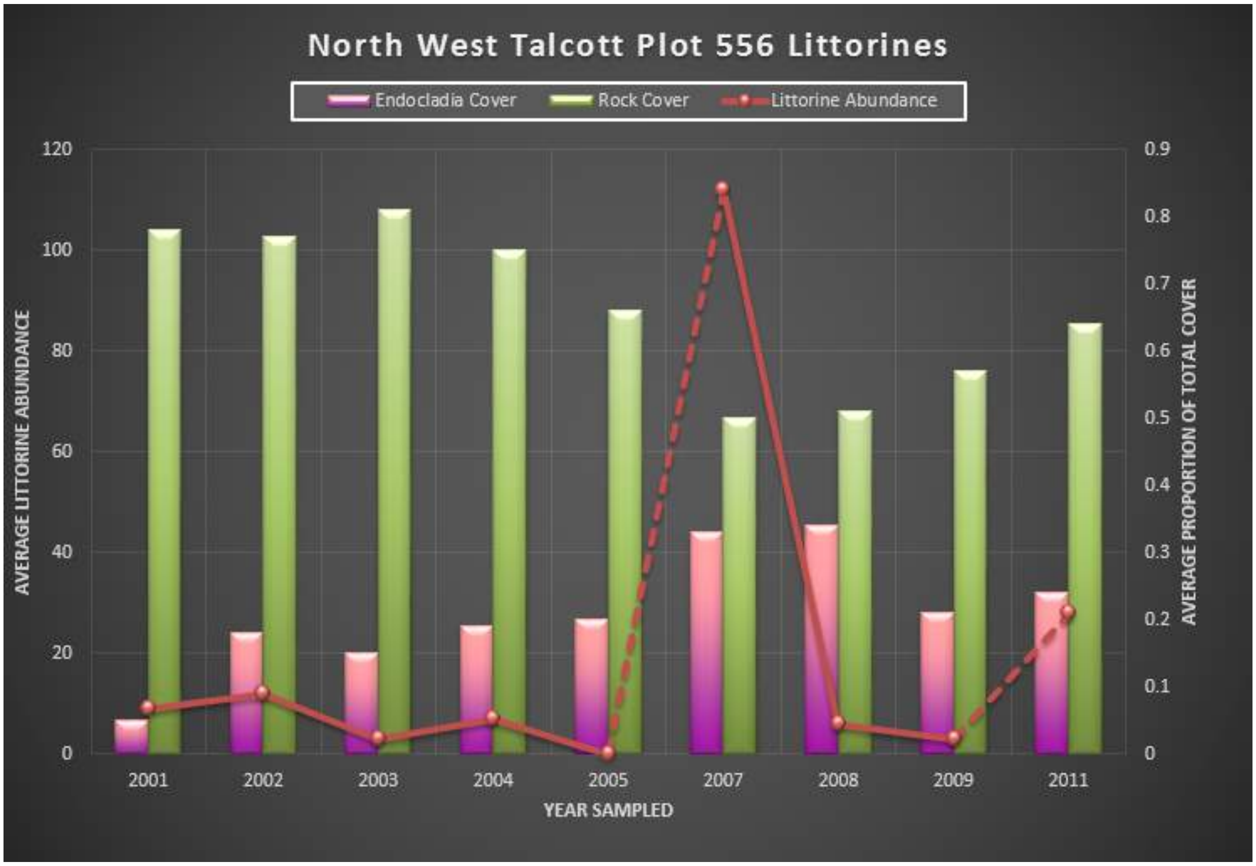
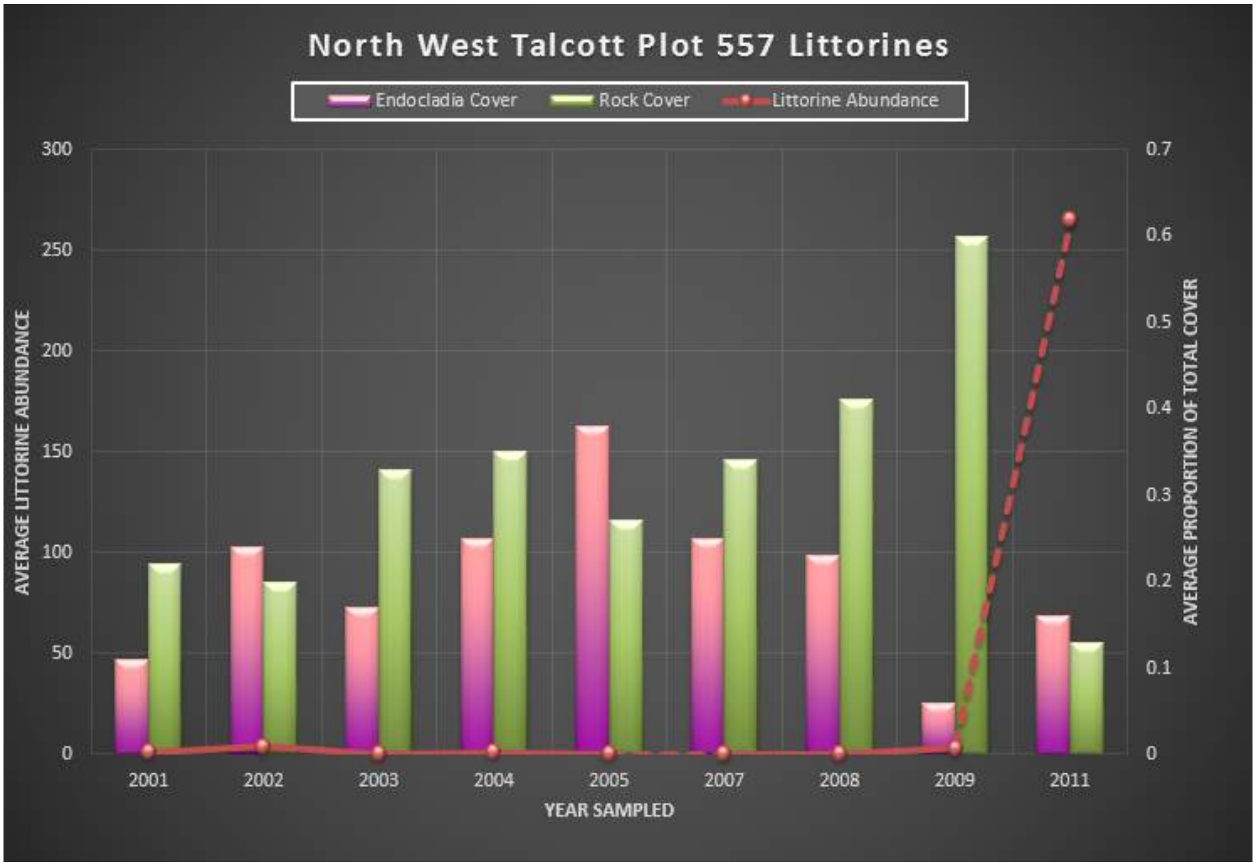
2009
2011
YEAR SAMPLED

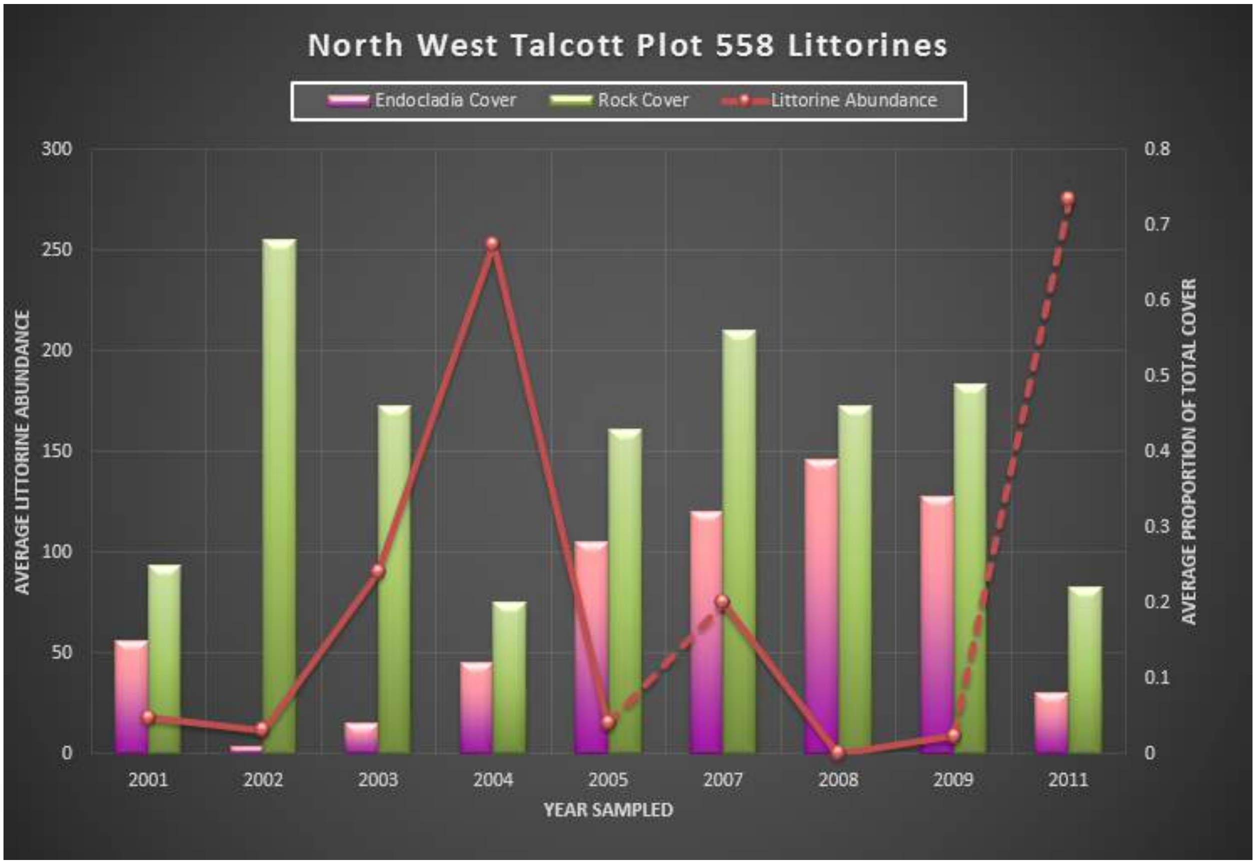

Johnson's Lee Plot 508 Littorines
Endocladia Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
400
350
300
250
200
150
100
50
0
AVERAGE PROPORTION OF TOTAL COVER
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
2001
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

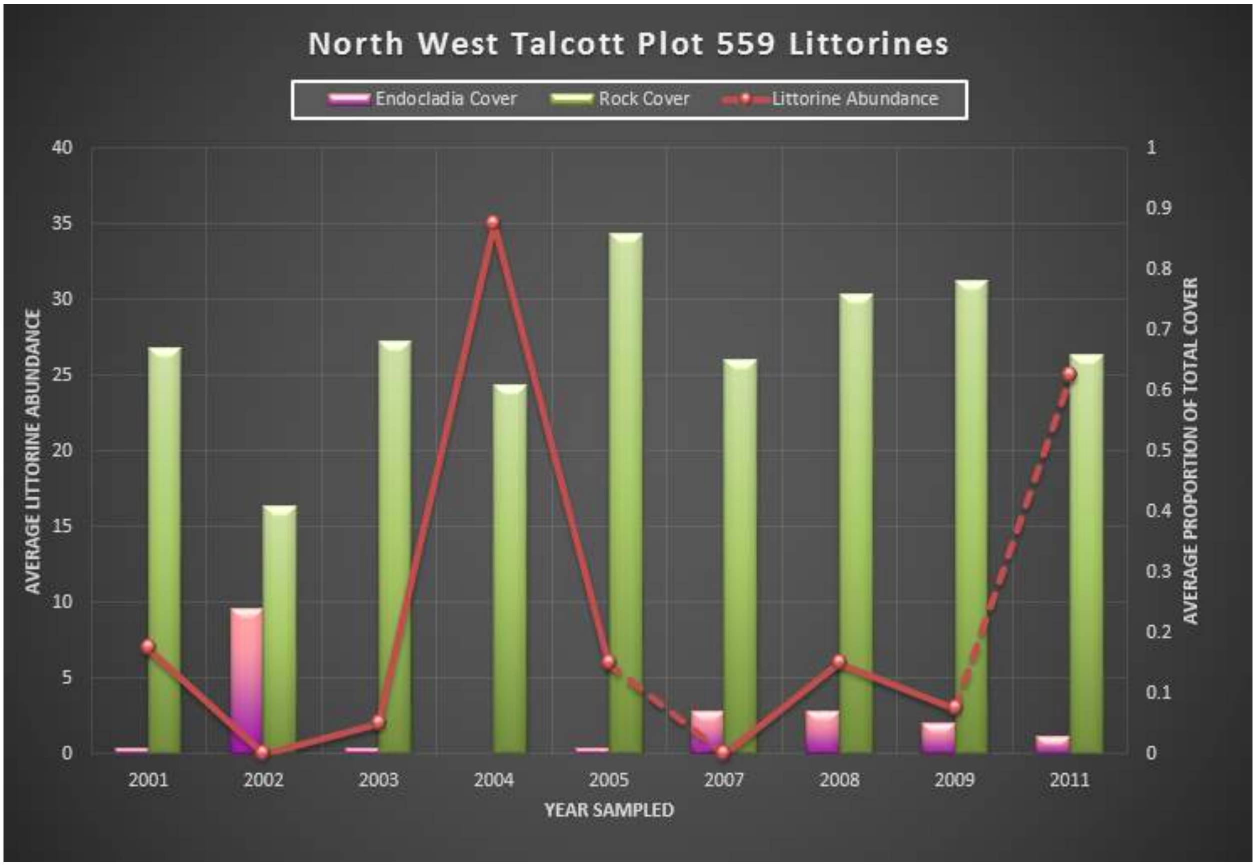

Johnson's Lee Plot 509 Littorines
Endocladia Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
0
50
100
150
200
250
300
350
400
450
500
AVERAGE PROPORTION OF TOTAL COVER
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
2001
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED


North West Talcott Plot 555 Littorines
Endocladia Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
0
100
200
300
400
500
600
AVERAGE PROPORTION OF TOTAL COVER
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

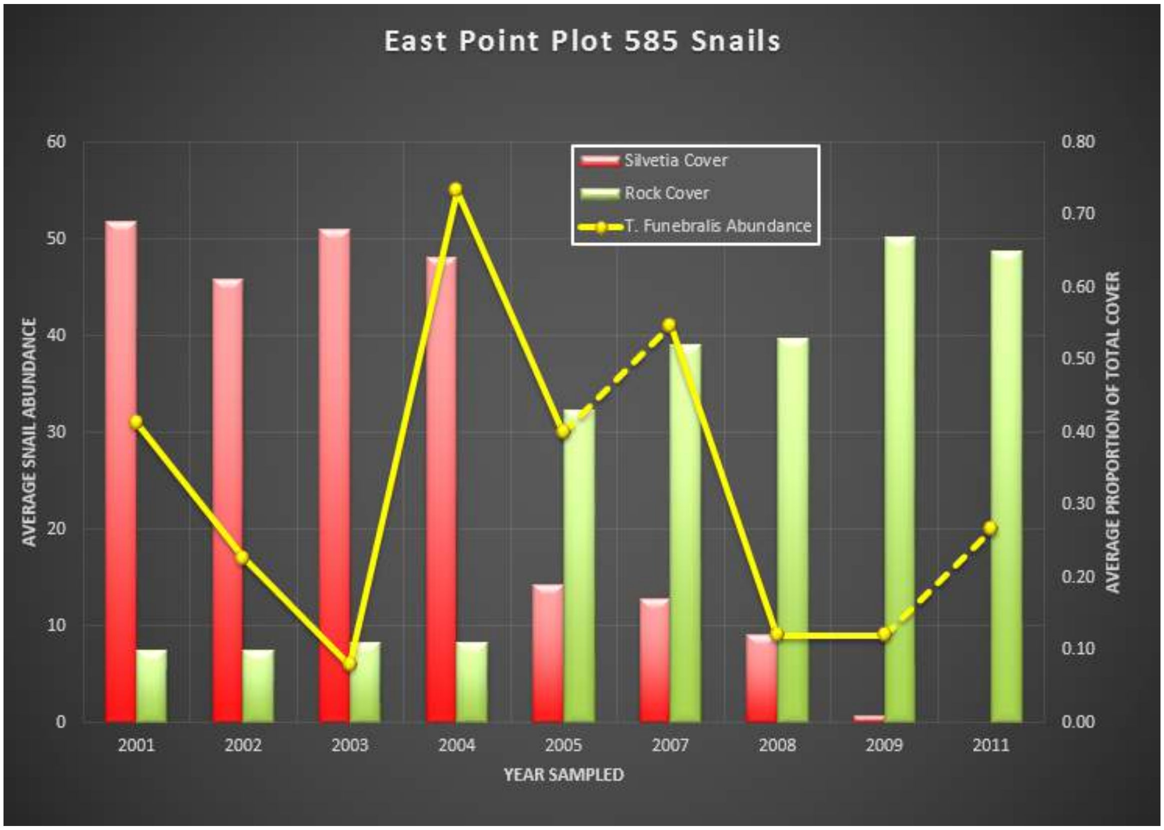

North West Talcott Plot 556 Littorines
Endocladia Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
0
20
40
60
80
100
120
AVERAGE PROPORTION OF TOTAL COVER
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

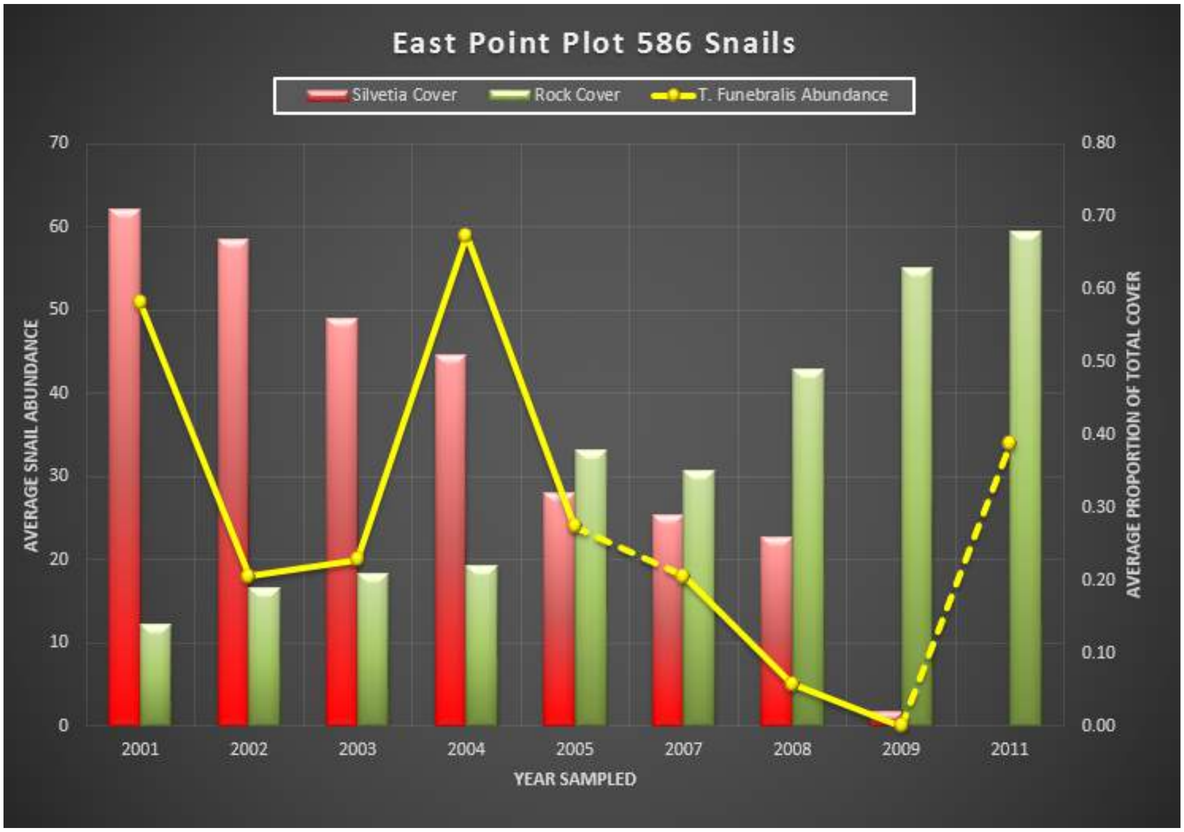

North West Talcott Plot 557 Littorines
Endocladia Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
0
50
100
150
200
250
300
AVERAGE PROPORTION OF TOTAL COVER
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

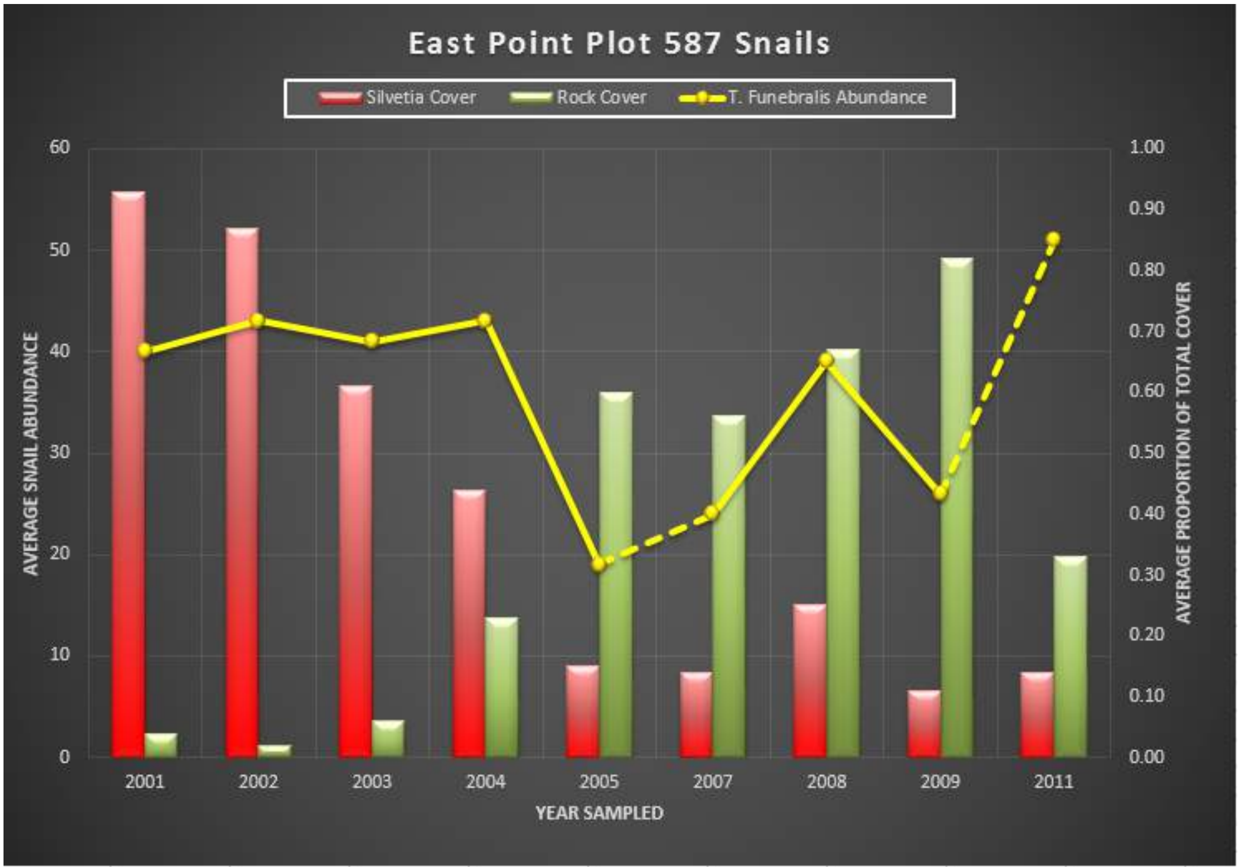

North West Talcott Plot 558 Littorines
Endocladia Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
300
250
200
150
100
50
0
AVERAGE PROPORTION OF TOTAL COVER
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

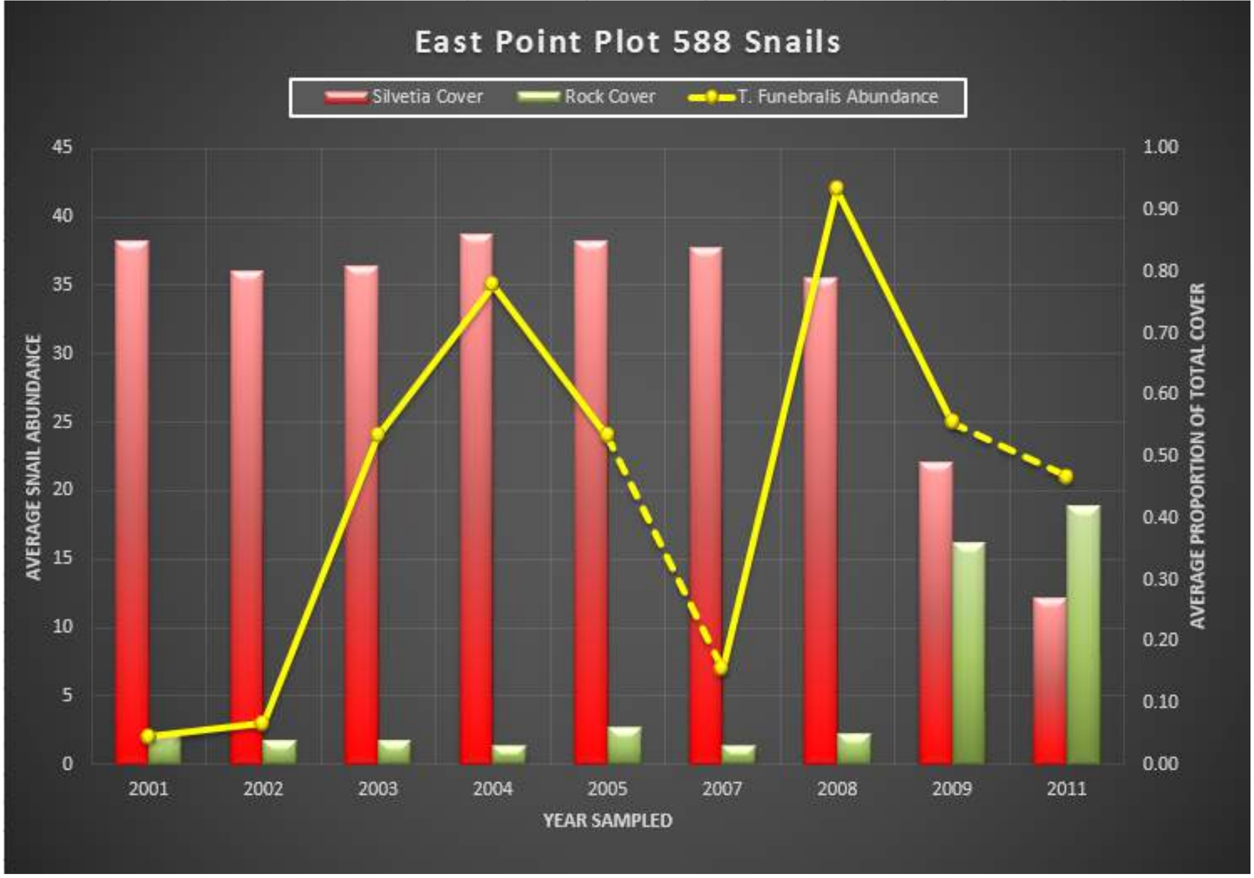

North West Talcott Plot 559 Littorines
Endocladia Cover
Rock Cover
Littorine Abundance
AVERAGE LITTORINE ABUNDANCE
40
35
30
25
20
15
10
5
0
AVERAGE PROPORTION OF TOTAL COVER
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

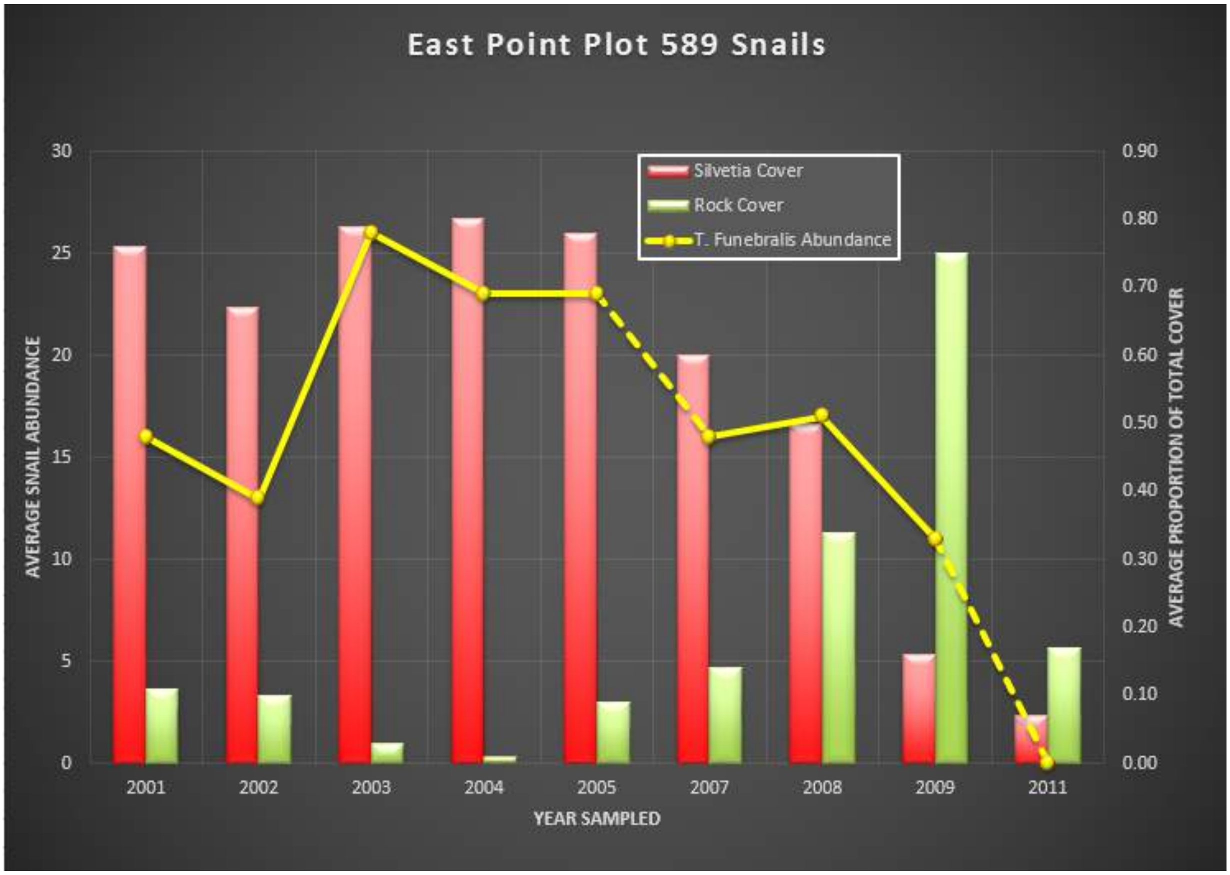
Appendix A.1.4 Tegula Funebralis Abundance vs. Sessile Cover (by plot)






East Point Plot 587 Snails
Silvetia Cover
Rock Cover
T. Funebralis Abundance
AVERAGE SNAIL ABUNDANCE
60
50
40
30
20
10
0
AVERAGE PROPORTION OF TOTAL COVER
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED


East Point Plot 588 Snails
Silvetia Cover
Rock Cover
T. Funebralis Abundance
AVERAGE SNAIL ABUNDANCE
45
40
35
30
25
20
15
10
5
0
AVERAGE PROPORTION OF TOTAL COVER
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED


East Point Plot 589 Snails
Silvetia Cover
Rock Cover
T. Funebralis Abundance
AVERAGE SNAIL ABUNDANCE
30
25
20
15
10
5
0
AVERAGE PROPORTION OF TOTAL COVER
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
2001
2002
2003
2004
2005
2007
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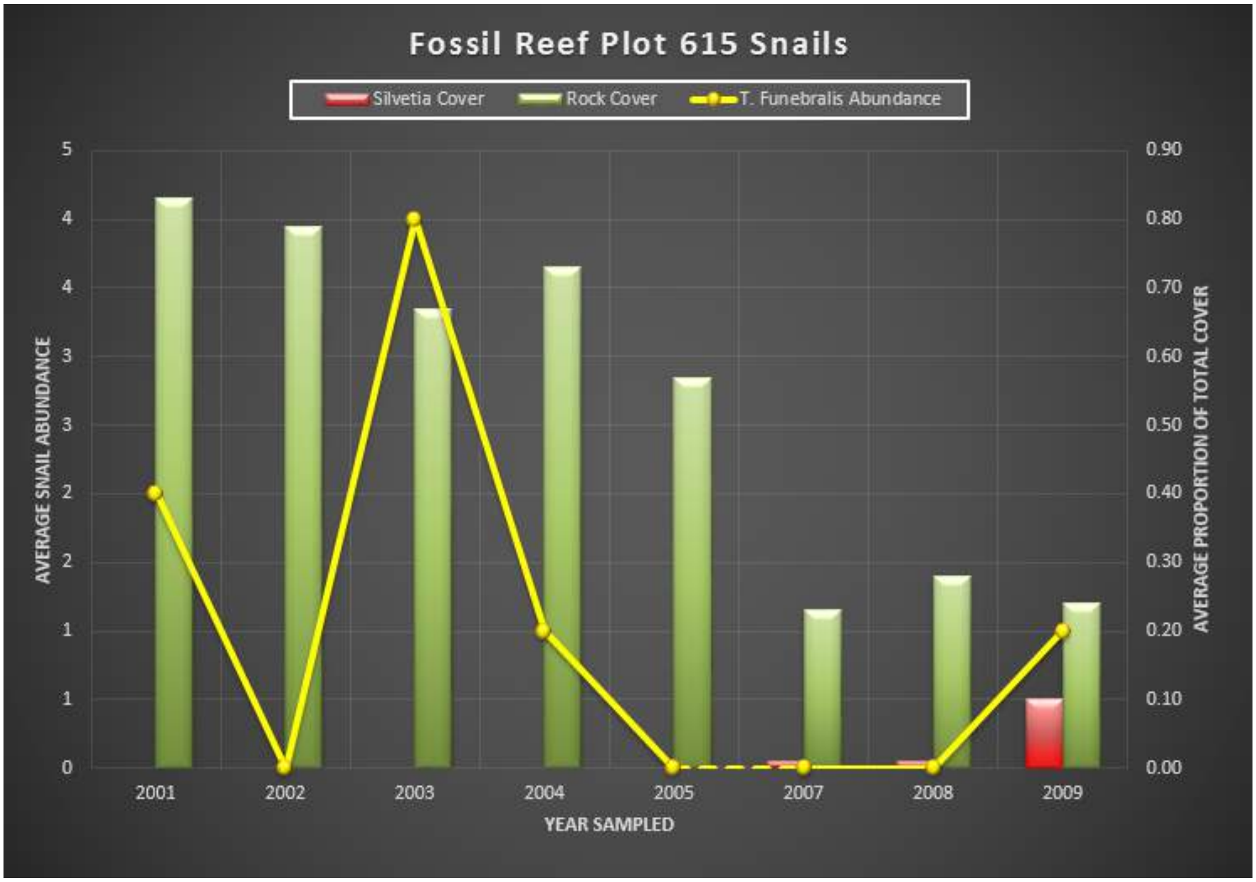
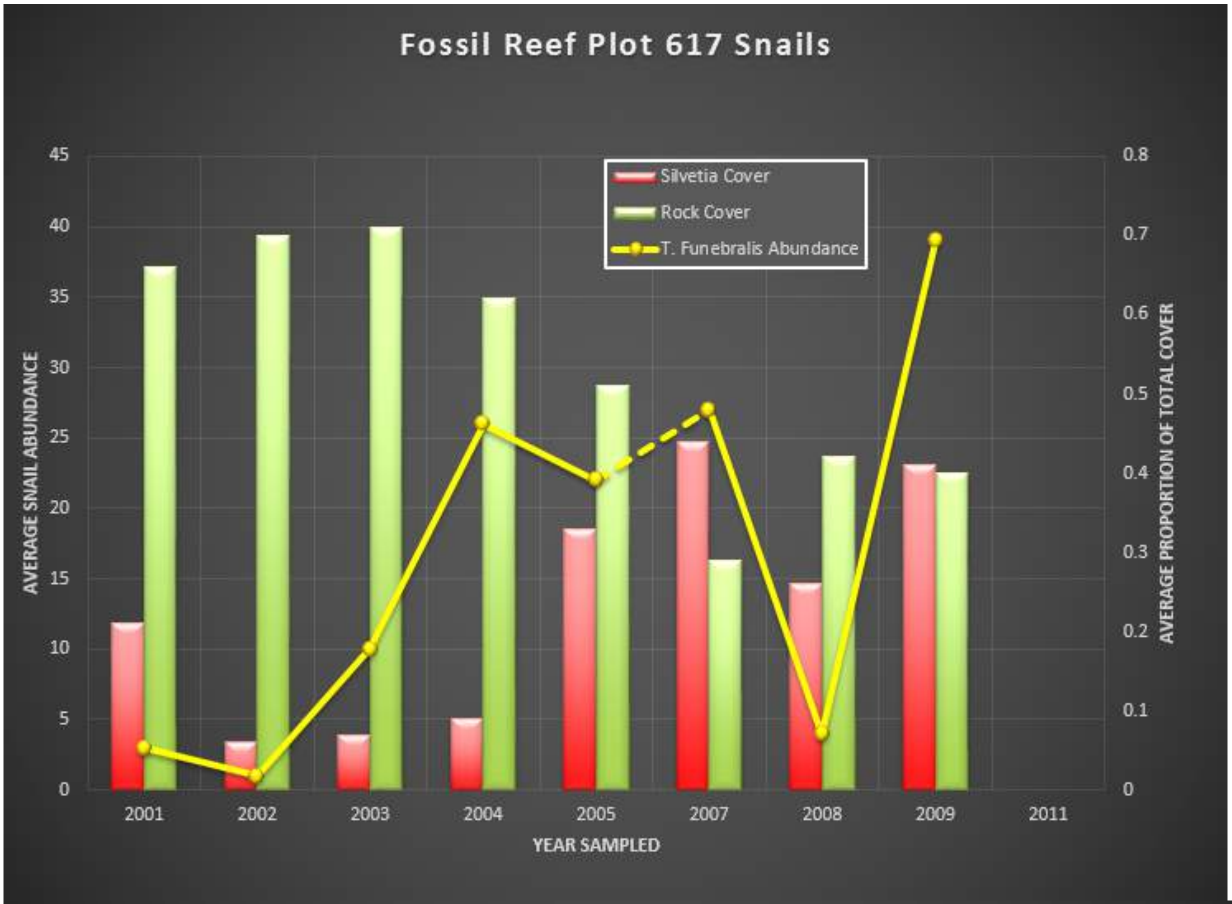
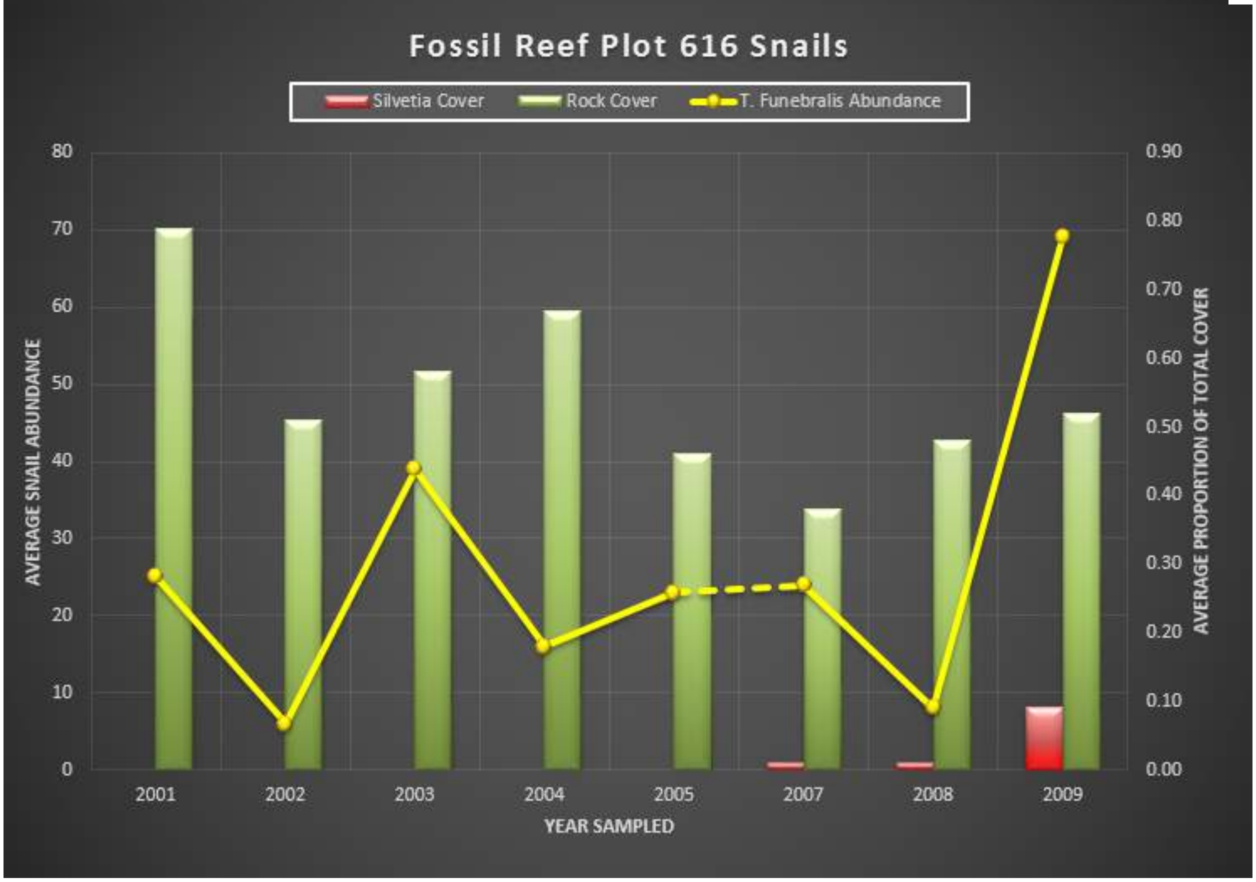
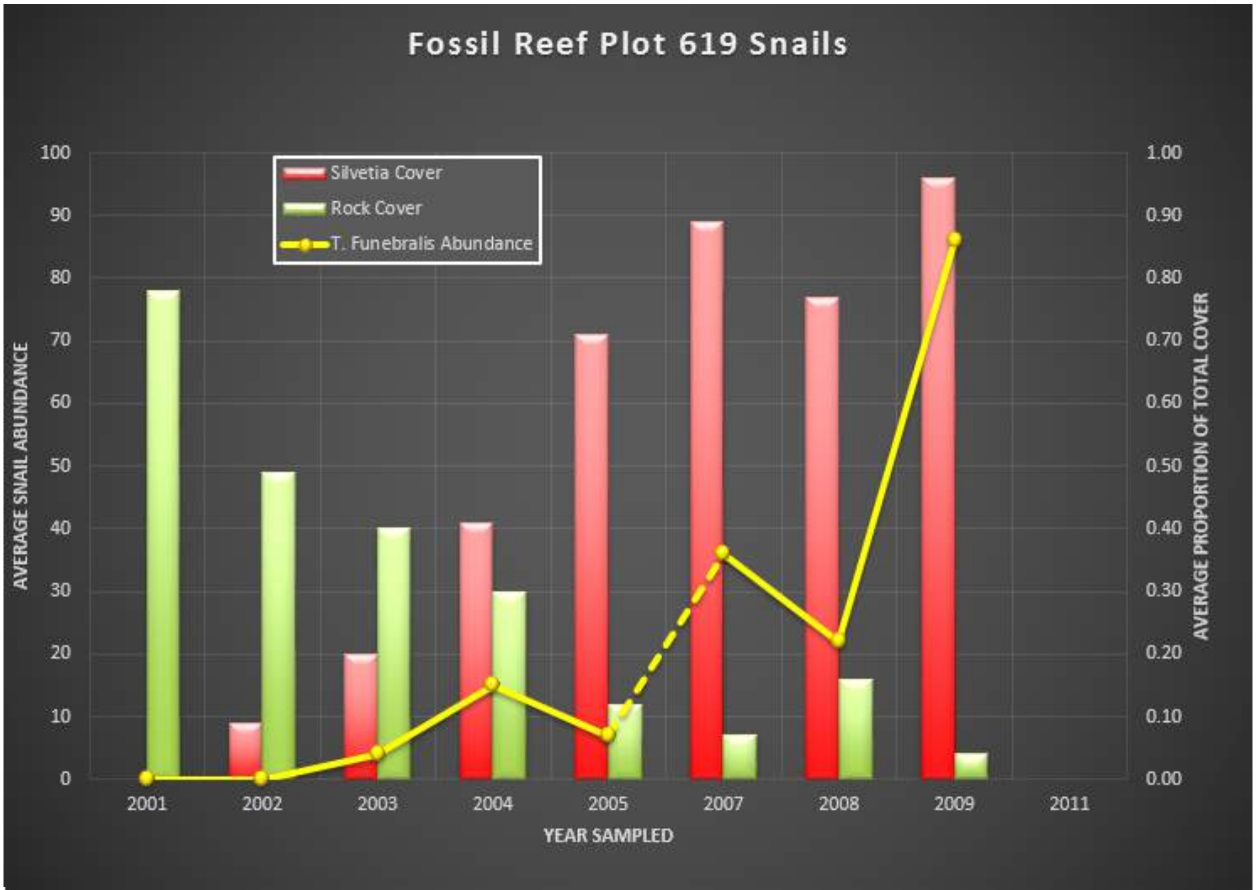
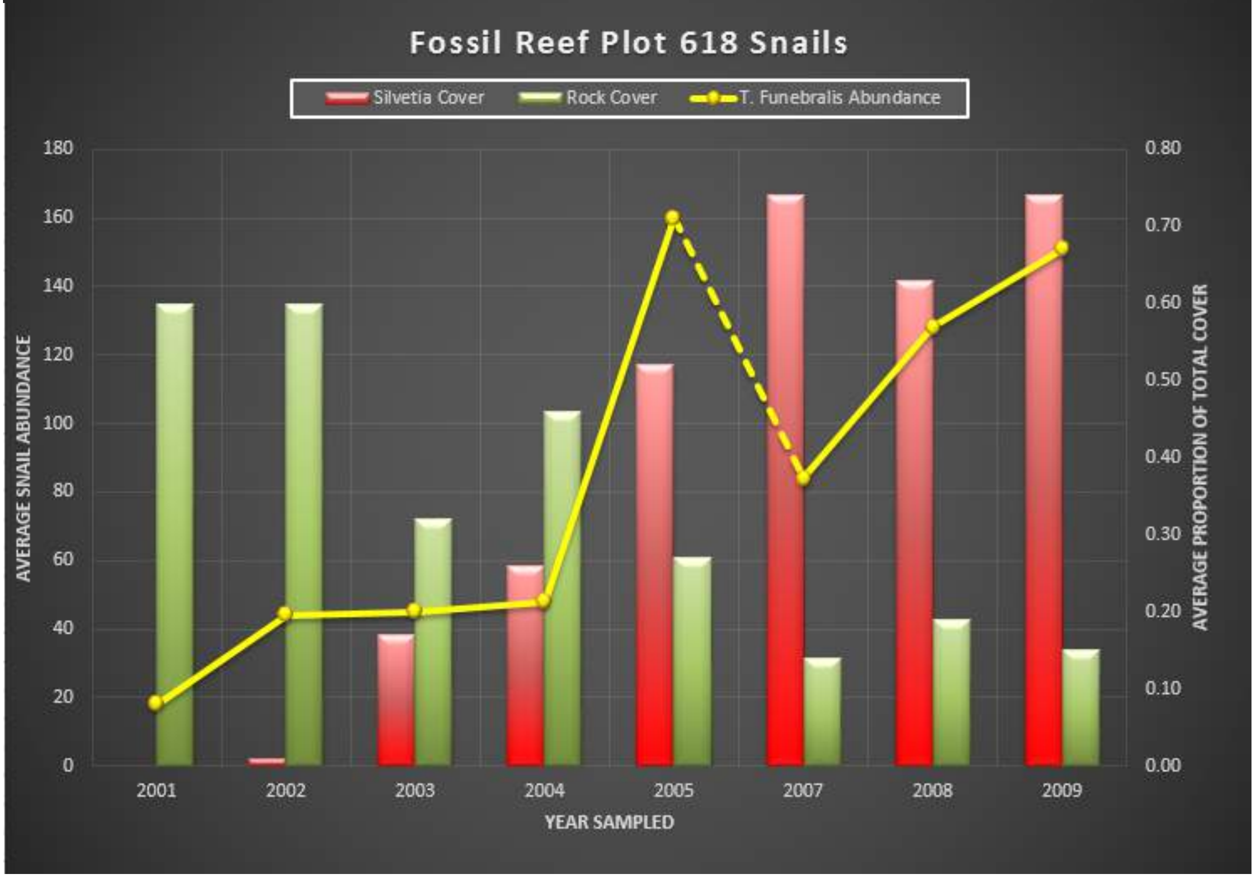
2009
2011
YEAR SAMPLED

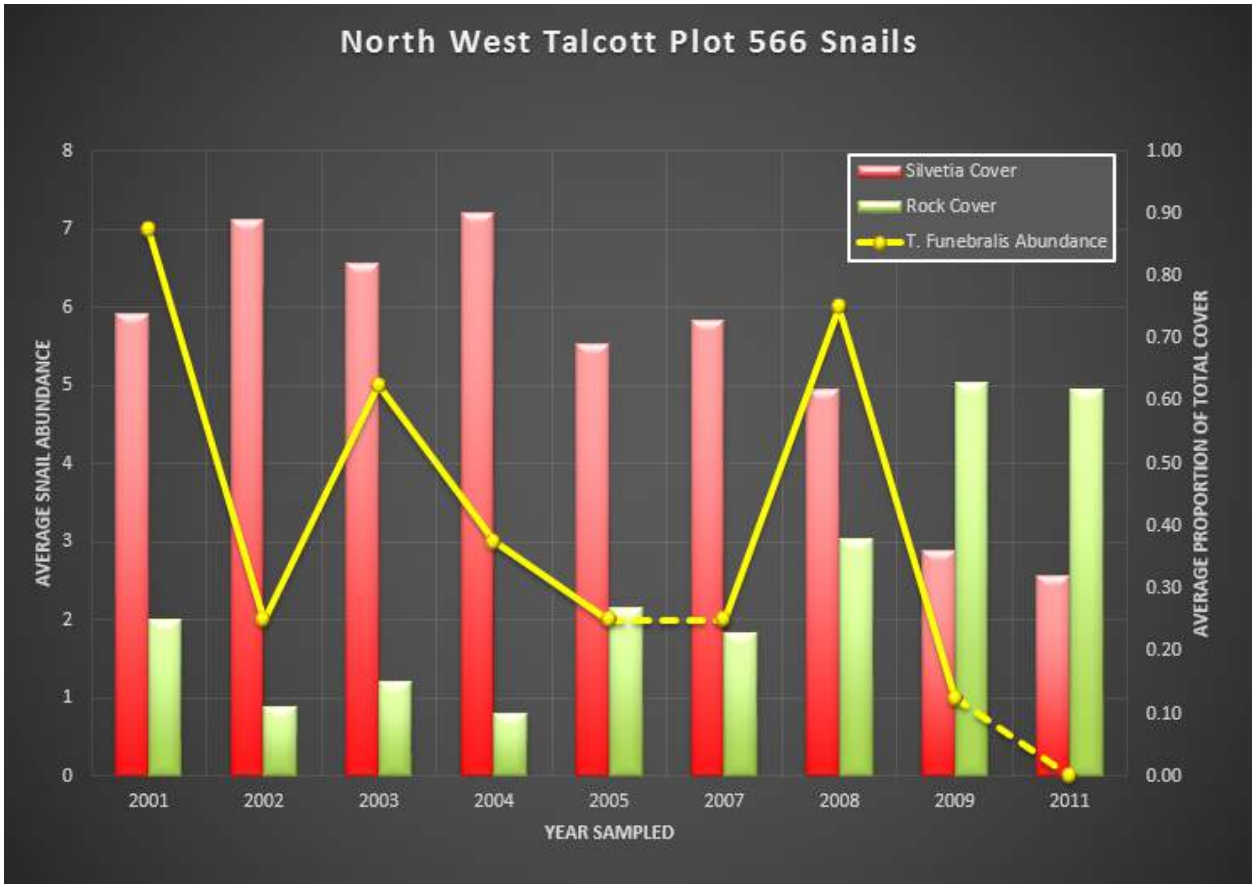

Fossil Reef Plot 615 Snails
Silvetia Cover
Rock Cover
T. Funebralis Abundance
AVERAGE SNAIL ABUNDANCE
5
4
4
3
3
2
2
1
1
0
AVERAGE PROPORTION OF TOTAL COVER
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
2001
2002
2003
2004
2005
2007
2008
2009
YEAR SAMPLED

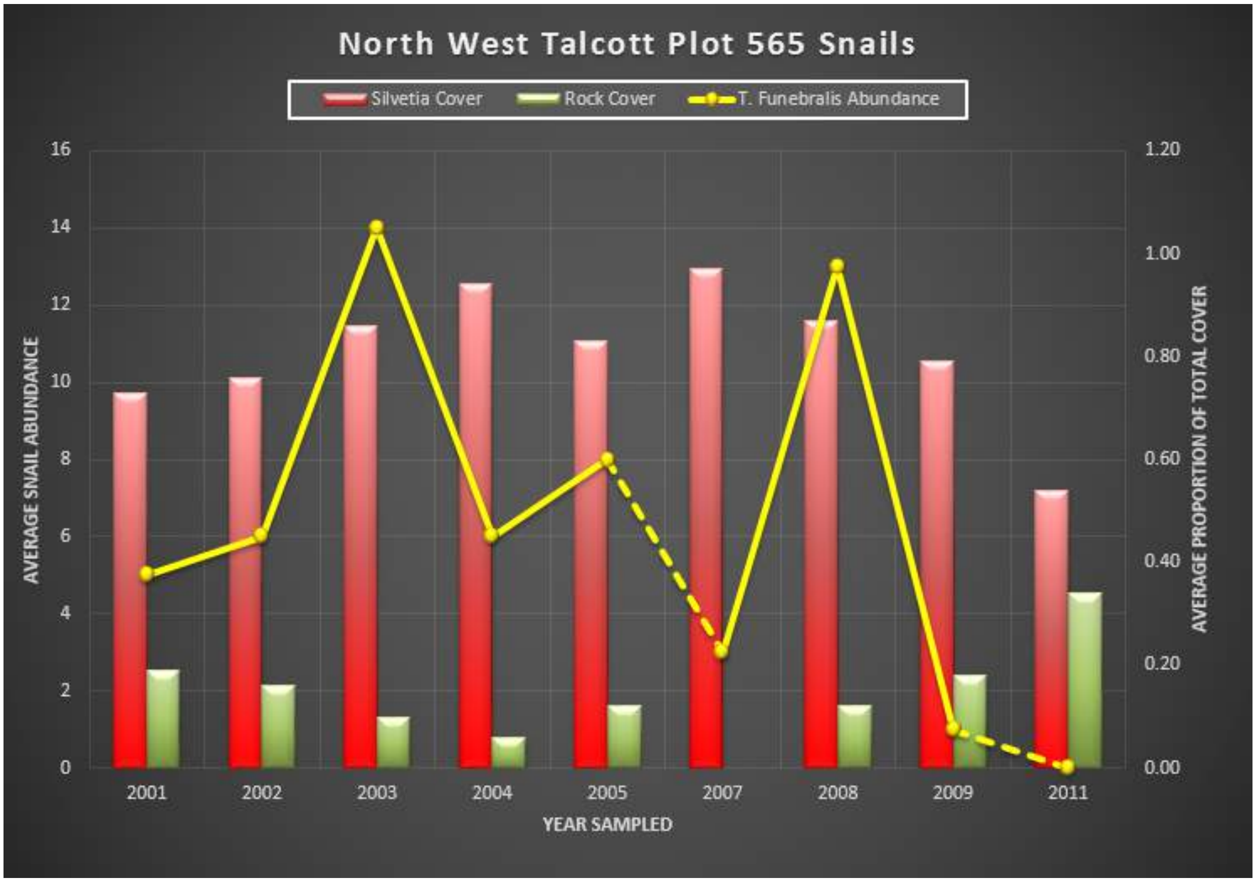

Fossil Reef Plot 617 Snails
Silvetia Cover
Rock Cover
T. Funebralis Abundance
AVERAGE SNAIL ABUNDANCE
45
40
35
30
25
20
15
10
5
0
AVERAGE PROPORTION OF TOTAL COVER
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

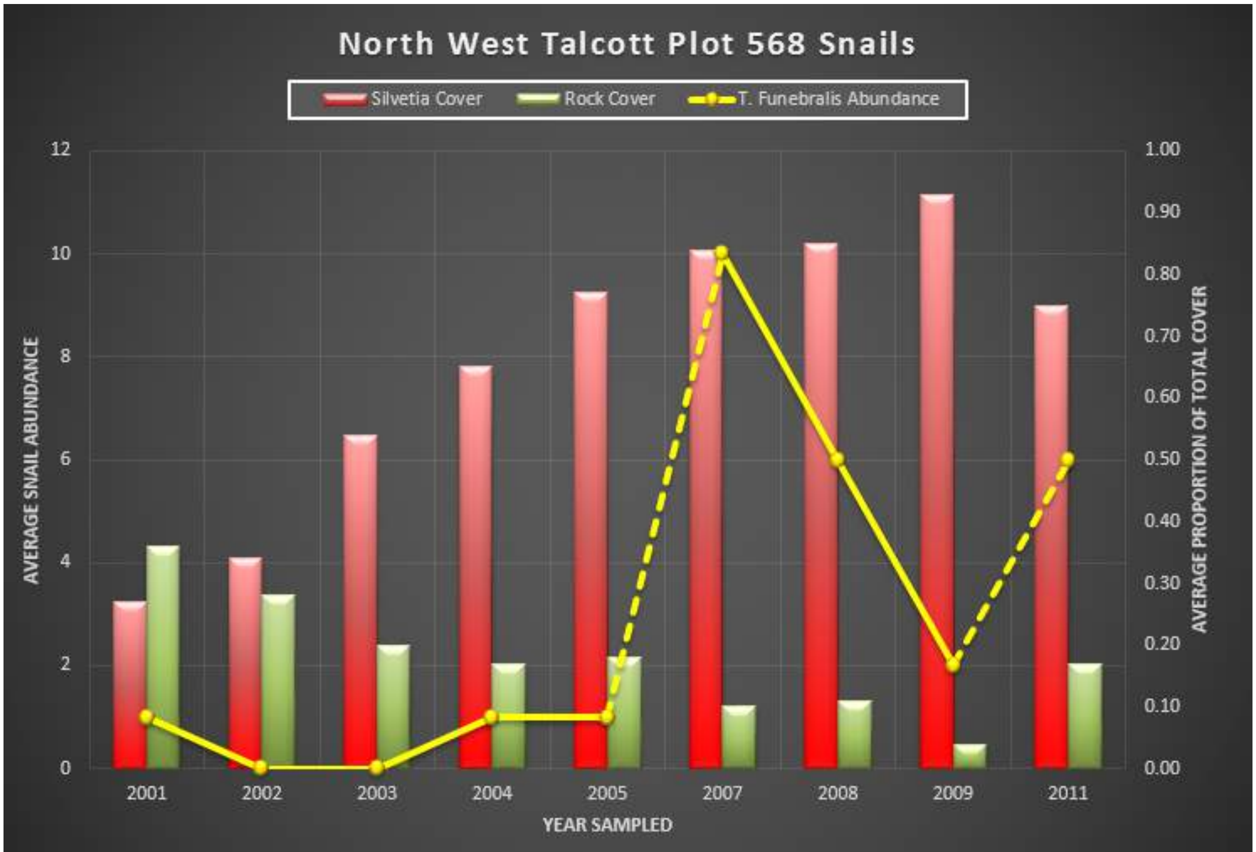

Fossil Reef Plot 616 Snails
Silvetia Cover
Rock Cover
T. Funebralis Abundance
AVERAGE SNAIL ABUNDANCE
80
70
60
50
40
30
20
10
0
AVERAGE PROPORTION OF TOTAL COVER
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
2001
2002
2003
2004
2005
2007
2008
2009
YEAR SAMPLED

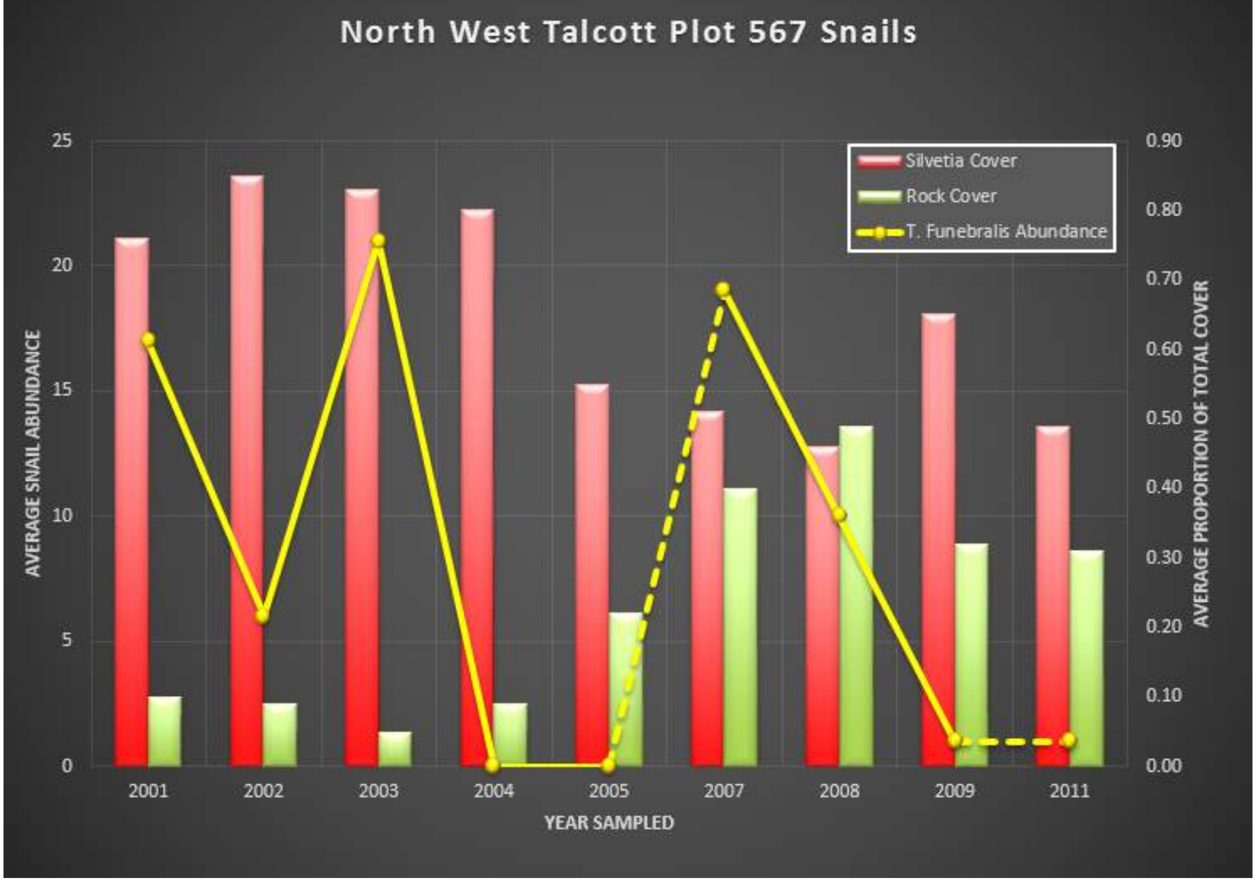

Fossil Reef Plot 619 Snails
Silvetia Cover
Rock Cover
T. Funebralis Abundance
AVERAGE SNAIL ABUNDANCE
0
10
20
30
40
50
60
70
80
90
100
AVERAGE PROPORTION OF TOTAL COVER
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

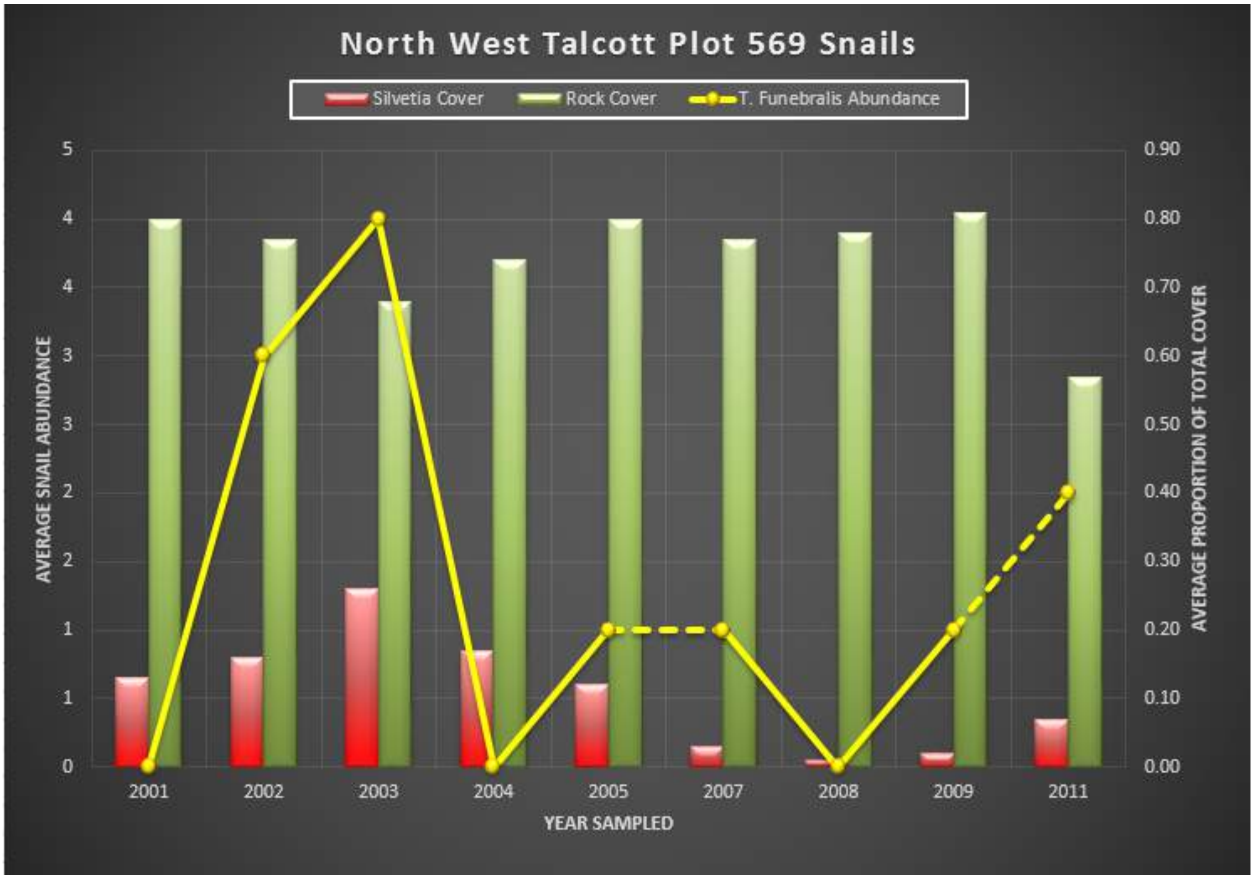

Fossil Reef Plot 618 Snails
Silvetia Cover
Rock Cover
T. Funebralis Abundance
AVERAGE SNAIL ABUNDANCE
0
20
40
60
80
100
120
140
160
180
AVERAGE PROPORTION OF TOTAL COVER
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
2001
2002
2003
2004
2005
2007
2008
2009
YEAR SAMPLED


North West Talcott Plot 566 Snails
Silvetia Cover
Rock Cover
T. Funebralis Abundance
AVERAGE SNAIL ABUNDANCE
0
1
2
3
4
5
6
7
8
AVERAGE PROPORTION OF TOTAL COVER
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED


North West Talcott Plot 565 Snails
Silvetia Cover
Rock Cover
T. Funebralis Abundance
AVERAGE SNAIL ABUNDANCE
0
2
4
6
8
10
12
14
16
AVERAGE PROPORTION OF TOTAL COVER
0.00
0.20
0.40
0.60
0.80
1.00
1.20
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

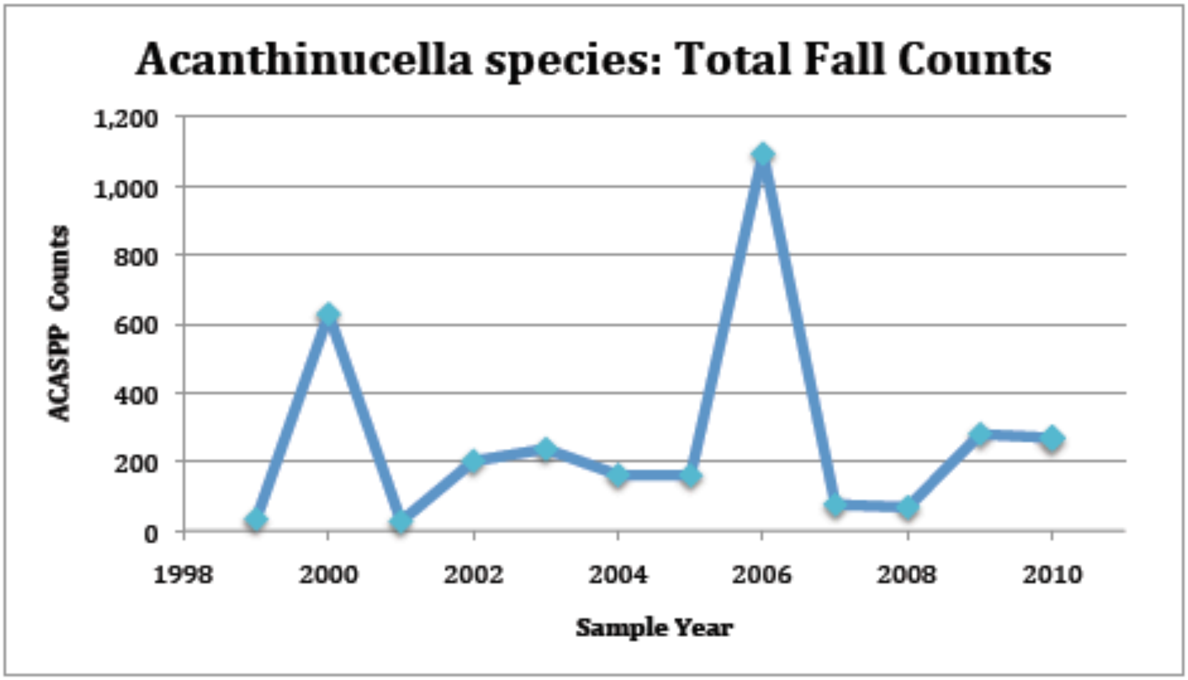

North West Talcott Plot 568 Snails
Silvetia Cover
Rock Cover
T. Funebralis Abundance
AVERAGE SNAIL ABUNDANCE
0
2
4
6
8
10
12
AVERAGE PROPORTION OF TOTAL COVER
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

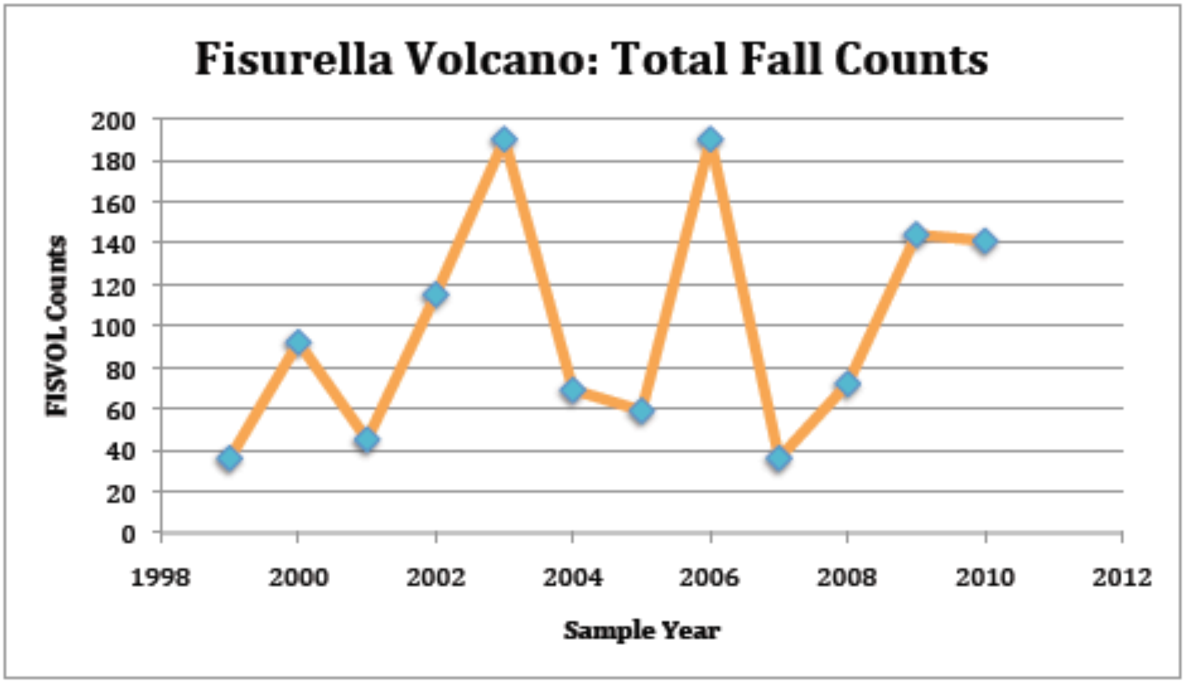

North West Talcott Plot 567 Snails
Silvetia Cover
Rock Cover
T. Funebralis Abundance
AVERAGE SNAIL ABUNDANCE
0
5
10
15
20
25
AVERAGE PROPORTION OF TOTAL COVER
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

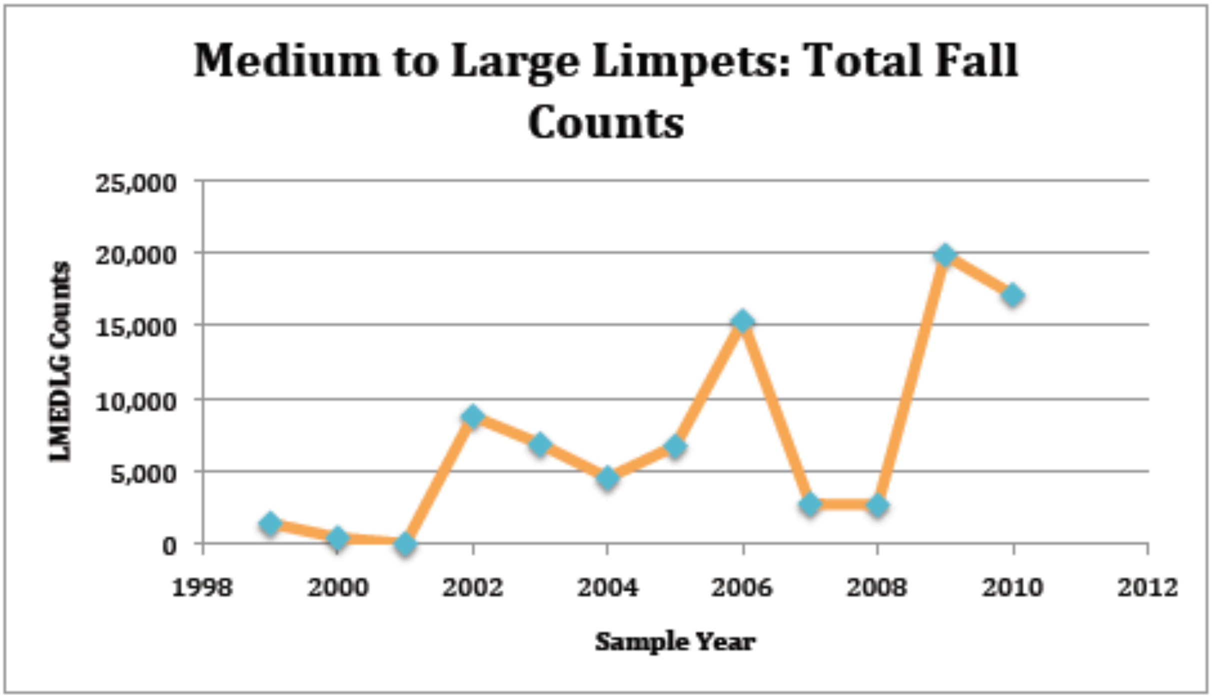

North West Talcott Plot 569 Snails
Silvetia Cover
Rock Cover
T. Funebralis Abundance
5
4
4
3
3
2
2
1
1
0
AVERAGE SNAIL ABUNDANCE
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
AVERAGE PROPORTION OF TOTAL COVER
2001
2002
2003
2004
2005
2007
2008
2009
2011
YEAR SAMPLED

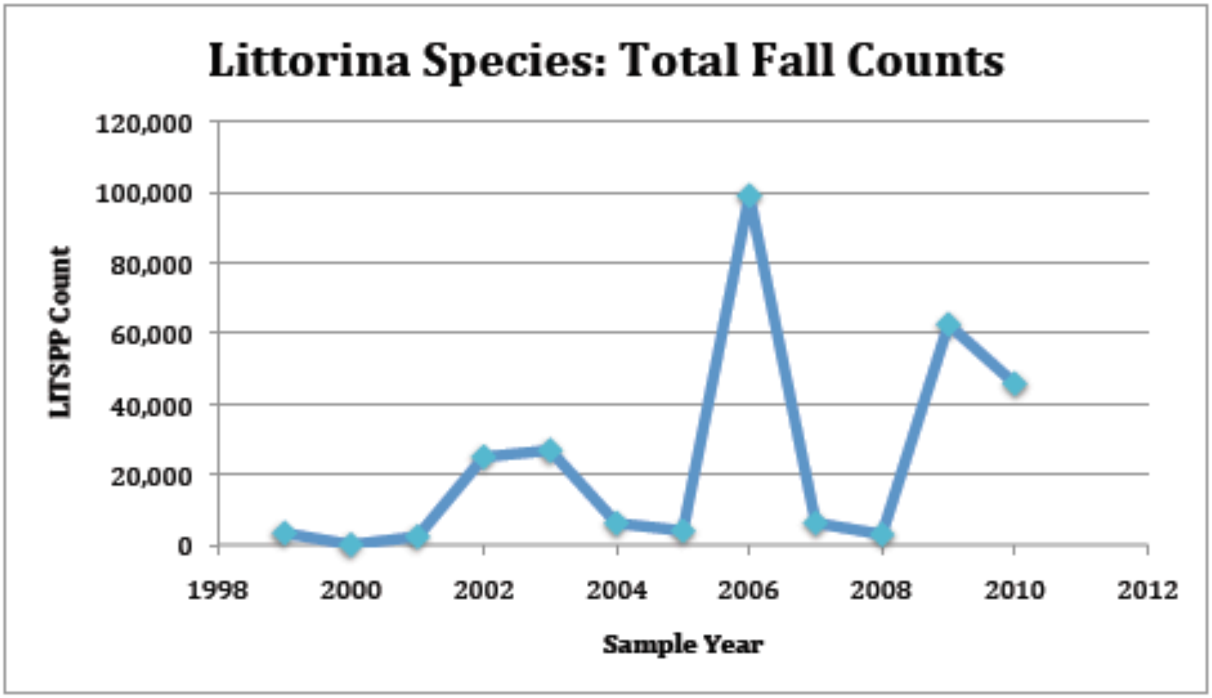
Appendix A.2 Core Species Count Summary Graphs

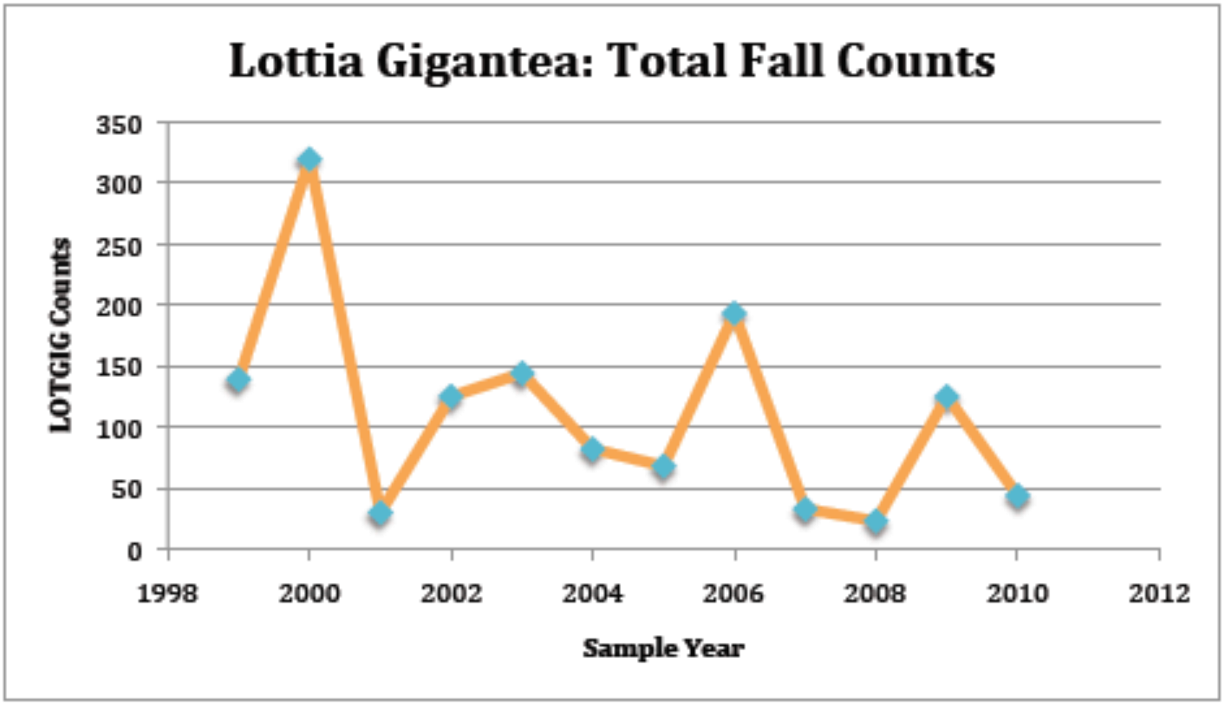
Appendix A.2.1 Total Fall Counts

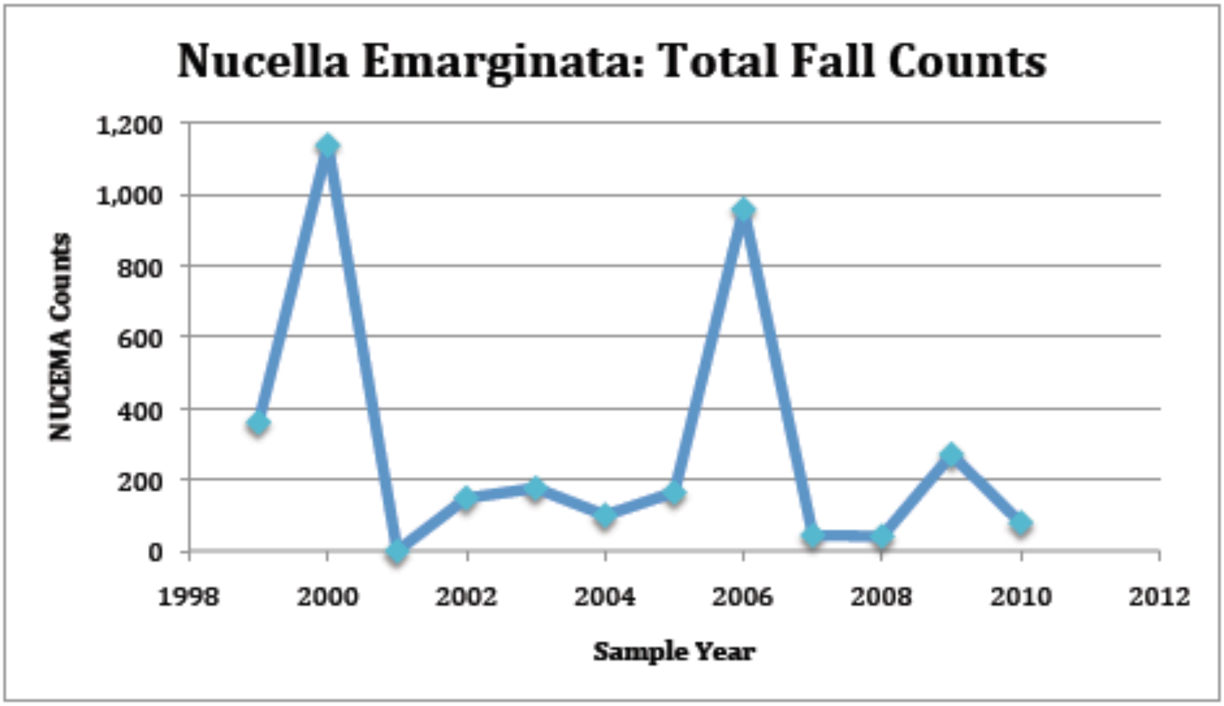


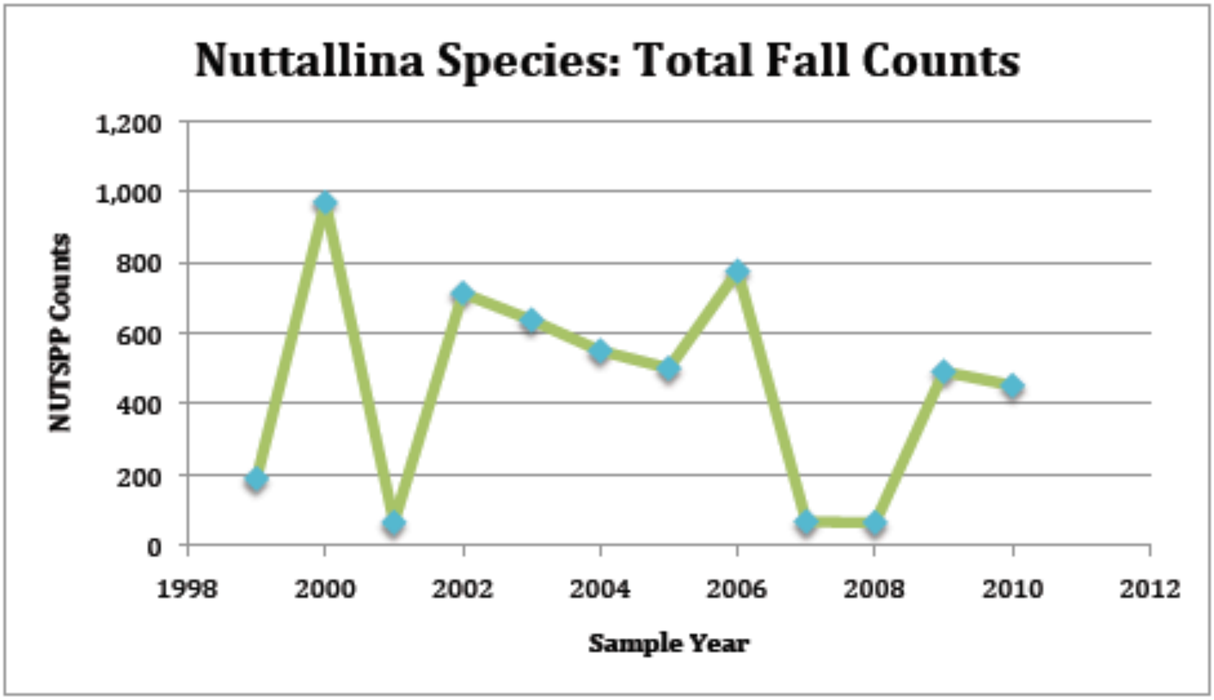


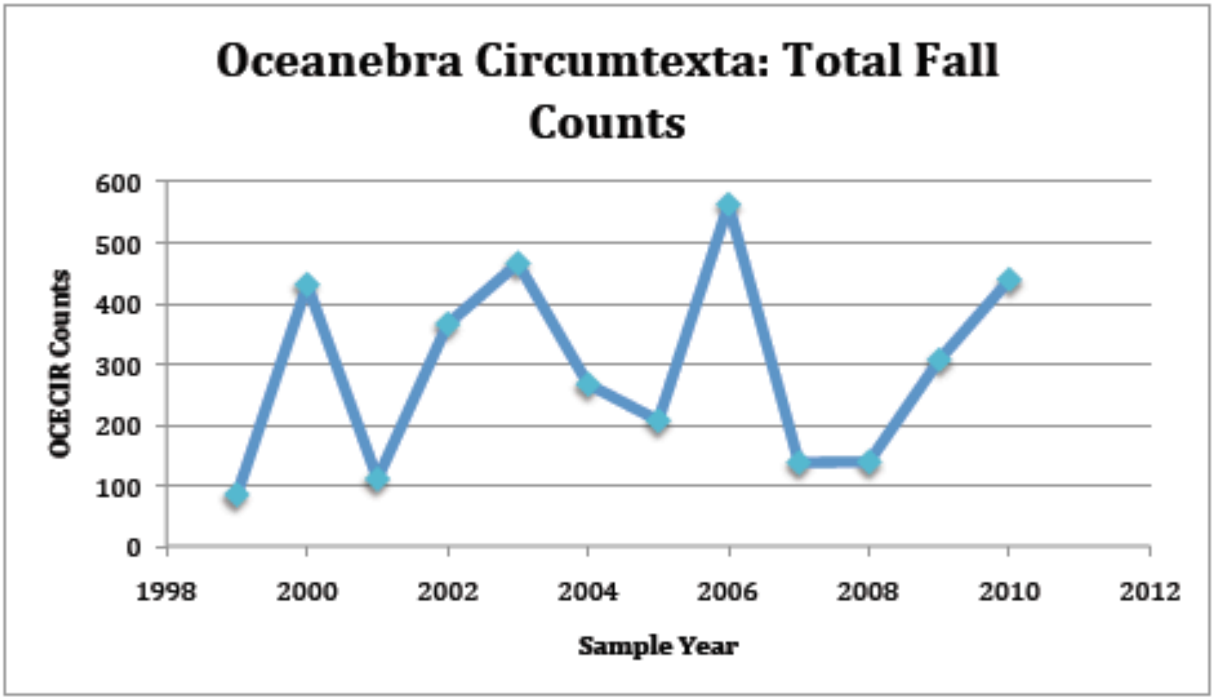

Medium to Large Limpets: Total Fall Counts
LMEDLG Counts
25,000
20,000
15,000
10,000
5,000
0
1998
2000
2002
2004
2006
2008
2010
2012
Sample Year

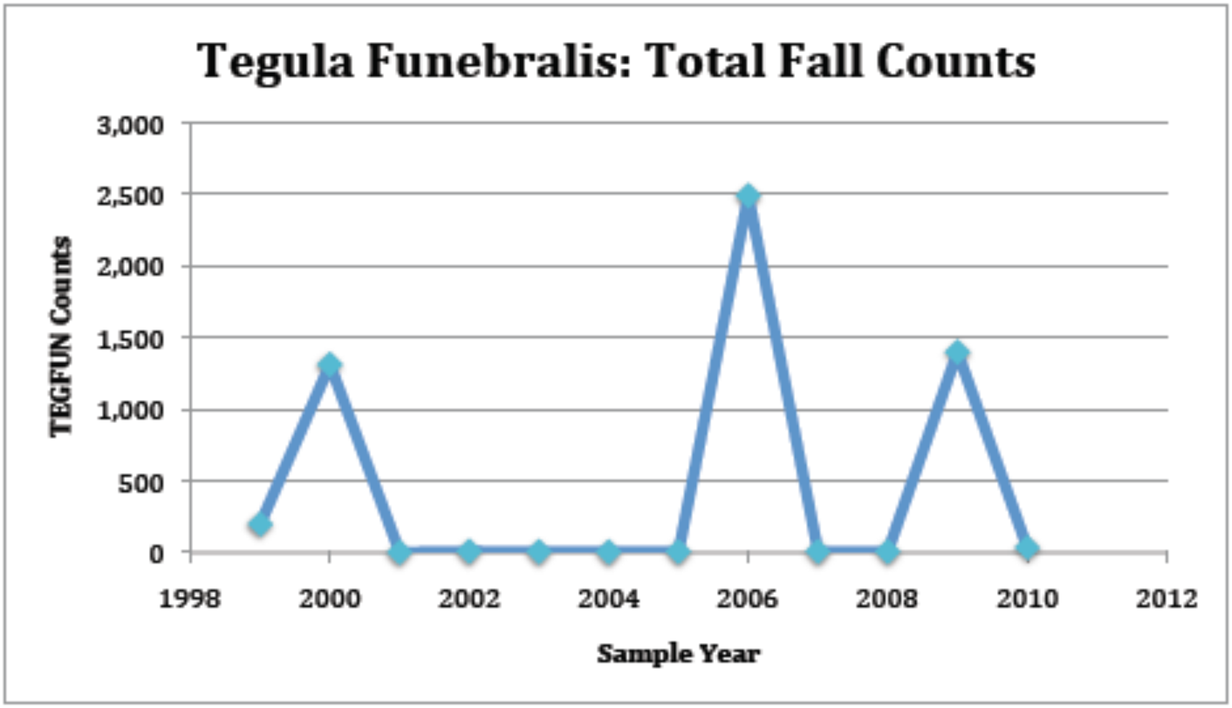

Littorina Species: Total Fall Counts
LITSPP Count
120,000
100,000
80,000
60,000
40,000
20,000
0
1998
2000
2002
2004
2006
2008
2010
2012
Sample Year

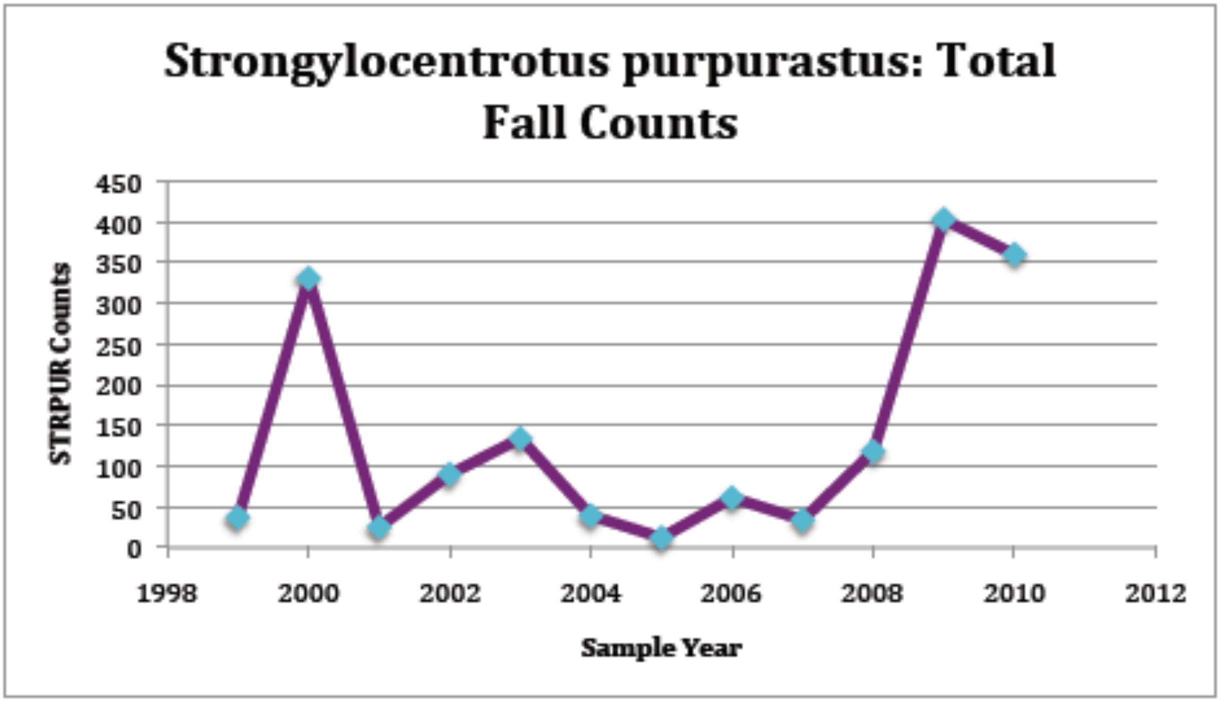

Lottia Gigantea: Total Fall Counts
LOTGIG Counts
350
300
250
200
150
100
50
0
1998
2000
2002
2004
2006
2008
2010
2012
Sample Year

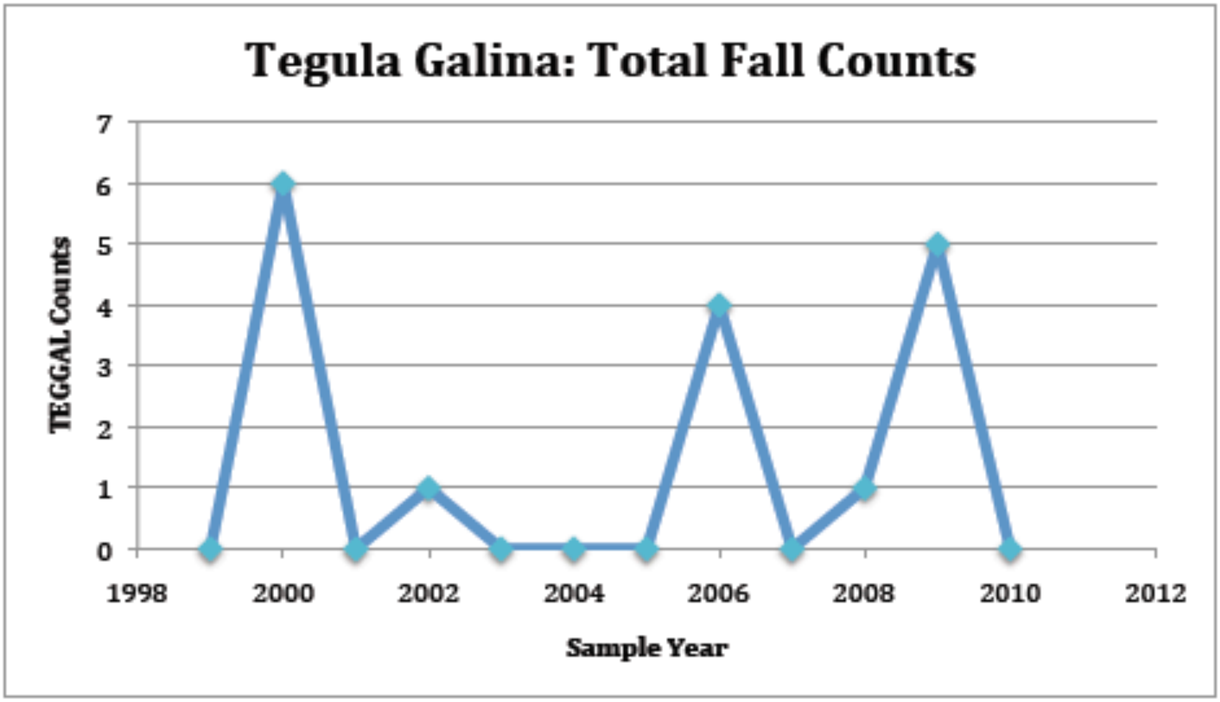

Nucella Emarginata: Total Fall Counts
NUCEMA Counts
1,200
1,000
800
600
400
200
0
1998
2000
2002
2004
2006
2008
2010
2012
Sample Year


Nuttallina Species: Total Fall Counts
NUTSPP Counts
1,200
1,000
800
600
400
200
0
1998
2000
2002
2004
2006
2008
2010
2012
Sample Year

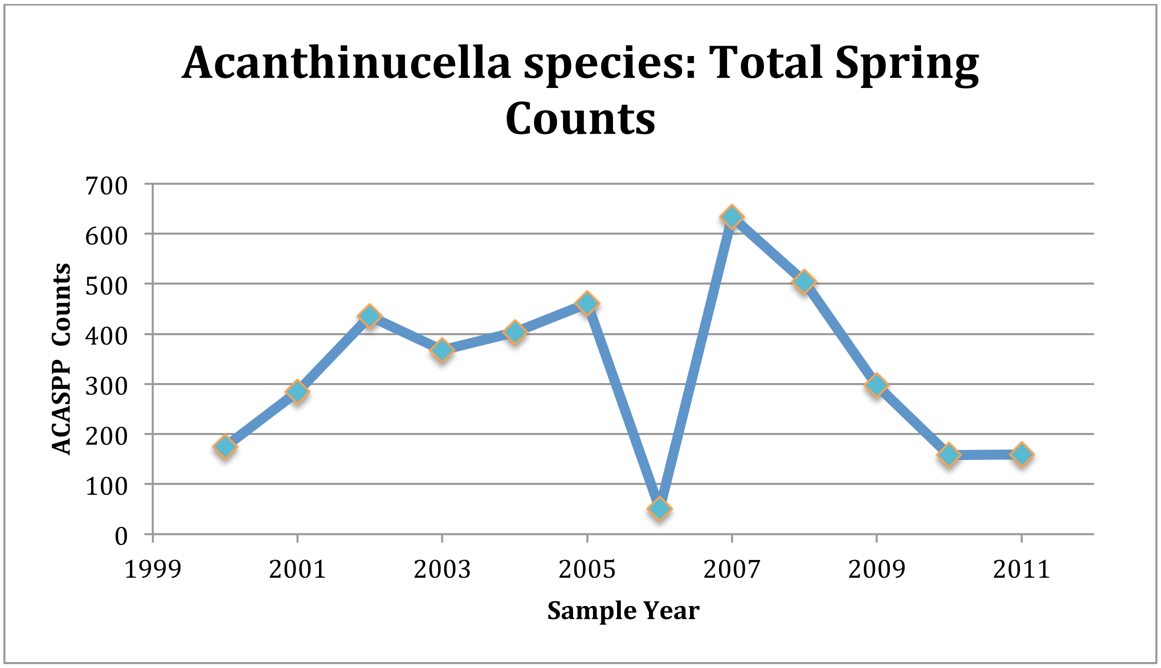

Oceanebra Circumtexta: Total Fall Counts
OCECIR Counts
600
500
400
300
200
100
0
1998
2000
2002
2004
2006
2008
2010
2012
Sample Year

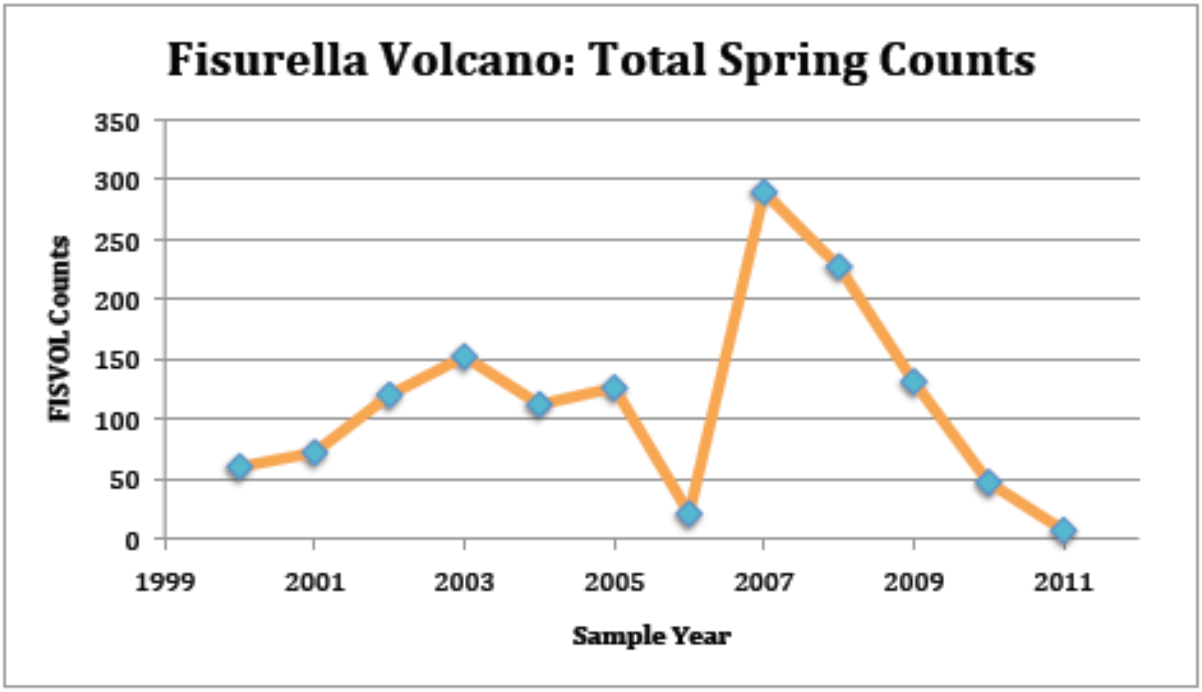

Tegula Funebralis: Total Fall Counts
TEGFUN Counts
3,000
2,500
2,000
1,500
1,000
500
0
1998
2000
2002
2004
2006
2008
2010
2012
Sample Year

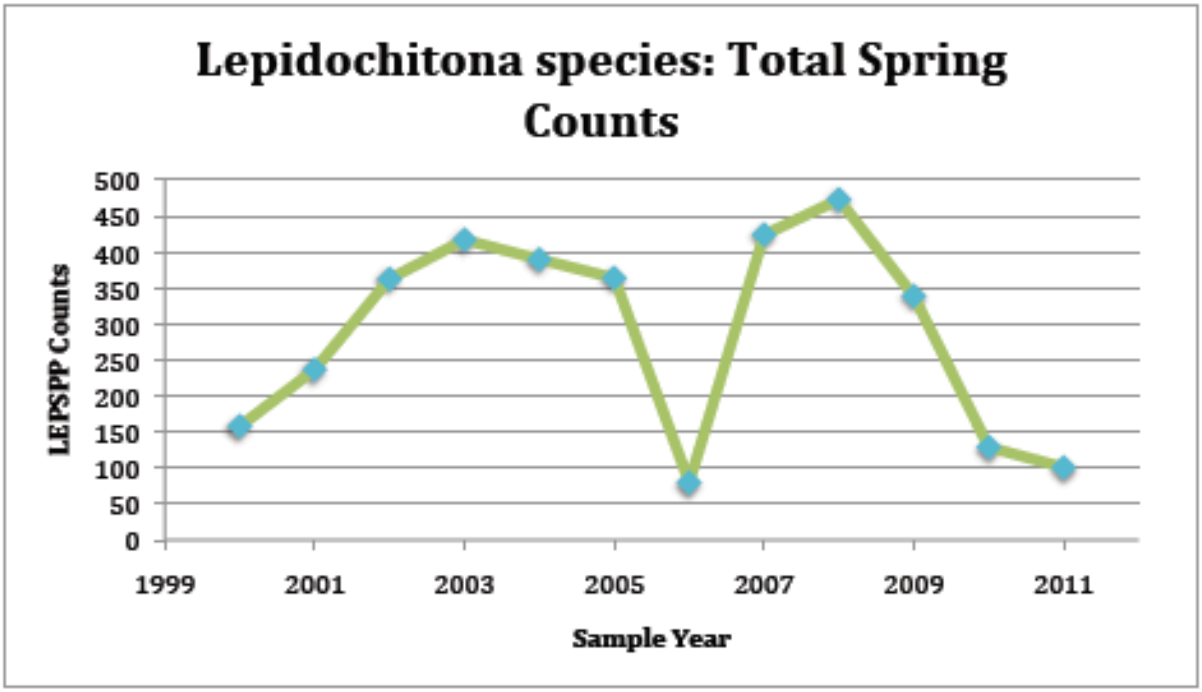

Strongylocentrotus purpurastus: Total Fall Counts
450
400
350
300
250
200
150
100
50
0
STRPUR Counts
1998
2000
2002
2004
2006
2008
2010
2012
Sample Year

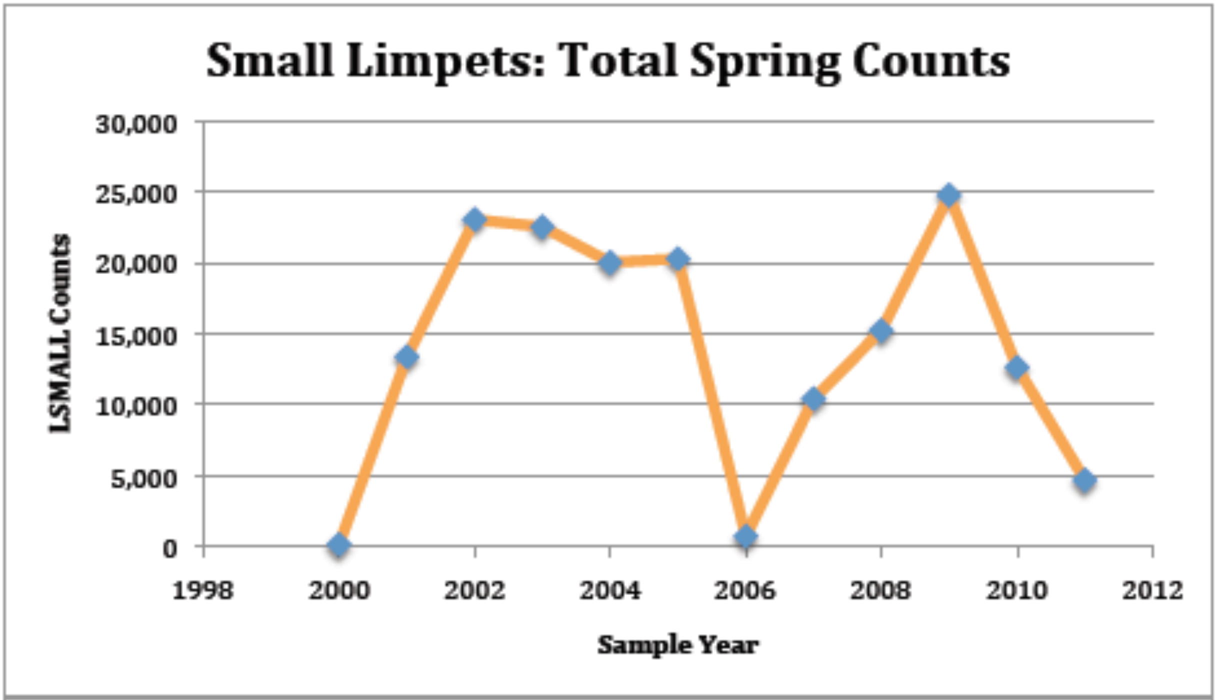

Tegula Galina: Total Fall Counts
7
6
5
4
3
2
1
0
TEGGAL Counts
1998
2000
2002
2004
2006
2008
2010
2012
Sample Year

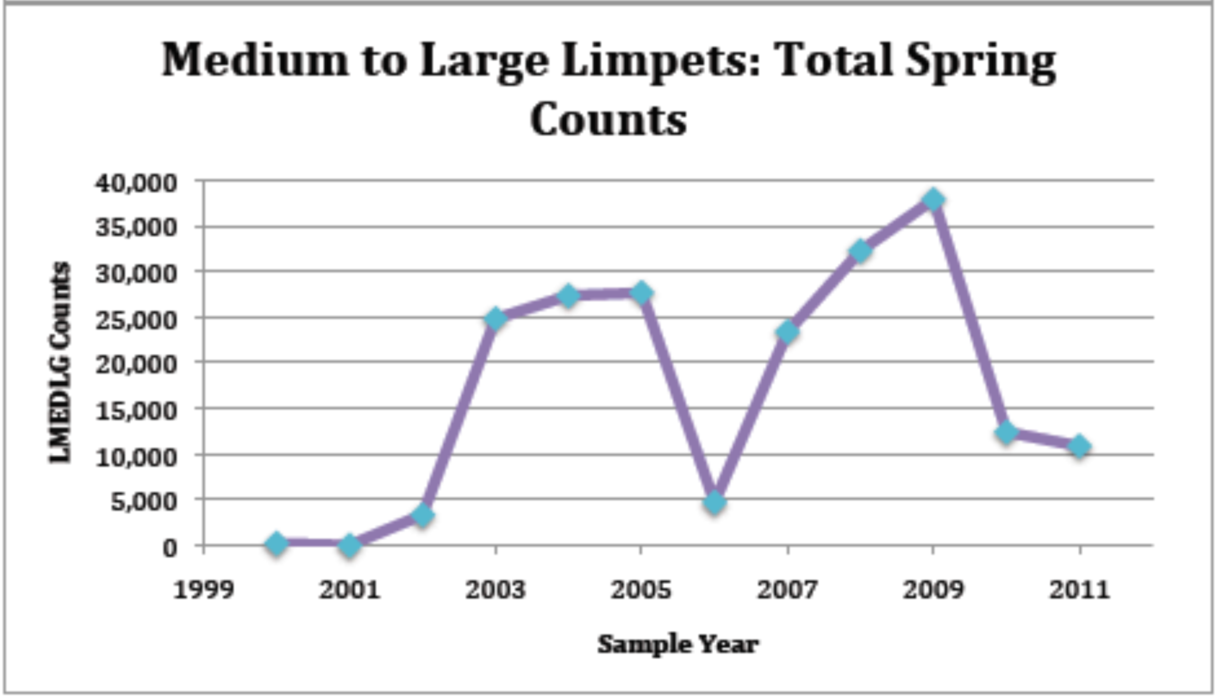
Appendix A.2.2 Total Spring Counts

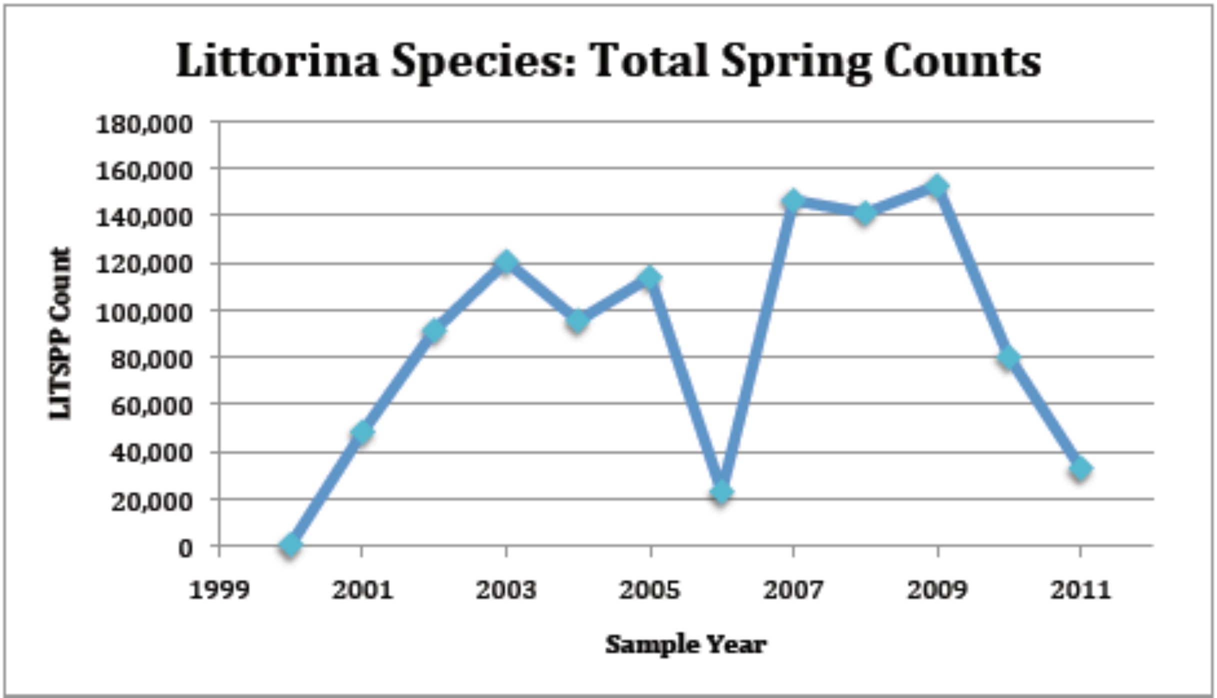


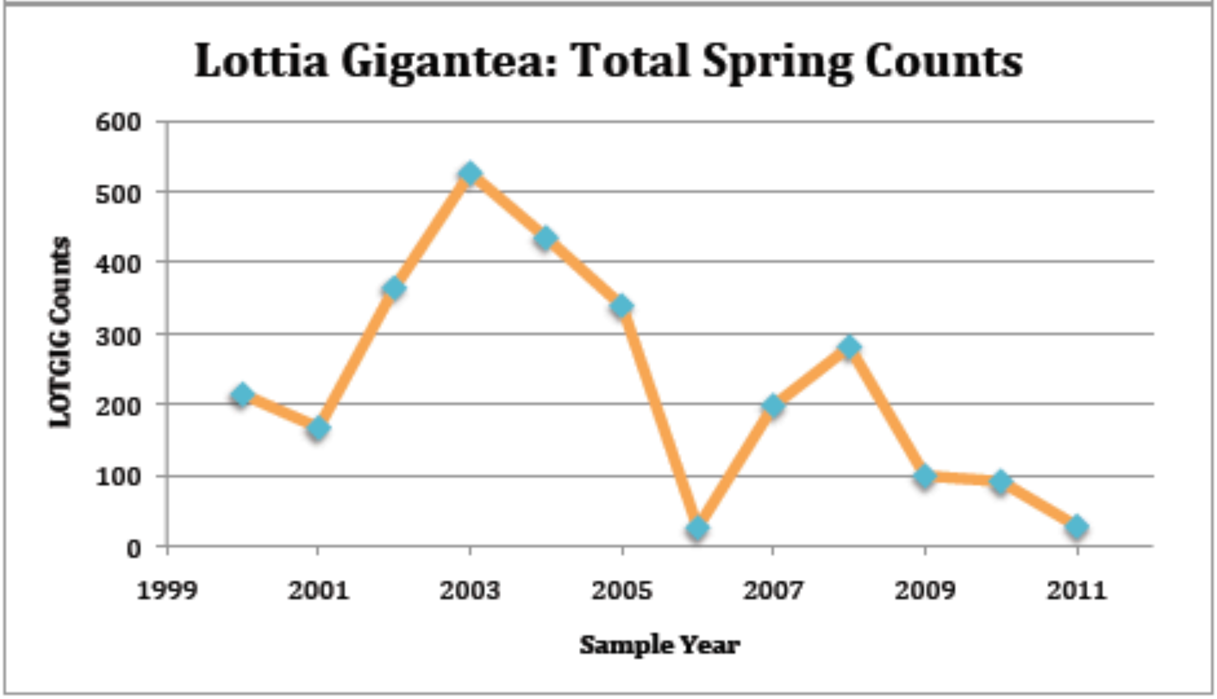

Fisurella Volcano: Total Spring Counts
FISVOL Counts
350
300
250
200
150
100
50
0
1999
2001
2003
2005
2007
2009
2011
Sample Year

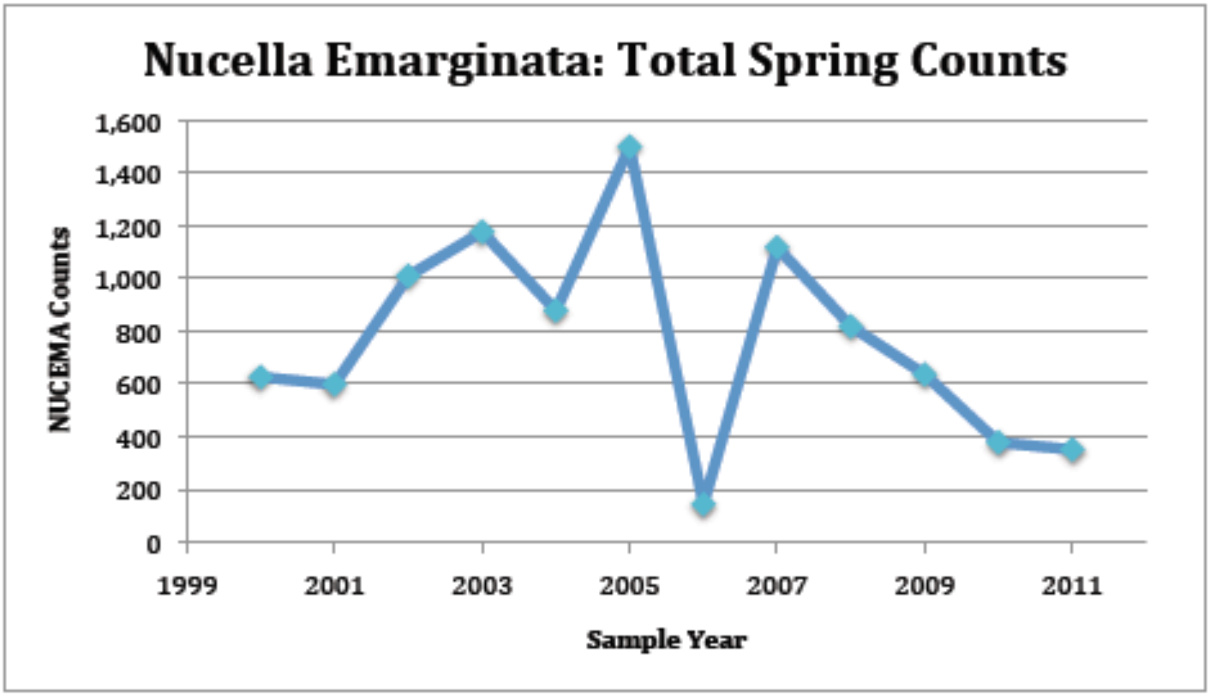

Lepidochitona species: Total Spring Counts
LEPSPP Counts
500
450
400
350
300
250
200
150
100
50
0
1999
2001
2003
2005
2007
2009
2011
Sample Year

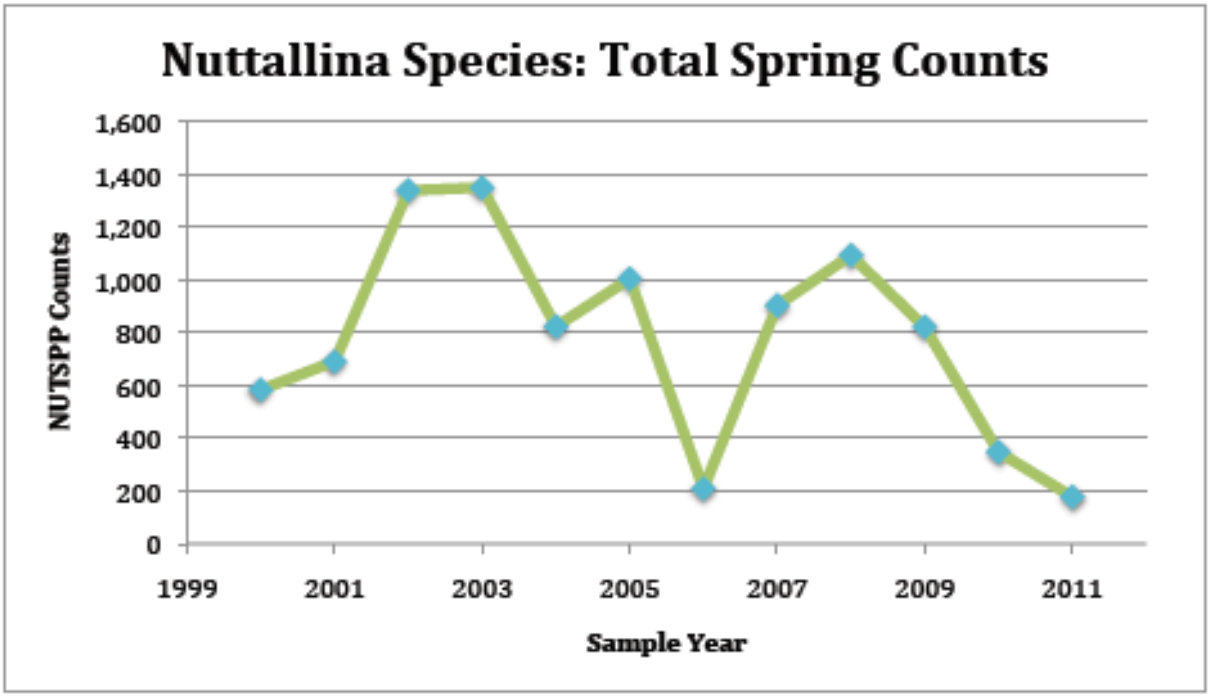

Small Limpets: Total Spring Counts

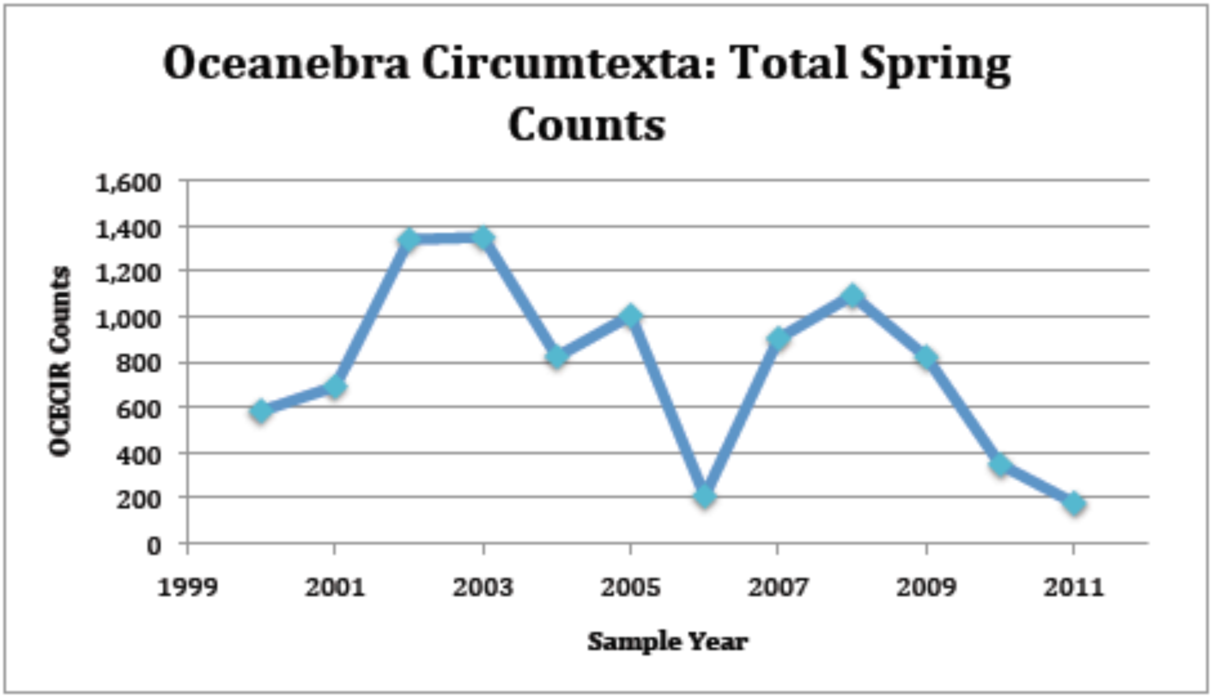

Medium to Large Limpets: Total Spring Counts

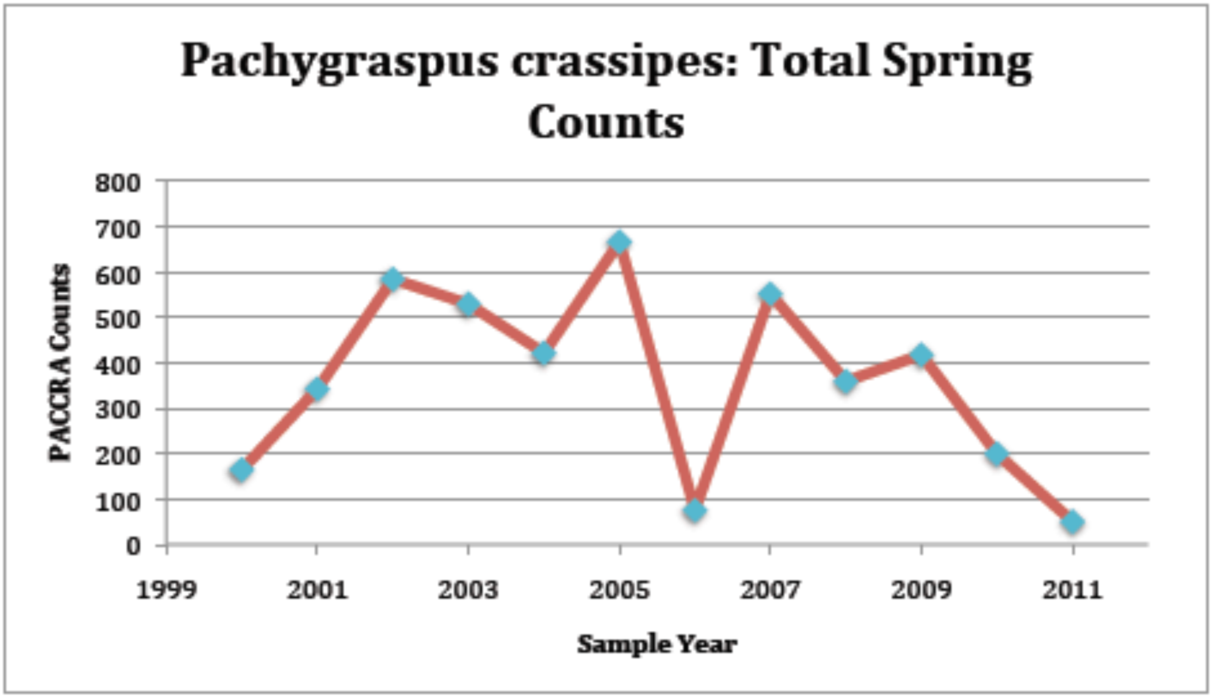

Littorina Species: Total Spring Counts
LITSPP Count
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
1999
2001
2003
2005
2007
2009
2011
Sample Year

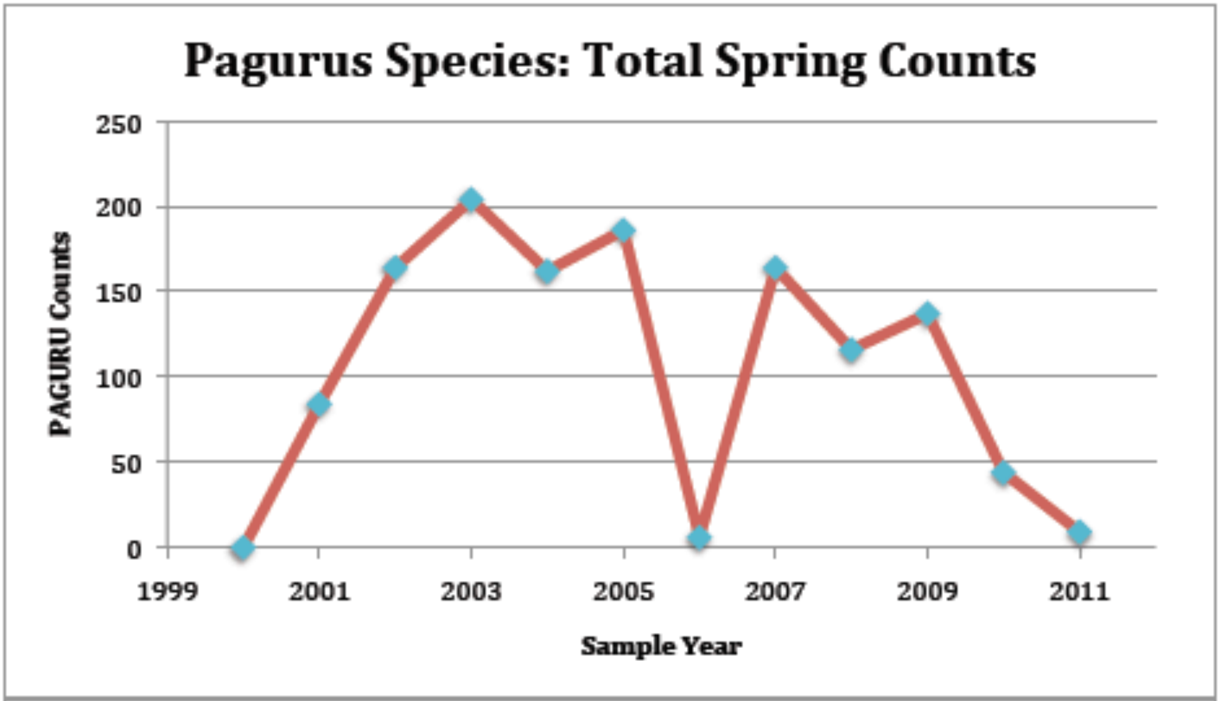

Lottia Gigantea: Total Spring Counts
LOTGIG Counts
600
500
400
300
200
100
0
1999
2001
2003
2005
2007
2009
2011
Sample Year

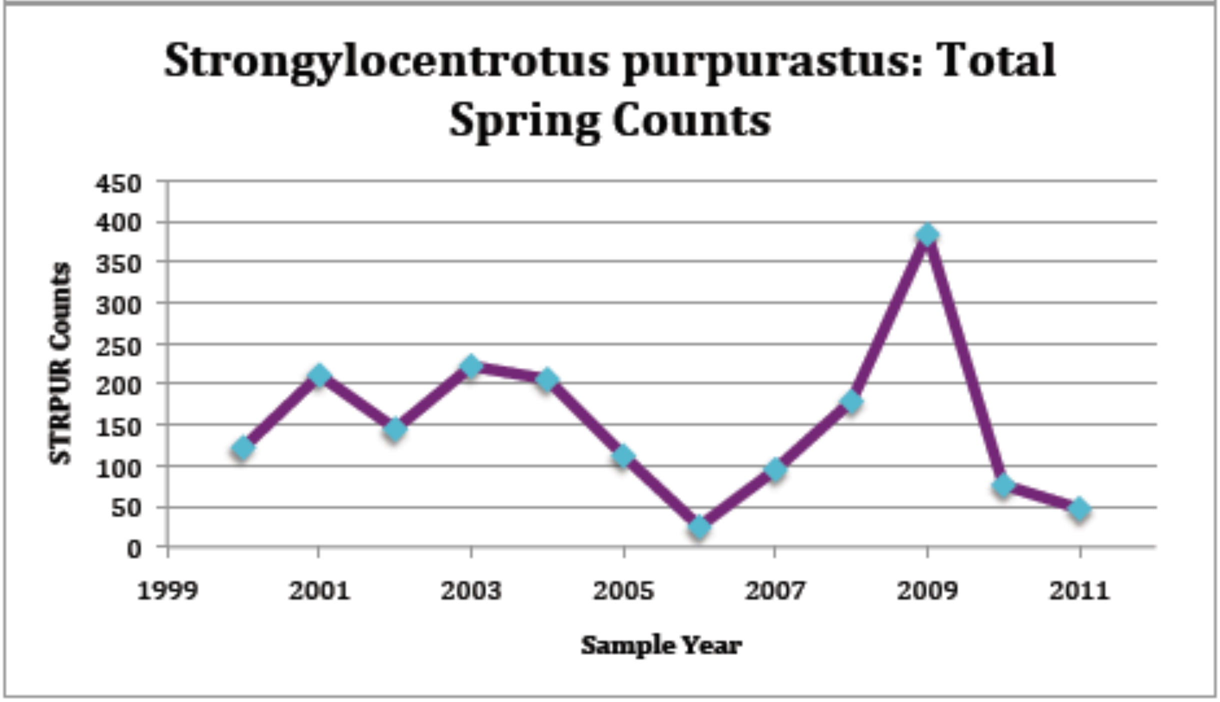

Nucella Emarginata: Total Spring Counts
1,600
1,400
1,200
1,000
800
600
400
200
0
NUCEMA Counts
1999
2001
2003
2005
2007
2009
2011
Sample Year

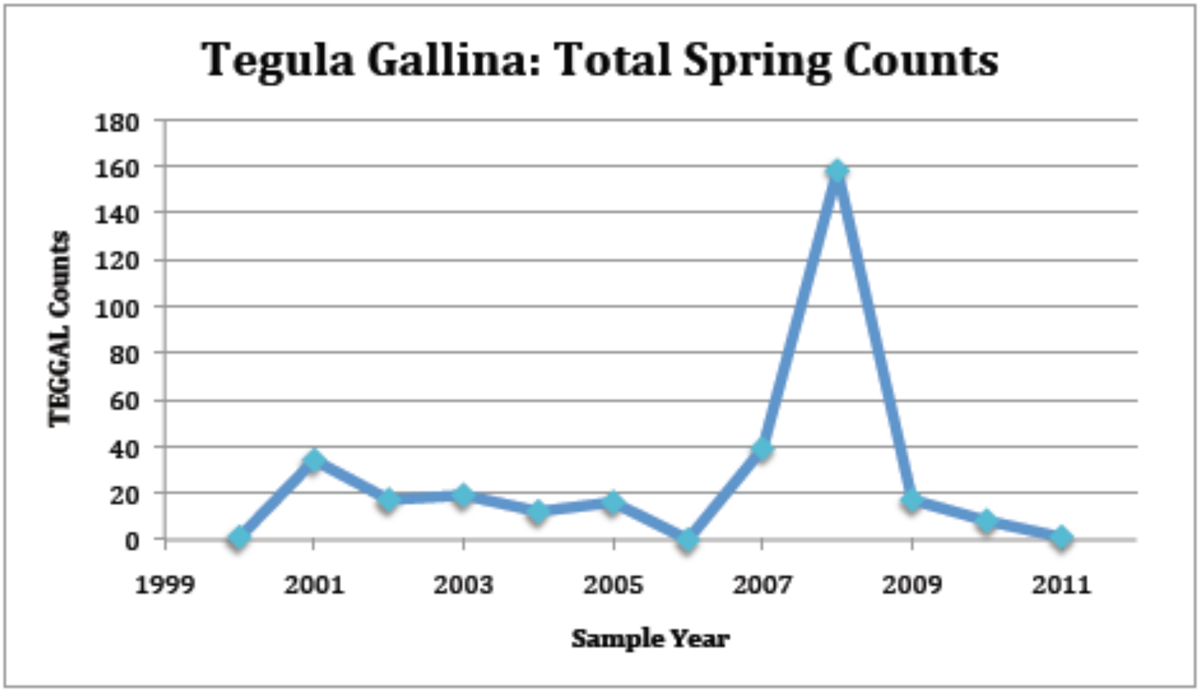

Nuttallina Species: Total Spring Counts
1,600
1,400
1,200
1,000
800
600
400
200
0
NUTSPP Counts
1999
2001
2003
2005
2007
2009
2011
Sample Year


Oceanebra Circumtexta: Total Spring Counts
OCECIR Counts
1,600
1,400
1,200
1,000
800
600
400
200
0
1999
2001
2003
2005
2007
2009
2011
Sample Year


Pachygraspus crassipes: Total Spring Counts
PACCRA Counts
800
700
600
500
400
300
200
100
0
1999
2001
2003
2005
2007
2009
2011
Sample Year


Pagurus Species: Total Spring Counts

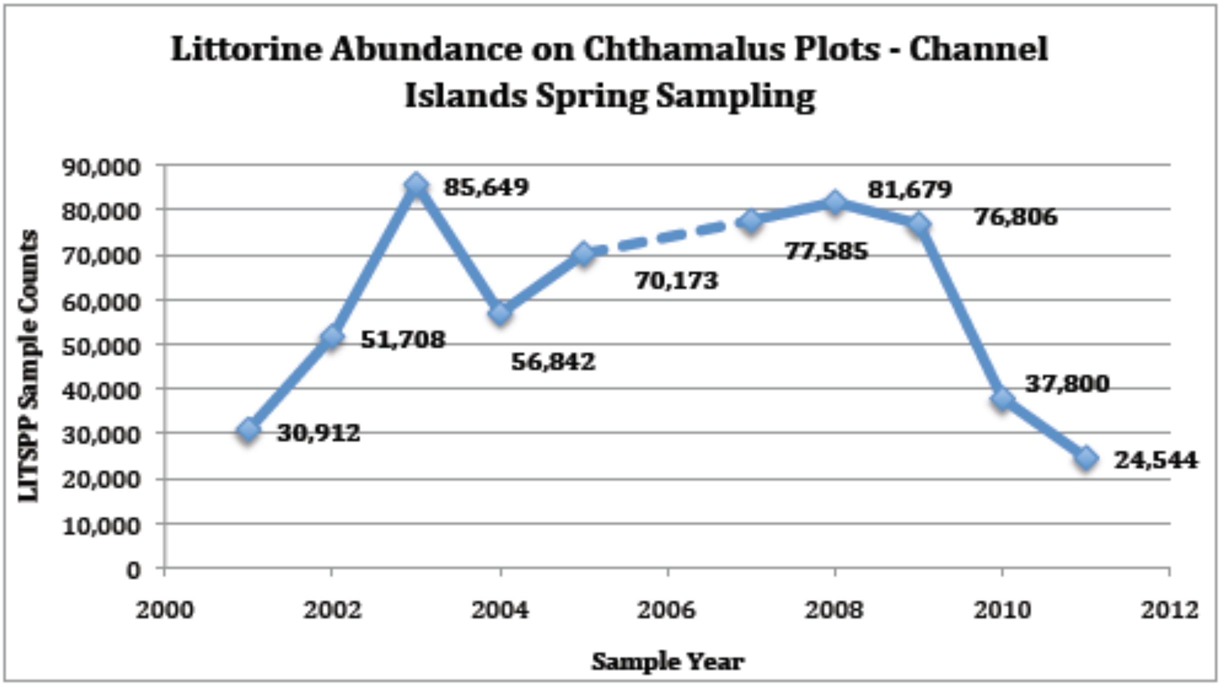

Strongylocentrotus purpurastus: Total Spring Counts



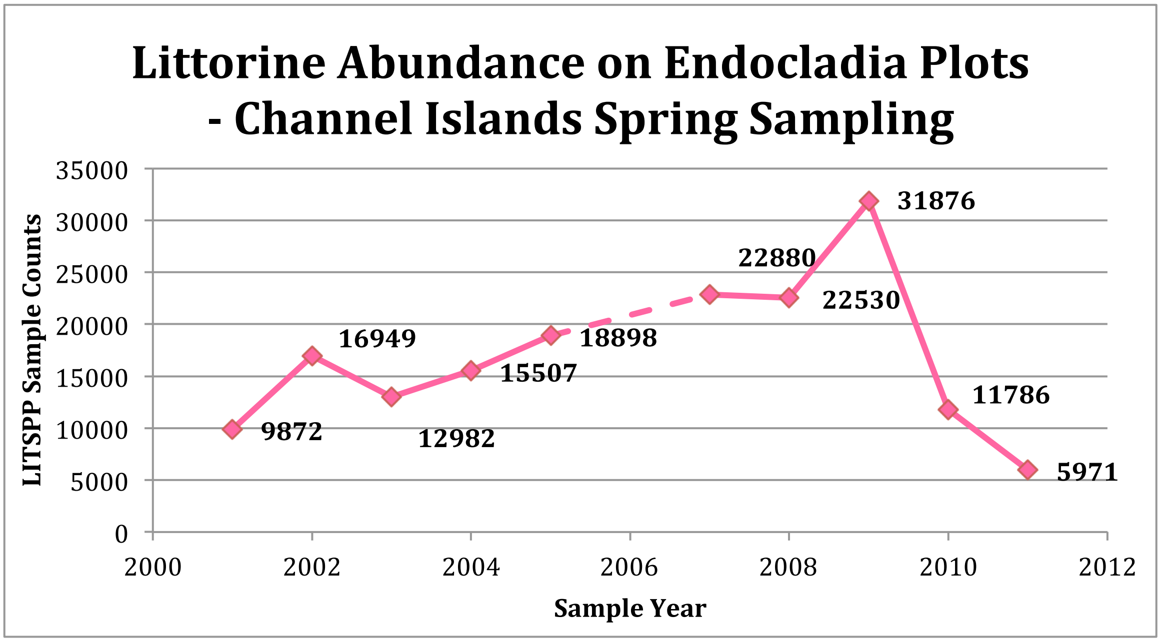
Appendix A.2.3 Biotic Zone Counts

Note: Dashed lines represent years with too few sites being sampled. The blue color represents *Chthamalus/Balanus*, the pink *Endocladia*, the green *Silvetia*, and the orange *Mytilus*.

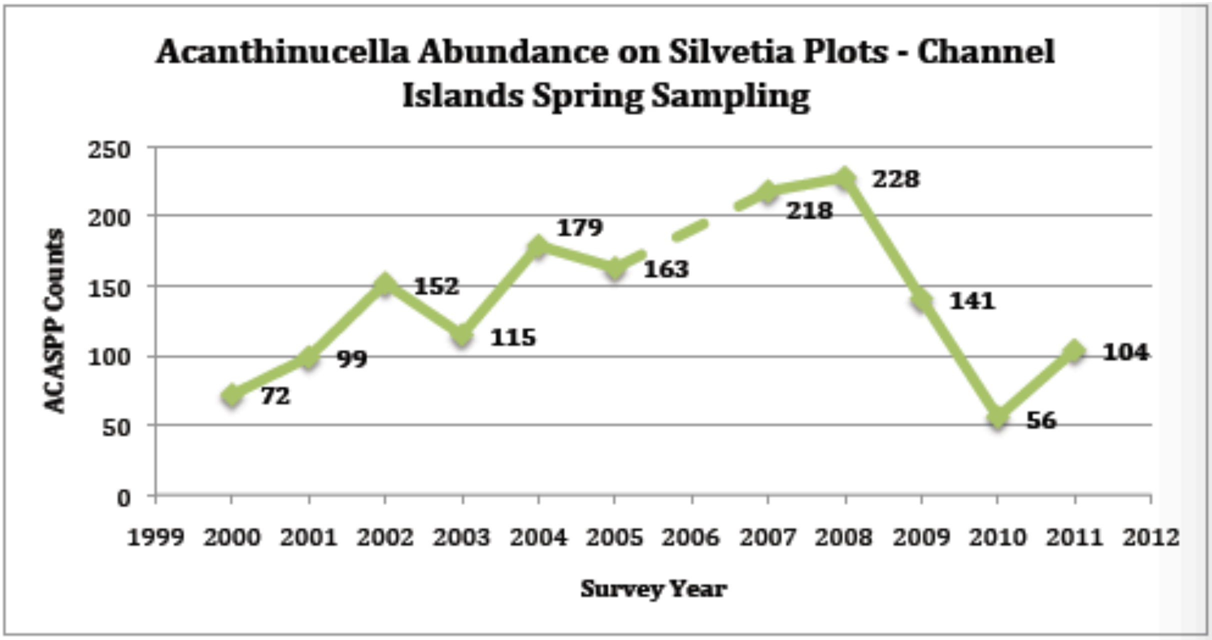
Appendix A.2.3.1 Littorine Abundance on Chthamalus Plots

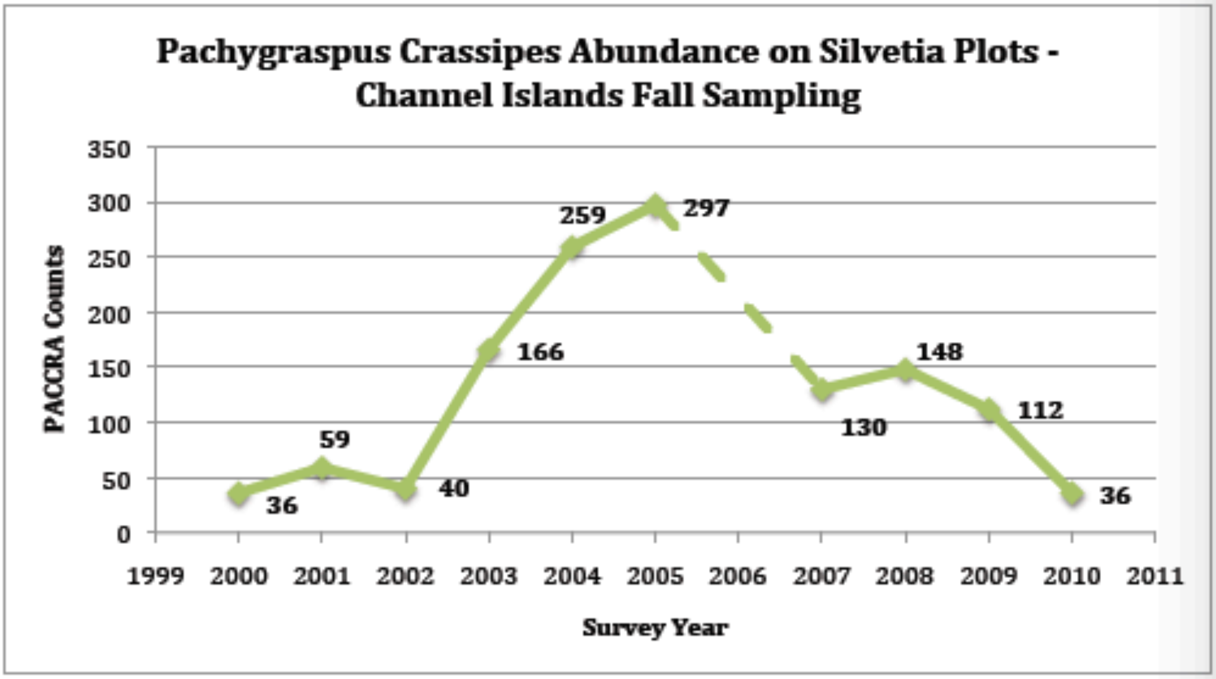


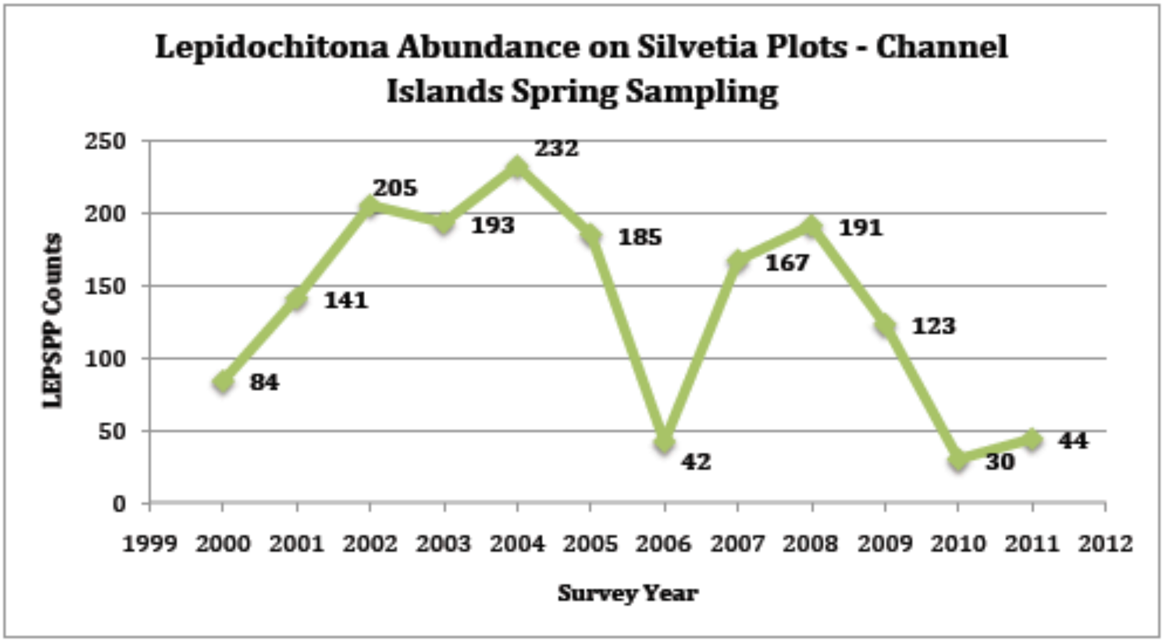
Appendix A.2.3.2 Littorine Abundance on Endocladia Plots

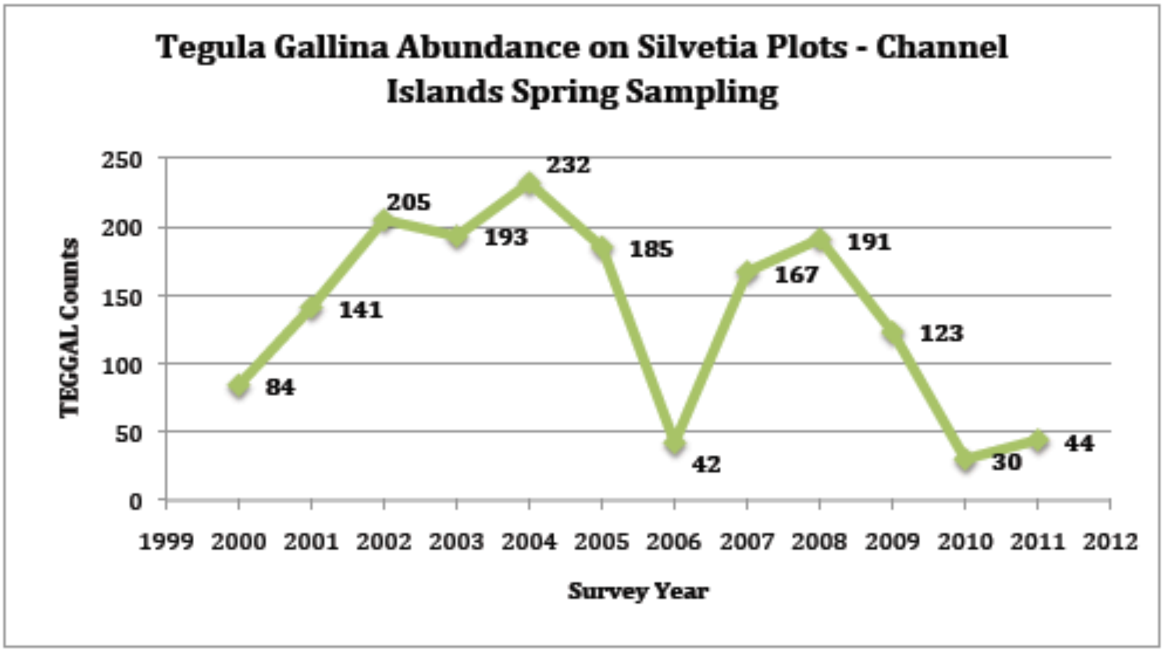


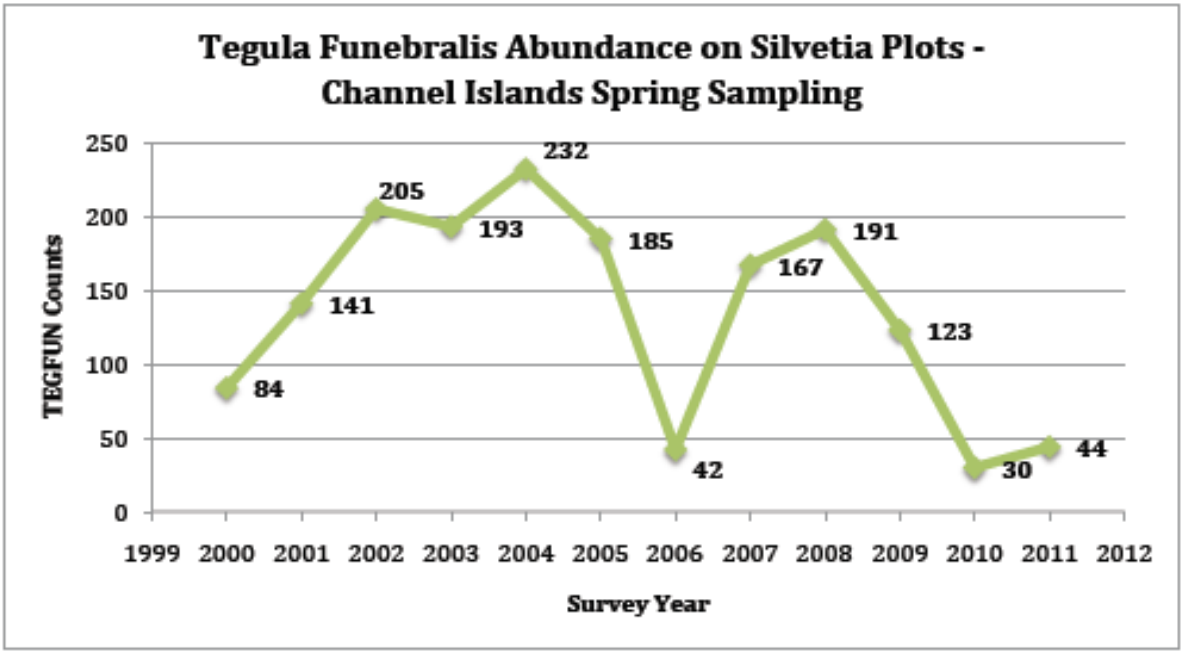
Appendix A.2.3.3 Species Count on Silvetia Plots


Acanthinucella Abundance on Silvetia Plots - Channel Islands Spring Sampling

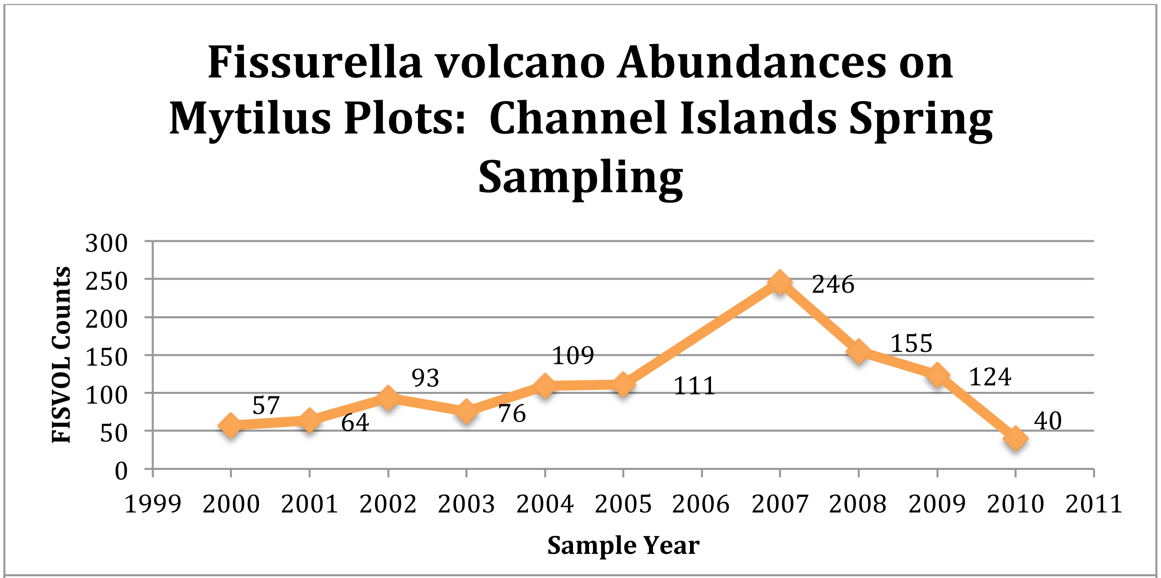

Pachygraspus Crassipes Abundance on Silvetia Plots - Channel Islands Fall Sampling

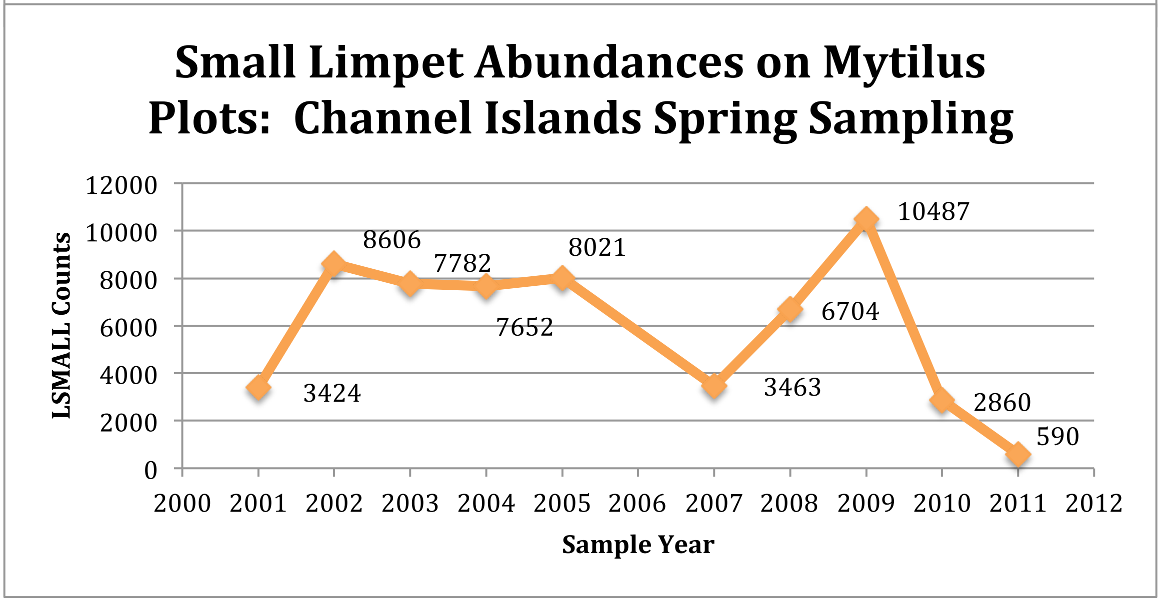

Lepidochitona Abundance on Silvetia Plots - Channel Islands Spring Sampling
LEPSPP Counts
0
50
100
150
200
250
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Survey Year
84
141
205
193
232
185
42
167
191
123
30
44

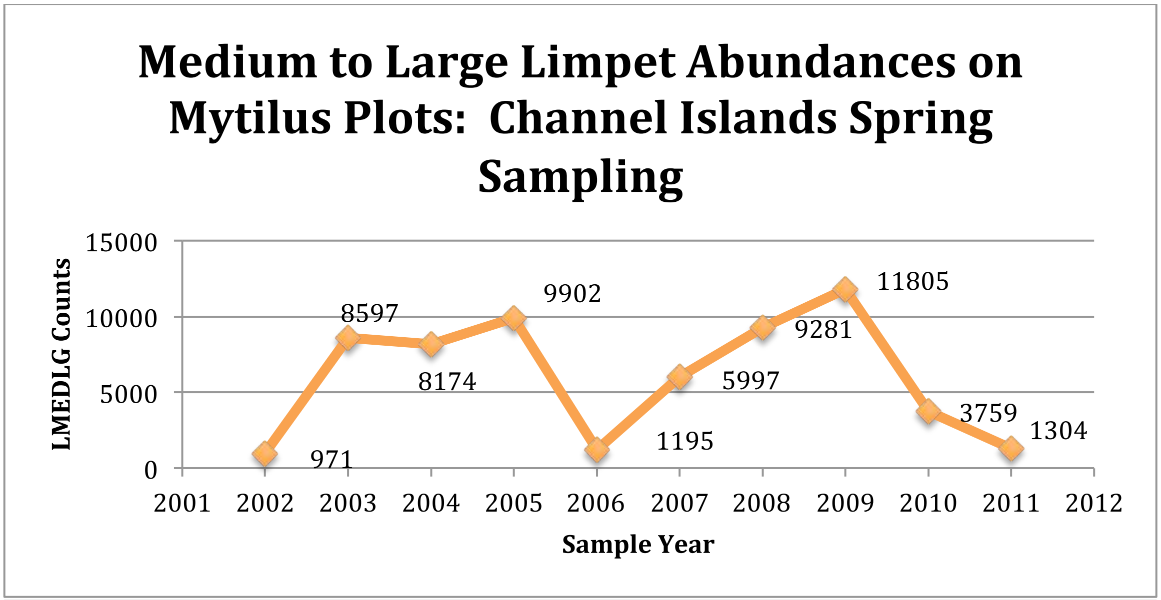

Tegula Gallina Abundance on Silvetia Plots - Channel Islands Spring Sampling
TEGGAL Counts
0
50
100
150
200
250
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Survey Year
84
141
205
193
232
185
42
167
191
123
30
44

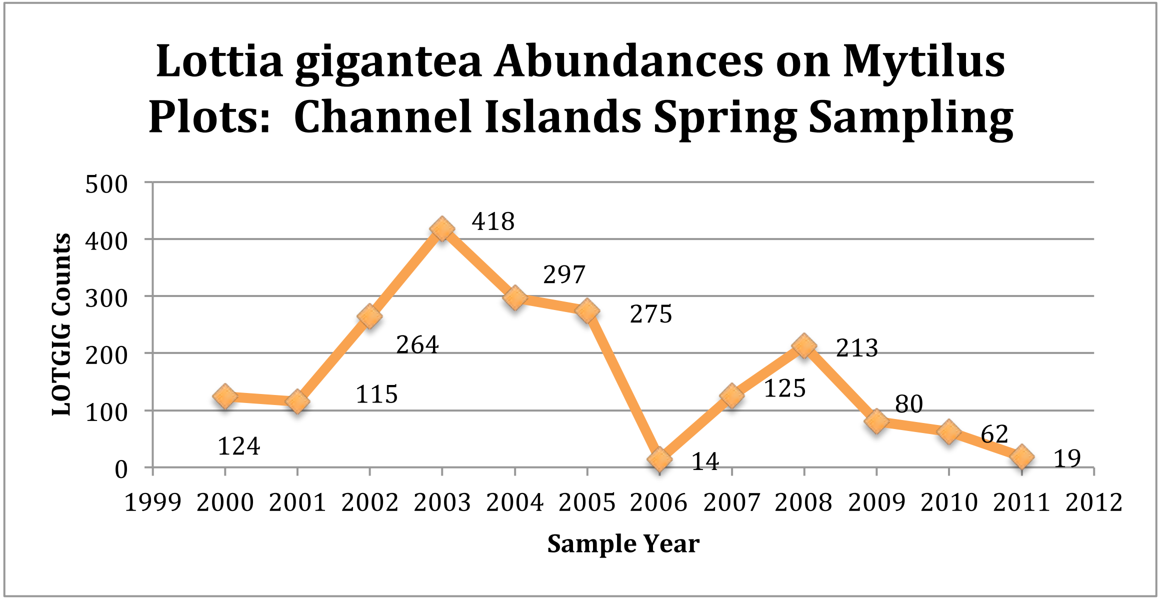


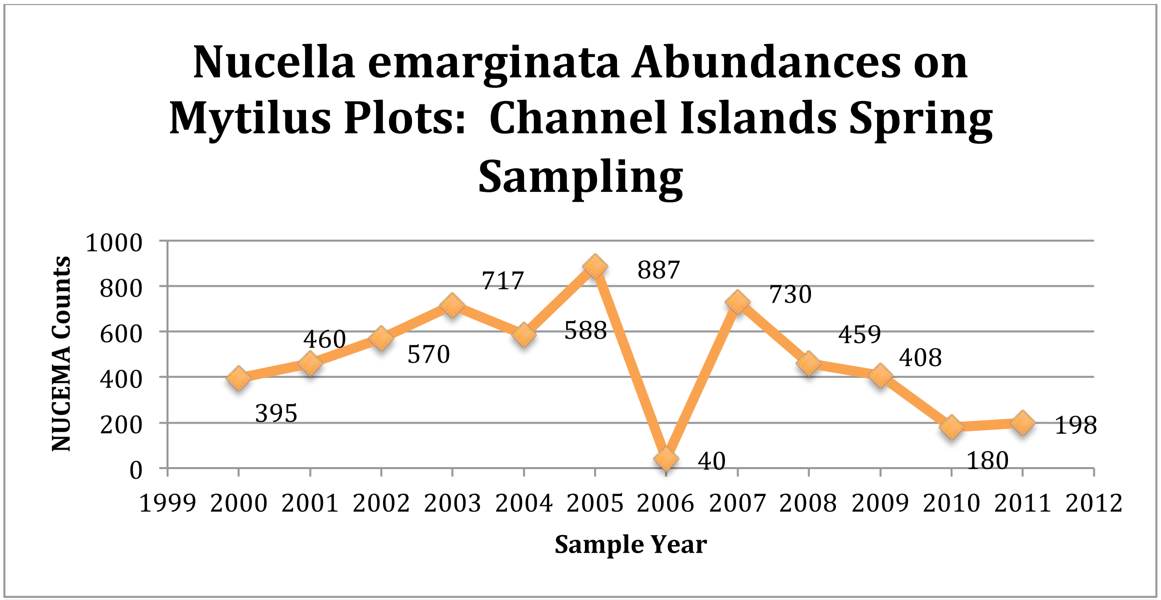
Appendix A.2.3.4 Species Abundance on Mytilus


Fissurella volcano Abundances on Mytilus Plots: Channel Islands Spring Sampling
FISVOL Counts
300
250
200
150
100
50
0
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
Sample Year
57
64
93
76
109
111
246
155
124
40

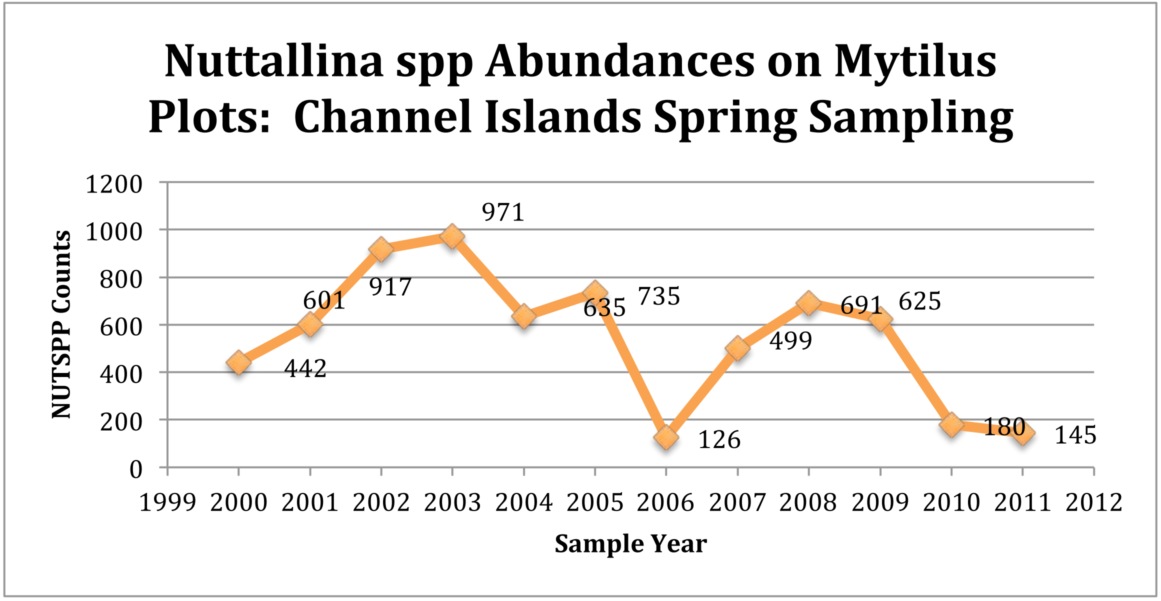

Small Limpet Abundances on Mytilus Plots: Channel Islands Spring Sampling
LSMALL Counts
12000
10000
8000
6000
4000
2000
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Sample Year
3424
8606
7782
7652
8021
3463
6704
10487
2860
590


Medium to Large Limpet Abundances on Mytilus Plots: Channel Islands Spring Sampling
LMEDLG Counts
0
5000
10000
15000
971
8597
8174
9902
1195
5997
9281
11805
3759
1304
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Sample Year

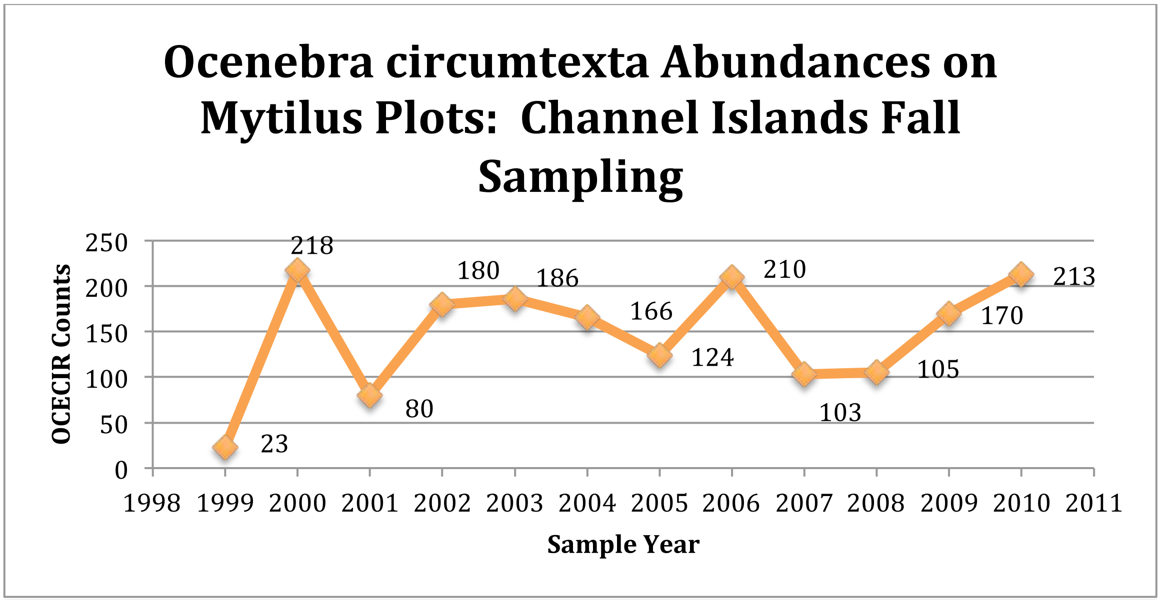

Lottia gigantea Abundances on Mytilus Plots: Channel Islands Spring Sampling
LOTGIG Counts
0
100
200
300
400
500
124
115
264
418
297
275
14
125
213
80
62
19
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Sample Year

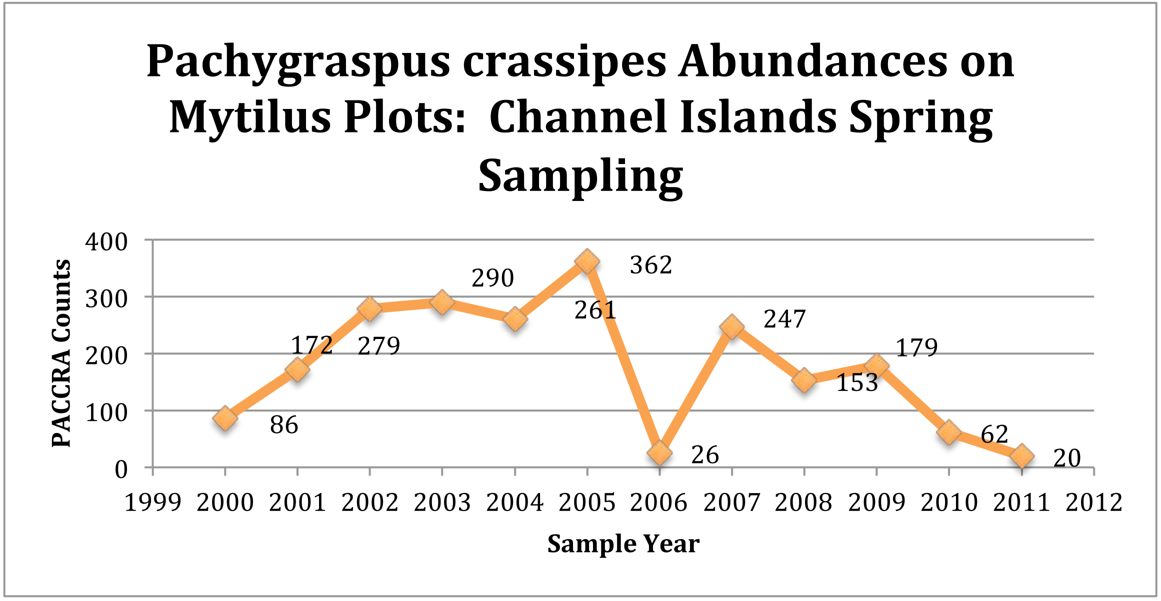


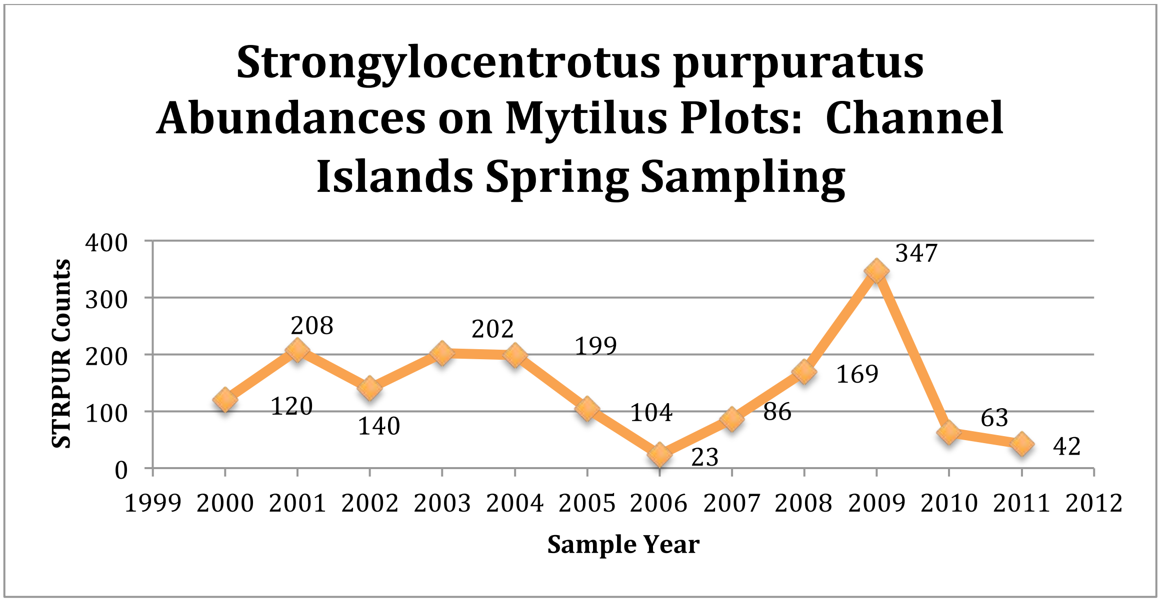
Nucella emarginata Abundances on Mytilus Plots: Channel Islands Spring Sampling



Nuttallina spp Abundances on Mytilus Plots: Channel Islands Spring Sampling

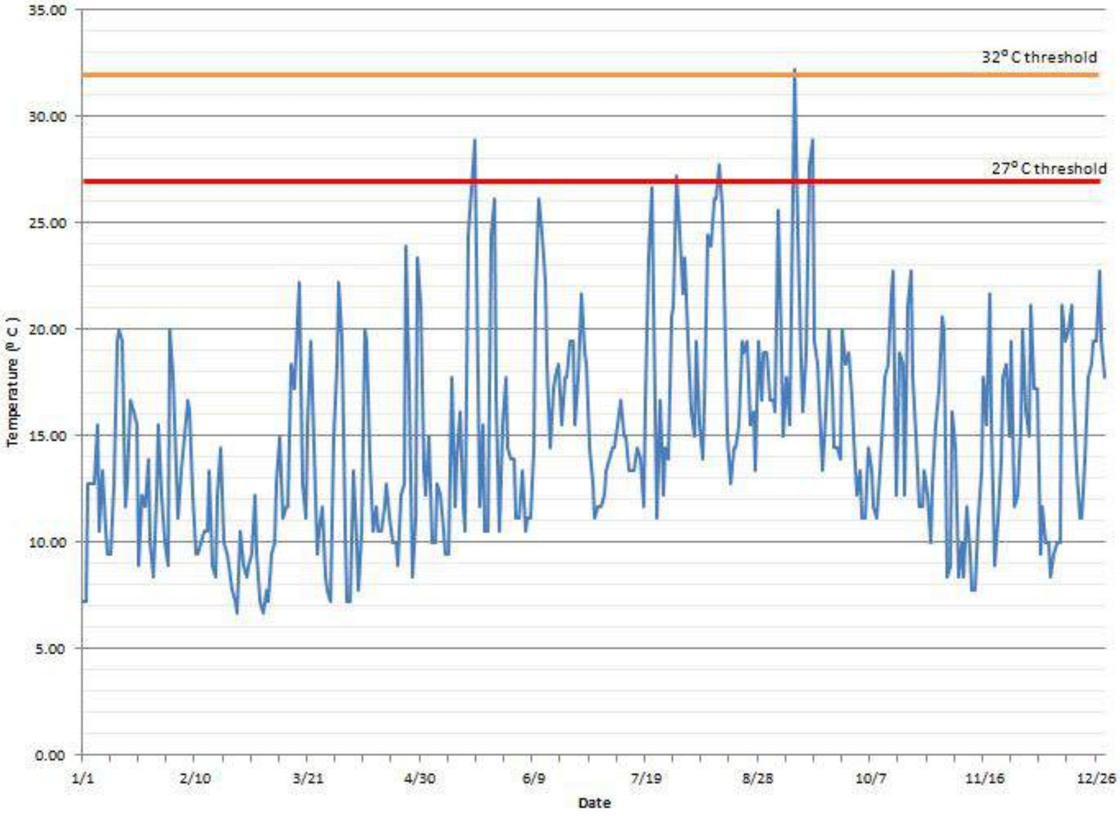

Ocenebra circumtexta Abundances on Mytilus Plots: Channel Islands Fall Sampling


Pachygraspus crassipes Abundances on Mytilus Plots: Channel Islands Spring Sampling

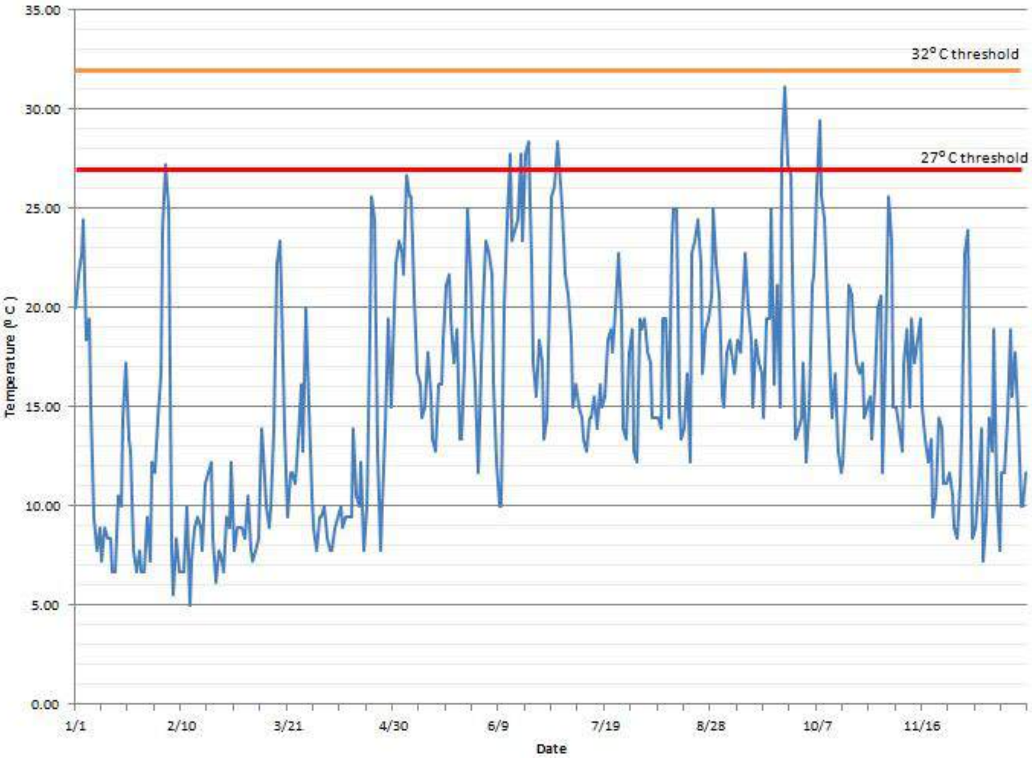


Appendix A.3 Climate Graphs

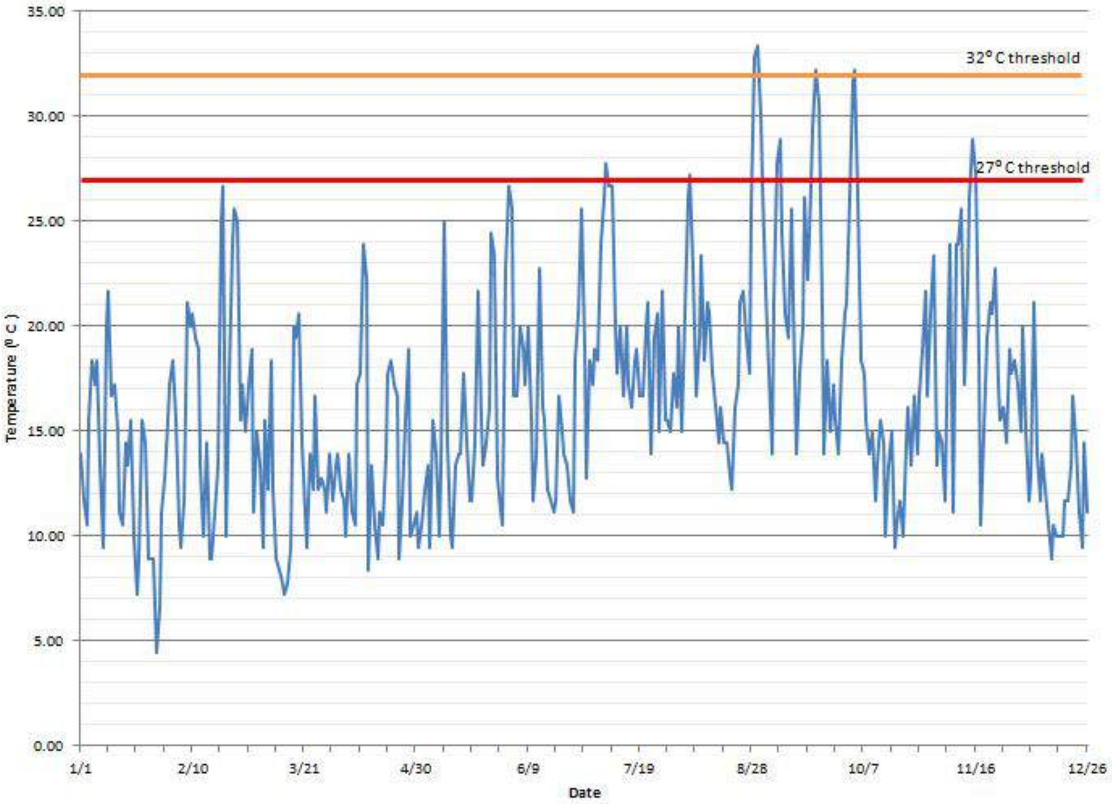
Appendix A.3.1 Santa Rosa 2000 Average Monthly High Temperatures (F) Above Threshold



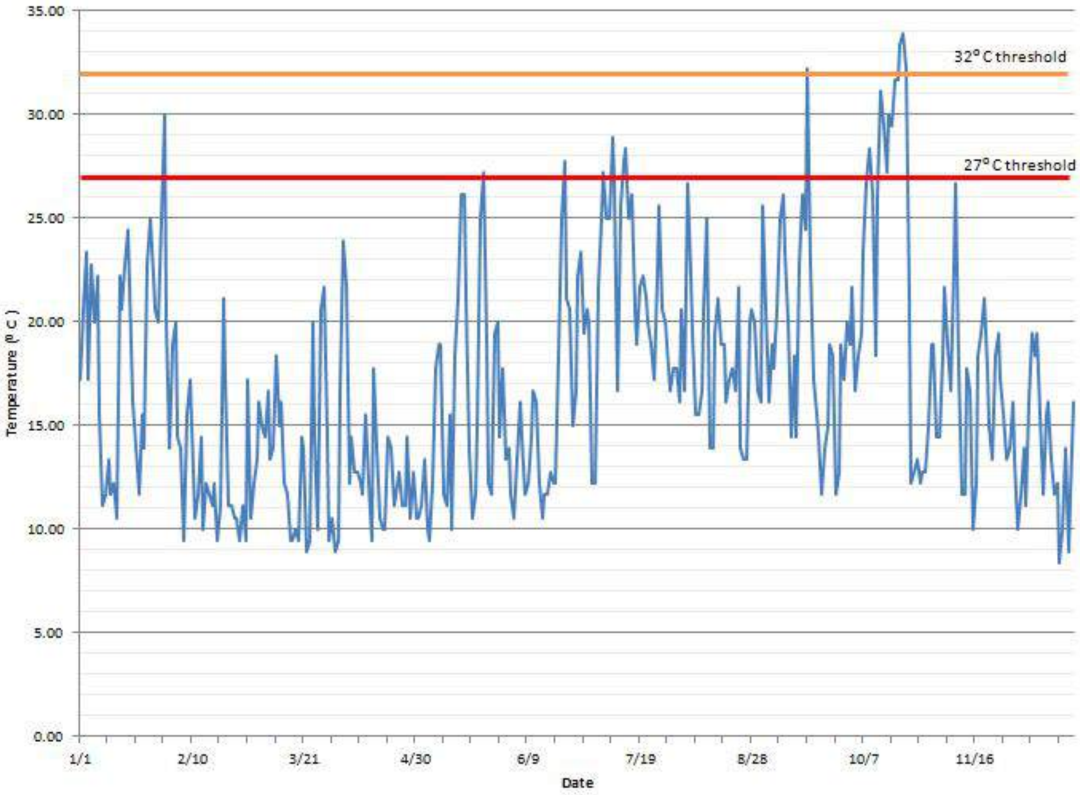
Appendix A.3.2 Santa Rosa 2001 Average Monthly High Temperatures (F) Above Threshold



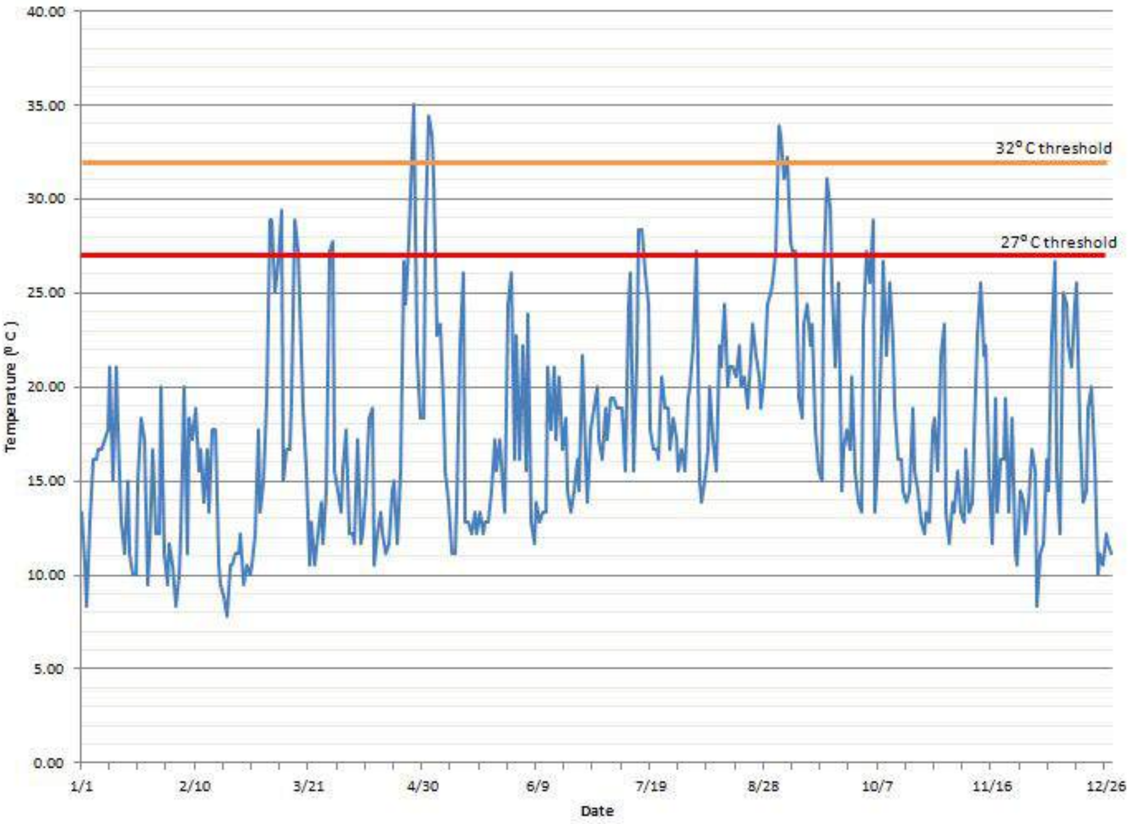
Appendix A.3.3 Santa Rosa 2002 Average Monthly High Temperatures (F) Above Threshold



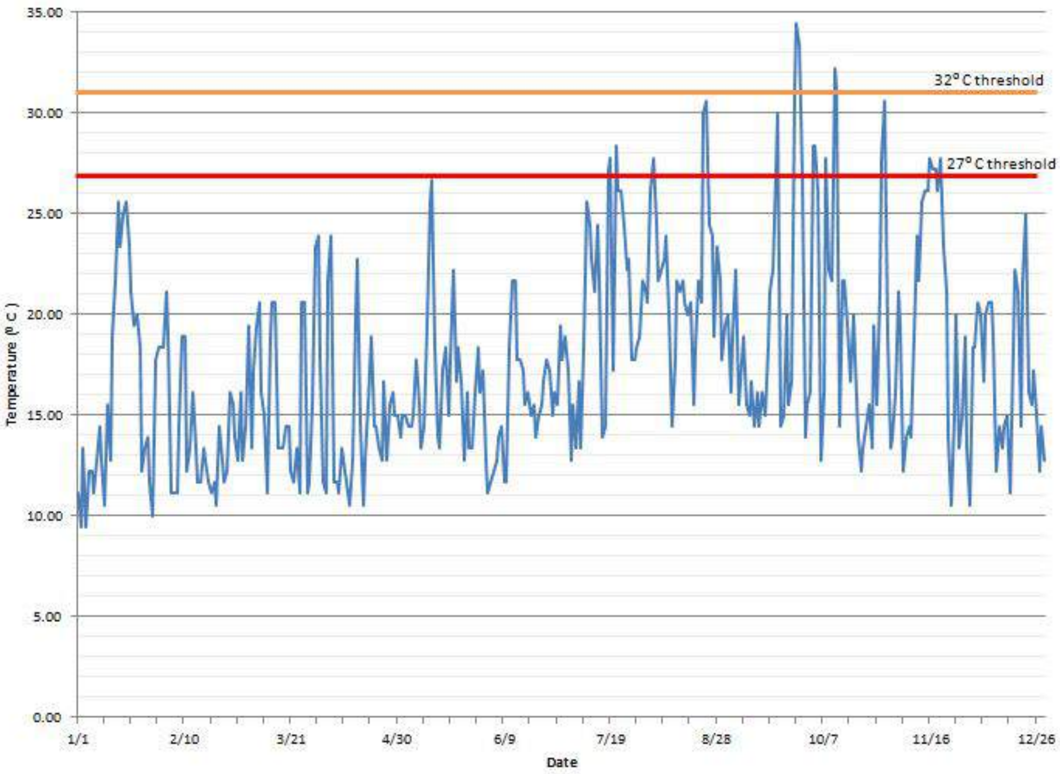
Appendix A.3.4 Santa Rosa 2003 Average Monthly High Temperatures (F) Above Threshold



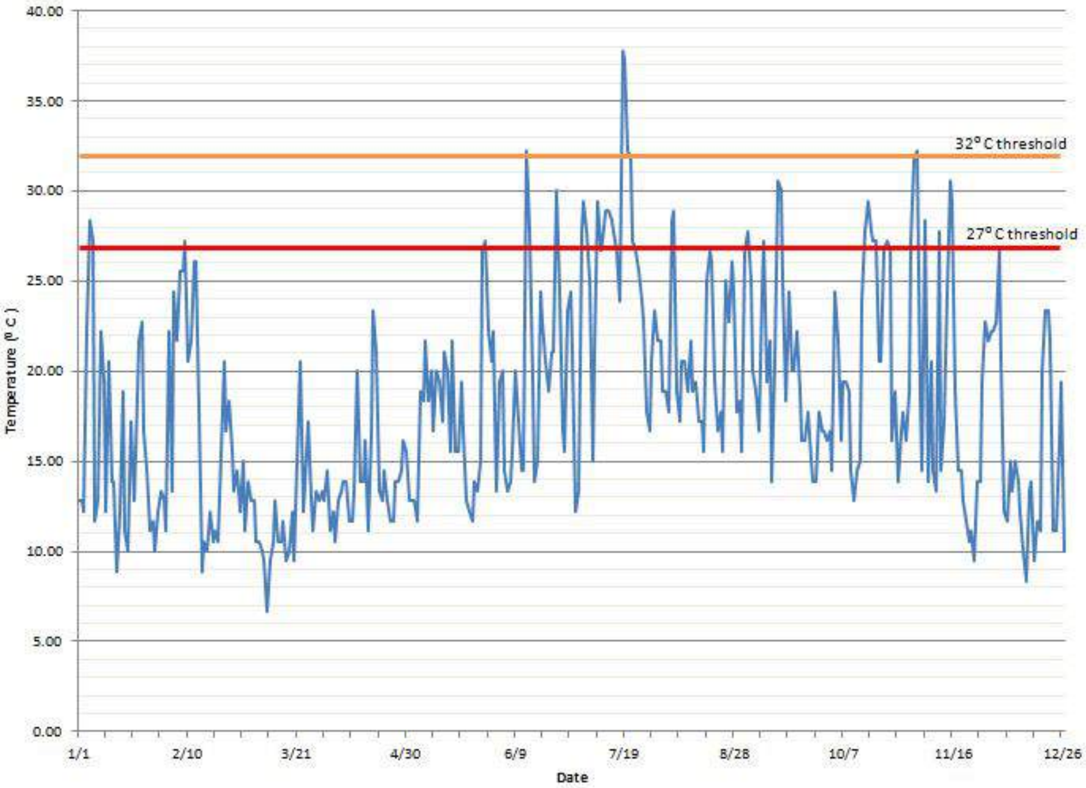
Appendix A.3.5 Santa Rosa 2004 Average Monthly High Temperatures (F) Above Threshold



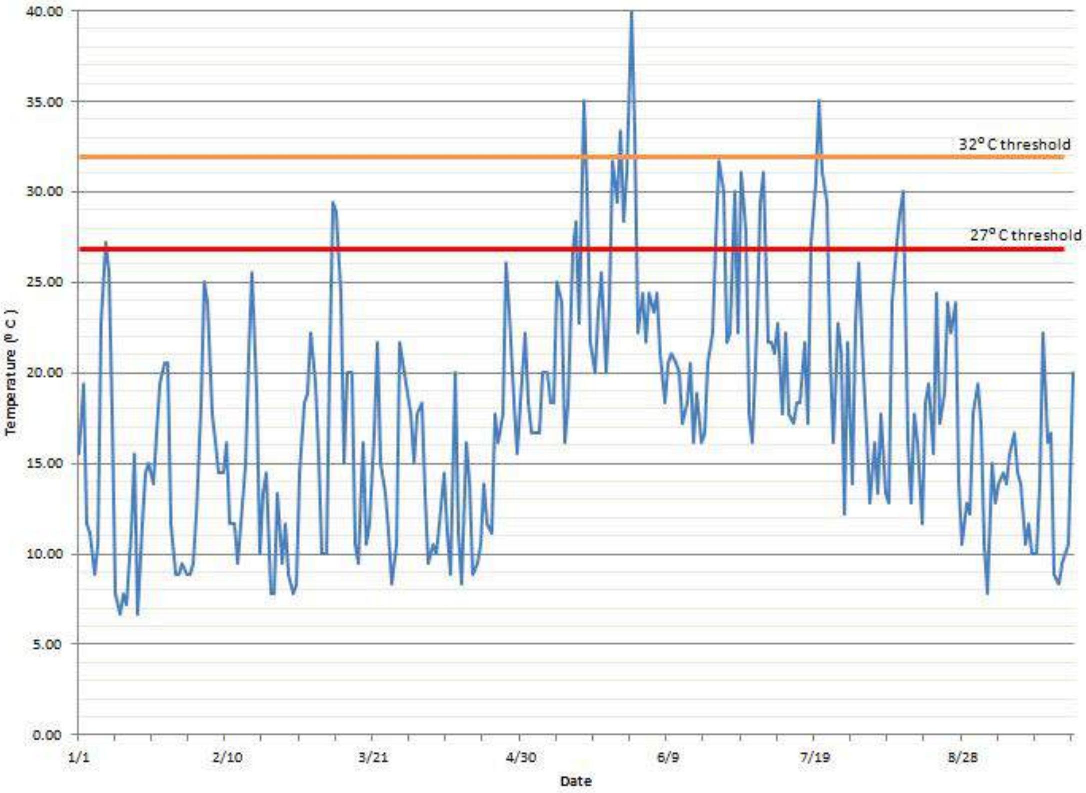
Appendix A.3.6 Santa Rosa 2005 Average Monthly High Temperatures (F) Above Threshold



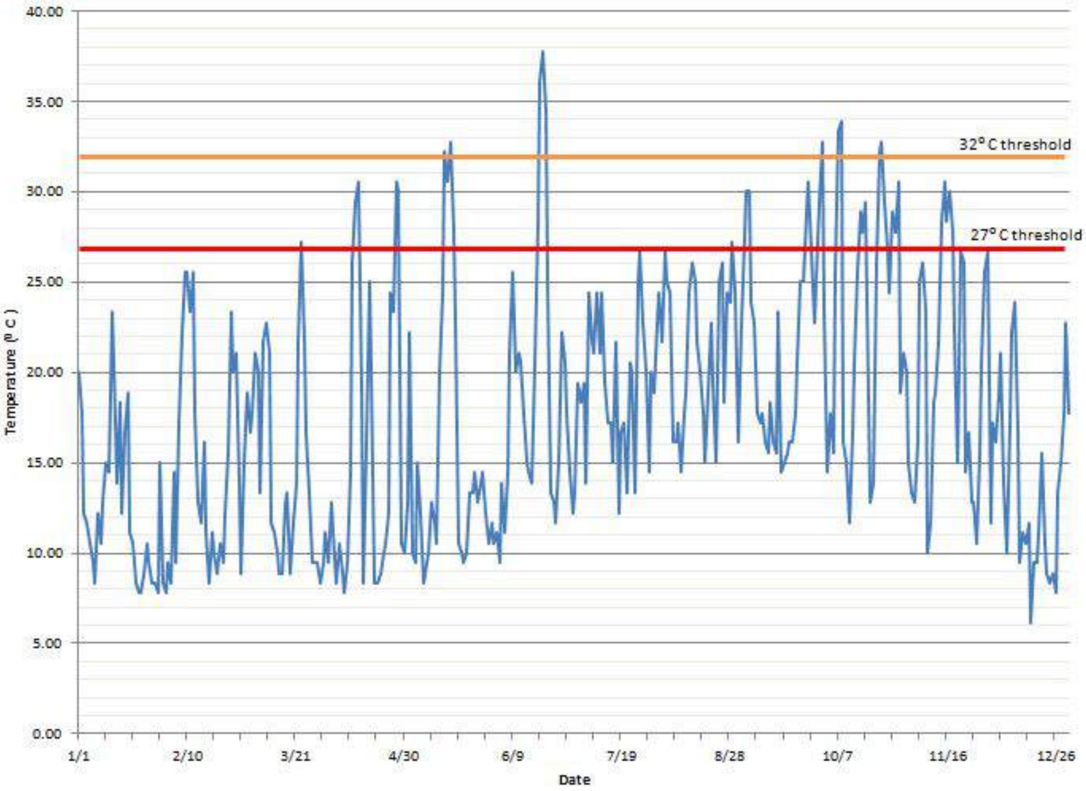
Appendix A.3.7 Santa Rosa 2006 Average Monthly High Temperatures (F) Above Threshold



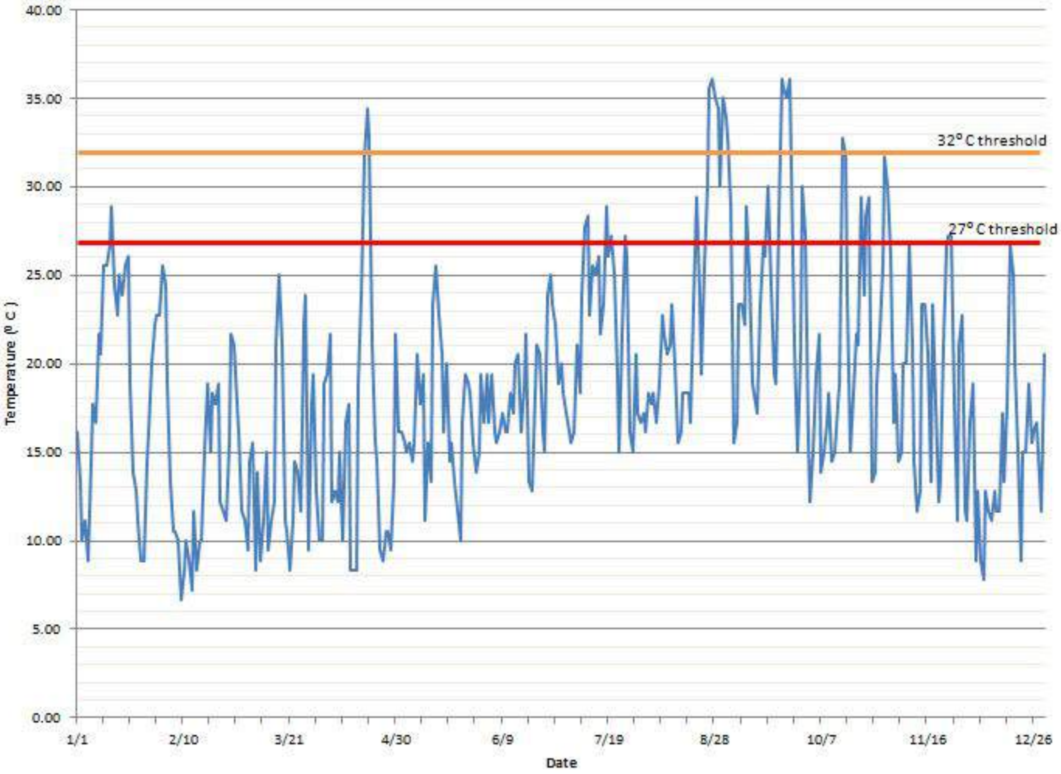
Appendix A.3.8 Santa Rosa 2007 Average Monthly High Temperatures (F) Above Threshold



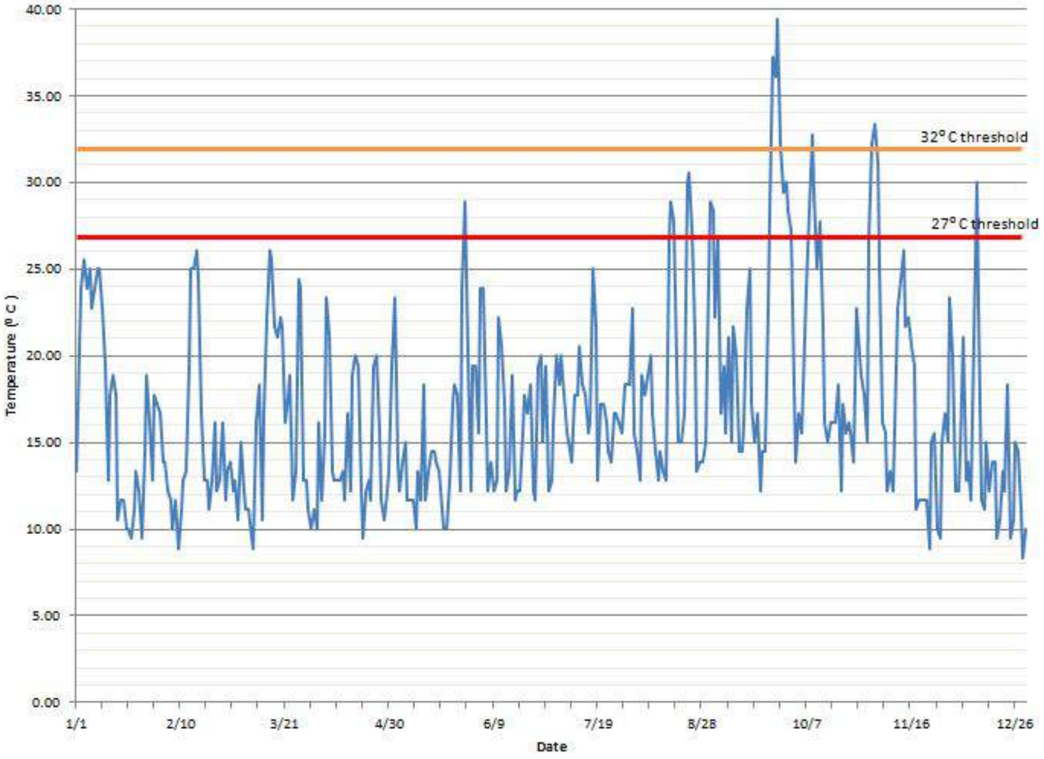
Appendix A.3.9 Santa Rosa 2008 Average Monthly High Temperatures (F) Above Threshold



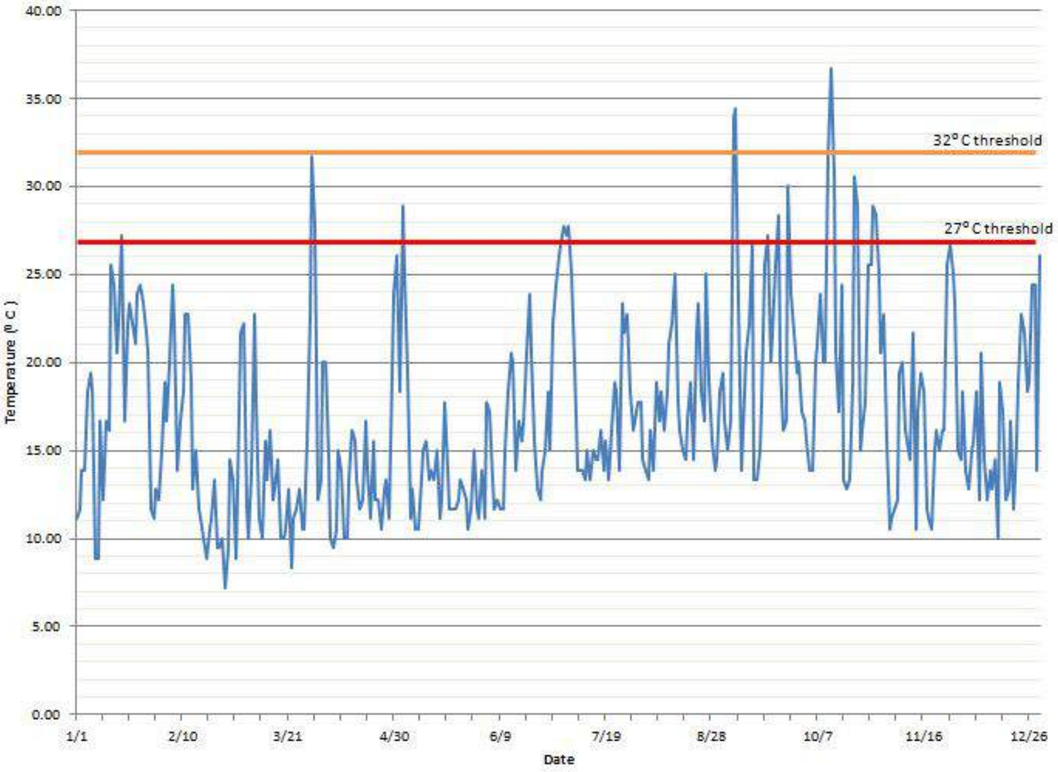
Appendix A.3.10 Santa Rosa 2009 Average Monthly High Temperatures (F) Above Threshold



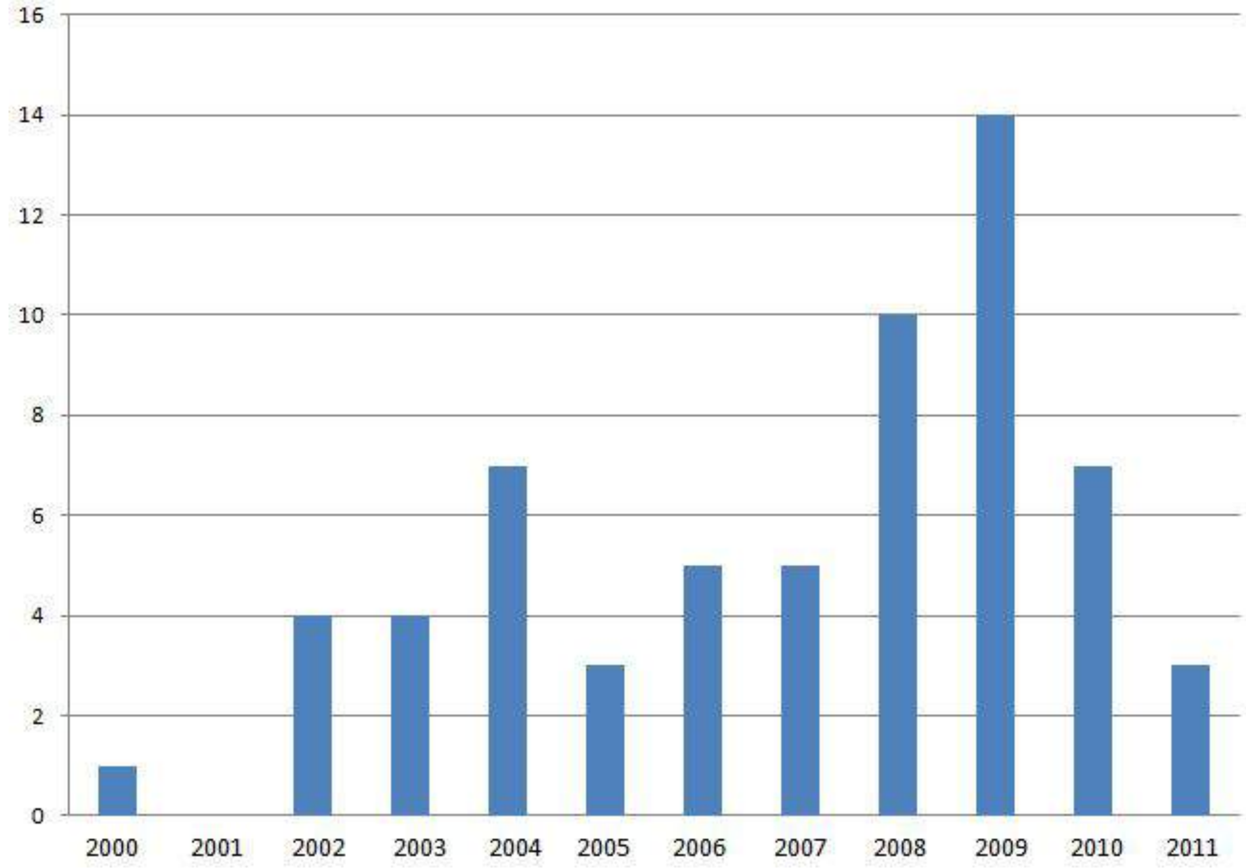
Appendix A.3.11 Santa Rosa 2010 Average Monthly High Temperatures (F) Above Threshold



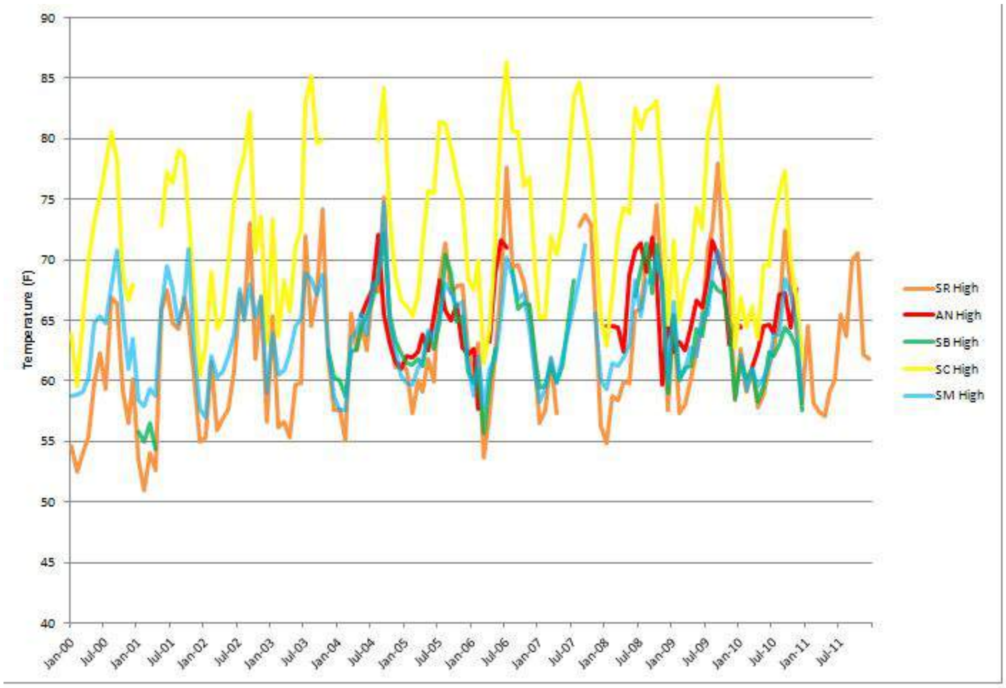
Appendix A.3.12 Santa Rosa 2011 Average Monthly High Temperatures (F) Above Threshold



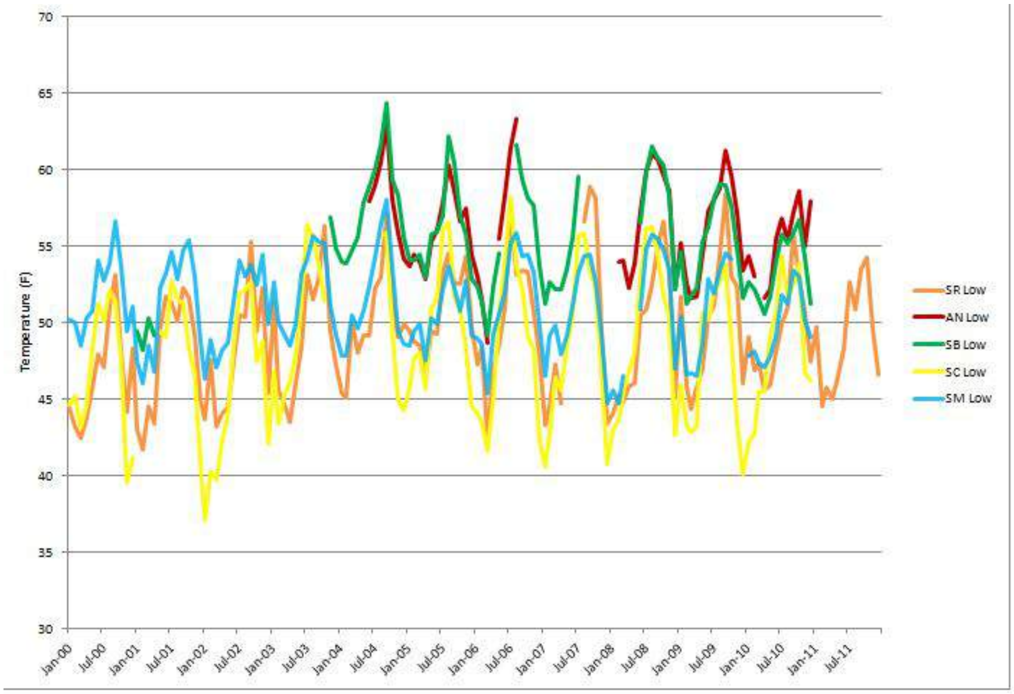
Appendix A.4 Number of Days Above Threshold From 2000-2011



Appendix A.5 Yearly Average High Temperatures in Channel Islands

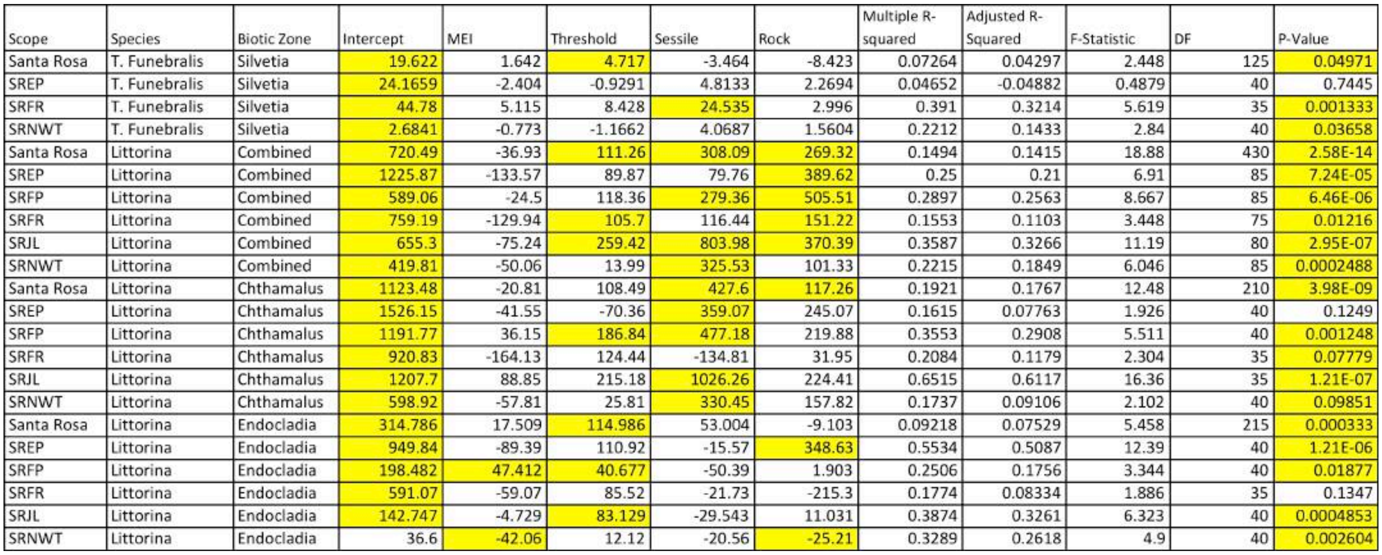


Appendix A.6 Yearly Average Low Temperatures in Channel Islands



Appendix B Tables

Appendix B.1 Multiple Linear Regression Results



Scope	Species	Biotic Zone	Intercept	MEI	Threshold	Sessile	Rock	Multiple R-squared	Adjusted R-Squared	F-Statistic	DF	P-Value
Santa Rosa	T. Funebralis	Silvetia	19.622	1.642	4.717	-3.464	-8.423	0.07264	0.04297	2.448	125	0.04971
SREP	T. Funebralis	Silvetia	24.1659	-2.404	-0.9291	4.8133	2.2694	0.04652	-0.04882	0.4879	40	0.7445
SRFR	T. Funebralis	Silvetia	44.78	5.115	8.428	24.535	2.996	0.391	0.3214	5.619	35	0.001333
SRNWT	T. Funebralis	Silvetia	2.6841	-0.773	-1.1662	4.0687	1.5604	0.2212	0.1433	2.84	40	0.03658
Santa Rosa	Littorina	Combined	720.49	-36.93	111.26	308.09	269.32	0.1494	0.1415	18.88	430	2.58E-14
SREP	Littorina	Combined	1225.87	-133.57	89.87	79.76	389.62	0.25	0.21	6.91	85	7.24E-05
SRFP	Littorina	Combined	589.06	-24.5	118.36	279.36	505.51	0.2897	0.2563	8.667	85	6.46E-06
SRFR	Littorina	Combined	759.19	-129.94	105.7	116.44	151.22	0.1553	0.1103	3.448	75	0.01216
SRJL	Littorina	Combined	655.3	-75.24	259.42	803.98	370.39	0.3587	0.3266	11.19	80	2.95E-07
SRNWT	Littorina	Combined	419.81	-50.06	13.99	325.53	101.33	0.2215	0.1849	6.046	85	0.0002488
Santa Rosa	Littorina	Chthamalus	1123.48	-20.81	108.49	427.6	117.26	0.1921	0.1767	12.48	210	3.98E-09
SREP	Littorina	Chthamalus	1526.15	-41.55	-70.36	359.07	245.07	0.1615	0.07763	1.926	40	0.1249
SRFP	Littorina	Chthamalus	1191.77	36.15	186.84	477.18	219.88	0.3553	0.2908	5.511	40	0.001248
SRFR	Littorina	Chthamalus	920.83	-164.13	124.44	-134.81	31.95	0.2084	0.1179	2.304	35	0.07779
SRJL	Littorina	Chthamalus	1207.7	88.85	215.18	1026.26	224.41	0.6515	0.6117	16.36	35	1.21E-07
SRNWT	Littorina	Chthamalus	598.92	-57.81	25.81	330.45	157.82	0.1737	0.09106	2.102	40	0.09851
Santa Rosa	Littorina	Endocladia	314.786	17.509	114.986	53.004	-9.103	0.09218	0.07529	5.458	215	0.000333
SREP	Littorina	Endocladia	949.84	-89.39	110.92	-15.57	348.63	0.5534	0.5087	12.39	40	1.21E-06
SRFP	Littorina	Endocladia	198.482	47.412	40.677	-50.39	1.903	0.2506	0.1756	3.344	40	0.01877
SRFR	Littorina	Endocladia	591.07	-59.07	85.52	-21.73	-215.3	0.1774	0.08334	1.886	35	0.1347
SRJL	Littorina	Endocladia	142.747	-4.729	83.129	-29.543	11.031	0.3874	0.3261	6.323	40	0.0004853
SRNWT	Littorina	Endocladia	36.6	-42.06	12.12	-20.56	-25.21	0.3289	0.2618	4.9	40	0.002604

Appendix B.2 Shapiro-Wilk Test Results

Species	Plot ID	W	p-value	W log	p-value log
Tegula	565	0.9316	0.497	0.9181	0.3767
	566	0.9215	0.405	0.9407	0.5898
	567	0.8419	0.06061	0.8603	0.09661
	568	0.8116	0.02767	0.9026	0.2673
	569	0.8667	0.1133	0.8913	0.2056
	585	0.9241	0.4274	0.9491	0.6807
	586	0.9315	0.4953	0.836	0.05218
	587	0.9006	0.2554	0.8665	0.1128
	588	0.9218	0.4077	0.8428	0.06207
	589	0.9257	0.4414	0.6386	0.000272
	615	0.7705	0.01374	0.8247	0.05223
	616	0.86	0.1202	0.9613	0.822
	617	0.9079	0.3398	0.9075	0.3365
	618	0.8863	0.2163	0.9146	0.3879
	619	0.7675	0.01272	0.9379	0.5901
Littorina- Chthamalus	500	0.9549	0.76	0.9491	0.7018
	501	0.8866	0.2176	0.7442	0.007039
	502	0.9546	0.7576	0.9771	0.9474
	503	0.9417	0.6278	0.9731	0.9215
	504	0.6895	0.001714	0.9218	0.4444
	520	0.8912	0.2052	0.8834	0.1704
	521	0.9076	0.2996	0.865	0.1086
	522	0.9807	0.9678	0.9446	0.6316
	523	0.925	0.4353	0.939	0.5716
	524	0.8986	0.2442	0.9137	0.5275
	560	0.9331	0.5117	0.8816	0.1631
	561	0.609	0.000122	0.8999	0.2515
	562	0.7819	0.01266	0.9362	0.5422
	563	0.8317	0.0466	0.9457	0.6425
	564	0.5641	3.62E-05	0.9835	0.9798
	575	0.7847	0.01363	0.9764	0.9432
	576	0.8225	0.03676	0.9671	0.8688
	577	0.9464	0.6502	0.9553	0.7478
	578	0.8745	0.1373	0.888	0.1901
	579	0.904	0.2762	0.9231	0.4184
	605	0.9534	0.7449	0.9305	0.5207
	606	0.9012	0.2965	0.7225	0.004032
	607	0.8366	0.0692	0.8843	0.207
	608	0.8574	0.1132	0.8865	0.2171
	609	0.9641	0.848	0.9675	0.8781
Littorina- Endocladia	505	0.838	0.05484	0.9212	0.4023
	506	0.8667	0.1132	0.7388	0.004018
	507	0.9799	0.9639	0.7574	0.006597
	508	0.9625	0.8238	0.7449	0.004727
	509	0.7792	0.01179	0.7594	0.00697
	525	0.8589	0.09324	0.9516	0.7081
	526	0.9297	0.4786	0.9077	0.3003
	527	0.9575	0.7717	0.9431	0.6146
	528	0.8744	0.1371	0.9361	0.5417
	529	0.8212	0.03556	0.9202	0.3935
	555	0.4293	9.41E-07	0.8545	0.08345
	556	0.576	5.00E-05	0.9646	0.8449
	557	0.4031	4.62E-07	0.6722	0.000671
	558	0.746	0.004877	0.9323	0.5039
	559	0.7493	0.00533	0.9337	0.5171
	580	0.9336	0.51610	0.8826	0.1672
	581	0.8408	0.05894	0.9397	0.5787
	582	0.8707	0.1251	0.9777	0.9516
	583	0.8684	0.1182	0.9438	0.6226
	584	0.7177	0.002284	0.9204	0.3952
	610	0.8869	0.2191	0.9596	0.8059
	611	0.9233	0.4573	0.9491	0.7022
	612	0.8521	0.1	0.9179	0.4127
	613	0.94	0.6109	0.9487	0.6982
	614	0.7299	0.004882	0.9799	0.9626

Appendix B.3 Multiple Regression Analysis Results

Appendix B.3.1 Tegula-Silvetia Abundance

Abundance											
Species	Plot ID	Intercept	MEI	Temp	Sessile	Rock	Multiple R	Adjusted R	F-statistic	DF	p-value
Tegula- Silvetia	565	-12.111	-2.573	-4.105	-28.678	-17.097	0.7573	0.5147	3.121	4	0.1481
	566	-7.1435	-0.8908	-0.6581	17.475	12.4906	0.491	-0.01801	0.9646	4	0.5135
	567	2.9261	-1.6487	-0.5884	13.6502	7.7066	0.08121	-0.8376	0.08839	4	0.9813
	568	8.3525	-0.664	4.2632	2.7082	10.4256	0.8672	0.7344	6.53	4	0.0483
	569	8.8078	0.95008	-0.22971	0.05496	-4.66604	0.6141	0.2282	1.591	4	0.3318
	585	13.0334	-0.5583	13.8902	-46.6717	-57.459	0.4124	-0.1751	0.7019	4	0.63
	586	15.434	-9.743	-11.129	-63.638	-72.375	0.485	-0.02991	0.9419	4	0.5224
	587	36.544	-5.739	1.779	3.817	-4.375	0.7531	0.5061	3.05	4	0.1528
	588	18.171	-8.075	2.83	49.353	45.631	0.2733	-0.4535	376	4	0.8168
	589	13.705	-0.802	1.452	12.394	4.02	0.8653	0.7306	6.425	4	0.4954
	615	10.10233	-0.643	0.06515	7.67686	1.17519	0.2571	-0.7333	0.2596	3	0.8872
	616	222.834	5.443	1.7	156.611	5.502	0.7421	0.3982	2.158	3	0.2768
	617	20.632	12.24	4.1	-14.161	-21.5	0.7042	0.3098	1.785	3	0.3308
	618	98.1	5.395	-49.783	106.678	11.022	0.9485	0.8798	13.81	3	0.02832
	619	18.232	16.592	11.43	31.768	24.683	0.817	0.573	3.348	3	0.1742

Appendix B.3.2 Littorina-Chthamalus Abundance

Littorina- Chthamalus	500	8495.7	412.6	704.4	-9995.8	-11193	0.9522	0.8886	14.95	3	0.02535
	501	7518.5	-345.6	331.8	-8540.7	-9276.4	0.6766	0.2455	1.569	3	0.3705
	502	7747.64	230.54	37.64	-9521.2	-11510.9	0.952	0.888	14.87	3	0.02554
	503	1856.19	-28.61	869.15	-730.95	129.8	0.7844	0.497	2.729	3	0.2179
	504	331.64	34.43	16.12	500.31	249.7	0.9054	0.7792	7.177	3	0.06862
	520	1355.66	-19.31	354.58	-343.17	-737.43	0.4273	-0.1454	0.7461	4	0.6083
	521	572.2649	80.88112	-0.09519	985.297	774.7482	0.1153	-0.7693	0.1304	4	0.9632
	522	1776.77	289.23	312.99	379.11	81.38	0.4565	-0.08701	0.8399	4	0.5651
	523	292.37	295.71	-21.78	-70.38	-410	0.4766	-0.04684	0.9105	4	0.5351
	524	703.17	-262.59	57.12	1510.88	969.83	0.9128	0.8256	10.47	4	0.02147
	560	1100.8	-307.6	-283.5	1489.7	2102.2	0.3675	-0.2651	0.5809	4	0.6942
	561	813.86	56.68	63.67	-1439.06	-1963.22	0.6274	0.2548	1.684	4	0.3131
	562	245.86	440.83	-247.16	21.26	-532.46	0.7649	0.5299	3.254	4	0.1398
	563	169.498	12.002	6.605	101.034	-10.511	0.7412	0.4824	2.864	4	0.1663
	564	130	-113.5	303.7	591.7	318.9	0.3072	-0.3856	.44.4	4	0.7749
	575	3668.1	-156.4	-138.4	-4101.2	-4452.9	0.1841	-0.6118	0.2409	4	0.9016
	576	561	-143.1	109.9	-335.7	-337.5	0.2077	-0.5845	0.2622	4	0.8885
	577	-462.7	110.7	-429.4	-824.3	-491.1	0.2959	-0.4082	0.4202	4	0.7892
	578	6099.06	74.99	33.26	-5944.62	-6713.62	0.2222	-0.5556	0.2857	4	0.8738
	579	1177.987	-81.729	-6.835	1986.11	1789.675	0.2299	-0.5401	0.2986	4	0.8657
	605	430.103	0.3237	57.233	604.7415	390.8471	0.9014	0.7699	6.856	3	0.07283
	606	865.57	-90.17	104.52	135.23	-112.78	0.3518	-0.5125	0.4071	3	0.7973
	607	254.9	391.4	168.5	1301.5	673.3	0.7777	0.4813	2.624	3	0.2271
	608	1806.7	-560.2	174.3	-852.1	-925.2	0.6251	0.1253	1.251	3	0.4447
	609	1853.9	-220.1	484.5	-483.6	-1274.4	0.5294	-0.09809	0.8437	3	0.5792

Appendix B.3.3 Littorina-Endocladia Abundance

Littorina- Endocladia	505	55.03	13.048	66.534	-57.223	-4.722	0.9076	0.8152	9.822	4	0.02404
	506	222.34	-36.96	137.69	-38.86	66.94	0.6809	0.3618	2.134	4	0.2405
	507	41.285	-7.469	18.764	42.448	48.997	0.6737	0.3473	2.064	4	0.25
	508	121.38	27.63	55.17	-189.97	-55.32	0.8867	0.7734	7.825	4	0.03561
	509	226.47	19.98	86.33	-117.56	-59.75	0.6646	0.3293	1.982	4	0.262
	525	106.87	48.74	45.99	84.98	108.46	0.9054	0.8108	9.568	4	0.02517
	526	223.27	-10.299	-34.456	2.623	-76.961	0.3387	-0.3226	0.5122	4	0.7335
	527	267.49	26.63	76.29	-77.41	-88.89	0.3085	-0.3831	0.4461	4	0.7732
	528	127.379	51.502	37.492	-52.416	-2.853	0.7061	0.4122	2.402	4	0.2084
	529	448.98	81.5	125.77	-392.33	-295.43	0.878	0.756	7.197	4	0.04102
	555	122.63	-117.6	98.79	324.59	104.49	0.8221	0.6441	4.62	4	0.08372
	556	84.25	2.23	-14.95	14.94	-35.67	0.4049	-0.1901	0.6805	4	0.6409
	557	-11.357	-71.036	-4.976	46.365	-107.934	0.914	0.828	10.63	4	0.02092
	558	17.13	-28.84	39.32	-97.53	-47.53	0.7215	0.443	2.591	4	0.1895
	559	-5.881	-2.962	5.097	-31.775	-18.958	0.6084	0.2168	1.554	4	0.3399
	580	548.43	34.31	139.66	55.66	149.75	0.8699	0.7399	6.689	4	0.04634
	581	936.16	-139.97	-19.19	-47.06	497.21	0.9571	0.9143	22.33	4	0.005352
	582	862.14	-15.29	73.11	58.8	346.33	0.759	0.5181	3.15	4	0.1462
	583	1143.173	-4.329	498.775	24.778	232.514	0.8516	0.7033	5.741	4	0.0595
	584	305.094	169.026	221.565	-7.129	-489.334	0.1191	-0.7618	0.1352	4	0.9608
	610	783.8	130.1	443.8	-572.3	-681.1	0.4721	-0.2318	0.6707	3	0.6552
	611	507.806	-60.579	-6.453	-99.407	-308.717	0.8627	0.6796	4.712	3	0.1167
	612	198.67	15.09	193.01	-220.33	-26971	0.7322	0.3752	2.051	3	0.2907
	613	468.16	-30.45	-132.1	116.54	124.66	0.4417	-0.3026	0.5935	3	0.6935
	614	446.47	-307.45	165.73	37.93	-130.44	0.376	-0.4559	0.452	3	0.7709

Appendix B.3.4 Tegula-Silvetia Log of Abundance

Species	Plot ID	Intercept	MEI	Temp	Sessile	Rock	Multiple R	Adjusted R	F-statistic	DF	p-value
Tegula- Silvetia	565	-0.66303	-0.13978	-0.33337	1.74766	0.70039	9212	0.8423	11.69	4	0.01766
	566	-0.66728	-0.05744	-0.03706	2.04652	1.39828	0.5654	0.1308	1.301	4	0.4025
	567	0.2675	-0.1519	-0.1855	1.4874	1.1519	0.239	-0.5221	0.314	4	0.856
	568	1.02459	-0.07539	0.38937	0.55692	1.37429	0.9189	0.8377	11.32	4	0.01868
	569	1.671	0.2352	-0.0543	-0.3109	-1.0721	0.6126	0.2252	1.581	4	0.3339
	585	1.05749	-0.01376	0.1887	-1.02121	-1.13515	0.2575	-0.485	0.3468	4	0.8352
	586	0.8817	-0.3977	-0.391	-2.2032	-2.521	0.8271	0.6543	4.785	4	0.07931
	587	1.55952	-0.07454	0.03884	0.08431	-0.04266	0.7443	0.4887	2.911	4	0.1627
	588	1.2243	-0.1746	0.128	1.1045	1.1072	0.29	-0.4201	0.4084	4	0.7965
	589	1.063174	-0.00442	0.078887	0.743941	0.367449	0.9863	0.9726	71.87	4	0.00056
	615	2.59521	-0.13437	0.06068	2.00389	0.292	0.4132	-0.3693	0.528	3	0.7281
	616	2.868	0.1363	0.1082	1.2906	0.1098	0.5025	-0.1608	0.7576	3	0.6154
	617	1.2333	0.2653	0.1182	-0.2309	-0.5205	0.4641	-0.2504	0.6496	3	0.6654
	618	1.89265	0.03417	-0.18401	0.45195	-0.04576	0.8613	0.6764	4.658	3	0.1184
	619	0.91103	0.03036	0.30438	0.23846	-0.10071	0.9148	0.8012	8.051	3	0.05901

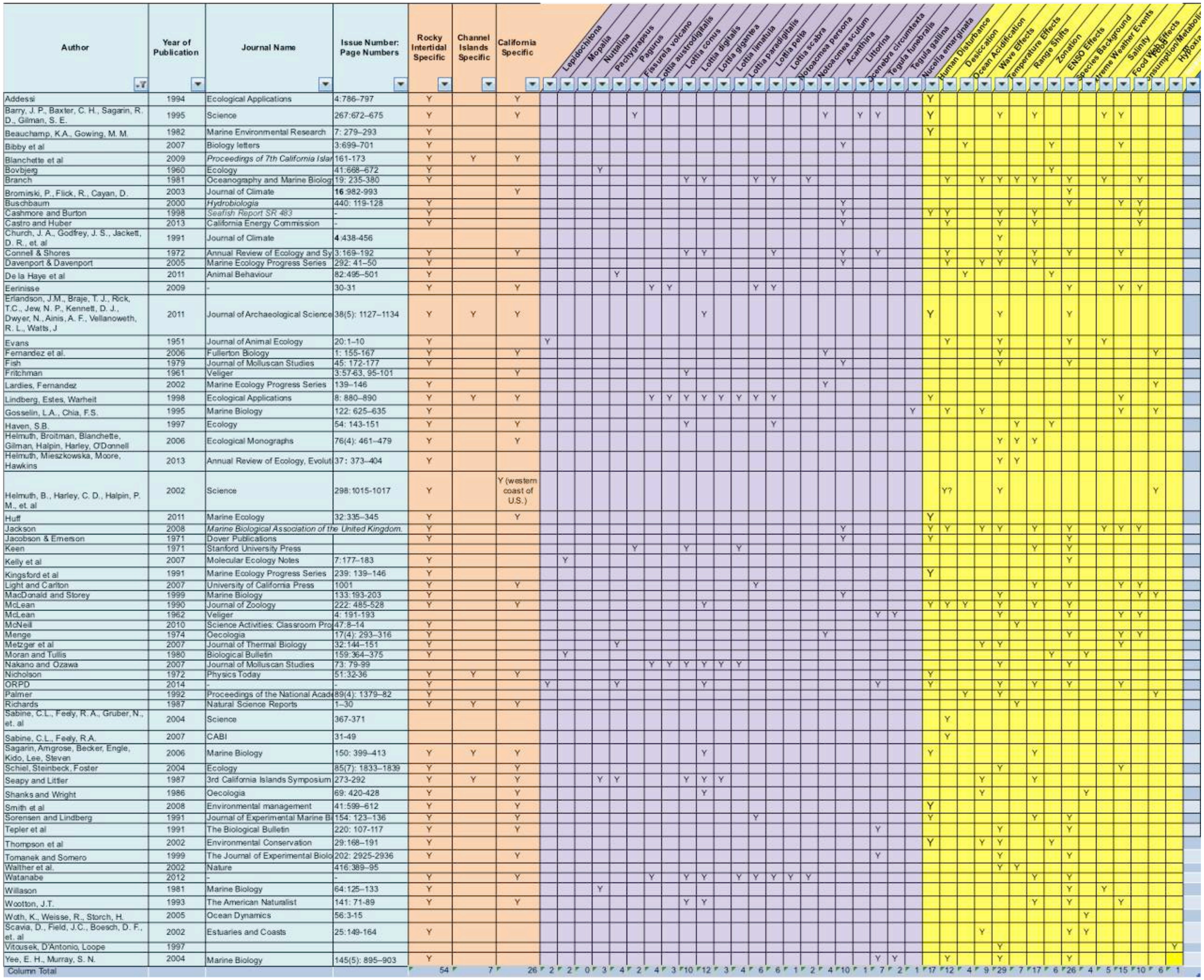
Appendix B.3.5 Littorina-Chthamalus Log of Abundance

Littorina- Chthamalus	500	4.38005	0.07491	0.13293	-1.68374	-1.89501	0.8951	0.7553	6.401	3	0.07957
	501	5.18923	-0.07407	0.124	-2.96189	-3.1477	0.556	-0.03603	0.9391	3	0.5426
	502	5.626222	0.009341	0.069913	-4.03614	-4.63556	0.9462	0.8745	13.2	3	0.03017
	503	3.2652	-0.04253	0.25974	-0.28566	0.05162	0.8335	0.6116	3.755	3	0.1528
	504	2.30746	0.02781	-0.15366	1.24795	0.48422	0.5549	-0.03857	0.935	3	0.5441
	520	3.04551	-0.05008	0.12315	-0.05304	-0.23093	0.3546	-0.2908	0.5494	4	0.712
	521	2.86557	0.03411	-0.02082	0.23978	0.09931	0.1462	-0.7076	0.1712	4	0.9421
	522	2.94919	0.08365	0.09939	0.57424	0.52876	0.4697	-0.06055	0.8858	4	0.5454
	523	2.58903	0.26034	0.02556	0.03991	-0.26083	0.645	0.2899	1.817	4	0.2887
	524	2.81761	-0.11912	0.08432	0.54084	0.40747	0.9042	0.8084	9.438	4	0.02578
	560	2.8557	-0.09782	-0.12675	0.71505	1.00447	0.5754	0.1707	1.412	4	0.3732
	561	2.491884	0.001961	0.118067	-0.46209	-0.85953	0.4558	-0.08844	0.8375	4	0.5662
	562	1.8808	0.5458	-0.7817	-0.4308	-1.1928	0.7205	0.441	2.578	4	0.1907
	563	2.16453	0.04262	0.06854	0.68058	-0.24384	0.5792	0.1584	1.376	4	0.3822
	564	1.6261	-0.342	0.6527	0.7911	-0.3125	0.7948	0.5896	3.873	4	0.1091
	575	3.92562	-0.08277	-0.13791	-1.60474	-1.80765	0.4138	-0.1725	0.7058	4	0.6281
	576	2.94456	-0.06602	-0.06166	-0.03041	-0.00826	0.1733	-0.6534	0.2096	4	0.9203
	577	2.09494	0.06589	-0.28958	-0.60162	-0.26747	0.2996	-0.4007	0.4279	4	0.7844
	578	4.07796	0.01667	0.01242	-1.13743	-1.29692	0.2928	-0.4143	0.4141	4	0.793
	579	3.189782	-0.0163	-0.0018	0.183016	0.116518	0.301	-0.398	0.4306	4	0.7827
	605	2.61739	-0.01669	0.04037	0.47161	0.34756	0.923	0.8203	8.986	3	0.05098
	606	2.92313	-0.12597	0.12164	0.02119	-0.06529	0.422	-0.3488	0.5475	3	0.7176
	607	2.50103	0.18141	0.08343	0.84455	0.53329	0.7749	0.4748	2.582	3	0.2309
	608	3.27492	-0.17784	0.04507	-0.1175	-0.26317	0.5377	-0.07867	0.8724	3	0.5678
	609	3.25428	-0.09303	0.15547	-0.06328	-0.31516	0.4969	-0.174	0.7407	3	0.6229

Appendix B.3.6 Littorina-Endocladia Abundance

Littorina- Endocladia	505	1.72952	-0.0568	0.70864	-0.07455	-0.23528	0.7325	0.435	2.738	4	0.1764
	506	1.8616	-0.3721	0.5808	0.5596	0.2624	0.7113	0.6225	4.298	4	0.09343
	507	1.4127	-0.257	0.3514	0.6226	0.2681	0.7871	0.5743	3.698	4	0.1166
	508	1.98211	-0.21042	0.62662	0.2718	-0.08912	0.6877	0.3755	2.203	4	0.2316
	509	1.6294	-0.1188	0.5225	0.4325	0.1459	0.589	0.1781	1.433	4	0.3679
	525	2.04216	0.26003	0.18177	-0.11736	-0.04318	0.766	0.532	3.274	4	0.1386
	526	2.302742	-0.02059	-0.0481	-0.00359	-0.13164	0.1571	-0.6857	0.1864	4	0.9337
	527	2.36316	0.05398	0.16092	-0.15152	-0.19	0.3622	-0.2757	0.5678	4	0.7015
	528	2.06082	0.29139	0.14166	-0.35796	-0.0901	0.7885	0.577	3.728	4	0.1153
	529	3.01291	0.21226	0.3554	-1.3584	-1.09457	0.8479	0.6959	5.576	4	0.06233
	555	1.1363	-0.4534	0.3262	1.0677	0.8671	0.7476	0.4952	2.962	4	0.159
	556	1.7557	-0.1308	-0.3377	0.0287	-0.5303	0.4237	-0.1525	0.7353	4	0.6135
	557	-0.1114	-0.5258	-0.1341	0.326	-1.1956	0.9003	0.8005	9.027	4	0.02785
	558	0.85798	0.03455	0.30407	-0.88808	-0.28797	0.5886	0.1773	1.431	4	0.3684
	559	-0.47363	-0.15993	0.08782	-1.20706	-0.32785	0.5785	0.157	1.373	4	0.3832
	580	2.64436	-0.02896	0.1128	0.11501	0.23924	0.7393	0.4787	2.836	4	0.1684
	581	2.70643	-0.13757	-0.07475	0.17653	0.61047	0.9095	0.8189	10.04	4	0.02311
	582	2.70127	0.05503	0.06547	0.21063	0.23377	0.711	0.422	2.46	4	0.2023
	583	2.81451	-0.05287	0.26421	0.1666	0.14459	0.8629	0.7259	6.296	4	0.05121
	584	2.57564	0.06214	0.1401	0.02374	-0.23658	0.2606	-0.4787	0.3525	4	0.8316
	610	2.909611	0.003648	0.1609	-0.05219	-0.12248	0.3323	-0.5581	0.3732	3	0.8176
	611	2.61231	-0.08373	0.01349	-0.14092	-0.26333	0.9152	0.8021	8.094	3	0.0586
	612	2.296	-0.04845	0.26387	-0.1268	-0.30473	0.4419	-0.3023	0.5938	3	0.6933
	613	2.637748	-0.02891	-0.13604	0.002461	0.066234	0.5	-0.1666	0.7501	3	0.6187
	614	2.26139	-0.55301	0.39962	0.16753	0.01512	0.5097	-0.1441	0.7796	3	0.6058

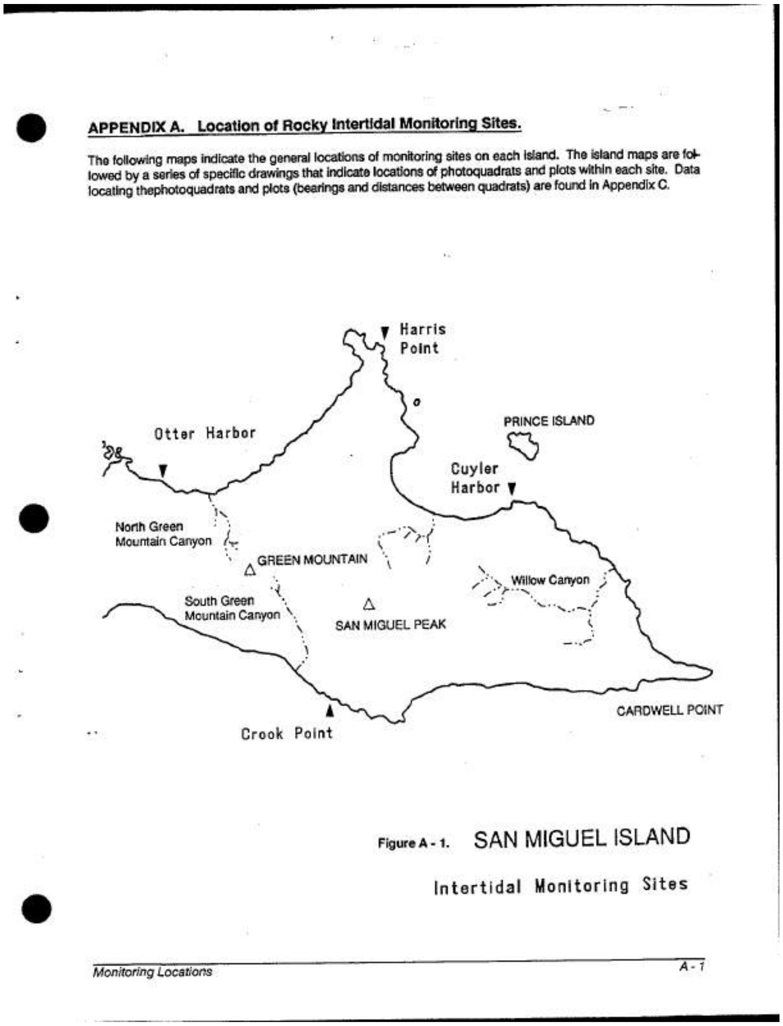
Appendix B.4 Species Source Table



Author	Year of Publication	Journal Name	Issue Number: Page Numbers	Rocky Intertidal Specific	Channel Islands Specific	California Specific	Lepidochitona	Mopalia	Nuttalina	Pachygrapsus	Pagurus	Fissurela volcano	Lottia austrodigitalis	Lottia conus	Lottia digitalis	Lottia gigantea	Lottia limatula	Lottia paradigitalis	Lottia pelta	Lottia scabra	Notoacmea persona	Notoacmea scutum	Acanthina	Littorina	Ocenebra circumtexta	Tegula funebralis	Tegula gallina	Nucella emarginata	Human Disturbance	Desiccation	Ocean Acidification	Wave Effects	Temperature Effects	Range Shifts	Zonation	ENSO Effects	Species Background	Extreme Weather Events	Salinity	Food Web Effects	Consumption/Metabol	Hypoxia	
Addessi	1994	Ecological Applications	4:786–797	Y		Y																							Y														
Barry, J. P., Baxter, C. H., Sagarin, R. D., Gilman, S. E.	1995	Science	267:672–675	Y		Y						Y											Y		Y	Y			Y				Y		Y				Y	Y			
Beauchamp, K.A., Gowing, M. M.	1982	Marine Environmental Research	7: 279–293	Y																									Y														
Bibby et al	2007	Biology letters	3:699–701	Y																				Y							Y					Y				Y			
Blanchette et al	2009	*Proceedings of 7th California Isla*	161-173	Y	Y	Y																																					
Bovbjerg	1960	Ecology	41:668–672	Y						Y																										Y							
Branch	1981	Oceanography and Marine Biolog	19: 235-380	Y											Y	Y			Y	Y		Y								Y		Y	Y	Y	Y		Y		Y		Y		
Bromirski, P., Flick, R., Cayan, D.	2003	Journal of Climate	**16**:982-993			Y																															Y						
Buschbaum	2000	*Hydrobiologia*	440: 119-128	Y																				Y													Y			Y	Y		
Cashmore and Burton	1998	*Seafish Report SR 483*	-	Y																				Y					Y	Y			Y		Y						Y		
Castro and Huber	2013	California Energy Commission	-	Y																				Y						Y			Y		Y						Y		
Church, J. A., Godfrey, J. S., Jackett, D. R., et. al	1991	Journal of Climate	**4**:438-456																														Y										
Connell & Shores	1972	Annual Review of Ecology and Sy	3:169–192	Y		Y									Y	Y				Y				Y		Y				Y			Y		Y		Y			Y			
Davenport & Davenport	2005	Marine Ecology Progress Series	292: 41–50	Y																				Y						Y		Y	Y		Y								
De la Haye et al	2011	Animal Behaviour	82:495–501	Y							Y																				Y					Y							
Eerinisse	2009	-	30-31	Y		Y							Y	Y					Y	Y																	Y			Y	Y		
Erlandson, J.M., Braje, T. J., Rick, T.C., Jew, N. P., Kennett, D. J., Dwyer, N., Ainis, A. F., Vellanoweth, R. L., Watts, J	2011	Journal of Archaeological Science	38(5): 1127–1134	Y	Y	Y										Y													Y				Y				Y						
Evans	1951	Journal of Animal Ecology	20:1–10	Y			Y																							Y			Y				Y		Y				
Fernandez et al.	2006	Fullerton Biology	1: 155-167	Y		Y																	Y										Y									Y	
Fish	1979	Journal of Molluscan Studies	45: 172-177	Y																				Y									Y				Y						
Fritchman	1961	Veliger	3:57-63, 95-101			Y									Y																												
Lardies, Fernandez	2002	Marine Ecology Progress Series	139–146	Y																			Y																			Y	
Lindberg, Estes, Warheit	1998	Ecological Applications	8: 880–890	Y	Y	Y							Y	Y	Y	Y	Y	Y	Y	Y									Y											Y			
Gosselin, L.A., Chia, F.S.	1995	Marine Biology	122: 625–635	Y																								Y		Y		Y								Y		Y	
Haven, S.B.	1997	Ecology	54: 143-151	Y		Y									Y					Y														Y		Y							
Helmuth, Broitman, Blanchette, Gilman, Halpin, Harley, O'Donnell	2006	Ecological Monographs	76(4): 461–479	Y		Y																											Y	Y	Y								
Helmuth, Mieszkowska, Moore, Hawkins	2013	Annual Review of Ecology, Evoluti	37: 373–404	Y																													Y	Y									
Helmuth, B., Harley, C. D., Halpin, P. M., et. al	2002	Science	298:1015-1017	Y		Y (western coast of U.S.)																								Y?			Y									Y	
Huff	2011	Marine Ecology	32:335–345	Y		Y																							Y														
Jackson	2008	*Marine Biological Association of the United Kingdom.*		Y																				Y					Y	Y		Y	Y		Y		Y		Y	Y	Y		
Jacobson & Emerson	1971	Dover Publications		Y																				Y					Y								Y						
Keen	1971	Stanford University Press										Y			Y			Y																	Y		Y						
Kelly et al	2007	Molecular Ecology Notes	7:177–183	Y				Y																													Y						
Kingsford et al	1991	Marine Ecology Progress Series	239: 139–146	Y																									Y														
Light and Carlton	2007	University of California Press	1001	Y		Y													Y																Y		Y			Y	Y		
MacDonald and Storey	1999	Marine Biology	133:193-203	Y																				Y									Y								Y	Y	
McLean	1990	Journal of Zoology	222: 485-528	Y		Y										Y													Y	Y	Y		Y		Y		Y						
McLean	1962	Veliger	4: 191-193																							Y	Y						Y				Y			Y	Y		
McNeill	2010	Science Activities: Classroom Pro	47:8–14	Y																														Y									
Menge	1974	Oecologia	17(4): 293–316	Y																			Y														Y			Y	Y		
Metzger et al	2007	Journal of Thermal Biology	32:144–151	Y							Y																					Y	Y							Y			
Moran and Tullis	1980	Biological Bulletin	159:364–375	Y				Y																												Y		Y					
Nakano and Ozawa	2007	Journal of Molluscan Studies	73: 79-99										Y	Y	Y	Y	Y	Y															Y				Y						
Nicholson	1972	Physics Today	51:32-36	Y	Y	Y																							Y														
ORPD	2014	-	-	Y			Y				Y					Y										Y			Y				Y		Y		Y			Y			
Palmer	1992	Proceedings of the National Acad	89(4): 1379–82	Y																											Y		Y									Y	
Richards	1987	Natural Science Reports	1–30	Y	Y	Y																												Y									
Sabine, C.L., Feely, R. A., Gruber, N., et. al	2004	Science	367-371																											Y													
Sabine, C.L., Feely, R.A.	2007	CABI	31-49																											Y													
Sagarin, Amgrose, Becker, Engle, Kido, Lee, Steven	2006	Marine Biology	150: 399–413	Y	Y	Y										Y													Y						Y								
Schiel, Steinbeck, Foster	2004	Ecology	85(7): 1833–1839	Y		Y																											Y							Y			
Seapy and Littler	1987	3rd California Islands Symposium	273-292	Y	Y	Y				Y	Y				Y	Y	Y															Y			Y								
Shanks and Wright	1986	Oecologia	69: 420-428	Y		Y										Y																Y						Y					
Smith et al	2008	Environmental management	41:599–612	Y		Y																							Y														
Sorensen and Lindberg	1991	Journal of Experimental Marine Bi	154: 123–136	Y		Y													Y										Y						Y		Y						
Tepler et al	1991	The Biological Bulletin	220: 107-117	Y		Y																				Y							Y				Y						
Thompson et al	2002	Environmental Conservation	29:168–191	Y																									Y			Y	Y			Y							
Tomanek and Somero	1999	The Journal of Experimental Biolo	202: 2925-2936	Y		Y																				Y							Y				Y						
Walther et al.	2002	Nature	416:389–95																														Y	Y									
Watanabe	2012	-	-	Y		Y							Y		Y	Y		Y	Y	Y	Y	Y													Y		Y						
Willason	1981	Marine Biology	64:125–133	Y						Y																											Y		Y				
Wootton, J.T.	1993	The American Naturalist	141: 71-89	Y		Y									Y	Y																			Y		Y			Y			
Woth, K., Weisse, R., Storch, H.	2005	Ocean Dynamics	56:3-15																																			Y					
Scavia, D., Field, J.C., Boesch, D. F., et. al	2002	Estuaries and Coasts	25:149-164	Y																												Y					Y	Y					
Vitousek, D'Antonio, Loope	1997																																Y										Y
Yee, E. H., Murray, S. N.	2004	Marine Biology	145(5): 895–903	Y																						Y	Y			Y			Y				Y						
Column Total				54	7	26	2	2	0	3	4	2	4	3	10	12	3	4	6	6	1	2	4	10	1	7	2	1	17	12	4	9	29	7	17	6	26	4	5	15	10	6	1

Appendix C Monitoring Protocol Figures

Appendix C.1 Channel Islands Intertidal Monitoring Sites



APPENDIX A. Location of Rocky Intertidal Monitoring Sites.

The following maps indicate the general locations of monitoring sites on each island. The island maps are followed by a series of specific drawings that indicate locations of photoquadrats and plots within each site. Data locating thephotoquadrats and plots (bearings and distances between quadrats) are found in Appendix C.

Figure A - 1. SAN MIGUEL ISLAND

Intertidal Monitoring Sites

Monitoring Locations A - 1

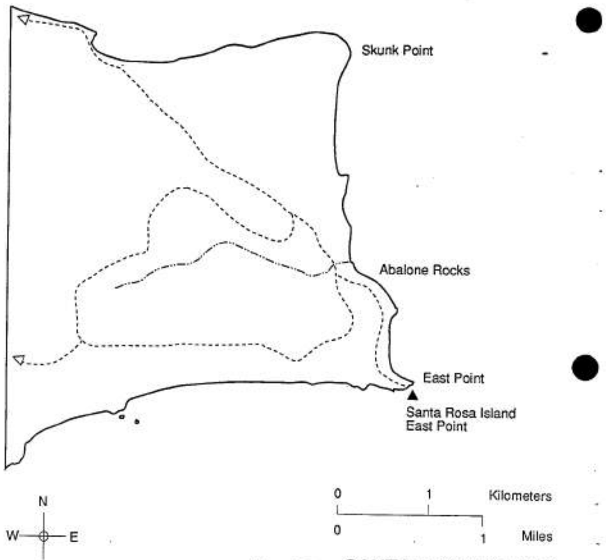


Figure A - 2. SANTA ROSA ISLAND

Intertidal Monitoring Sites

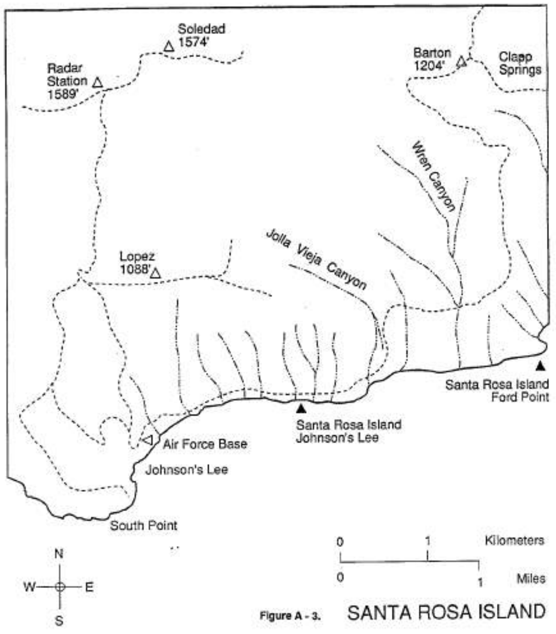


Figure A - 3. SANTA ROSA ISLAND

Intertidal Monitoring Sites

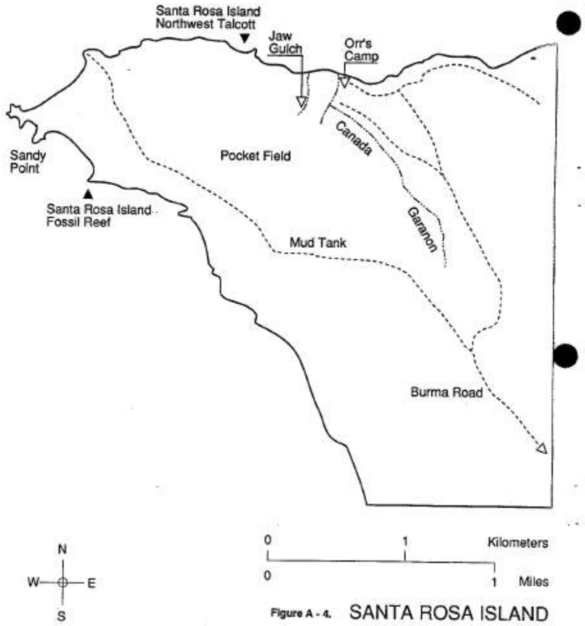


Figure A - 4. SANTA ROSA ISLAND

Intertidal Monitoring Sites

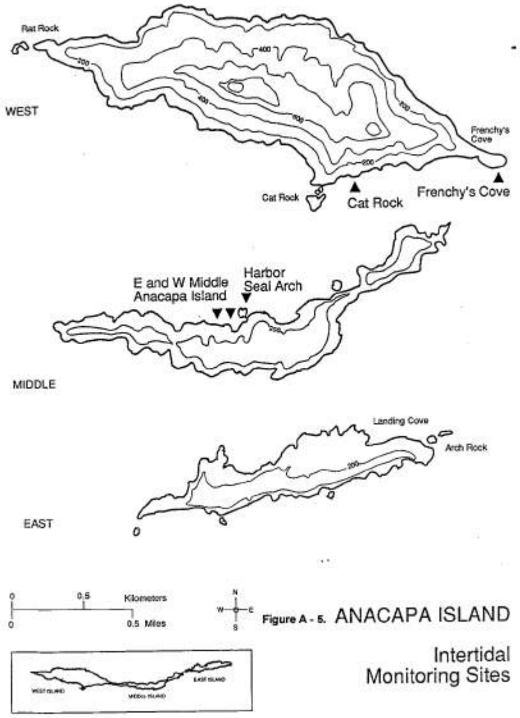


Figure A - 5. ANACAPA ISLAND

Intertidal
Monitoring Sites

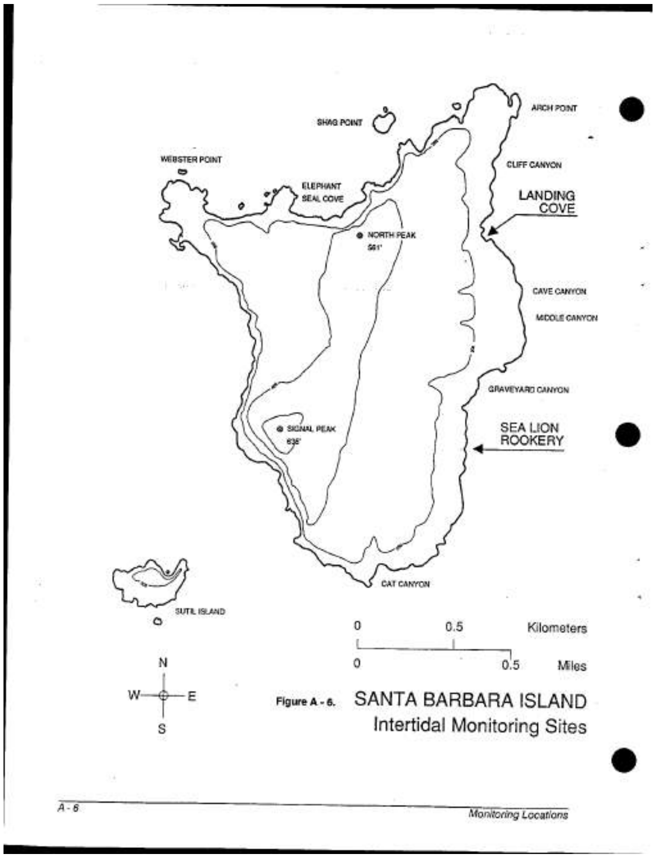
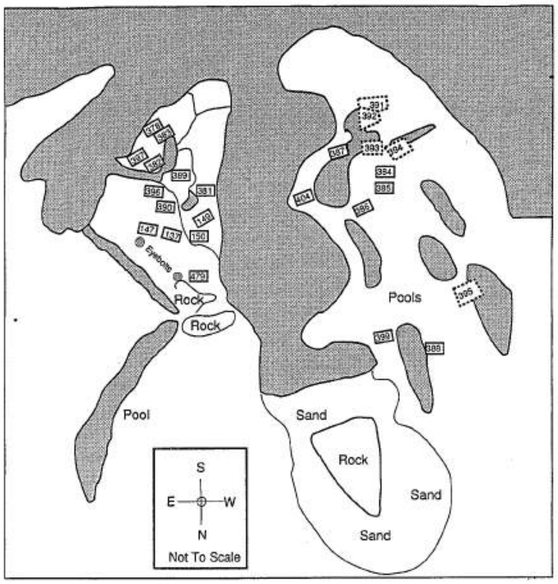


Figure A - 6. SANTA BARBARA ISLAND
Intertidal Monitoring Sites

A - 6 *Monitoring Locations*

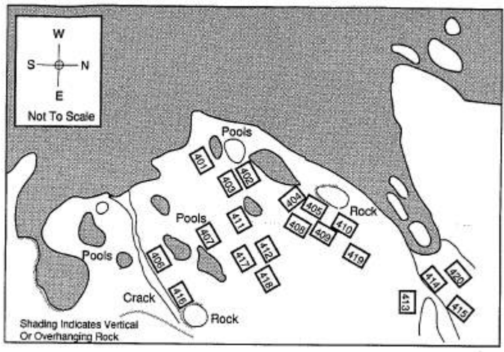
Appendix C.2 San Miguel Island Individual Monitoring Sites



	QUADRAT NUMBERS	
☐	Barnacle	137 - 150, 479
	Endocladia	386 - 390
	Mussel	381 - 385
	Rockweed	396 - 400
⬚	Abalone Plots	391 - 395

Figure A - 7. SAN MIGUEL ISLAND
Crook Point
Intertidal Monitoring Site
Established March 1985

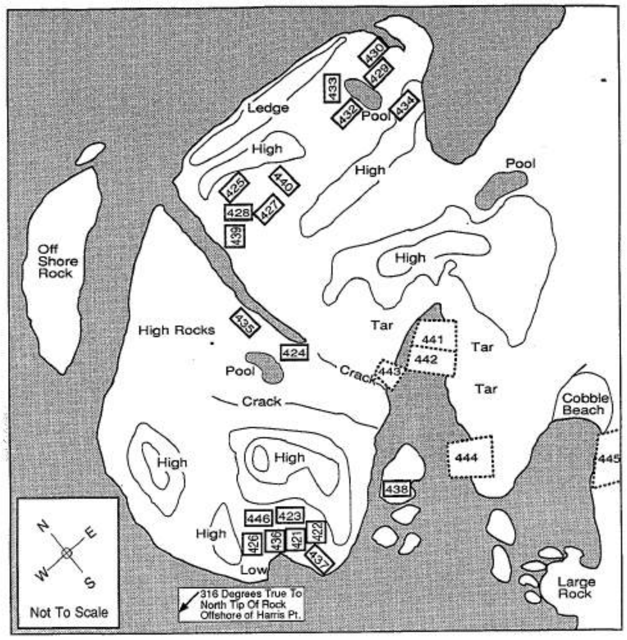
Monitoring Locations *A - 7*



QUADRAT NUMBERS

▭		
	Barnacle	416 - 420
	Endocladia	411 - 415
	Mussel	401 - 405
	Rockweed	406 - 410

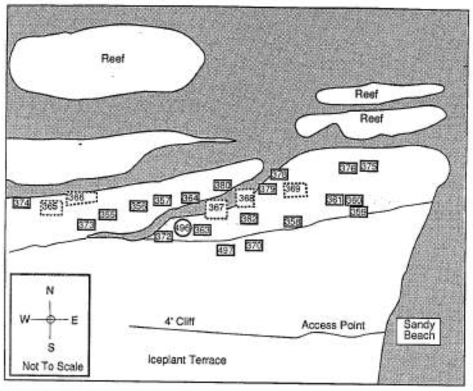
Figure A - 8. SAN MIGUEL ISLAND
Cuyer Harbor
Intertidal Monitoring Site
Established April 1985



QUADRAT NUMBERS

▭	Barnacle	436 - 440
	Endocladia	431 - 435
	Mussel	426 - 430
	Rockweed	421 - 425
⬚	Abalone Plots	441 - 445

Figure A - 9. SAN MIGUEL ISLAND
Harris Point
Intertidal Monitoring Site
Established April 1985

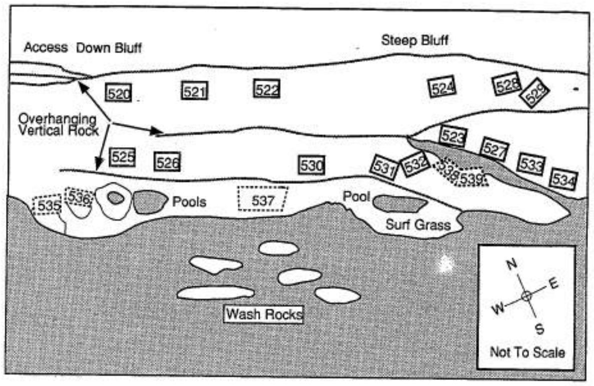


QUADRAT NUMBERS

▭	Barnacle	370 - 374, 497
	Endocladia	360 - 364
	Mussel	375 - 380
	Rockweed	355 - 359
⬚	Abalone Plots	365 - 369
○	Lottia	496 Bolt For Transect

Figure A - 10. SAN MIGUEL ISLAND
Otter Harbor
Intertidal Monitoring Site
Established March 1985

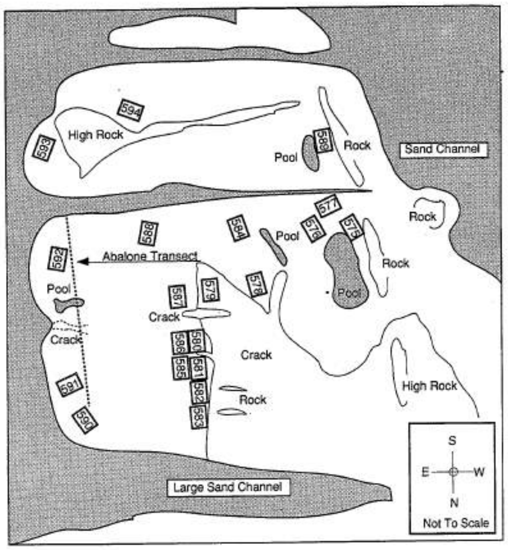
Appendix C.3 Santa Rosa Individual Intertidal Monitoring Sites



	QUADRAT NUMBERS	
▭	Barnacle	520 - 524
	Endocladia	525 - 529
	Mussel	530 - 534
⬚	Abalone Plots	535 - 539

Figure A - 12. SANTA ROSA ISLAND
Ford Point
Intertidal Monitoring Site
Established December 1985

A - 12 *Monitoring Locations*

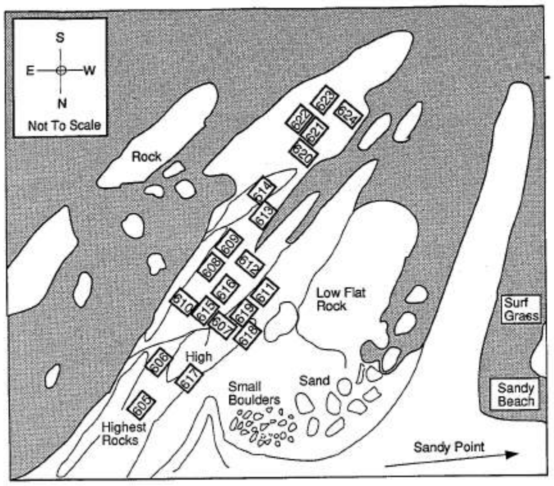


QUADRAT NUMBERS

☐	Barnacle	575 - 579
	Endocladia	580 - 584
	Mussel	590 - 594 Bolt in upper right corner of mussel quadrats
	Rockweed	585 - 589

Figure A - 11. SANTA ROSA ISLAND
East Point
Intertidal Monitoring Site

Established December 1986

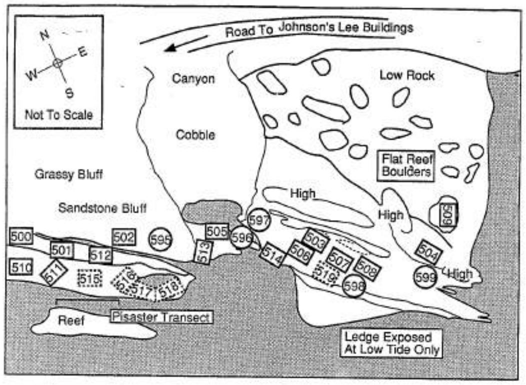


QUADRAT NUMBERS

☐	Barnacle	605 - 609
	Endocladia	610 - 614
	Mussel	620 - 624
	Rockweed	615 - 619

Figure A - 13. SANTA ROSA ISLAND
Fossil Reef
Intertidal Monitoring Site

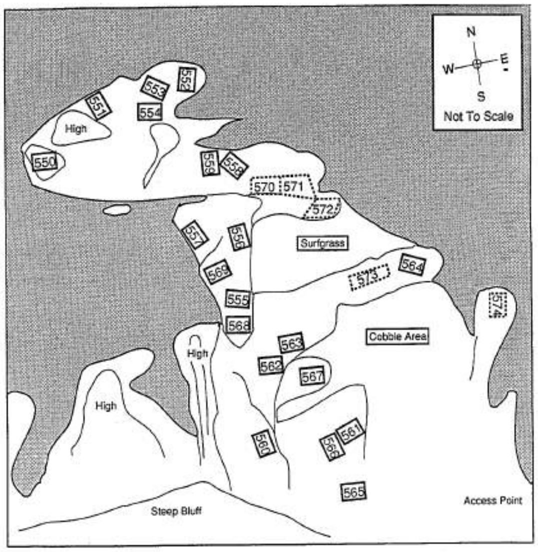
Established March 1988



QUADRAT NUMBERS

▭	Barnacles Endocladia Mussel	500 - 504 505 - 509 510 - 514
⬚	Abalone Plots	515 - 519
○	Lottia	595 - 599 One Bolt Only

Figure A - 14. SANTA ROSA ISLAND
Johnson's Lee
Intertidal Monitoring Site
Established December 1985

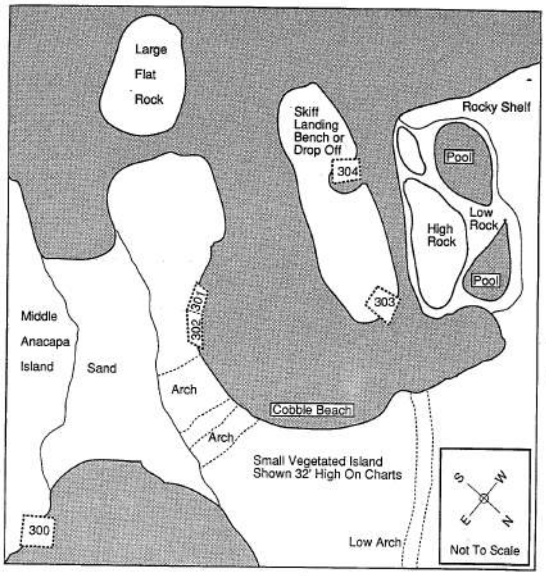


QUADRAT NUMBERS

▭	Barnacle Endocladia Mytilus Rockweed	560 - 564 555 - 559 550 - 554 565 - 569
⬚	Abalone Plots	570 - 574

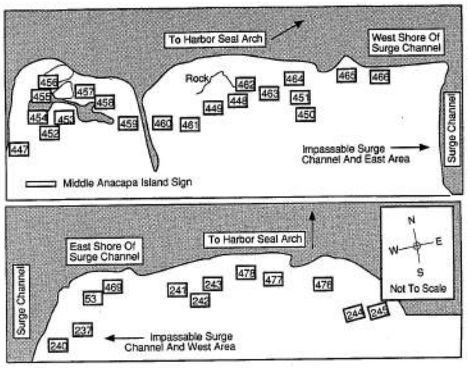
Figure A - 15. SANTA ROSA ISLAND
Northwest Talcott
Intertidal Monitoring Site
Established November 1986

Appendix C.4 Anacapa Island Individual Intertidal Monitoring Sites



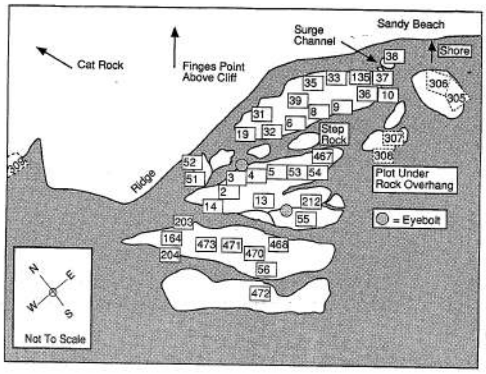
⬚	Abalone Plots	300 - 304

Figure A - 16. ANACAPA ISLAND
Harbor Seal Arch
Intertidal Monitoring Site
Established March 1985



QUADRAT NUMBERS Figure A - 17. MIDDLE ANACAPA ISLAND
West and East
Intertidal Monitoring Sites
Established 1982

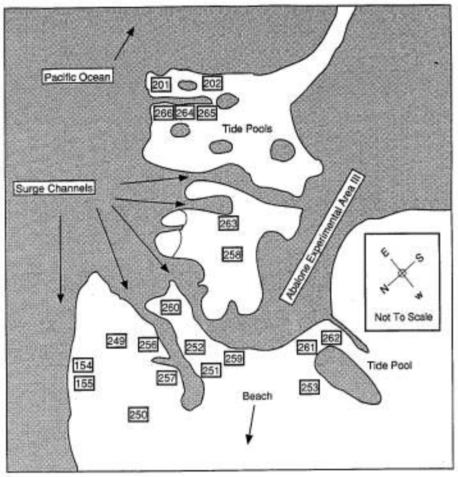
▭	Barnacle	243 - 245, 447 - 451
	Endocladia	240 - 242, 457 - 461
	Mussel	476 - 478, 462 - 466
	Rockweed	53, 237, 469, 452 - 456,



QUADRAT NUMBERS

▭	Barnacle	31 - 33, 35 - 39, 135
	Endocladia	13, 14, 19
	Mussel	51 - 54, 212, 467 56, 164, 203, 204, 468, 470 - 473
	Rockweed	2 - 6, 8 - 10, 55
⬚	Abalone Plots	305 - 309

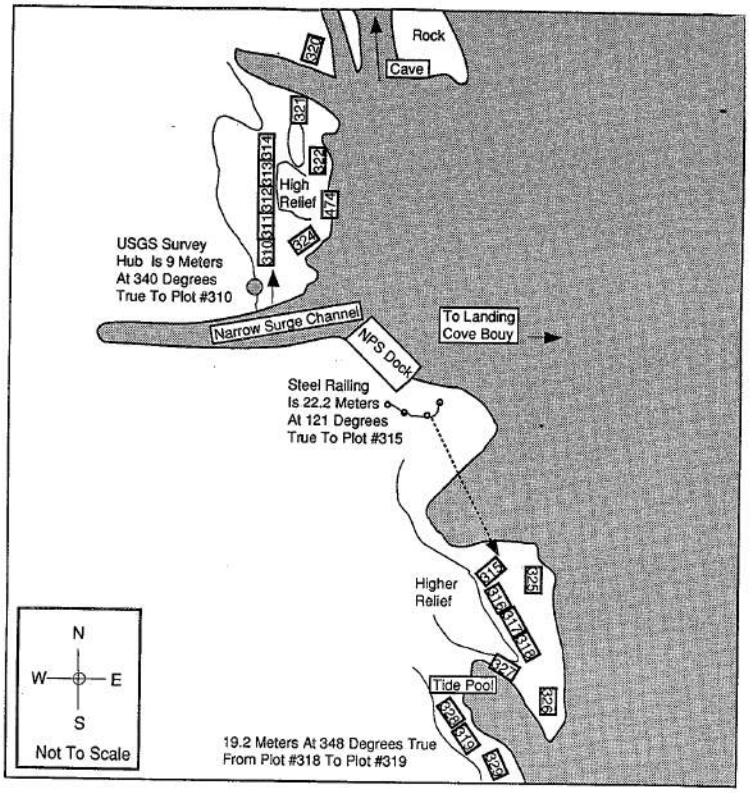
Figure A - 18. WEST ANACAPA ISLAND
Cat Rock
Intertidal Monitoring Site
Established 1982



QUADRAT NUMBERS Figure A - 19. WEST ANACAPA ISLAND
Frenchy's Cove
Intertidal Monitoring Site
Established 1982

▭	Barnacle	249 - 253
	Endocladia	254 - 258
	Mussel	201 - 202, 264 - 266
	Rockweed	259 - 263

Appendix C.5 Santa Barbara Individual Monitoring Sites



QUADRAT NUMBERS

▭	Barnacle	315 - 319
	Mussel	325 - 329
	Red Algal Turf	320 - 322, 324, 474
	Rockweed	310 - 314
		Bolts in upper right corner

Figure A - 20. SANTA BARBARA ISLAND
East and West Landing Cove
Intertidal Monitoring Site

Established March 1985

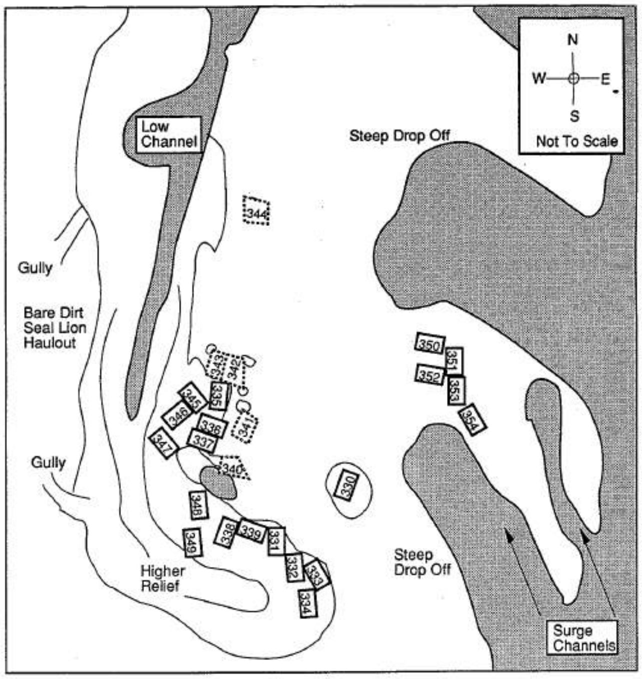


Figure A - 21. SANTA BARBARA ISLAND
Sea Lion Rookery
Intertidal Monitoring Site

Established March 1985

	QUADRAT NUMBERS	
▭	Barnacle	345 - 349
	Endocladia	335 - 339
	Mussel	350 - 354
	Rockweed	330 - 334
⬚	Abalone Plots	340 - 344

Appendix D Literature Review

1. Introduction

The rocky intertidal is a coastal region flanked by the ocean and land. It is periodically covered or uncovered by water depending on daily tidal fluctuations. Because the area is affected by both land and sea, a steep environmental gradient develops (Thompson et al. 2002). Organisms' range limits create distinct bands of species habitats called vertical zonation. Vertical zonation of organisms occurs due to the biological and physical stresses an organism has to endure (McNeill 2010). Rocky intertidal organisms develop an upper and lower limit of distribution determined by biological factors for lower limits and physical factors for upper limits (McNeill 2010). For example, a barnacle cannot settle too high on a rock face due to the possibility of desiccation and cannot settle too low in danger of predation. These factors limit the range in which an organism can settle on the rocky intertidal zone. Intertidal rocky shores and tide pools are subject to naturally fluctuating environmental conditions such as oscillating pH, salinity, temperature, and oxygen concentrations. Environmental conditions change depending on weather, time of day, tidal height, and neighboring organisms (de la Haye et al. 2011).

The rocky intertidal is a dynamic environment that a diverse array of species inhabit. With a changing world due to human development and climate change, rocky intertidal species may be challenged to adapt to unnatural environmental conditions. The following literature review will highlight some rocky intertidal species that are the focus of our study and their vulnerabilities to human and climate change impacts.

2. Description of Intertidal Zones

The rocky intertidal is separated into distinct biotic zones that each consist of specific organisms. The splash zone is the highest rocky intertidal zone and is usually dry. The few species that live here include small barnacles, periwinkles, and ribbed limpets. The high intertidal zone, also known as the *Balanus/Chthalamus* (barnacle) zone, includes the area from the average high tide to just below average sea level and is covered only during high tides. Some species found in this zone include acorn barnacles, hermit crabs, shore crabs, black turban snails, and rockweeds. The *Endocladia* (turfweed) zone occurs on the upper intertidal below the barnacle zone and is dominated mainly by sea algae. Species found in the turfweed zone include Littorina snails and small and medium size limpets. Below the turfweed zone is the rockweed zone. The *Silvetia* (rockweed) zone is located within the mid-intertidal zone, which extends just below average sea level to the upper limit of the average lowest tides. *Tegula funebralis*, *Lepidochitona*, and limpets are found in the rockweed zone. The mid-intertidal zone is exposed at low tides usually twice a day. It is inhabited by brown algae and other rockweed algal species. The lower mid-intertidal is home to the *Mytilus* (mussel) zone, where mussels are the dominant species living there. Mussels may compete for resources with larger barnacle species such as the goose-necked barnacle. The low intertidal zone is mostly submerged and only exposed at lowest tides. This zone is mainly dominated by algae and is thus called the Algal zone. Sea stars and feather boa kelp also reside in the low intertidal zone (Richards 1987, Tidal Zones 2014). Certain species may reside in more than one intertidal zone as Figure 1 shows a rough illustration of the intertidal species zonation. Table 1 shows the vertical distribution of each biotic zone with the inhabited species.

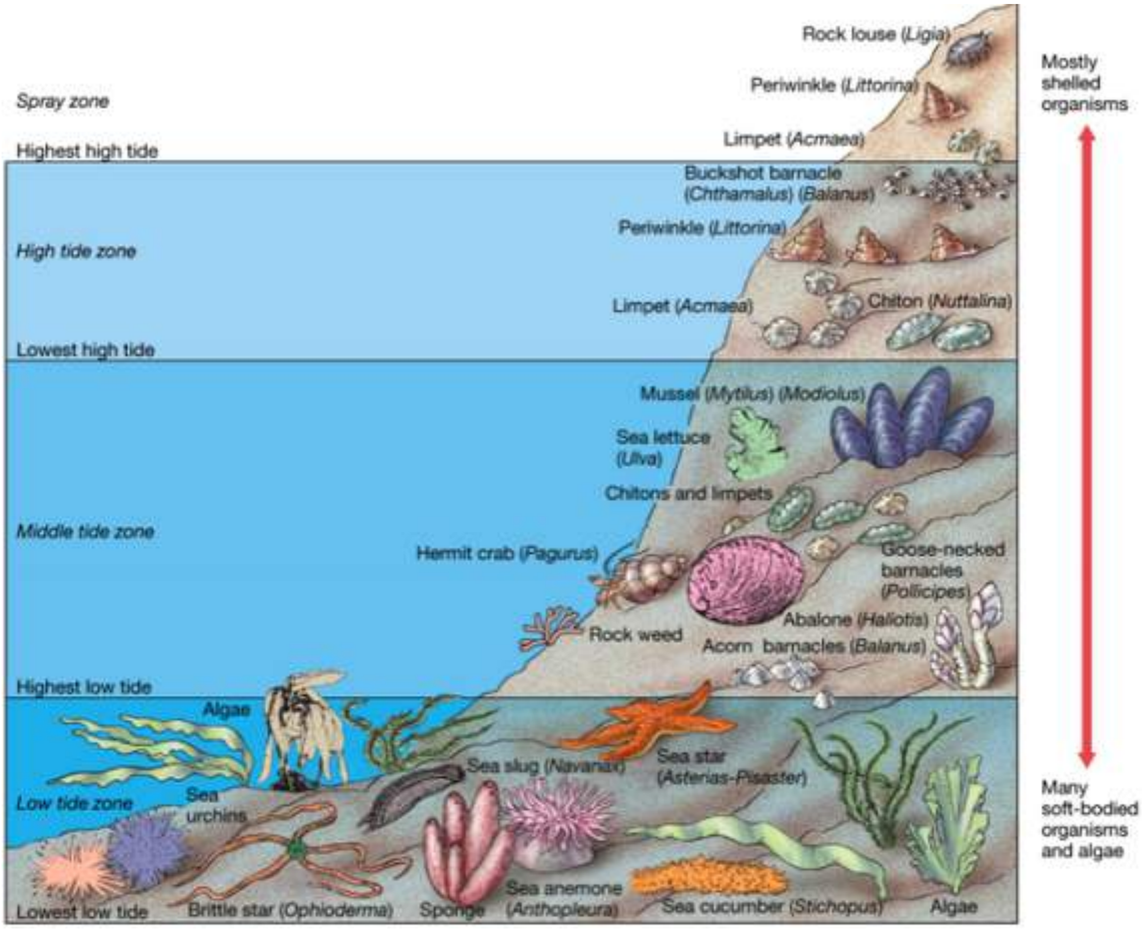
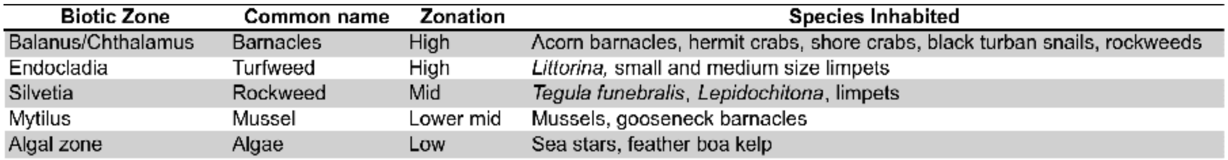


Figure 1. Intertidal Zonation of Rocky Intertidal Species (Thurman and Trujillo 2013).



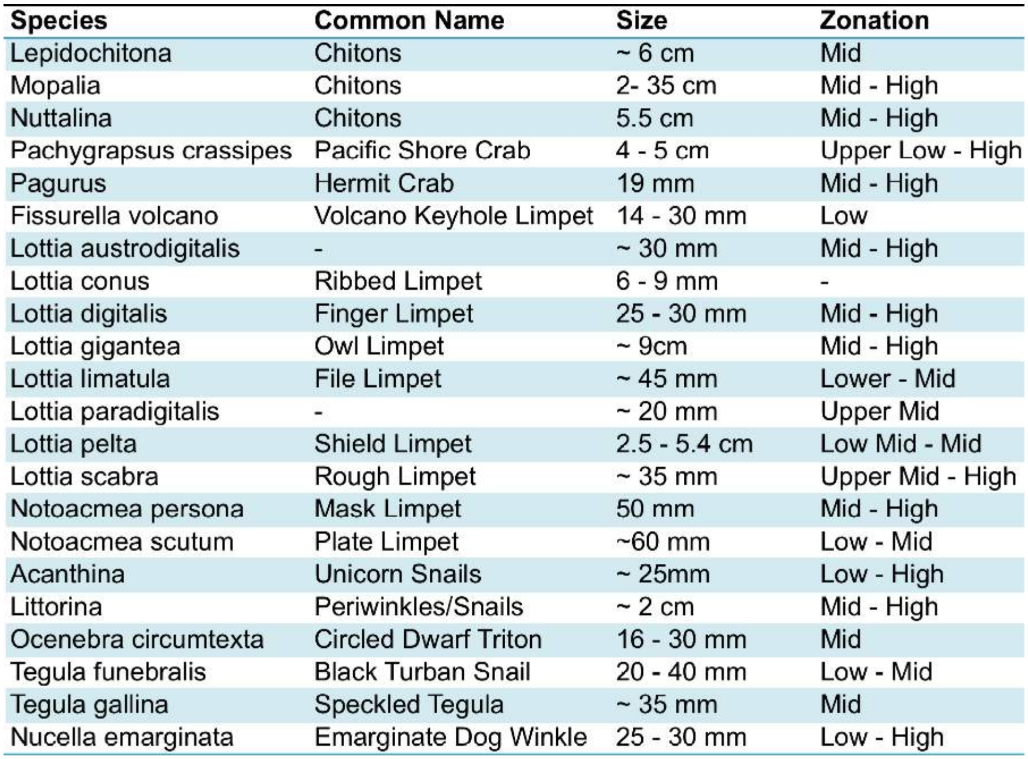
Biotic Zone	Common name	Zonation	Species Inhabited
Balanus/Chthalamus	Barnacles	High	Acorn barnacles, hermit crabs, shore crabs, black turban snails, rockweeds
Endocladia	Turfweed	High	*Littorina*, small and medium size limpets
Silvetia	Rockweed	Mid	*Tegula funebralis*, *Lepidochitona*, limpets
Mytilus	Mussel	Lower mid	Mussels, gooseneck barnacles
Algal zone	Algae	Low	Sea stars, feather boa kelp

Table 1. Vertical Distribution of Biotic Zone and Inhabited Species.

3. Biology & Natural History

3.1. Study Species

The following motile invertebrate species are found on the Channel Islands. Table 2 lists our study species organized based on genera and includes common name, size, and inhabited intertidal zone.



Species	Common Name	Size	Zonation
Lepidochitona	Chitons	~ 6 cm	Mid
Mopalia	Chitons	2- 35 cm	Mid - High
Nuttalina	Chitons	5.5 cm	Mid - High
Pachygrapsus crassipes	Pacific Shore Crab	4 - 5 cm	Upper Low - High
Pagurus	Hermit Crab	19 mm	Mid - High
Fissurella volcano	Volcano Keyhole Limpet	14 - 30 mm	Low
Lottia austrodigitalis	-	~ 30 mm	Mid - High
Lottia conus	Ribbed Limpet	6 - 9 mm	-
Lottia digitalis	Finger Limpet	25 - 30 mm	Mid - High
Lottia gigantea	Owl Limpet	~ 9cm	Mid - High
Lottia limatula	File Limpet	~ 45 mm	Lower - Mid
Lottia paradigitalis	-	~ 20 mm	Upper Mid
Lottia pelta	Shield Limpet	2.5 - 5.4 cm	Low Mid - Mid
Lottia scabra	Rough Limpet	~ 35 mm	Upper Mid - High
Notoacmea persona	Mask Limpet	50 mm	Mid - High
Notoacmea scutum	Plate Limpet	~60 mm	Low - Mid
Acanthina	Unicorn Snails	~ 25mm	Low - High
Littorina	Periwinkles/Snails	~ 2 cm	Mid - High
Ocenebra circumtexta	Circled Dwarf Triton	16 - 30 mm	Mid
Tegula funebralis	Black Turban Snail	20 - 40 mm	Low - Mid
Tegula gallina	Speckled Tegula	~ 35 mm	Mid
Nucella emarginata	Emarginate Dog Winkle	25 - 30 mm	Low - High

Table 2. Common name, size, and inhabited zone of study species.

3.1.1. Sea Snails

3.1.1.1. *Acanthina* species

Species within the *Acanthina* genus are most commonly known as unicorn snails, which are small (approx. 25mm) predatory murex or rock snails. During low tides, *Acanthina* forages and hunts for food.During high tides, they hide in crevices in order to reduce potential harm from wave action and consume prey (Menge 1974). Some specific examples found along the California and Channel Island coastlines are *Acanthina monodon* and *Acanthina punctulata*. *A. punctulata*, found in the middle to upper zone of the intertidal community, is a common predator of barnacles and other snails, known for drilling a hole into the shell in order to reach the flesh (Barry et al. 1995, Menge 1974). *A. monodon* inhabits the lower portions of the intertidal zone (Fernandez et al. 2006), and depends on the availability of oxygen as a limiting factor for growth (Lardies & Fernandez 2002).

3.1.1.2. *Nucella emarginata*

The emarginate dog winkle, or *Nucella emarginata*, is a predatory rock snail that is approximately 25-30 mm and can be identified by its distinct orange and grey stripes (Robin 2008). Predation and desiccation are two factors that limit the growth of these rock snails, especially smaller juveniles, which hatch during May and September (Gosselin & Chia 1995).

3.1.1.3. *Ocenebra circumtexta*

Oceanebra circumtexta, more commonly referred to as the circled dwarf triton, is a fairly typical snail that feeds on barnacles, and is endemic to the coast of California and the Channel Islands, with a conch-shaped shell about 16-30 mm large (Barry et al. 1995, Robin, 2008).

3.1.1.4. *Littorina*

Littorina are marine intertidal gastropods, commonly known as periwinkles or snails. Periwinkles can grow up to 22 mm in size. They can be found in the upper to mid-intertidal zones and are very tolerant of high temperatures compared to other motile invertebrates. These species are epifaunal and thus depend on substratum for survival (Jackson 2008). The adult species prey on algae. Reproduction season peaks in the late spring or early summer (Fish 1979). *Littorina* can live up to 5-10 years, with most living to 3 years (Jackson 2008). Predators include shore birds, fish, crabs, and lobsters. *Littorina* are highly abundant in the rocky intertidal zone and are important grazers for the ecosystem that feed mainly on algae. Without *Littorina* grazing the rocky shore, trophic cascades will occur and detrimental consequences will ensue for associated organisms (Bibby et al. 2007).

3.1.1.5. *Tegula funebralis*

The black turban snail, or *Tegula funebralis,* is an herbivorous snail of the mid- to low intertidal zone that feeds mainly on kelp and seaweed with a shell size of 20-40 mm (Yee & Murray 2004, Robin 2008). This specific snail prefers cold to warm water, from about 11^{0}C to 23^{0}C, a relatively broad temperature range, in which they are most productive, but have experienced a decline in a their numbers within the past few decades (Yee & Murray 2004). Due to their broad temperature range, *T. funebralis* habitat also ranges widely from Vancouver Island, British Columbia to Baja California, Mexico.

3.1.1.6. *Tegula gallina*

Speckled tegula (*Tegula gallina*) is a predatory turban snail with a purplish-grey conical shell size of 1.9 to 4.1 cm big (Robin 2008). *T. gallina* prefers warmer water, and has become more abundant during the 1970s-1900s (Yee & Murray 2004). Larger *T. gallina* can be found in the southern-most part of its range, which expands from Santa Barbara County to Baja California (Redher 1981).

3.1.2. Limpets

3.1.2.1. *Lottia*

The genus *Lottia*, also known as true limpets, resides along the rocky intertidal shores of California from the upper littoral zone to shallow subtidal, while a select few live on kelp and sea grasses (McLean 1990). Reproduction occurs annually during the wintertime and is aided by turbulent seawaters that disperse eggs and sperm. The diet of limpets includes algae that grow on rocks and other surfaces. Predators of the limpet species include starfish, shorebirds, fish, seals, and humans. Limpets typically survive for long periods of time, with some specimens living over 10 years (Nakano and Ozawa 2007).

3.1.2.2. *Lottia gigantea*

One species found in abundance along the California Coast and Channel Islands is the owl limpet, or *Lottia gigantea*, which can grow to be about 9 cm large (Robin 2008). Due to their larger size, owl limpets are commonly hunted by the black oyster catcher and humans for food (Erlandson et al. 2011, Seapy et al. 1975, Connell 1972). Owl limpets are hermaphroditically protandrous, which means they are males as juveniles, and some in the population will later transform into females in their adult stage (Erlandson et al. 2011, Sagarin et al., 2007).

3.1.2.3. *Lottia digitalis (Collisella digitalis)*

L. digitalis, known as the finger limpet, appears greenish gray to dull brown and ranges from 25 to 30 mm in size (Haven 1971). On the posterior side, the shell has strong rough ribs. Its light colored shell closely resembles that of a barnacle (Wootton 1993). *L. digitalis* prefers to reside in steep slopes in the upper (splash) zone among barnacles and algae, with oldest and largest animals in the highest regions. These cold water species are found more abundant in winter than in the summer; reproduction occurs in the winter and spring season with peak recruitment in the spring (Haven 1971, Fritchman 1961). Crowding of species will decrease its growth rate. *L. digitalis* are seldom found permanently submerged and are better adapted to desiccation compared to other limpets (Frank 1965c, Keen 1971). *L. digitalis* grazes on algae and diatoms during high tide. Its predators include sea stars, oyster catchers, shorebirds, and shore crabs. Moreover, *L. digitalis* closely resembles *L. austrodigitalis* in appearance and behavior (Watanabe 2012).

3.1.2.4. *Lottia austrodigitalis (Collisella austrodigitalis)*

A sibling species of *L. digitalis*, *L. austrodigitalis* grow about 30 mm long, having brown to olive with white checkering on its shell. The shell has an apex near the front that is moderately high. This southern species are found abundantly on rocks from the mid to high intertidal zone. *L. austrodigitalis* sometimes attaches itself to gooseneck barnacles and mussels (Watanabe 2012).

3.1.2.5. *Lottia paradigitalis (Collisella paradigitalis)*

Another similar species to *L. digitalis* and *L. austrodigitalis* is *L. paradigitalis,* a rather tiny limpet at 20 mm in length. The shell is gray-green, slightly eroded by the white color, and includes fine concentric lines but no ribs. The interior is completely white. *L. paradigitalis* is a common species found on the top of the middle intertidal zone. *L. digitalis* is considered the closest species to *L. paradigitalis* (Watanabe 2012, Keen 1971).

3.1.2.6. *Lottia conus (Collisella conus)*

The species *L. conus*, ribbed limpet, has limited information available, especially because it is difficult to distinguish apart from its northern counterpart, *L. scabra*, in terms of appearance. *L. conus* is often combined with *L. scabra* in many scientific observations. As one of the smaller limpet sizes, *L. scabra*'s shell size ranges between 6 to 9 mm. Out of the 14 *Lottia* species, *L. conus* is the only one that does not have a range extending to north of Point Conception and is also much less abundant than *L. scabra* (Eerinisse 2009).

3.1.2.7. *Lottia limatula (Collisella limatula)*

L. limatula (file limpet) grow to about 45 mm long with noticeable scale-like radiating ribs that appear corroded. The number of these species is abundant and found in middle to lower intertidal zones. For food, *L. limatula* consumes both microscopic and macroscopic algae, usually during high tide. Predators of *L. limatula* include the purple sea star and shore crab (Watanabe 2012).

3.1.2.8. *Lottia scabra (Collisella scabra)*

L. scabra (rough limpet) has a shell appearance of rough, wavy outer edge and radial ribs. The color of the shell contains blotches of tan, gray, and white. *L. scabra* can grow up to 35 mm and are abundant, residing predominantly in the high splash zone on horizontal or sloping surface and also live on *L. gigantea* (Watanabe 2012). During high tides, *L. scabra* scavenge for algae and diatoms to consume. *L. scabra*'s main predator is *Pisaster ochraceus* (purple sea star). Haven (1973) found that when caged together with *L. digitalis*, *L. scabra* grew at a slower rate because *L. digitalis* was able to move up and down the shore more readily and better utilize resources in response to the changing climate.

3.1.2.9. *Lottia pelta (Collisella pelta)*

L. pelta (shield limpet) can grow from 2.5 to 5.4 cm and grows particularly faster than *L. digitalis* at a rate of 30 mm in 3 years. The shell color varies but usually has gray, radial stripes with white in between. Some species are found with a checkered pattern. The shell color can change as *L. pelta* moves on the rock (Sorensen and Lindberg 1991). At tidal level, these limpets reside just below *L. digitalis* and *N. persona* on rocks that are not covered by the waves, typically the mid to lower mid-intertidal region. These particular species are not common in bays but found more on the outer coast. *L. pelta* remains reproductively active during the year as its eggs and sperm are shed into the sea, spawning at temperatures 48.5°-60°F. For food, this grazing herbivore consumes mostly red and brown algae. The main predator of shield limpets is sea stars (Light and Carlton 2007).

3.1.2.10. *Fissurela volcano*

Fissurela volcano, better known as the volcano keyhole limpet, is identifiable by its keyhole-like opening in its shell, and can grow to be about 14-30 mm large (Robin 2008). The volcano keyhole limpet is an herbivorous grazer that prefers warmer water, but is still considered a cosmopolitan species, meaning that it is widely distributed along the coast of California, with a range extending as far north as Alaska (Schiel et al., 2004).

3.1.2.11. *Notoacmea Persona*

N. persona, the mask limpet, possesses a large shell at 50 mm, appearing dark olive-green with white specks and has fine radial grooves. The apex is moderately high with an eroded dark brown tint. Though *N. persona* are common in the high to mid-intertidal zones, it is often obscured by its surrounding and can be found in caves and small crevices. This species is nocturnal, preferring to feed on microscopic algae when rocks are moist (Watanabe 2012).

3.1.2.12. *Notoacmea Scutum*

Noctoacmea, a southern genus of true limpets, is synonymous with *Lottia* in terms of behavior and appearance. It can be found in the mid intertidal zone. This plate limpet possesses a head with golden tentacles. Its shell is fairly flat, containing fine radial riblets, and can grow up to 60 mm long. The color varies from tan, brown to grayish green. *N.scutum* are found abundant in nature around the low to mid intertidal zones (Watanabe 2012).

3.1.3. Chitons

3.1.3.1. ***Lepidochitona***

Lepidochitona are commonly known as chitons that live in shallow tidal pools. These chitons can also be found along the mid-intertidal zone. Chitons attach to rocks with their feet and live in rock crevices. Chitons can also burrow into substrate to establish a place of residence (Evans 1951). *Lepidochitona* are distinguishable by their flat, depressed tail valves. They can grow up to approximately 6 cm in size.

3.1.3.2. ***Mopalia***

Mopalia is a genus of chitons that commonly lives near shore to the rocky intertidal zone. These chitons mainly inhabit the upper and mid- intertidal zones. They can range in size from 2 to 35 cm. *Mopalia*'s habitat range extends from Baja California to British Columbia. *Mopalia* has 23 species within its genus. Subtle morphological differences in the species make it very difficult to distinguish between organisms (Kelly et al. 2007).

3.1.3.3. ***Nuttalina***

The *Nuttalina* species are chitons that are commonly found in the mid to high intertidal zones of rocky shores. There are three main species that live along the Pacific coasts of North America. These three species are *Nuttalina californica*, *Nuttalina fluxa, and Nuttalina fluxa.* They are about 28mm in size. They can be distinguished from each other by gill morphology, color , valve shape, geographical range, abundance, and intertidal distribution (White 1998).

3.1.4. Crabs

3.1.4.1. ***Pachygrapsus crassipes***

Pachygrapsus crassipes is an amphibious Pacific shore crab. They are commonly known as striped shore crabs or lined shore crabs. Their body size can range from 4-5 cm large. The crab occupies the tide pools and rocky shore of the rocky intertidal zone. Adult *P. crassipes* are able to occupy the high zone above the surf, while juveniles tended to occupy near the water. The crabs remain within moist rock crevices and live in burrows (Bovbjerg 1960, Willason 1981). The intertidal range of *P. crassipes* is Mean Lower Low Water (MLLW) plus five to eight feet in depth, which basically extends from upper low intertidal to high intertidal zones. Adult *P. crassipes* can be very aggressive during competitions with other adult crabs. *P. crassipes* have an omnivorous diet and consume other crabs, fish, and algae (Bovbjerg 1960).

3.1.4.2. ***Pagurus***

The *Pagurus* species is commonly known as hermit crabs. Adult hermit crabs are found mostly in rocky intertidal tide pools. They can found along the high and mid-intertidal zones. They are very miniscule organisms approximately 19 mm in size. *Pagurus* have an asymmetrical, membranous abdomen that is very soft and vulnerable. Therefore, hermit crabs need to find empty gastropod shells to protect their soft bodies from predators and environmental stress conditions. In order to grow, hermit crabs constantly find new, larger shells as their homes either through searching for an empty shell or competing against other hermit crabs to attain a shell (de la Haye et al. 2011).

4. Human Disturbance

Some species not only have to adapt to extreme weather changes but also must survive human predation, trampling, rock overturning, litter, and invasive species. More than half of the United States' population live along the coasts and about 90% of tourism occurs along the coastal states (Huff 2011). The high diversity of these coastal areas makes it a very attractive location for humans to explore. Nevertheless, human visitation to rocky intertidal regions can be devastating to organisms that live there. Human activities include "tide pooling; collecting for food, aquaria, or research; educational field trips; seaside strolling; photographing; and fishing" (Addessi 1994). Due to the growing population of people living and visiting the Channel Islands, these effects have become much more potent.

4.1. Human Predation

One such species that has suffered the effects of human predation is the owl limpet *(Lottia gigantea)*. Due to the slow growth, low mobility, large size, and a non-cryptic adult stage, owl limpets are extremely vulnerable to human impacts on the rocky intertidal zone (Erlandson et al. 2011). Poachers usually target *L. gigantea* because of its larger size. Not only has there been an overall decrease in the owl limpet population, but also a decrease in the mean size of owl limpets, because people have harvested the larger and older owl limpets since the establishment of the Channel Islands (Erlandson et al. 2011, Sagarin et al. 2006). Since owl limpets are a hermaphroditic protandrous species (males as juveniles and some mature to become females), it has been much harder for smaller and younger male limpets to find a larger and older female mate. Another source of human predation comes from supplying for fish markets. *Littorina* species are considered a delicacy and are thus extracted to be shipped and sold to fish markets. Periwinkles are sold primarily in Europe, but have gained popularity in North America (Jacobson & Emerson 1971). Therefore, harvesting marine species for commercial purposes can lead to significant reductions in population.

4.2. Collection and extraction

Humans may also decide to collect organisms and thus remove them from their habitat. Removal of organisms can result in changes to community structure. Collecting and harvesting organisms can affect the size structure of a community. Humans tend to choose the largest specimens to collect (Smith et al. 2008). Therefore, the collection of large organisms leaves the small, unwanted organisms behind to make up the community structure. Leaving behind the small or young individuals "may result in a disproportionate decrease in the reproductive ability of the population because the reproductive potential (i.e., gonad volume in invertebrates) increases exponentially with size" (Smith et al. 2008). The community will have low reproduction and thus possible lower abundances of harvested species.

Similarly, fisherman can have a significant influence on community structure by reducing the density and proportionality of a community according to Kingsford et al. (1991). Fisherman would only choose to catch and keep larger organisms for food or bait and thus smaller organisms would remain in the end. This shift in community structure can lead to trophic cascades such as a flourishing abundance in prey species if predatory fish are caught (Addessi 1994).

4.3. Trampling

The Channel Islands and the California coastline have become a popular place for visitation, hiking, exploring, and other recreational activities. While visitation has allowed people to feel closer to nature and has its economic advantages, people do not always know how to interact properly with certain species. This makes intertidal organisms, which live on rocks or on the shore where many people walk, susceptible to harm via trampling and dislodgement.

Trampling on organisms can result in indirect and direct effects. Organisms can be affected directly by either being crushed or dislodged or attachment to substrate can be weakened (Huff 2011). Organism can be indirectly affected by disrupting biological associations (such as competition, predation, or habitat provision) with neighboring organisms according to Brosnan and Crumrine (1994). Trampling can result in a decrease in abundance, height, and coverage area of organisms (Huff 2011). Morphological damage to organisms by being crushed can reduce fitness because physiological and reproductive processes could be impaired (Smith et al. 2008).

Some species specifically affected by human trampling include the owl limpet, *Lottia gigantea* (Sagarin et al. 2006, Lindberg et al. 1998) and other snails, limpets, barnacles, and mussels (Beauchamp & Gowing, 1982). Trampling by humans damages species possessing shells, eventually leading to death (Sagarin et al. 2006). People may not fully understand the issues surrounding trampling and how their actions affect the intertidal community.

4.4. Overturning rocks

As humans traverse rocky intertidal pools and shores for leisure or research purposes, they may overturn rocks to investigate what organisms dwell on the underside of the boulders. Natural disturbances such as wave action that overturns rocks are common, but with increasing human visitation to rocky intertidal zones, organisms are subject to being overturned more often than usual (Addessi 1994). Overturned rocks have very little biota growing on the top and bottom of them due to the continual disturbance of the rock (Addessi 1994). The high disturbance rate does not allow for fauna and flora to settle and grow on the rocks because humans may intentionally or unintentionally damage or remove organisms (Addessi 1994). Organisms that occupy rocks as shelter are often prone to having their habitat tampered with by humans.

4.5. Litter and Oil Spills

All of California’s storm drains lead directly to the ocean, without treatment. This means that any litter or chemicals found in the streets have a direct, channelized route to the ocean. This litter can wash up on shores and rocky intertidal zones, where they get trapped in between rocks and infringe on the diverse community living on and within these rocks. In some cases, species are vulnerable to litter and floating debris found in waves, which can cause dislodgement or a disruption in food availability such in the case of *Nucella emarginata* (Gosselin et al. 1995). Oil spills can immensely affect the productivity of rocky intertidal zones. In 1969, two oil spills occurred off the coast of Santa Barbara, not far from the Channel Islands; following these spills were a drastic kill of fish, worms, crustaceans, and mollusks, including snails and limpets (Nicholson 1972). Oil selectively adheres to warm, dry surfaces, like exposed rocks, and takes several months to be removed from the habitat’s system (Nicholson 1972). Litter and oil spills can greatly decrease the amount of habitat available for these snails and limpets.

4.6. Invasion of non-native species

Humans have directly caused the introduction of non-native species by deliberately or inadvertently transporting certain species across the ocean and bringing new species into the rocky intertidal zone. The spread of non-native species has many biological consequences, such as competition for habitat and resources, which can be detrimental to the rocky intertidal community (Vitoųsek et al. 1997).

5. Climate Change

Climate-related changes are closely tied to changes in the physical, chemical, and biological changes within the intertidal zone community, due to the rise in air temperature and subsequent warming of ocean water. The increase in surface temperatures imposes desiccation and heat stress on species, leading to shifts in habitat ranges to avoid pressures from climate change. Moreover, warmer water is less capable than cold water to contain dissolved gases, such as oxygen, as solubility decreases when temperatures increase. Inadequate amounts of oxygen lead to hypoxia, which affects species' reproduction and metabolism rates. Since many of these motile and non-motile species have a semi-permeable, mucous skin layer, the temperature of the water and the air directly influences these species in a multitude of ways.

5.1.1. Water Temperature

In recent times, climate change has caused warming of the atmosphere leading to increases in ocean temperatures. Over the last 45 years, the mean temperature of the top 300 meters of the Earth's ocean has risen by 0.31°C (Scavia et al. 2002). Warmer temperatures have lead to glacial melting, which further increases global temperatures. Over the last 20 years, the aerial size of arctic ice has deteriorated by up to 7% per decade and thinned by up to 15% per decade, and evidence implies that these declines are associated with human activities (Scavia et al. 2002).

Another consequence of warmer oceans relates to the molecular structure of water. Temperature is a measure of the movement of particles, so a higher temperature corresponds to greater movement of molecules. The increase in motion causes molecules to prefer to spread out more when in liquid form, compared to a rigid structure in solid forms of matter. The expanding of volume due to increased temperatures (thermal expansion) is occurring in our oceans. It is estimated that the volume of the ocean is causing sea level to rise by approximately 0.115 m/yr (Church et al. 1991). Change in volume from thermal expansion has additional implications that will be discussed in section 5.4.

5.1.1. Heat Stress

As the climate warms, rocky intertidal species experience multiple stressors. *Tegula funebralis* has an optimal body temperature of about 21°C. Heart failure occurs at temperatures lower than 3°C and higher than 39.4°C (Tepler et al. 2011). *Tegula funebralis* is a heat tolerant species, but as temperatures rise toward 27°C, the black turban snail begins to express heat shock proteins. These heat shock proteins are released at the onset of thermal stress. Expressing heat shock proteins is very energetically costly and thus may maximize the energy reserves of the snail if heat stress is prolonged. (Tomanek & Somero 1999).

5.1.1.1. Reproduction

Since many of these species have a mucous membrane and interact directly with the water, change in temperature can affect reproduction and reproductive success rate. Because temperature is inversely proportional to amount of dissolved oxygen in a body of water, the lack of oxygen availability causes an increase in the number of undeveloped *Acanthina monodon* embryos (Fernández et al. 2006). Marine species require a specified temperature range for reproduction. *Tegula funebralis* prefers a 11^0C to 23^0C range for optimum productivity, but have experienced a decline in a their numbers within the past few decades (Yee & Murray 2004). Therefore, a warmer climate will disrupt reproduction patterns and negatively affect the population and diversity of these snails.

5.1.1.2. Food & Metabolism

Climate change also can alter the food availability for particular species, including *Tegula funebralis* and *Tegula gallina*, two other types of snails found in the Channel Islands rocky intertidal zone, which feed directly on seaweed and kelp (Yee and Murray 2004). Temperature has a direct correlation with these *Tegula* species affecting both food consumption and metabolism, as well as the availability of food (McLean 1962). In order to deal with heat stress, many of these species will slow down metabolism in order to conserve energy and water, which, if sustained for too long, may lead to death of these individuals (Yee and Murray 2004).

Blanchette et al. (2009) found that sessile species of macroalgae, such as the rockweed *Silvetia*, are most abundant in cold water regions. This relationship also determines the distribution of herbivores that graze on these macroalgae to belong to coldwater regions as well. For example, *Tegula funebralis*, a coldwater species depending on inhabited region, follows the same distribution as its coldwater food source, *Silvetia*. This strong correlation between ocean temperature and species distribution suggest that sea surface temperatures can drive the spatial pattern seen in intertidal communities (Blanchette et al. 2009).

Moreover, the mutual interaction between *Littorina* and sessile species can affect abundance for both species. *Littorina* species are epifaunal and thus depend on substratum for survival (Jackson 2008). Variations to substratum percent cover due to climate change may affect species abundance. *Littorina* also mainly graze on algae; a reduction in food availability will likely reduce growth rates and reproductivity of *Littorina* (Jackson 2008). The presence of algae and barnacles in the same zone inhabited by *Littorina* introduces a trophic cascade of indirect and direct effects on species density. As explained in a study on the tidal area of Wadden Sea, Buschbaum (2000) found that a positive effect occurs for barnacles as the grazing activity of *Littorina* suppresses algal growth, thus increasing barnacle cover. Subsequently, the increase in barnacle cover negatively affects *Littorina* survival as they compete for space and resources. During grazing activity, *Littorina* may accidentally dislodge and consume barnacle larvae, decreasing survival rate of newly-settled barnacles. Researchers also conducted cage experiments in which they discovered a strong negative correlation between *Littorina* and barnacle abundance. Nonetheless, fluctuations in *Littorina* density and their grazing behavior are key factors for the variation in barnacle cover in the rocky intertidal area.

Opposite of *Littorina*'s detrimental grazing influence on barnacle cover, the chiton *Nuttalina californica* enhances the abundance of barnacles (de Vogelaere 1987). De Vogelaere (1987) hypothesizes that barnacle cover increases due to *Nuttalina* grazing because the soft girdles of the chiton create a suitable substrate for barnacles to attach to rather than the scraping style of grazing that *Littorina* performs. *Nuttalina californica* also influences the abundance of Ulva macroalgae, in which case, the absence of the chiton increases algal cover because the algae is not being grazed (de Vogelaere 1987).

5.1.2. Hypoxia/Calcification

Some areas surrounding the Channel Islands suffer from hypoxia, or a decrease in dissolved oxygen in a body of water, due to the increase of surface water temperatures. Many of these species, submerged for more than or about half of the day depend on the amount of dissolved oxygen in order to complete respiration. As stated above, many gastropod embryos, including the *Acanthina monodon*, are underdeveloped under conditions of hypoxia or apoxia (Fernandez et al. 2006). A lack of dissolved oxygen can also lead to calcification, or the buildup of calcium in a body tissue, which can disrupt normal bodily processes, especially respiration (Palmer 1992). Calcification affects many of the *Tegula* species in the Channel Islands, and can be detrimental to the survival of these snails (Maeda-Martinez 1985, Cancino et al. 2003). Moreover, there are also other species that can endure extended periods of being deprived by oxygen, such as *Littorina littorea*. Macdonald and Storey (1999) discovered that these snails cope with hypoxia by significantly reducing their metabolic rate by about 20% of their original. Although this appears as an advantageous characteristic, this process causes a reduction in feeding rate, which may stagger growth rates and increase mortality (MacDonald and Storey 1999).

5.2. Air Temperature

5.2.1. Desiccation

With the increase in air temperatures, the risk of desiccation also increases going up the intertidal zone as upper limits receive less moisture from the waves. Desiccation refers to organisms drying out due to increased sunlight, wind speed, and water evaporation. Species living in intertidal zones, especially those with a permeable skin layer, such as the gastropods of interest, rely on the tides to refresh their water sources. The availability of water is vital in the intertidal community because the different subzones are actually classified by heat stress and desiccation (Connell 1972, Davenport & Davenport 2005).

The *Nucella emarginata*, one type of intertidal snail found in the Channel Islands, does not directly suffer from a warmer surface temperature but instead is vulnerable to the indirect effects of a warmer climate, due to an increase in potential for desiccation (Gosselin & Chia 1995). In certain experiments researchers extrapolated that during low-tide, when snails are out of the water, air temperatures of about 30° C and above could be lethal for hatchlings, and most did not survive emersion for 6 hours (Gosselin & Chia 1995). The *Tegula funebralis* copes with desiccation stress by decreasing its metabolic rate in order to conserve water and energy (Yee & Murray 2004). If *T. funebralis* were to suffer from an increase in aerial exposure, this species would face the serious threat of death via desiccation. *Lepidochitona cinereus* is an organism that is subject to desiccation risk at high temperatures. Chitons prefer to live in areas of low light intensity and tend to aggregate in shady regions on the shore or under rocks (Evans 1951). If exposed, *L. cinereus* respond orthokinetically to reposition themselves back to shady areas under rocks. According to Evans (1951), "chitons are extremely sensitive to desiccation and are unable to recover in windy, sunny conditions". The largest chitons can die within an hour of exposure to wind and sunlight and smaller chitons die even quicker in less than thirty minutes (Evans 1951). Therefore, it is vital for chitons, such as *L. cinereus*, and other intertidal species to burrow or hide in rock crevices and tidal pools to escape desiccation (Evans 1951).

Littorina littorea are a robust group of snails that have developed a high tolerance to extended periods of high temperature. They have behaviorally adapted to desiccation, gravitating towards damp crevices or aggregating together to reduce moisture loss. Periwinkles can survive for several hours during prolonged exposure to air by creating a dried mucus seal around their shell to counter evaporation effects (Jackson 2008). Most periwinkles are found in the upper intertidal zone because of their ability to breathe air and withstand extreme temperatures (Castro and Huber 2013). In a report produced by Cashmore and Burton (1998) for a fisheries business in Scotland, they state that *Littorina* experiences heat coma with prolonged air exposure to temperatures above 32°C and mortality at 42°C. Since *Littorina* tend to reside in upper intertidal zones that do not come into contact with water, we suspect that *Littorina* will be affected more by air temperatures than by water temperatures.

In a comparison among several studies, scientists discovered that the limpet's tolerance to desiccation stress is associated with zonation patterns, where high-shore species exhibit increased tolerance (Branch 1981). When low-shore limpets were moved higher, they retreated back to damp sites to avoid desiccation. Wolcott (1973) suggests that the critical factor leading to death for limpets is ionic concentration, rather than water loss. Desiccation may cause death because of osmotic stress, in which moisture loss accumulates in the tissue ions. Limpets are unable to effectively regulate their body volumes, consequently gaining ions from being immersed in a hyperosmotic solution (Branch 1981).

5.3. Ocean Acidification

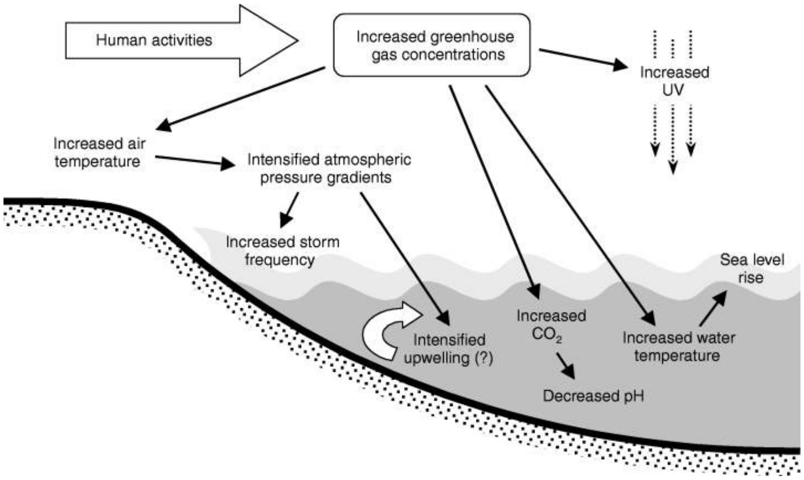


Figure 2. Ocean acidification process (Harley et al. 2006).

Of all of the carbon released from anthropogenic activities between 1800 and 1994, about half is now stored in oceans (Sabine et al. 2004). Currently, the ocean takes up roughly 30% of recent emissions (Sabine and Feely 2007), which would be approximately 127 billion metric tons since the beginning of the industrial era (Feely et al. 2008). While acting as a "carbon sink" is beneficial for the atmosphere by mitigating the greenhouse gas effect, increased levels of CO_2 in the ocean lower the pH and alter fundamental chemical balances. This reduction in pH is commonly known as ocean acidification. Throwing off the balance that had previously existed in the oceans has brought about new challenges and concerns, especially coastal waters with special attention to the rocky intertidal region.

Ocean acidification occurs as the oceans absorb CO_2 from the atmosphere, leading to a lower pH level in the ocean. This process particularly affects organisms with a calcium carbonate skeleton. Marine organisms that calcify appear to be more sensitive to temperature increases. Acidification reduces carbonate mineral saturation in the ocean, removing the availability of aragonite and calcite which are key components for calcifying shells (Byrne and Przeslawski 2013). Thus, calcifying organisms are not able to develop their shells properly. If an organism's shell dissolves or cannot form completely, its vulnerability to predation increases.

In Bibby et al.'s (2007) experiment on *Littorina littorea*, the researchers discovered how ocean acidification disrupted the snail's defense against predators. The snails were grown and observed over the course of 15 days under normal and low pH conditions. When *L. littorea* detect a chemical equivalent to predator (crab) cue used for the experiment, they adapted to produce thicker shells in response. At low pH (high acidity), these natural defenses were interrupted and *L. littorina* were unable to form thicker shells due to the reduced availability of calcium carbonate ions in water. Researchers suspect that shell thinning causes *L.littorina* to become more vulnerable to predation and are easily crushed by the crab's pinchers, though more research is required to fully assess these implications. To compensate for their heightened susceptibility to predation, *L. littorina* increased their avoidance behaviors to defend themselves against predation, which was measured by the amount of time spent above or at the surface level in trials. However, increasing avoidance behaviors when exposed to predator cues and living in a high stress environment meant that *L. littorina* spent less time on other important activities such as feeding and foraging (Bibby et al. 2007).

In conjunction with *L. littorea*'s response to ocean acidification, *Pagurus bernhardus*'s natural activities were also disrupted by increasing acidity. According to de la Haye et al. (2007), "reduced sea water pH altered the normal shell assessment and selection behavior of *P. bernhardus*." Under low pH conditions, the hermit crabs were significantly unmotivated to search for a new shell. The hermit crabs were less likely to change their shells and for those who decided to do so, it took the crabs significantly longer to change shells compared to normal pH conditions (de la Haye et al. 2011). According to de la Haye et al. (2011), the physiological stress on the hermit crabs altered their neurological and olfactory functions. These disruptions may have been responsible for disturbing the crabs' decision-making process and reduced antennular flicking. Reduced antennular flicking could indicate an inability of the crab to detect chemical stimuli of shells. Thus, the crabs were unable to detect the presence or assess the value of a potentially new shell home. Hermit crabs need to constantly find new shells to upgrade to in order to grow. By not changing shells, the hermit crabs are forcing themselves to stay in a suboptimal position. Remaining in an inferior shell, hermit crabs are reducing their fitness, potential for growth, and protection from predators.

5.4. Sea Level Rise

Due to the thermal expansion of water and the melting of glacial ice caps, an increase in the global temperature could lead to sea level rise. Global sea level rose approximately 1.8 mm/year during the twentieth century, and climate change is projected to continue to raise global average sea levels into the present century (Cayan et al. 2008). Sea level along the California coast has risen over the past several decades at a rate of approximately 17-20 cm per century, which is roughly the same as estimates of the global rate of sea level rise (Cayan et al. 2009). Over the next century, potential sea level rise will increase a significant amount over its historical rate. A report by Cayan (2009) predicts that, by 2050, sea level will rise anywhere from 30 cm to 45 cm compared to the level in 2000.

California coastal regions are at risk of sea level extremes. Sea level rise will increase the severity and the frequency of the impacts of extreme storms and other wave events (Cayan et al. 2009). Increases in the length of storm-induced high sea levels will increase the chance that they occur at the time of a high tide. This could result in higher sea levels that could cause severe flooding and erosion of these habitats (Cayan et al. 2008). Because water carries sediment, changes in the sea level may alter the terrain of the coast as well. The waves can erode sediments in the lower intertidal and redeposit them on the upper intertidal, raising the surface (Pethick 2001). With sea level rise, many of these areas will experience more erosion and could therefore change the landscape and the habitats of these motile species.

Sea level rise also poses a hazard of submerging many intertidal and low-lying coastal areas. Current intertidal habitat is expected to suffer losses ranging between 20% and 70%, even with the conservative assumption of an increase in global temperatures of 2°C over the next century (Galbraith et al. 2002). Sites where the coastline cannot move inland, due to cliffs or other rocky obstructions, like seawalls, are likely to incur the most severe losses, as these habitats are unable to migrate landward in response to a rise in sea level. These land regions are home to many ecosystems and species, as well as provide a feeding habitat for migrating shorebirds. Despite even the most successful efforts to stabilize greenhouse gas emissions, the rate at which sea level is rising is likely to continue to increase past the year 2100 due to response time required for the oceans and ice sheets to reach a state of equilibrium with the atmosphere (Scavia et al. 2002).

5.5. Salinity

Similar to all other variable environmental components of the rocky intertidal, salinity can also fluctuate. According to Boyle (1969) and Stickle and Ahokas (1975) (as cited in Moran and Tullis 1980), intertidal species can “experience salinity stress as freshwater run-off after heavy rain or tidal fluctuations of salinity”. Seawater can also increase salinity through increasing evaporation due to higher temperatures. As the ocean’s water is being evaporated into the atmosphere, heavier salts are left behind, and therefore, the remaining water has increased salinity (Rahel and Olden 2008).

A rapid decrease in seawater salinity can cause chitons, such as *Mopalia muscosa*, to take in water through osmosis which can disrupt physiological processes such as respiration, feeding, and locomotion (Moran and Tullis 1980). *Mopalia* are osmoconformers (Moran and Tullis 1980). Osmoconformers maintain their bodies’ osmolarity so that it remains equal to the surrounding seawater. Therefore, if the surrounding seawater has high salinity, *Mopalia* will also exhibit the same high salinity. *Mopalia* responds to salinity stress by adjusting their volume. However, if the water’s salinity is too high, the *Mopalia’s* foot can swell and lose their attachment to substrate (Moran and Tullis 1980). High salinity can be detrimental to *Mopalia* and other intertidal chitons if important biological processes, such as oxygen intake and feeding, are interrupted.

Another rocky intertidal organism that can be affected by salinity fluctuations is *Pachygrapsus crassipes*. In Willason’s study (1981), *Pachygrapsus crassipes* was found to have high mortality in low salinity conditions. Smaller crabs had low survivorship compared to larger crabs in low salinity environments.

5.5.1 Precipitation

Climate change alter not only the frequency of rare and extreme weather events, but the pattern of precipitation globally. Since the start of the 20th century, global land precipitation has increased by about 2% (Dore 2005). This increase is even greater in the Northern Hemisphere, especially during fall and winter, with precipitation over the United States having increased between 5% and 10% since 1900, and the increase being most evident during warmer seasons. While increases in precipitation is perceived as beneficial in many aspects, such as for agriculture or regions of low rainfall, precipitation only causes positive effects if it is consistent.

While there was an overall increase in precipitation since early of last century, it has not been consistent rainfall. In other words rainfall is intermittent with multiple years of drought and multiple years of dense rainfall within this time span. This inconsistency poses various harmful impacts on coastal waters. When there are years of much more rainfall sporadically dispersed between years of drought, urban communities may be unsure of how to prepare and cities may not make infrastructural adjustments for the reclamation of increased storm water. When surface water does not get collected, it eventually flows to the sea, accumulating toxins and chemical compounds as it travels. Surface water runoff is the primary cause of pollution in the urban ocean (Ahn et al. 2005). In arid regions, such as southern California, there is particular concern of the impact of stormwater runoff on coastal habitats because a large percentage of such pollutant-loaded runoff flows to the ocean (Ahn et al. 2005). This runoff can contain phosphates from fertilizer, which would cause cultural eutrophication of our coastal waters. An influx in nutrients in coastal waters can result in a rapid increase in growth, such as algae. This growth can impede light from penetrating the surface, affecting lower organisms that are light dependent. Additionally, algal growth can reduce the amount of dissolved oxygen in the surface ocean waters because the algae consume it at a rate at which it cannot be replenished. In Florida, a study was conducted that confirmed a large volume of fresh water accumulating along the entire southwest coast that contained an immense phytoplankton bloom (Hu 2004). This study also demonstrates how far reaching land runoff can be. The freshening of coastal waters after large storms can lead to unstable environments offshore. Sporadic rainfall could also lead to longer amounts of time that these sessile species are exposed to the sun, and therefore could increase the likelihood of death by desiccation.

5.6. Weather events

5.6.1. Waves

The strength and momentum generated by waves can have direct impacts on species zonation and abundance when the waves come in contact with the intertidal zone. Increases in wave exposure will cause dislodging of individual species, reducing population size. *Littorina* species attempt to escape dislocation from waves by forgoing their optimal grazing areas. This results in a lowered growth rate due to reduced food availability (Jackson 2008). In a study on Santa Barbara Island, Seapy and Littler (1987) observed the effect of wave surges on the vertical zonation and species diversity of macrophytes and macroinvertebrates using cluster analysis. Although the study area resided on the sheltered side of the island where there is less wave impacts, the zonation appeared to significantly shift upward. This change in vertical distribution is hypothesized to be caused by constant wave surges created by the refraction of northwesterly swells around northern and southern outskirts of the island. This study mentions a gradient of wave surge exposure that exists ranging from high to low; High exposures were observed on Santa Barbara Island, intermediate on Santa Catalina Island, and low on San Clemente Island. The wave surge intensity correlated with the height range of various species; vertical zonation was highest at Santa Barbara (high wave surge impact area), intermediate at Santa Catalina, and lowest at San Clemente Island (Seapy and Littler 1987).

In an observation by Shanks and Wright (1986) in various rocky intertidal zone in California, rocks and pebbles that have been sifting in the sea are brought up when waves crash on the intertidal zone, acting as projectiles that can damage and kill marine organisms. These wave-borne rocks can dent the shells of calcifying species. In a study site on the northwest side of San Nicolas Island, researchers observed the impact factor of wave-born debris versus damage and mortality of limpets. They found that there was an increased frequency of limpet damage with increase in shell size. This may be explained by the fact that the magnitude of impact necessary to kill a small limpet will only lead to a damage in a large limpet that is more robust. Due to the advantageous size, researchers suggest that small limpets may be less prone to projectiles as they are protected by roughness of the boulder and are also more concentrated in crevices. Through analysis of the data, Shanks and Wright (1986) suggest that damage to species become more intense near high water. The impact frequencies depend on the daily wave height and thus vary seasonally among different rocky intertidal habitats. In various sites on San Nicolas Island, populations of limpets were almost obliterated by large rock impacts during severe storm events. This study concluded that the intensity of damage is due to the local wave energy, amount of available projectiles, projectile size, and the slope of substratum (Shanks and Wright 1986).

5.6.2. Extreme Weather Events

Higher temperatures will alter atmospheric circulation patterns. The atmosphere and the ocean interact on many levels, so changes in atmospheric processes will likely have impacts on the ocean. Over the last 50 years, the number and intensity of mid-latitude cyclones in the central North Pacific has been increasing (Bromirski et al. 2003). Because these cyclones travel eastward, they eventually come into contact with California’s west coast. If these observed trends continue, the structures and ecosystems along the West Coast could experience serious consequences (Bromirski et al. 2003). The strength of hurricanes could also increase as a consequence of elevated sea surface temperatures; with a sea surface warming of 2.2°C, hurricane wind strength can increase by a possible 5-10% (Scavia et al. 2002). Climate change is also hypothesized to cause an increase in other extreme weather events, such as storm surges. A study done in the North Sea showed that the mean number of severe storm surge events along the southern North Sea coast was predicted to increase by around 2 events per year in the upcoming century, which is a 50-100% increase from data obtained in 1961-1990 (Woth et al. 2005). If these predictions can be applied to other oceans, namely the Pacific Ocean, then the stability of coastal communities along California’s coast may potentially be threatened.

In California, while major floods are historically common, climate change may lead to more frequent severe storms that cause flooding. Water vapor is transported from the tropics to the poles in “narrow, intense, filamentary bands of moist air, called atmospheric rivers (ARs),” in which ARs can develop into storms (Dettinger 2011). AR storms are becoming more widely understood as the cause of large amounts of the biggest floods in California, as noted by Dettinger (2011). Based on most climate change projections, it is expected that there will be more years consisting of many AR storms and that these storms will occasionally occur on much larger scales. Dettinger’s results indicate that warm, wet AR storms may increase California flood risks past those previously known. Greater risks of flooding present additional challenges for ecosystems inhabiting California’s coast.

5.7. Shifting Habitat

Organisms may need to shift their distribution ranges in order to compensate for increased temperatures and find a cooler place to situate. In response to warmer temperatures, species distributions are predicted to shift poleward and northward, and thus to cooler regions (Walther et al. 2002). However, “range shifts in response to changing temperature may not occur if latitudinal distributions are also limited by other factors such as light” for species such as corals (Walther et al. 2002).

Some models predict that global warming will lead to a poleward shift in organisms, as temperatures generally drop at higher latitudes and thus species will migrate to their thermal preference. Helmuth *et al.* (2002), however, reveals that organisms inhabiting the rocky intertidal zone may not follow that distribution pattern. Alternatively, along the western coast of the United States, the climate interacts with the timing of low tides to create an intricate mosaic of thermal environments (Helmuth et al. 2002). Species of the intertidal zone tend to live extremely close to their tolerance limits for temperature, but Helmuth's results showed that decreasing latitudes do not correlate to more thermally stressful body temperatures. There were no observations on strong latitudinal patterns for body temperature, and predictions of the effects of climate change on air and water temperature contrast significantly from that of body temperature. This conclusion highlights the gap of knowledge on how rocky intertidal ecosystems will adapt (or fail to adapt) to climate change.

Since many of these macroinvertebrates, specifically mollusks and gastropods, have a semi-permeable skin, they are much more sensitive to shifts in temperature than other species (Barry et al. 1995). In order to accommodate for warmer temperatures, species must reposition themselves for a more ideal habitat, such as two snails involved in a case study, *Ocenebra circumtexta* and *Acanthina punctulata*, and a limpet, the *Fissurela volcano,* which have been measured moving north, along the latitudes, in search of colder water (Barry et al.1995). These species are either non-motile or slow-moving, which means that if colder temperatures can only be found farther north, they would have to move quickly enough so that they do not undergo the full-fledged effects of warmer water. Other organisms that depend on these moving species may have to adapt to life without them, and the community of the new habitats may have to adjust to an influx of these snails and limpets.

As a response to warmer climate, limpets have adapted physiologically to increase survival. Therefore, migration of smaller limpet species occur, where in the winter, 56% of *L. digitalis* population tends to move upward along the coast. In the summer, the limpets had a net downward movement of 26% and only a 2% upward movement on the California coast (Wooton 1993). This behavior may be due to the fact that the limpets are counteracting the rise in temperatures by moving to cooler habitats.

Cancer pagurus narrowed its geographic distribution range because of rising temperatures. With warmer temperature conditions, *Cancer pagurus*'s thermal tolerance window has decreased (Metzger et al. 2007). Furthermore, a downward shift of upper limit tolerance causes an organism's heat limit to be reached at a cooler temperature (Metzger et al. 2007). As a result, any increase in atmospheric temperature will cause an organism to reach its maximum heat capacity sooner since it is currenly at a lower threshold. For example, if *C. pagurus*'s maximum heat limit is now 20°C, then an increase in atmospheric temperatures to 25°C will overheat the crab.

6. El Nino Southern Oscillation (ENSO)

The El Niño/Southern Oscillation (ENSO) phenomenon is a cyclic atmospheric and oceanic variation occurring across the Pacific Ocean. This variation produces changes in atmospheric pressure at sea level, precipitation, wind patterns near tropical latitudes, and sea surface temperature (SST) that can last several months to years in the Pacific (Rasmusson 1988). Normal climate conditions along the equatorial band in the Pacific are shown in Figure 4, where easterly trade winds direct currents towards the west, noted by the arrows in blue. This creates a SST gradient where warmer waters collect in the west and colder waters are upwelled back towards the east (Neelin 1998).

A variety of atmospheric-oceanic conditions such as varying easterly trade winds or subsurface sea temperature can bring about ENSO conditions in the area. The warm phase of ENSO, known as El Niño, starts in part from weakened trade winds and results in warmer SST along of the equatorial band; this generates rainfall across the entire Pacific (Federov 2000). The cool phase of ENSO, known as La Niña, produces anomalous cold waters in the east and heavily concentrated rainfall in the western tropics due to strengthened easterly winds and currents (Fedrov 2000).

One of the main concerns of increased greenhouse gases and global warming has been how these changes will likely exacerbate the atmospheric-oceanic impacts from ENSO. In years prior to the 1980s, El Niño and La Niña events were fairly noticeable and cyclic due to sea surface temperatures, easterly wind speeds, and sea surface currents all changing in response to each other (Rasmusson 1988). Yet beginning in 1982, an unprecedented El Niño warming event took place that persisted the remainder of the year and exhibited greater SST and easterly winds than previously recorded, and similarly strong ENSO warm phase events occurred again in 1992 and 1997 (Federov 2000). The role of climate feedbacks such as increased sea surface warming from more solar radiation may have a large impact on creating stronger and more frequent El Niño events in the Pacific (Timmermann 1999). Future models charting ENSO conditions noted that a change in mean conditions created by global warming would lead to strong interannual variability and rapid successions from warm to cold phase (Timmermann 1999). As a result, the future impacts of ENSO make it difficult for local ecological systems in the climate system to adapt to such rapid and large-scale changes in the Pacific.

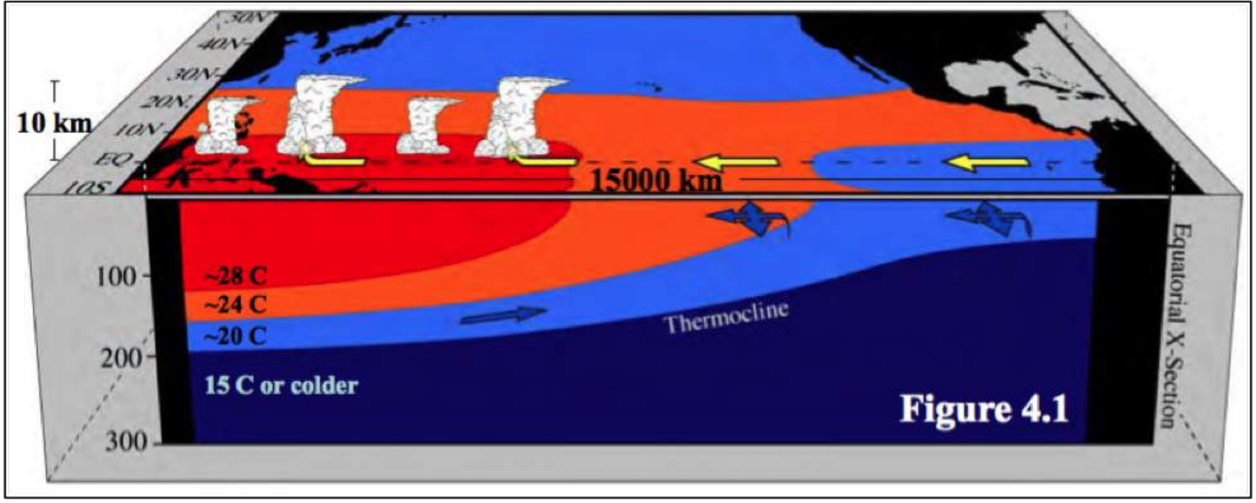


Figure 3. Normal atmospheric and oceanic conditions across the equatorial band in the Pacific Ocean (Neelin 1998).

7. Conclusion

Climate change and human influence on rocky intertidal species result in a vast array of complex responses and consequences. Increasing temperatures due to global warming puts pressure on intertidal species to adapt to desiccation risks and forces organisms to shift their geographical distribution patterns to accommodate higher temperatures. Since rocky intertidal organisms are interconnected, trophic cascades can ensue if abundances shift in species dependent on each other. Due to increasing anthropogenic carbon dioxide emissions, the ocean has correspondingly increased in acidity. The decrease in pH levels of the ocean causes extreme stress to organisms that depend on calcification to build their shells. Salinity fluctuations pose a threat to maintaining homeostasis and can impair important biological functions within a species. Sea level rise and increased precipitation can cause more intense weather events that can bring about destructive waves, storms, and floods to coastal communities. El Niño and La Niña events can become more severe and frequent leading to constant fluctuations in warm and cold conditions.

Besides anthropogenic influences on climate, humans can have a direct effect on rocky intertidal organisms through activities such as trampling, rock overturning, and collection. These human activities create a disruptive, stressful environment to marine species and are detrimental to the health of the individual and to the community.

Organizations and researchers are still conducting studies to determine the actual effects of climate change and other human influences on these specific species residing in the rocky intertidal of the Channel Islands. A variety of agencies, including the National Park Service, are working to create a comprehensive monitoring system to help facilitate restoration and conservation of these ecologically-sensitive areas. With a better idea of how these species react to changes in their system by taking population data and surveys, we may better be able to understand the long-term effects of climate change and human interaction on the rocky intertidal zone community, and the complete roles of these species in their ecosystem.

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