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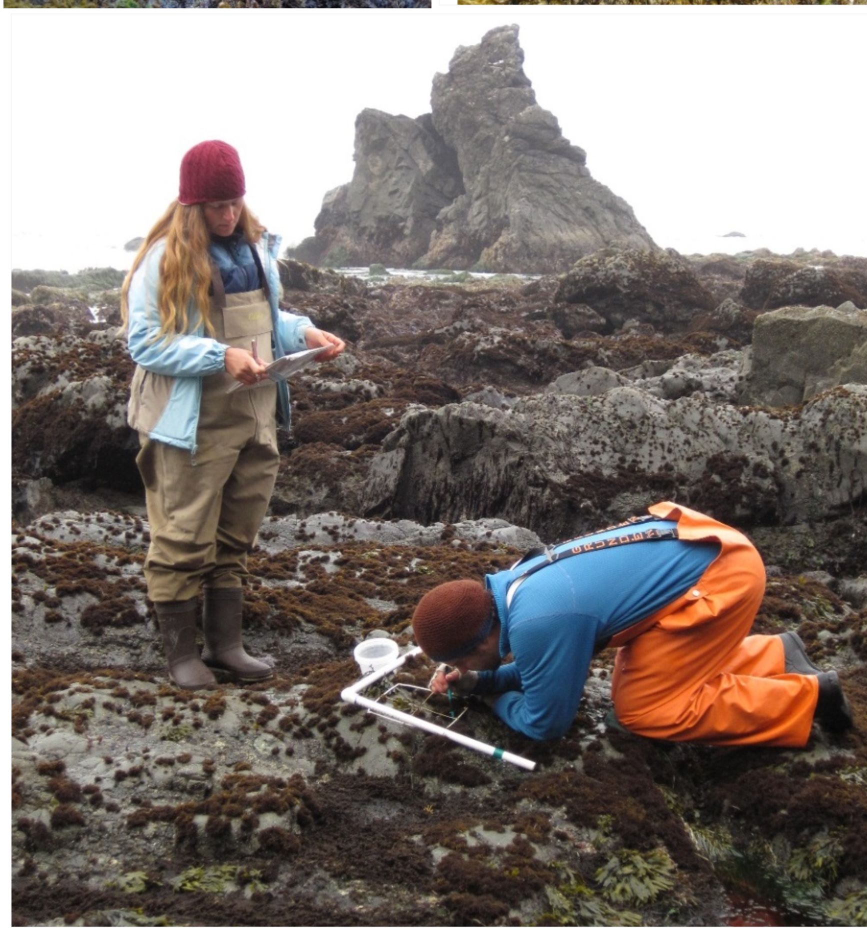
Rocky Intertidal Monitoring

2004–2013 Trends and Synthesis Report for Redwood National and State Parks

Natural Resource Report NPS/KLMN/NRR—2017/1469



ON THE COVER
Ochre sea star (top left), Whelks (top right), Researchers sampling the intertidal community at Damnation Creek, Redwood National and State Parks (bottom).
Photographs by: D. Lohse.

Rocky Intertidal Monitoring

2004–2013 Trends and Synthesis Report for Redwood National and State Parks

Natural Resource Report NPS/KLMN/NRR—2017/1469

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Executive Summary

This report presents the results of the monitoring and inventory surveys done between 2004-2013 of the rocky intertidal community at three sites within the Redwood National and State Parks (RNSP) in Del Norte County, California. These sites are part of MARINe (Multi-Agency Rocky Intertidal Network), a regional intertidal monitoring network sponsored by the Bureau of Ocean Energy Management (BOEM), with additional funding and support from local and state governments, universities, and private organizations (see www.marine.gov). Funding for RNSP sampling is provided by the National Park Service (NPS) through a cooperative agreement with the University of California at Santa Cruz.

This monitoring program, adapted from MARINe protocols, was designed to identify and follow temporal trends in populations of the common and/or ecologically important organisms in the rocky intertidal community at three RNSP sites. To accomplish this, sites are sampled twice a year, and data are collected from permanent plots established to monitor changes in sessile invertebrates, algae, and the ochre star (*Pisaster ochraceus*), and from permanent transects to monitor surfgrass (*Phyllospadix* spp.) and sea palms (*Postelsia palmaeformis)*. These data are analyzed to determine seasonal and annual changes to the community, and to explore broader spatial and temporal trends. This report also includes a biodiversity survey that occurred in 2004 at one RNSP site.

The rocky intertidal monitoring program, which was initiated in RNSP in 2004, continues to progress successfully. The SOPs used for data collection, management, and analysis have generally been working well, although we are applying lessons learned from early years of sampling and improving our ability to meet our monitoring objectives through upcoming modifications and/or additions of SOPs. In order to maintain consistency among the groups within the MARINe network, there have been some minor revisions and additions to these protocols due to changing priorities within the monitoring network. These revisions are discussed in the methods section and non-protocol additions refer to added protocols that were not included in the original protocol (Ammann et al. 2008). Changes are based on group discussions within the MARINe network and have undergone extensive testing and review within the MARINe network before implementation.

Within the RNSP intertidal monitoring sites some species show seasonal differences, while others lack seasonal signals. Although populations varied over time, few long-term changes were noted. Data have reflected disturbances that created open space by removing target species from rock, but have also shown these populations recovering. There is also some evidence that annual differences in abundance are linked to oceanographic conditions.

The MARINE network has recently created an interactive, public website (http://www.eeb.ucsc.edu/pacificrockyintertidal/) to synthesize the decades of monitoring research conducted by the group. The website includes a summary of data, methods, and products of this research, with interactive mapping and graphing features. Much of this RNSP trend report comes

directly from the website. Users are encouraged to interact with the website for more information and for updated data.

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Introduction

Rocky Intertidal Monitoring

Anthropogenic events, like oil spills and the introduction of invasive species, can alter the structure of natural communities. To detect and mitigate the effects of such events, resource managers often rely on the data from long-term monitoring programs that establish the baseline condition of the community and follow how it changes over time (Davis 2005). Such programs provide the type of information needed to distinguish natural changes in community structure from those caused by unnatural/anthropogenic events.

Starting in the early 1990's a long-term monitoring program was established to monitor the distribution and abundance of "key" intertidal species along the southern California coast (Ambrose et al. 1992). The species targeted by this program included those that were most common in the community, as well as those that shape the structure of the community either by creating habitat for other species, or through activities such as grazing or predation. Abundances were monitored using fixed plots to document changes in percent cover, or abundance of targeted species or species assemblages. This fixed-plot approach allows the dynamics of rocky intertidal species to be monitored with reasonable sampling effort and provides sufficient statistical power to detect changes over space or time.

Although initial funding was supplied by the Minerals Management Service (now known as the Bureau of Ocean Energy Management (BOEM)), this program has expanded to include over 20 academic and government organizations, including several National Parks and networks. This consortium, known as MARINe (Multi-Agency Rocky Intertidal Network), monitors intertidal sites all along the entire western coast of North America, from Alaska to Baja, Mexico. Because such monitoring allows changes to be tracked within and between communities over seasonal and yearly time scales, it provides critical information needed to make informed management decisions.

Starting in 2004, a program to monitor the rocky intertidal community at three sites within Redwood National and State Parks (RNSP) was established. The protocols used to conduct these Community Structure (CS) surveys were adapted from those used by MARINe (i.e. Engle 2005). This facilitates comparisons between the RNSP sites and those elsewhere along the coast. The specific monitoring objectives of the RNSP Rocky Intertidal monitoring program are:

- Monitor the temporal dynamics of target invertebrate, algal, and surfgrass species across accessible, representative, and historically sampled rocky intertidal sites at Redwood National and State Parks that can feasibly be monitored with the Network's intertidal monitoring budget ($30k/yr) to: 1) Evaluate potential impacts of visitor use or other park-specific activities; and 2) Provide monitoring information to help assess level of impacts and changes outside normal limits of variation due to oil spills, non-point source pollution, or other anthropogenic stressors that may come from outside the parks.

- Determine status through time of morphology, color ratios, and other key parameters describing population status (e.g., size, structure) of the selected intertidal organisms.

- Integrate with and contribute to a monitoring network spanning a broad geographic region in order to evaluate trends at multiple scales, from the park to region-wide, taking advantage of greater sample sizes at broader scales.

- Detect and document invasions, changes in species ranges, the spread of diseases, and the rates and scales of processes affecting the structure and function of rocky intertidal populations and communities to better understand normal limits of variation.

The specific measurement and analysis objectives of the program are:

- Provide a photographic record of sessile invertebrates and algae (and potentially oil and other non-point source pollutants) using fixed plots (photoplots) as reference.

- Determine the abundance (percent cover) of organisms within select fixed plots (interchangeably called photoplots or photoquadrats).

- Within fixed plots, determine the abundance of sea stars, snails, chitons, limpets, and crabs (mobile invertebrates) that may serve as an indicator of overall or specific ecosystem health.

- Determine surfgrass abundance by measuring cover along fixed point-intercept transects.

- Identify changes that are inconsistent with the established baseline conditions, whether they are park-specific or broader in scale, and whether there are potential management actions needed to mitigate them.

- Prepare annual summary reports and this peer reviewed trend analysis report showing data relevance following National Park Service reporting guidelines. Reports will display any major changes in the abundance of target taxa between sampling intervals as a highlight for potential management actions.

The rocky intertidal monitoring program implemented by RNSP was developed to help promote the importance of its marine resources. This report will present the findings of the first nine years of this monitoring program. Analyses were conducted to look for both short-term (seasonal) and long-term temporal trends in the structure of the community and specific populations. Because these data also integrate with the spatially extensive MARINe program, this effort will translate into a greater appreciation of these resources and an awareness of the importance of maintaining them for future generations.

Rocky Intertidal Biodiversity Surveys

By using fixed plots to monitor changes in abundance, the RNSP long-term monitoring program should be able to detect relatively small changes in abundance at effort levels that can be sustained for the long-term. However, because this approach only targets specific species, it does not give a true representation of the species richness of a site. Such information is collected by Biodiversity Surveys, and such a survey was conducted at Damnation Creek in 2004. These surveys are more labor intensive and require a higher-level of expertise to identify marine algae and invertebrates than that needed for the CS surveys conducted at RNSP. However, because they sample a larger area, they give a better depiction of the species richness of a site, and more detailed information about the site-wide distribution and abundances of the species targeted by the CS surveys. A single group at UC Santa Cruz (cbsurveys.ucsc.edu) conducts these surveys on a less frequent schedule, typically every 3-5 years. Biodiversity surveys were conducted at all three RNSP sites in 2014-2015 through the California Marine Protected Area (MPA) Monitoring Enterprise and Ocean Science Trust (more info at www.OceanSpaces.org). This report will only present findings of the biodiversity survey conducted at Damnation Creek in 2004.

Study Area

California's north coast includes the southern tip of the temperate rainforests of the Pacific Northwest, and is home to many of California's largest rivers. The region is a mixture of habitat types, including estuaries, bays, rocky headlands, sandy beaches, and mudflats. Historically, logging was a major industry in this region. However, recent changes in the timber economy and pressure to preserve forest land and restore watershed areas have resulted in the downsizing of this once-dominant industry. Lasting impacts of deforestation continue to affect watershed areas, bringing increased levels of sediment to streams, rivers, and ultimately, the coast. This northernmost region of the California coast is the least densely populated coastal section of the state, thus impacts from visitors to the shoreline are substantially less than in areas to the south.

Three rocky intertidal sites are monitored within RNSP; Enderts Beach, Damnation Creek, and False Klamath Cove (Figure 1). These index sites are approximately 5 km apart and span the nearly 20 km of rocky intertidal habitat present in RNSP. Panoramic photographs are taken during each survey from permanent markers at various locations at each site to show broad spatial scale patterns (Figure 2).

Enderts Beach, located at the southern end of Crescent Beach, is at the northern edge of RNSP. The site consists of a large, gently sloping bench (approximately 100 m wide) and a series of three smaller benches separated by surge channels, a few scattered boulders and cobble beds (Figure 2a). Rocky intertidal monitoring occurs on the three rocky benches.

Damnation Creek is 5 km south of Enderts Beach and 6.5 km north of False Klamath Cove. It is an extensive rocky bench cut by channels, with a few large sedentary boulders at its seaward edge. The landward edge of the bench has an accumulation of smooth cobble and small boulders (Figure 2b). Although the site is near the mouth of Damnation Creek, most of the monitoring plots are established far enough away from the creek's outflow to avoid direct freshwater input. The exception to this are a series of mussel plots established within the path of the creek's outflow.

False Klamath Cove is located just south of Wilson Creek, about 8 km north of the Klamath River. This site has variable substrata ranging from coarse sand to large boulders (Figure 2c). There is potential for temporal variation in sand scour and boulder movement. The intertidal study site is peninsula-like with the ocean to the north and south and a sea stack (approximately 75 m tall and 100 m wide) at the west end. The peninsula stretches approximately 250 m long with a width of approximately 100 m. The site consists of a gently sloping field of boulders and small benches. The vast majority of the sampling takes place on variously sized boulders.

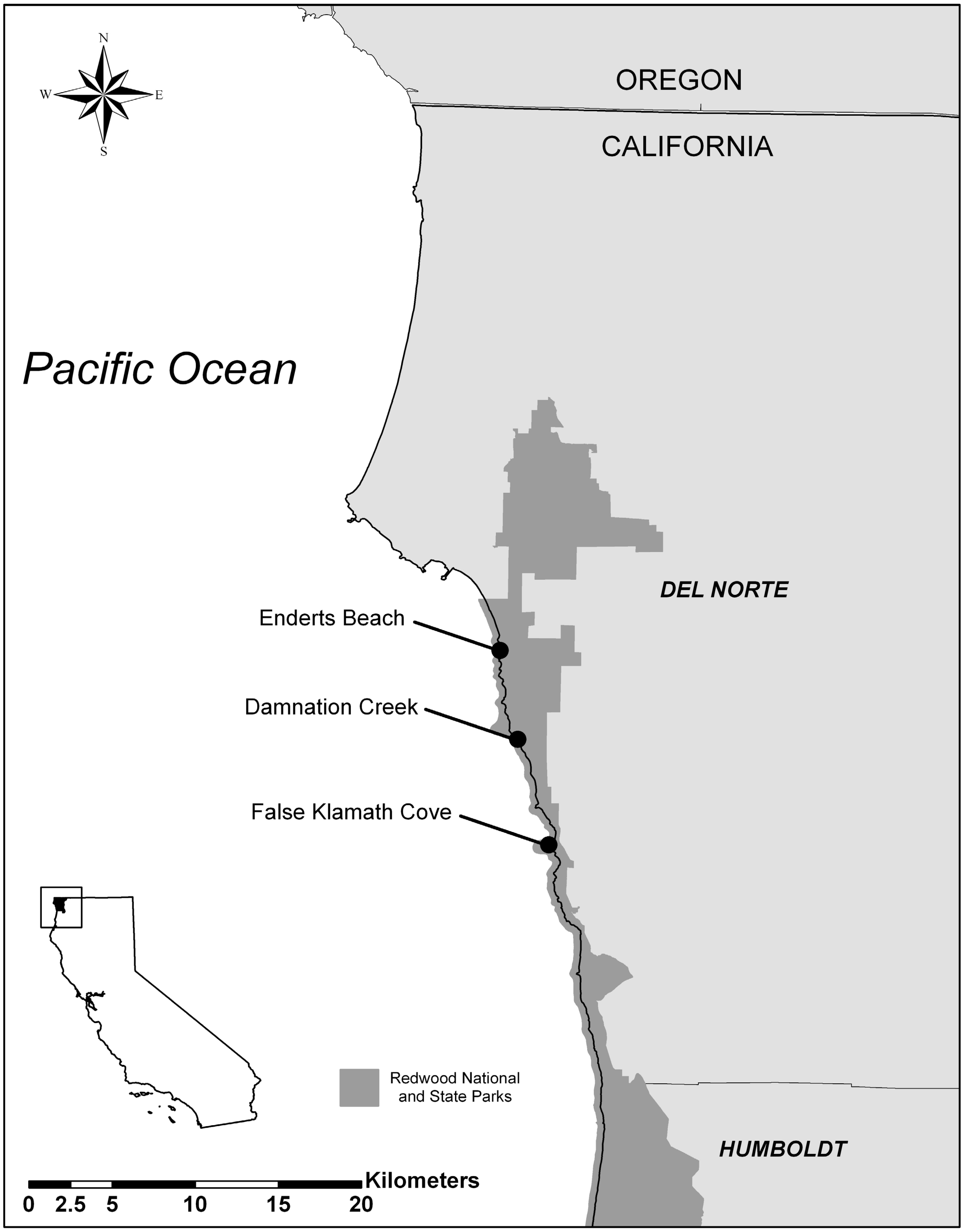


Figure 1. Map of northern California showing the locations of the study sites within Redwood National and State Parks.

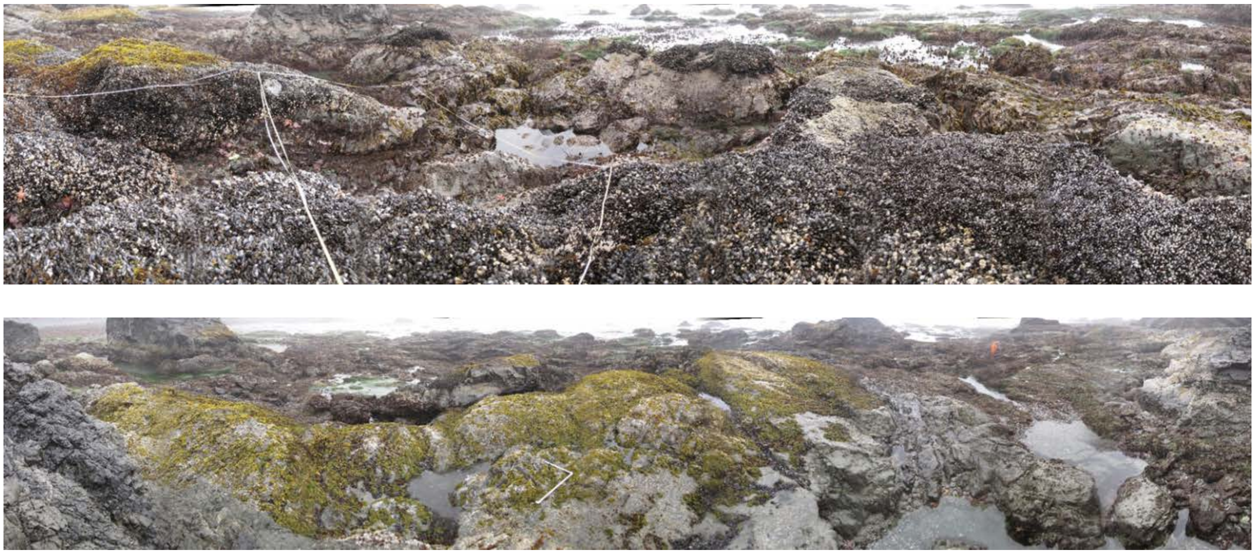


Figure 2a. Panoramic photographs of intertidal sites at Enderts Beach within Redwood National and State Parks.

Figure 2b. Panoramic photographs of intertidal sites at Damnation Creek within Redwood National and State Parks.

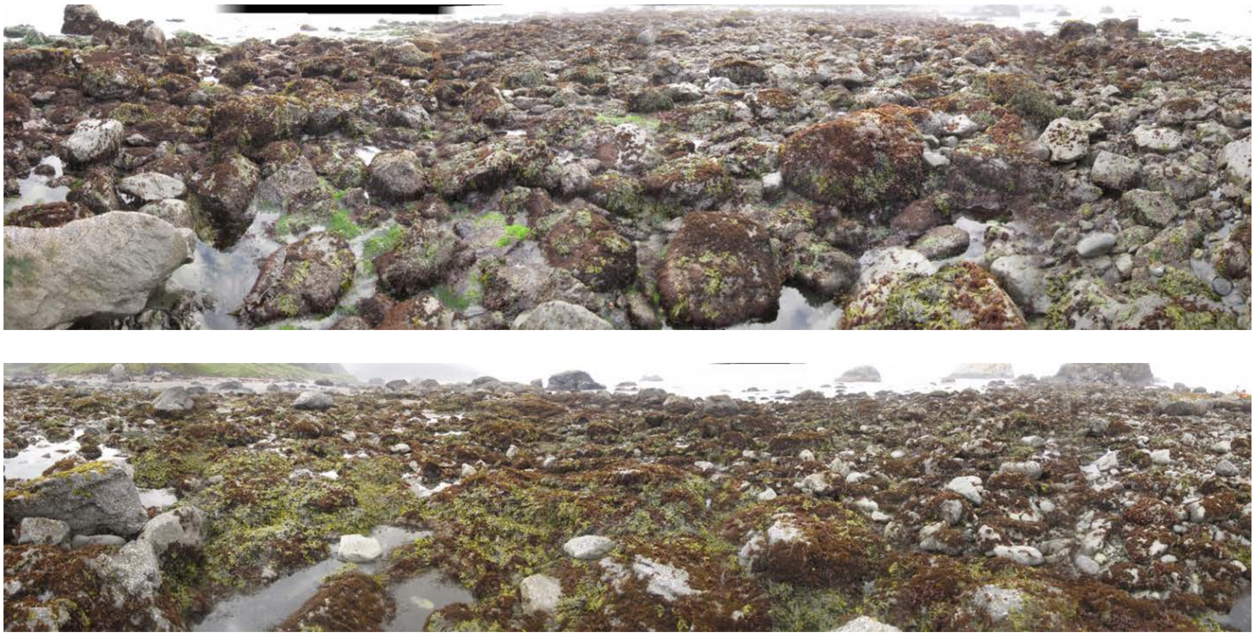


Figure 2c. Panoramic photographs of intertidal sites at False Klamath Creek within Redwood National and State Parks.

Methods

Long-Term Monitoring Sample Design

The methods used for monitoring algal and invertebrate species in RNSP are based on the protocols developed by MARINe (www.marine.gov), and are explained in detail in the Klamath Network rocky intertidal monitoring protocol (Ammann and Raimondi 2008). In brief, the abundance of ecologically important organisms are measured in discrete, fixed plots that have been established in targeted assemblages. This methodology allows the dynamics of these species to be monitored with reasonable sampling effort, and maximizes the statistical power to detect changes in their abundance over time. Fixed plots were placed where target species were abundant to minimize variation among plots and maximize ability to detect impacts of acute stressor events. Due to their nonrandom placement, no inference can be made to the larger site dynamics. Replicate plots can be collated for an averages and variance estimation, and resulting inferences may be made only to the area covered by the collective plots (1.875 m^2). Smaller (50 x 75cm) fixed plots are used to monitor algae and both sessile and small mobile invertebrates, while larger plots and transects are used to monitor larger mobile species and surfgrass. These plots are sampled twice each year, in late spring/early summer (May) and late fall/early winter (December).

Field Log

Field logs were kept to provide a record of general observations made during the surveys at the monitoring sites. Included were notes on weather conditions (temperature, wind, and levels of rain), physical conditions of the site (tidal information, sand scour, trash, plant wrack, dead animals and trash), who participated in the survey, changes to or deviations from the protocols, and any unique or unusual occurrences. Counts of birds, marine mammals, and humans observed at the site were included, as were the site-wide abundance of a set list of intertidal species, including some not targeted in the permanent plots. The same list was used at all MARINe sites from San Diego to Washington which permits coast-wide comparisons to be made. Note: the categories used for these site-wide abundances are currently being reviewed and revised by MARINe to reflect current needs. Therefore, from 2010-2013 only the presence/absence of these species was recorded.

Photoplots

At each site, small permanent photoplots (50 x 75cm in size) were established to monitor changes in abundance (% cover) of conspicuous, abundant, and ecologically important species. These species included mussels (*Mytilus californianu*s), barnacles (*Chthamalus dalli/Balanus glandula*), and three species of algae (turfweed [*Endocladia muricata*], dwarf rockweed [*Pelvetiopsis limitata*], and rockweed [*Fucus gardneri*]) (Figure 3). The natural histories of target organisms are presented in Appendix B. Initial selection of target species are based on abundance at a site. Protocols require that photoplots be established with sufficient (>75%) cover of each of the target species (Engle 2008). The corners of each photoplot were marked by bolts drilled into the rock, and five replicate photoplots were established for each target species at each site. No rockweed (*Fucus*) plots were established at Enderts Beach, or dwarf rockweed (*Pelvetiopsis*) plots at Damnation Creek because these species were not common at these sites. At Damnation Creek, five additional mussel plots were established in the outflow of Damnation Creek, where salinity is often much lower than in the other mussel plots (Cox and McGary 2006) (Table 1).

Figure 3. Photographs depicting the five target species sampled in permanent photo plots.

During each survey these photoplots were photographed using a digital camera (minimum resolution of 8 megapixal) mounted on a PVC photo-framer. The abundances (% cover) of all sessile species in the photoplots were determined using a rectangular grid of 100 uniformly spaced points. This grid was superimposed over the plot, and the taxon under each point was identified.

Table 1. Summary of photoplot species monitored at Redwood National and State Parks sites, including number of replicate plots.

	Mussels	**Barnacles**	**Rockweeds/Sessile algae**		
Site	***Mytilus* spp.**	***Chthamalus/ Balanus***	***Pelvetiopsis limitata***	***Endocladia muricata***	***Fucus gardneri***
Enderts Beach	5 plots	5 plots	5 plots	5 plots	—
Damnation Creek	10 plots*	5 plots	—	5 plots	5 plots
False Klamath Cove	5 plots	5 plots	5 plots	5 plots	5 plots

Mobile Invertebrates

The photoplots were also used to measure the abundance (density) of mobile invertebrates. With the exception of burrowing organisms and amphipods, all mobile invertebrates within each photoplot were counted. In addition, for some of the more common species, size information was collected to determine size distributions. For limpets, this was done by counting the individuals by size class (<5mm, 5 to15mm, >15mm). For the black turban snails (*Chlorostoma* (=*Tegula*) *funebralis*) and dog winkles (*Nucella emarginata* and *N. canaliculata*), the size of the first 10 individuals encountered within each photoplot were measured with a caliper to the nearest mm; whorl diameter was measured for the turban snail, spire height for the two dog winkles.

Barnacle Clearings

To monitor the settlement of the barnacles *Balanus glandula* and *Chthamalus dalli* (Figure 4), a small clearing (10 x 10cm) was established near each of the barnacle photoplots at each site. During each summer survey the individuals in these plots were counted with a hand lens, after which the plots were scraped clean. These plots were established at the sites in the summer of 2006, and were first sampled in the summer of 2007.

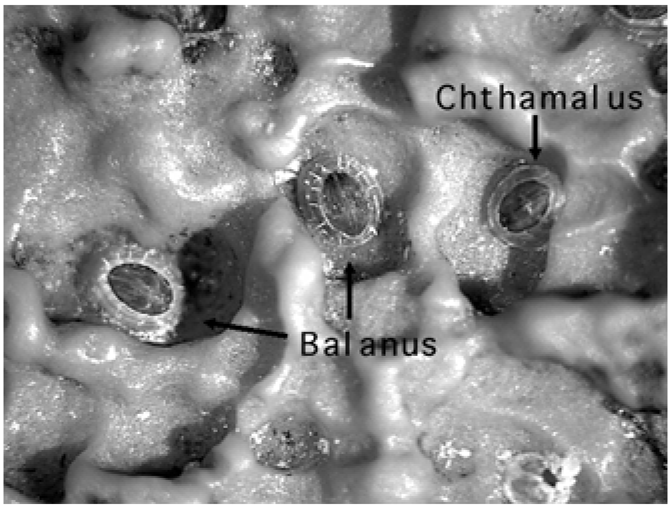


Figure 4. Image (10x) of barnacle recruits (*Balanus glandula* and *Chthamalus dalli*) taken through microscope.

Sea Star Counts and Sizes

Three large, permanent plots were established at Damnation Creek and False Klamath Cove, and two at Enderts Beach, to monitor the size and abundance of the ochre sea star, *Pisaster ochraceus*. All ochre sea stars within each plot were counted, measured, and had their color (purple/orange) noted. Other rarer sea stars, such as the bat star (*Patiria miniata*), giant sea star (*Pisaster giganteus*), sunflower star (*Pycnopodia helianthoides*), six-armed star (*Leptastarias hexactis*), and leather sea star (*Dermasterias imbricate*), were also counted, as were the number of black Katy chitons (*Katharina tunicata*). Note: Because these plots were established in areas where sea stars were particularly abundant, the numbers measured may not accurately reflect the overall density of sea stars at each site.

Starting in fall 2013, additional non-protocol data were collected to monitor the effects of the sea star wasting disease impacting populations of sea stars all along the western coast of North America (Hewson et al. 2014). All individuals within the plots were examined for evidence of disease, and categorized as either healthy (category 0), or diseased (categories 1-4 depending upon the severity of the symptoms). Photographic evidence of the disease was also collected. More information about Sea Star Wasting Disease can be found at http://www.eeb.ucsc.edu/pacificrockyintertidal.

Surfgrass and Postelsia Transects

To measure the abundance (% cover) of surfgrass (*Phyllospadix scouleri/torreyi*), permanent 10-m line transects were established at Damnation Creek, the only site where this was feasible. These transects were sampled every 10 cm by identifying the taxa under the point (for a total of 100 points). The thickness of the surfgrass was measured every meter along the transects.

In summer 2013, two permanent, 6-m line transects were established at False Klamath Cove to measure the abundance of sea palms (*Postelsia palmaeformis).* False Klamath Cove is the only RNSP site where *Postelsia* is present. The number of individual sea palms were counted within 1-m^2 boxes along both sides of each transect. These transects are sampled during summer (May) sampling only.

Mussel Measurement

Starting in 2011, additional non-protocol data were collected for mussel (*Mytilus californianu*s) plots: size and bed thickness/depth. Within each mussel photoplot (50 x 75 cm), a mini-quadrat (20 x 20 cm) was placed in the upper right, upper left, center, lower right and lower left of the photoplot. The length of ten individuals (more if the mussel bed was multilayered) was measured at two designated points on the mini-quads for each of the quad locations. The thickness/depth from five locations (center of each mini-quad) was also recorded. When combined with measures of mussel cover, these measurements can provide estimates of mussel biomass.

Sea Surface Temperature

Sea-surface temperature was measured at each site using small Tidbit temperature data loggers (Onset Computer Corporation). These units were housed within cages attached to the rock below the mussel zone, and were set to record temperatures every 15 minutes. Only those times of the day when the probe was underwater were used to calculate sea-surface temperature.

Biodiversity Survey

In June 2004 a biodiversity survey was conducted at Damnation Creek. Eleven parallel transect lines, spaced 3 m apart, were laid out from the high to low intertidal zones. Along each transect four types of data were collected. 1) **Point Contact Surveys** were used to record the diversity and abundance of algae and sessile invertebrates found at the site. One hundred points per transect were sampled, and host/epibiont and layering characteristics were recorded as appropriate. 2) **Quadrats** (50 x 50cm) were used to measure the diversity and abundance of mobile invertebrates at the site. Three quadrats were sampled per transect, one each in the high, mid, and low intertidal zones. 3) **Swath surveys** were conducted to measure the abundance of sea stars. The location along the transect (to the nearest half meter), and the number and species of all sea stars encountered within a 2m wide band centered over each transect were recorded. 4) **Topographic surveys** were conducted to measure elevations relative to mean sea level (MSL) along each transect. Height measurements were taken at each point with a change in elevation using a rotating lase leveler. These measurements were later converted to tidal elevations (meters above or below MSL) by relating them to fixed points with known elevations. Elevations at these fixed points were established using a Trimble Pathfinder GPS set to obtain a vertical accuracy better than 20cm.

Data Collection and Entry

Although during the first year of sampling the sites were sampled once per season (spring, summer, fall, winter), since then the RNSP intertidal sites have been surveyed twice each year, in late spring/early summer (May) and late fall/winter (December). A survey at a site can be completed by a team of four to six field biologists over the course of one low-tide sequence.

After the completion of each survey, researchers review the data forms for missing or incorrectly recorded data. Once complete, the data from field logs, photoplots, sea star plots, and surfgrass transects were entered into the MARINe Data Management System (MDMS), a system that provides a uniform data information storage and retrieval system for all MARINe institutions. Data for mobile invertebrate counts and sizes were entered into a Microsoft Excel spreadsheet.

Table 2. Sampling locations and 2004-2013 monitoring periods and inventory dates for Redwood National and State Parks rocky intertidal monitoring.

Site	Site Code	Latitude[1]	Longitude[1]	Summer 2004-2013	Fall 2004-2013
False Klamath Cove	FKC	41.59476	124.10643	May/June	Nov/Dec
Damnation Creek	DMN	41.65249	124.12784	May/June	Nov/Dec
Enderts Beach	END	41.69000	124.14257	May/June	Nov/Dec
Damnation Creek	DMN	41.65249	124.12784	**Biodiversity** June 2004	

[1] Site coordinates are Decimal Degree and NAD83 datum, source Bureau of Land Management.

Data Analysis

Temporal variation in the structure of the assemblage of sessile species in the photoplots was examined using non-metric Multi-Dimensional Scaling (MDS). MDS allows for visualization of the level of similarity of plots (Cox and Cox 2001). Comparisons were made using Bray-Curtis similarity indices calculated on non-transformed data. SIMPER analysis was used to identify which species were most responsible for the degree of similarity both within and among photoplot types. Similar analyses were done for the mobile fauna sampled in the photoplots.

The dynamics of the more common of sessile and mobile species identified by the SIMPER analysis were examined in more detail. Specifically, seasonal variations in abundance were looked for by comparing fall and summer samples using paired t-tests or by comparing the sign (+ or -) of the difference between subsequent samples using a non-parametric Runs test (Sprent and Smeeton 2007). Longer term patterns were examined using linear regression. These analyses were also used to examine the temporal dynamics of the ochre sea star (*Pisaster*) and the black Katy chiton (*Katharina*) (monitored in the irregular plots), and surfgrass (monitored along transect lines). Linear regression was used to determine whether variations in sea star abundance could be explained by differences in sea surface temperature (SST) (see Sanford 1999).

Power analysis was used to calculate the Minimum Detectable Difference (MDD) for the focal sessile species in each photoplot; MDD is a metric that estimates the change in abundance that can be statistically measured following a disturbance (Cohen 1988). To calculate MDD requires an estimate of the spatial variation among plots, and three different estimates of this variation were used to calculate MDD. Method 1 first calculated the average abundance across all samples for each photoplot, then calculated the MDD using the variation of these averages. Method 2 used the spatial variation among photoplots measured during the last survey (summer 2013). Method 3 calculated the MDD for each survey and then took the average across all surveys. In each case, a one-tailed paired t-test with $\alpha=\beta=0.2$ was used to test the null hypothesis H_0: d=0, and the alternate H_A: d>0, where d=the mean $Abundance_{before}$ -$Abundance_{after}$ difference.

Results and Interpretation

Raw data used to create this report are available upon request through MARINe or the National Park Service. Please contact the authors with requests. Interactive data are available at http://www.eeb.ucsc.edu/pacificrockyintertidal/target/index.html.

Field Log

Species List and Physical Conditions

The general observations made for each survey are presented in Appendix C-1. Although the site-wide estimates of abundances for the set list of species used at all MARINe sites are available, these have been condensed to presence/absence in Table 3. Recruitment levels, when observed, were also averaged over sample periods. Levels of damage, bleaching, and flowering are also available for algal species.

Table 3. Presence and average recruitment levels of core and optional species at Enderts Beach (E), Damnation Creek (D) and False Klamath Cove (F) during the 2004-2013 surveys. ✓=observed at site during study period. Recruitment levels: L=low, M=medium, H=high.

		Abundance			Recruitment		
Core Species	**Common Names**	**E**	**D**	**F**	**E**	**D**	**F**
Red Algae							
Caulacanthus ustulatus	—	0	0	0			
Endocladia muricata	turfweed	✓	✓	✓	L		
Mastocarpus papillatus	Turkish washcloth	✓	✓	✓	L	L	L
Mazzaella spp. (=*Iridaea* spp.)	iridescent weed	✓	✓	✓			
Neorhodomela larix	blackpine	✓	✓	✓			
Odonthalia spp. (optional)	tooth branch	✓	✓	✓			
Porphyra spp.	nori	✓	✓	✓			
Green Algae							
Ulva/Enteromorpha	sea lettuce	✓	✓	✓			
Brown Algae							
Egregia menziesii	feather boa kelp	✓	✓	✓			
Petalonia spp.	sea petals	0	0	✓			
Fucus gardneri	rockweed	✓	✓	✓	L	L	L
Halidrys dioica/Cystoseira spp.	bladder chain kelp	0	0	0			
Hesperophycus californicus	western alga	0	0	0			
Pelvetiopsis limitata	dwarf rockweed	✓	✓	✓	L	L	L

Table 3 (continued). Presence and average recruitment levels of core and optional species at Enderts Beach (E), Damnation Creek (D) and False Klamath Cove (F) during the 2004-2013 surveys. ✓=observed at site during study period. Recruitment levels: L=low, M=medium, H=high.

		Abundance			Recruitment		
Core Species	**Common Names**	**E**	**D**	**F**	**E**	**D**	**F**
Brown Algae (continued)							
Postelsia palmaeformis	sea palm	0	✓	✓			
Sargassum muticum	wireweed	0	0	0			
Scytosiphon spp.	leather tube	✓	0	✓			
Silvetia compressa	slender rockweed	0	0	0			
Surfgrass							
Phyllospadix scouleri/torreyi	surfgrass	✓	✓	✓			
Gastropods							
Acanthinucella spp.	unicorn snail	0	0	0			
Haliotis cracherodii	black abalone	0	0	0			
Katharina tunicata	black Katy chiton	✓	✓	✓			
Littorina spp.	periwinkle snail	✓	✓	✓	L	L	M
Lottia gigantea	owl limpet	0	0	0			
Nucella canaliculata	channeled dog winkle	✓	0	✓			
Nucella emarginata/ostrina	striped dog winkle	✓	✓	✓	L	L	L
Ocenebra circumtexta	circled rocksnail	0	0	0			
Chlorostoma (=*Tegula*) *funebralis*	black turban snail	✓	✓	✓			
Bivalves							
Mytilus californianus	California mussel	✓	✓	✓	L	L	L
Crustaceans							
Balanus glandula	acorn barnacle	✓	✓	✓	H	H	M
Chthamalus dalli/fissus	small acorn barnacle	✓	✓	✓	L	M	L
Idotea spp. (optional)	isopod						
Hemigrapsus nudus	purple shore crab	✓	✓	✓			
Pachygrapsus crassipes	lined shore crab	✓	✓	✓		L	L
Pollicipes polymerus	gooseneck barnacle	✓	✓	✓	L		
Semibalanus cariosus	thatched barnacle	✓	✓	✓			H

Table 3 (continued). Presence and average recruitment levels of core and optional species at Enderts Beach (E), Damnation Creek (D) and False Klamath Cove (F) during the 2004-2013 surveys. ✓=observed at site during study period. Recruitment levels: L=low, M=medium, H=high.

		Abundance			Recruitment		
Core Species	**Common Names**	**E**	**D**	**F**	**E**	**D**	**F**
Brown Algae (continued)							
Tetraclita rubescens	red thatched barnacle	0	0	0			
Anemones							
Anthopleura elegantissima/sola	sea anemone	✓	✓	✓			
Anthopleura xanthogrammica	giant green anemone	✓	✓	✓			
Echinoderms							
Pisaster ochraceus	ochre sea star	✓	✓	✓	L	L	
Patiria miniata	bat star	0	0	✓			
Strongylocentrotus purpuratus	purple urchin	✓	✓	✓			
Polycheate worms							
Phragmatopoma californica	sand castle worm	✓	✓	✓			
Total		**29**	**28**	**32**			

Shorebirds and Mammals

Summaries of the common shorebirds and mammals observed during the RNSP surveys are presented in Table 4 and Table 5, respectively. These data represent the greatest number of each species observed at any one time on or near the sampled reef. They are not intended as census data, but rather as field observations. Table 4 summarizes the common list of birds that all rocky intertidal MARINe monitoring groups recorded along the California and Oregon coast. Table 6 lists the additional bird species either noted on the reef or flying over the sampling sites at one or more occasions during the 2006-2013 monitoring surveys.

Table 4. Common shorebirds observed at Redwood National and State Parks monitoring sites during intertidal sampling trips in 2006-2013 (maximum seen at any one time).

		Cormorant	Gull	Oyster-catcher	Pelican	Blue Heron	
Site ID	**Season**	***Phalacrocorax* spp.**	***Larus* spp.**	***Haematopus bachmani***	***Pelicanus occidentalis***	***Ardea herodias***	**Small Shorebirds**
END	SU06	–	–	3	–	–	–
END	FA06	1	–	3	–	–	–
DMN	SU06	1	4	3	–	–	–

Table 4 (continued). Common shorebirds observed at Redwood National and State Parks monitoring sites during intertidal sampling trips in 2006-2013 (maximum seen at any one time).

		Cormorant	**Gull**	**Oyster-catcher**	**Pelican**	**Blue Heron**	
Site ID	**Season**	***Phalacrocorax* spp.**	***Larus* spp.**	***Haematopus bachmani***	***Pelicanus occidentalis***	***Ardea herodias***	**Small Shorebirds**
DMN	FA06	–	–	12	–	–	–
FKC	SU06	4	–	5	–	1	–
FKC	FA06	–	4	2	–	–	–
END	SU07	2	3	2	25	–	–
END	FA07	2	6	–	–	–	–
DMN	SU07	–	–	5	–	–	–
DMN	FA07	–	3	–	1	–	2
FKC	SU07	–	1	3	–	–	–
FKC	FA07	–	1	2	–	–	1
END	SU08	1	5	2	4	–	–
END	FA08	–	3	6	3	–	–
DMN	SU08	10	4	2	10	–	–
DMN	FA08	–	4	2	–	–	–
END	SU09	–		4	40	–	–
END	FA09	–	1	2	–	–	–
DMN	SU09	2	1	4	–	–	–
DMN	FA09	1	1	12	2	–	15
FKC	SU09	–	2	3	–	–	–
FKC	FA09	–	3	4	–	–	–
END	SU10	2		3	12	–	–
END	FA10	–	3	2	–	–	–
DMN	SU10	–	2	2	–	–	–
DMN	FA10	2	–	–	–	–	–
FKC	SU10	–	2	2	–	–	–
FKC	FA10	3	8	2	1	–	–
END	SU11	–	1	–	–	–	–
END	FA11	–	1	2	–	–	–

Table 4 (continued). Common shorebirds observed at Redwood National and State Parks monitoring sites during intertidal sampling trips in 2006-2013 (maximum seen at any one time).

		Cormorant	Gull	Oyster-catcher	Pelican	Blue Heron	
Site ID	**Season**	***Phalacrocorax* spp.**	***Larus* spp.**	***Haematopus bachmani***	***Pelicanus occidentalis***	***Ardea herodias***	**Small Shorebirds**
DMN	SU11	9	3	3	–	–	–
DMN	FA11	2	3	3	–	–	–
FKC	SU11	11	–	4	–	–	–
FKC	FA11	–	4	2	2	2	15
END	SU12	–	1	1	–	–	–
END	FA12	–	15	2	–	–	–
DMN	SU12	–	1	4	–	–	–
DMN	FA12	3	6	–	–	–	–
FKC	SU12	–	4	4	–	–	–
FKC	FA12	–	–	4	–	–	10
END	SU13	–	5	1	–	–	–
END	FA13	–	–	–	–	–	–
DMN	SU13	–	–	2	–	–	–
DMN	FA13	–	–	–	–	–	–
FKC	SU13	16	3	4	–	1	1
FKC	FA13	–	–	–	–	–	–

Table 5. Mammals observed at Redwood National and State Parks monitoring sites during intertidal sampling trips in 2006-2013 (maximum seen at any one time). The numbers of humans noted are not intended to be visitation data.

		Harbor Seal	California Sea Lion	River Otter		
Site ID	**Season**	***Phoca vitulina***	***Zalophus californianus***	***Lontra canadensis***	**Humans on reef**	**Humans on sand**
END	SU06	–	–	–	–	–
END	FA06	–	–	–	–	–
DMN	SU06	–	–	1	–	–
DMN	FA06	–	–	–	–	–
FKC	SU06	–	2	–	–	–

Table 5 (continued). Mammals observed at Redwood National and State Parks monitoring sites during intertidal sampling trips in 2006-2013 (maximum seen at any one time). The numbers of humans noted are not intended to be visitation data.

		Harbor Seal	California Sea Lion	River Otter		
Site ID	**Season**	***Phoca vitulina***	***Zalophus californianus***	***Lontra canadensis***	**Humans on reef**	**Humans on sand**
FKC	FA06	–	–	–	–	–
END	SU07	–	–	1	–	–
END	FA07	–	–	–	–	–
DMN	SU07	–	–	–	–	–
DMN	FA07	–	–	1	–	–
FKC	SU07	–	–	1	–	–
FKC	FA07	–	–	–	–	–
END	SU08	–	–	–	–	–
END	FA08	–	–	–	–	–
DMN	SU08	–	–	–	–	–
DMN	FA08	–	–	–	–	–
FKC	SU08	–	–	1	–	–
FKC	FA08	–	–	2	–	–
END	SU09	–	–	–	–	–
END	FA09	–	–	–	–	–
DMN	SU09	–	–	1	–	–
DMN	FA09	–	–	–	–	–
FKC	SU09	–	–	–	–	–
FKC	FA09	–	–	–	–	–
END	SU10	1	–	–	–	–
END	FA10	–	–	1	–	–
DMN	SU10	–	–	1	–	–
DMN	FA10	–	–	–	–	–
FKC	SU10	–	–	1	–	–
FKC	FA10	–	1	1	–	–
END	SU11	–	–	–	3	–
END	FA11	–	–	3	–	–

Table 5 (continued). Mammals observed at Redwood National and State Parks monitoring sites during intertidal sampling trips in 2006-2013 (maximum seen at any one time). The numbers of humans noted are not intended to be visitation data.

		Harbor Seal	California Sea Lion	River Otter		
Site ID	**Season**	***Phoca vitulina***	***Zalophus californianus***	***Lontra canadensis***	**Humans on reef**	**Humans on sand**
DMN	SU11	–	–	–	–	2
DMN	FA11	–	–	2	2	–
FKC	SU11	–	–	1	1	–
FKC	FA11	–	–	–	–	–
END	SU12	–	–	–	–	–
END	FA12	–	–	–	–	–
DMN	SU12	–	–	–	–	–
DMN	FA12	–	–	1	–	–
FKC	SU12	–	–	–	–	–
FKC	FA12	–	–	–	–	–
END	SU13	–	–	–	–	–
END	FA13	–	–	–	–	–
DMN	SU13	–	–	2	–	–
DMN	FA13	–	–	–	–	–
FKC	SU13	–	–	–	–	–
FKC	FA13	–	–	–	–	–
Totals	–	1	3	21	6	2

Table 6. List of additional bird species observed at least one time at Redwood National and State Parks intertidal sites during 2006-2013 sampling.

Common Name	**Latin Name**
American Goldfinch	*Carduelis tristis*
American Robin	*Turdus migratorius*
Bald Eagle	*Haliaeetus leucocephalus*
Barn Swallow	*Hirundo rustica*
Black Phoebe	*Sayornis nigricans*
Black Turnstone	*Arenaria melanocephala*

Table 6 (continued). List of additional bird species observed at least one time at Redwood National and State Parks intertidal sites during 2006-2013 sampling.

Common Name	Latin Name
Brandt's Cormorant	*Phalacrocorax penicillatus*
Common Murre	*Uria aalge*
Double Crested Cormorant	*Phalacrocorax auritus*
Glaucus Gull	*Larus hyperboreus*
Kingfisher	*Megaceryle alcyon*
Orange-crowned Warbler	*Vermivora celata*
Osprey	*Pandion haliaetus*
Peregrine Falcon	*Falco peregrinus*
Pigeon Guillemot	*Cepphus columba*
Raven	*Corvus corax*
Red-throated Loon	*Gavia stellata*
Song Sparrow	*Melospiza melodia*
Steller's Jay	*Cyanocitta stelleri*
Swainson's Thrush	*Catharus ustulatus*
Surfbird	*Aphriza virgata*
Tree Swallow	*Tachycineta bicolor*
Turkey Vulture	*Cathartes aura*
Varied Thrush	*Ixoreus naevius*
Vaux’s Swift	*Chaetura vauxi*
Violet Green Swallow	*Tachycineta thalassina*
Western Grebe	*Aechmophorus occidentalis*
White-crowned Sparrow	*Zonotrichia leucophrys*
Willet	*Tringa semipalmata*
Wilson's Warbler	*Wilsonia pusilla*
Winter Wren	*Troglodytes troglodytes*
Wrentit	*Chamaea fasciata*

Sea Surface Temperature

Between 2006-2014 mean sea surface temperatures ranged from lows of around 9º C during the winter to highs of nearly 15º C during the summer (Figure 5). Except for a period in 2007, there appeared to be little difference in temperature measured at the three RNSP sites. A grand mean was calculated of monthly temperatures recorded at all three sites across the 2006-14 study period. Comparing the average temperature of a given month to the overall grand mean that month revealed that the period of late 2007 to mid-2009 was generally colder than normal, while the early part of 2010 and the later parts of 2012 and 2013 were generally warmer than normal (Figure 5).

Photoplots

The total number of algal and sessile invertebrate taxa found in the photoplots at the three sites ranged from 29 to 35 (Table 7). Results of MDS analysis confirmed our expectation that species assemblages in each type of photoplot were distinct from one another (e.g., species assemblages in barnacle plots differed from rockweed plots) (Figure 6); there were no visible changes in species composition over time. Perhaps not surprisingly, the results of the SIMPER analysis suggest that these two patterns appear to be driven primarily by the abundance of the focal species in each of the photoplot types (Table 7). The one exception appeared to be the barnacle and turfweed plots at Damnation Creek, whose assemblages appeared less distinct primarily because of the amount of open space (e.g. rock) in these plots at that site (Table 7).

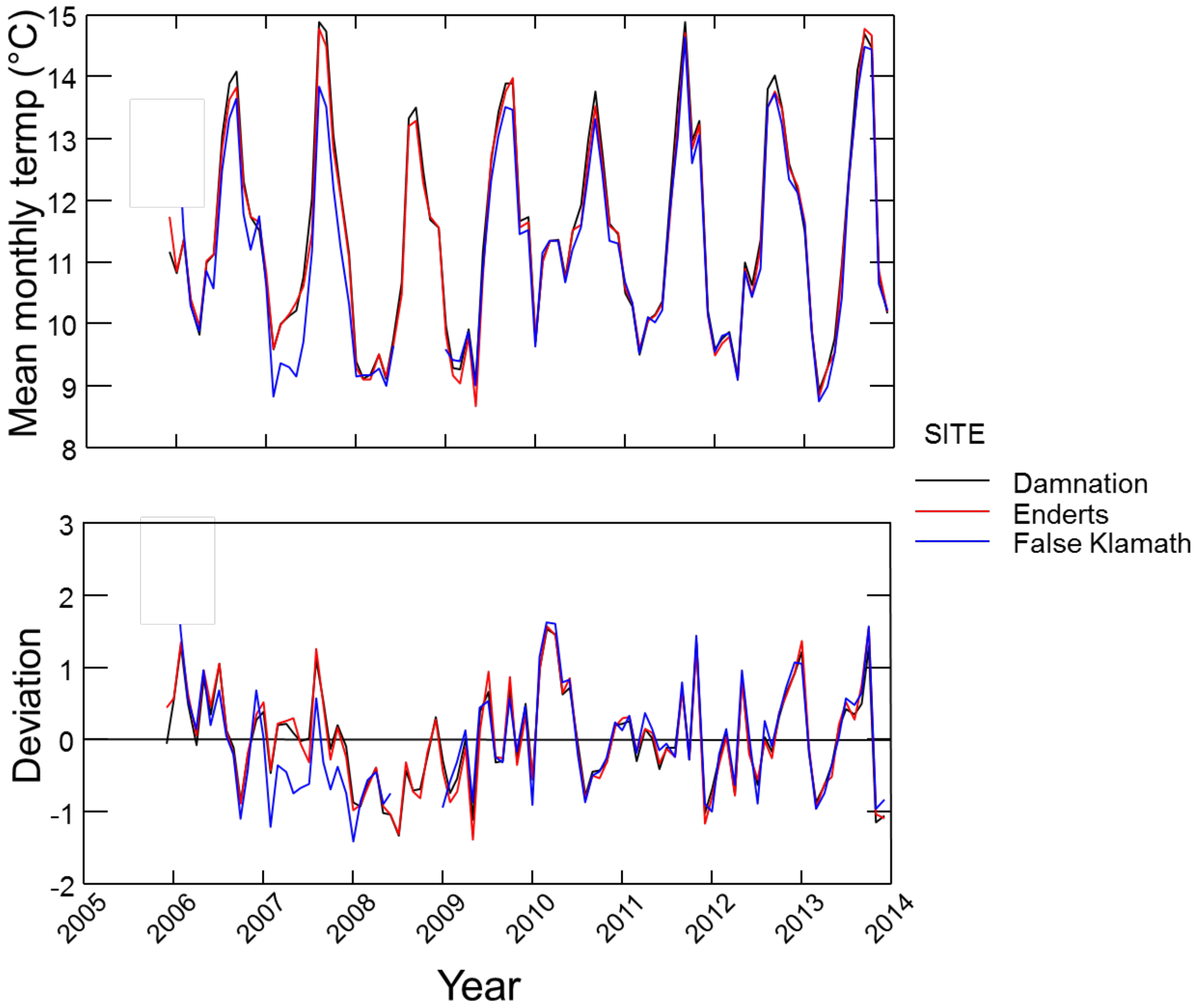


Figure 5. Sea-surface temperatures from three Redwood National and State Parks sites from 2006-2014 (top) and the deviation of the monthly mean from the overall grand monthly mean for temperature at each site from 2006-2014 (bottom). Data collected with Onset brand temperature loggers.

Table 7. Presence of sessile species in photoplots at Enderts Beach (E), Damnation Creek (D) and False Klamath Cove (F) during the 2004-2013 surveys. ✓ =observed at site during study period.

		Present		
Species	**Common Names**	**E**	**D**	**F**
Red Algae				
articulated corallines	articulated corallines	✓	✓	✓
Callithamnion spp.	beauty bush	✓	0	✓
Ceramium spp.		✓	✓	✓
crustose corallines	coralline crusts	✓	✓	✓
Cryptosiphonia woodii	bleached brunette	✓	✓	✓

Table 7 (continued). Presence of sessile species in photoplots at Enderts Beach (E), Damnation Creek (D) and False Klamath Cove (F) during the 2004-2013 surveys. ✓ =observed at site during study period.

		Present		
Species	**Common Names**	**E**	**D**	**F**
Red Algae (continued)				
Endocladia muricata	turfweed	✓	✓	✓
Gelidium spp.		0	✓	✓
Gloiopeltis furcata	jelly moss	✓	✓	✓
Mastocarpus spp.	Turkish washcloth	✓	✓	✓
Mazzaella affinis		✓	0	✓
Mazzaella parksii	horn-of-plenty	✓	0	✓
Mazzaella spp. *(=Iridaea* spp.*)*	iridescent weed	✓	✓	✓
Microcladia borealis	coarse sea lace	✓	✓	✓
Neorhodomela larix	blackpine	✓	✓	✓
Neorhodomela oregona	Oregon pine	0	✓	✓
Odonthalia spp.	tooth branch	✓	✓	✓
Petrocelis	tar spot algae	0	✓	✓
Plocamium violaceum		✓	0	0
Polysiphonia spp.		✓	0	✓
Porphyra spp.	nori	✓	✓	✓
Pterosiphonia spp.		✓	0	✓
Green Algae				
Chaetomorpha spp.	curly sea hair	✓	0	0
Cladophora columbiana	green tuft	✓	✓	✓
Ulva spp./*Enteromorpha* spp.	sea lettuce	✓	✓	✓
Brown Algae				
Analipus japonicus	sea fir	✓	✓	0
Colpomenia peregrina	bulb seaweed	✓	0	0
Egregia menziesii	feather boa kelp	✓	0	0
Endarachne binghamiae / Petalonia fascia	sea petals	0	✓	✓
Fucus gardneri	rockweed	✓	✓	✓
Pelvetiopsis limitata	dwarf rockweed	✓	✓	✓

Table 7 (continued). Presence of sessile species in photoplots at Enderts Beach (E), Damnation Creek (D) and False Klamath Cove (F) during the 2004-2013 surveys. ✓ =observed at site during study period.

		Present		
Species	**Common Names**	**E**	**D**	**F**
Brown Algae (continued)				
Ralfsia spp		0	✓	0
Scytosiphon spp.	leather tube	✓	0	✓
Bivalves				
Mytilus californianus	California mussel	✓	✓	✓
Mytilus trossulus/galloprovincialis	blue mussel	✓	0	0
Crustaceans				
Balanus glandula	acorn barnacle	✓	✓	✓
Chthamalus dalli/fissus	small acorn barnacle	✓	✓	✓
Pollicipes polymerus	gooseneck barnacle	✓	✓	✓
Semibalanus cariosus	thatched barnacle	✓	✓	✓
Anemones				
Anthopleura elegantissima/sola	sea anemone	✓	✓	✓
Polycheate worms				
Phragmatopoma californica	sand castle worm	✓	✓	✓
Total		**35**	**29**	**33**

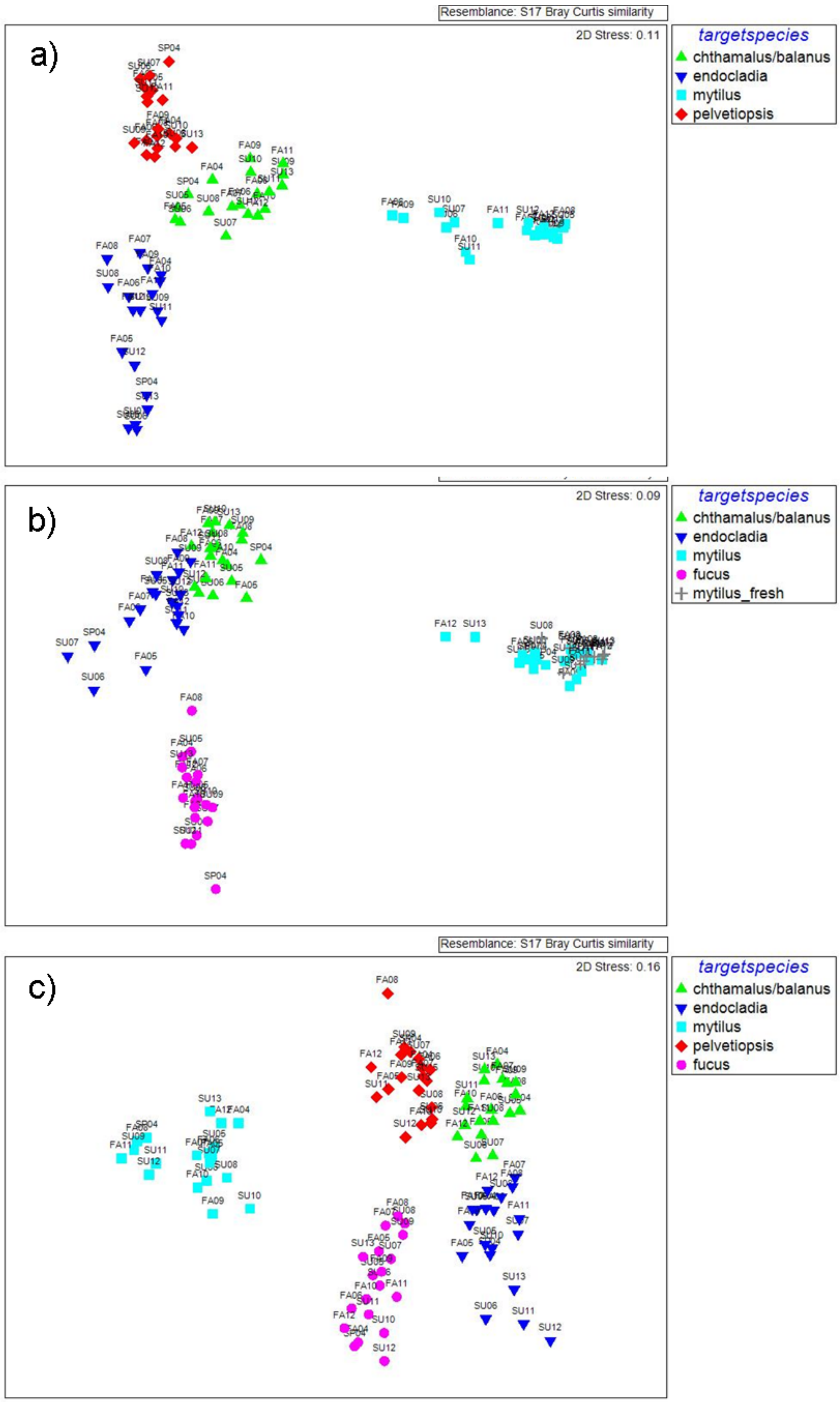


Figure 6. Multi-dimensional scaling (MDS) plots showing the similarity of sessile photoplots for a) Enderts Beach, b) Damnation Creek, and c) False Klamath Creek during surveys conducted from 2006-2013.

Although the assemblages within the photoplot types remained fairly distinct over time, the relative abundance of the taxa within them did vary temporally. The temporal trends of the most abundant taxa within each photoplot type are presented in the following sections. Photographic examples of some of these changes are presented in Figure 7 a-d.

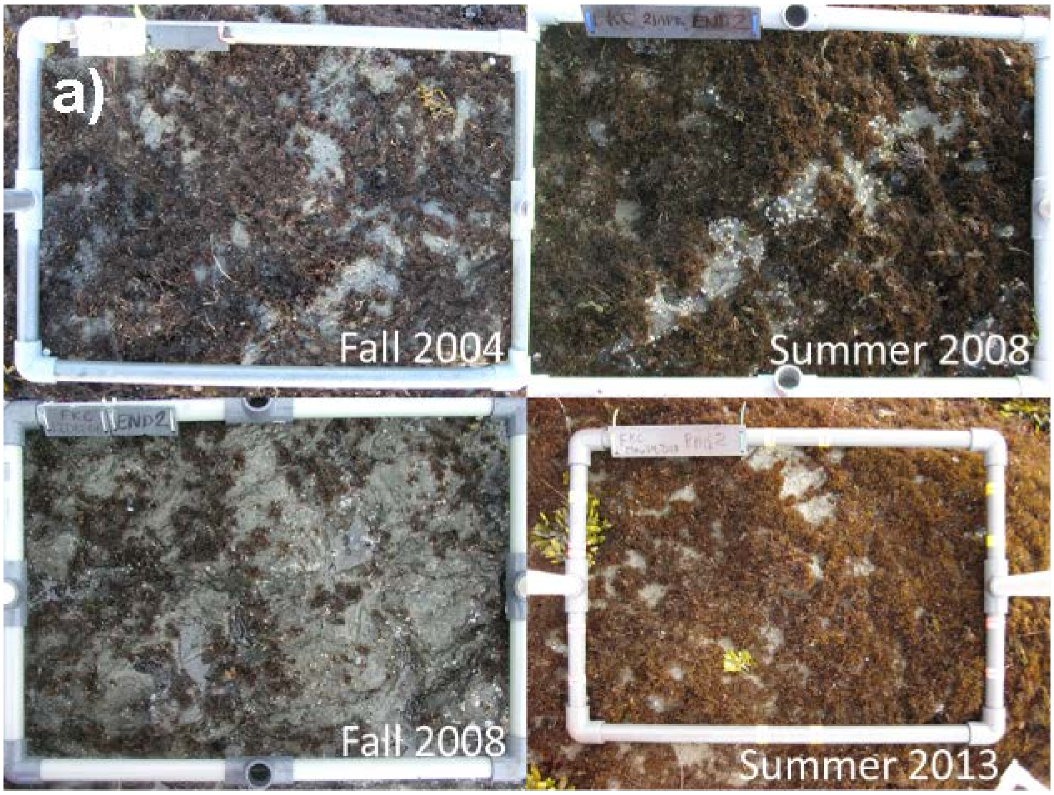


Figure 7a. Examples of photoplots from various surveys within Redwood National and State Parks intertidal sites. a) Turfweed (*Endocladia muricata*) plot 2 at False Klamath Cove.

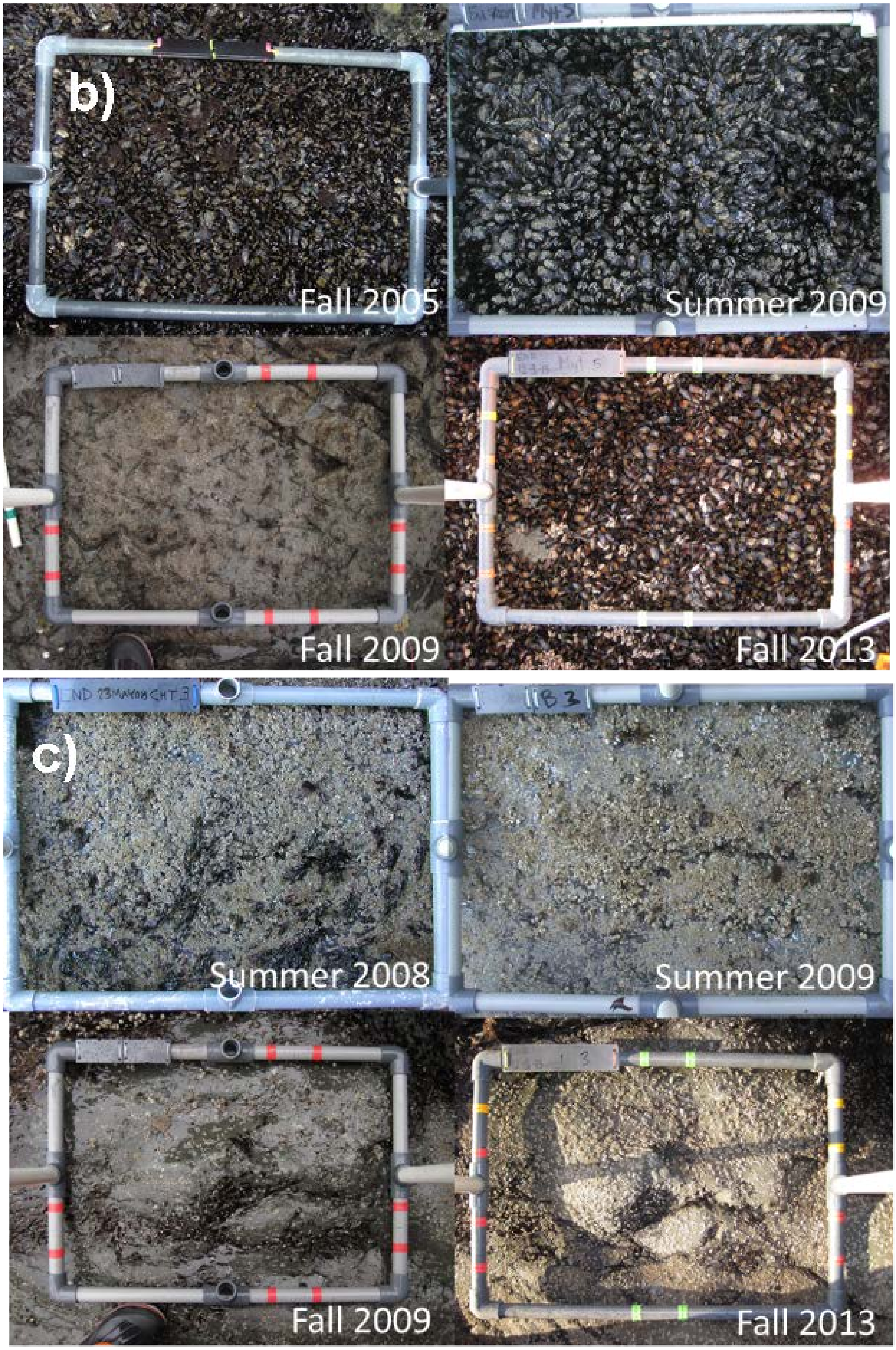


Figure 7b-c. Examples of photoplots from various surveys within Redwood National and State Parks intertidal sites. b) Mussel (*Mytilus californianus*) plot 5 at Enderts Beach, c) Acorn Barnacle (*Chthamalus* spp.) plot 3 at Enderts Beach.

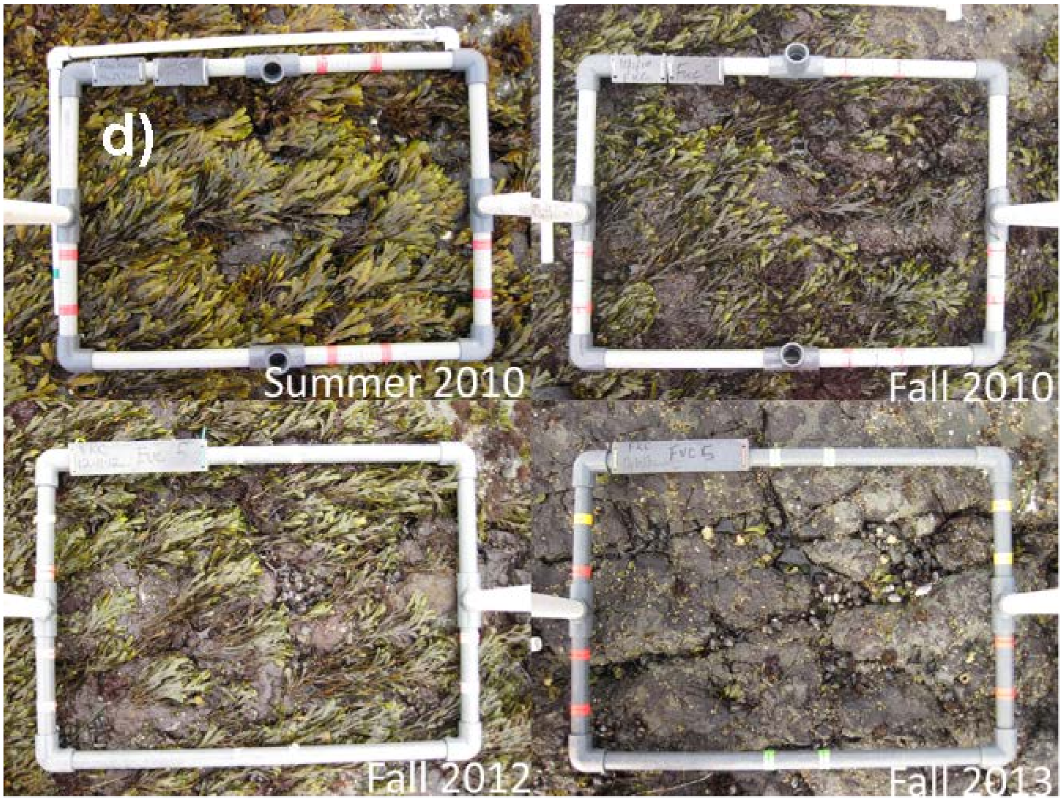


Figure 7d. Examples of photoplots from various surveys within Redwood National and State Parks intertidal sites. d) Rockweed (*Fucus gardneri*) plot 5 at False Klamath Cove.

Barnacle (Chthamalus dalli and Balanus glandula) photoplots

Over the course of the study, the abundance of the barnacles *Chthamalus dalli* and *Balanus glandula*, which were the most common taxa in the barnacle photoplots, varied between 10 and 70% at Enderts and Damnation Creek, and between 30 and 90% at False Klamath Cove (Figure 8). With a few exceptions, reductions in barnacle cover appeared to result in more open space, while increases in barnacle cover appeared to reduce the amount of open space. Thus, the dynamics of these barnacle populations do not appear to be driven by any of the other sessile species in these photoplots (Table 8). There was no significant linear or seasonal trend in barnacle abundance over the study period.

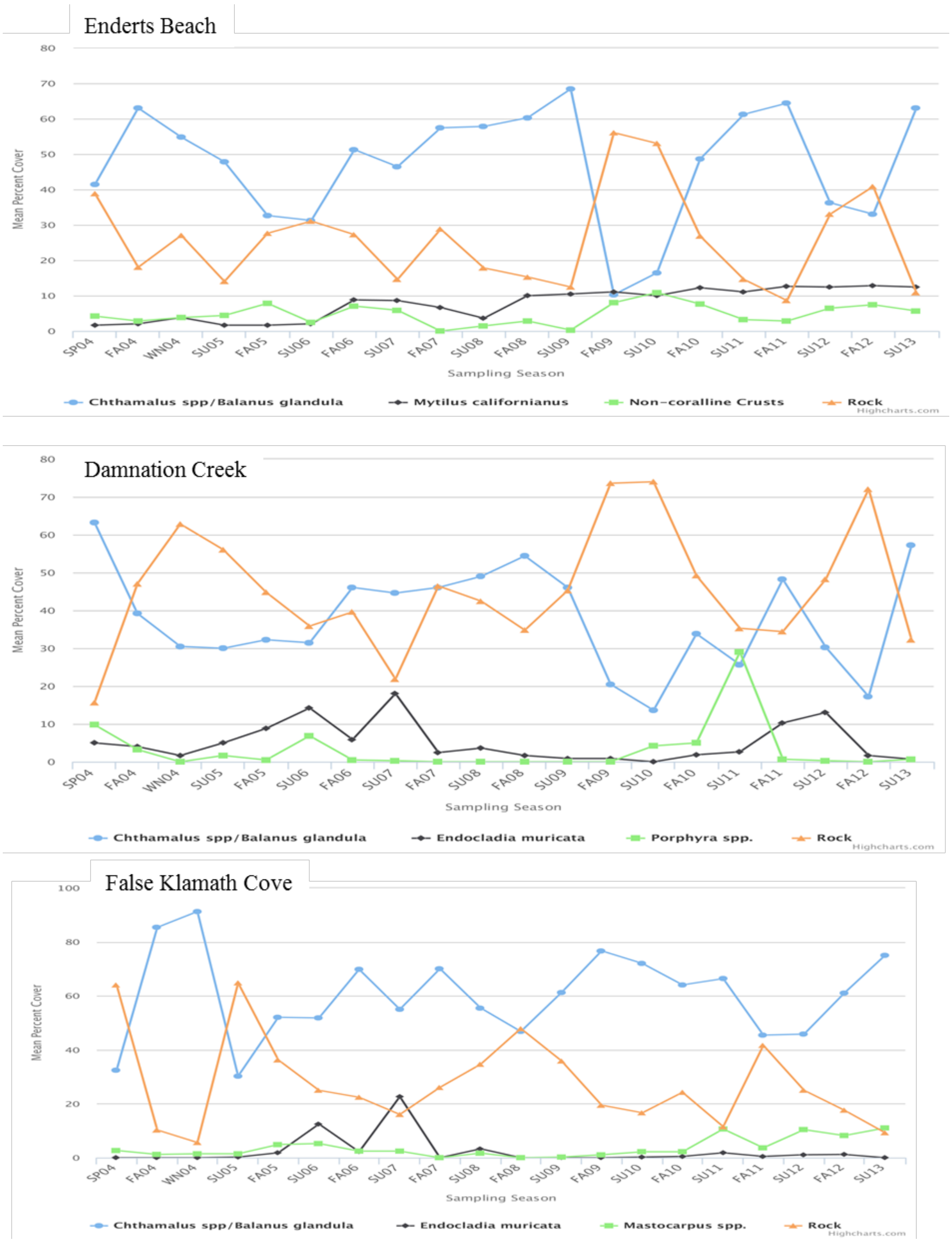


Figure 8. Mean percent cover of taxa in the barnacle (*Balanus*/*Chthamalus*) photoplots. Note that the same color line may represent different taxa in the three plots. Also note the different scales on the y axes.

Table 8. Results of SIMPER analysis showing the contribution of species and substrate to the similarity of sessile photoplots.

Photoplot	Species	Avg. similarity	*Chthamalus/ Balanus*	*Endocladia muricata*	*Fucus gardneri*	*Mastocarpus papillatus*	*Mazzaella parksii*	*Mytilus californianus*	Non-coralline crust	*Pelvetiopsis limitata*	*Porphyra* spp.	Rock
Enderts	**Contribution to similarity (%)**											
	Chthamalus/Balanus	69.8	52.6	1.7	–	1.6	–	7.8	4.4	3.5	0.6	25.7
	Endocladia	64.9	6.6	66.3	–	3.5	–	–	3.1	–	–	16.8
	Mytilus	85.7	1.0	–	–	–	–	97.0	–	–	–	0.8
	Pelvetiopsis	80	8.9	0.9	–	1.9	6.4	1.2	4.3	57.1	–	18.8
	Rank contribution											
	Chthamalus/Balanus	–	1	6	–	7	–	3	4	5	8	2
	Endocladia	–	3	1	–	4	–	–	5	–	–	2
	Mytilus	–	2	–	–	–	–	1	–	–	–	3
	Pelvetiopsis	–	3	8	–	6	4	7	5	1	–	2
Damnation Creek	**Contribution to similarity (%)**											
	Chthamalus/Balanus	71.9	39.8	3.4	–	0.8	–	1.3	0.9	–	0.8	49.7
	Endocladia	57.8	3.4	41.5	1.5	–	–	–	3.3	–	1.2	45.1
	Fucus	87.4	–	4.2	86.9	0.6	–	–	1.8	–	–	5.6
	Mytilus (plot 1-5)	94.5	–	–	–	–	–	99.1	–	–	–	–
	Mytilus (plot 6-10)	96.5	–	–	–	–	–	99.3	–	–	–	–

Table 8 (continued). Results of SIMPER analysis showing the contribution of species and substrate to the similarity of sessile photoplots.

Photoplot	Species	Avg. similarity	*Chthamalus/ Balanus*	*Endocladia muricata*	*Fucus gardneri*	*Mastocarpus papillatus*	*Mazzaella parksii*	*Mytilus californianus*	Non-coralline crust	*Pelvetiopsis limitata*	*Porphyra* spp.	Rock
Damnation Creek (continued)						**Rank contribution**						
	Chthamalus/Balanus	–	2	3	–	7	–	4	5	–	6	1
	Endocladia	–	3	2	5	–	–	–	4	–	6	1
	Fucus	–	–	3	1	5	–	–	4	–	–	2
	Mytilus (plot 1-5)	–	–	–	–	–	–	1	–	–	–	–
	Mytilus (plot 6-10)	–	–	–	–	–	–	1	–	–	–	–
False Klamath Cove						**Contribution to similarity (%)**						
	Chthamalus/Balanus	73.6	66.5	–	–	2.4	–	–	1.2	1.1	–	26.8
	Endocladia	73.5	2.4	73.2	3.2	1.3	–	–	–	–	–	18.0
	Fucus	79.6	1.1	2.5	77.0	3.8	–	0.6	9.8	–	–	4.5
	Mytilus	91.2	0.6	–	0.7	–	–	94.7		–	–	3.0
	Pelvetiopsis	82.8	11.0	0.9	0.6	0.4	–	0.7	4.2	73.0	–	8.3
						Rank contribution						
	Chthamalus/Balanus	–	1	1	–	3	–	–	4	5	–	2
	Endocladia	–	4	–	3	5	–	–	–	–	–	2
	Fucus	–	6	5	1	4	–	7	2	–	–	3
	Mytilus	–	4		3		–	1		–	–	2
	Pelvetiopsis	–	2	5	7	8	–	6	4	1	–	3

Turfweed (Endocladia muricata) photoplots

During the first three to four years of the study, the most abundant taxon in the turfweed plots was *Endocladia* (Figure 9). However, starting in late 2007 at Enderts and Damnation Creek, and 2008 at False Klamath Cove, turfweed cover dropped dramatically, falling below 20% at all three sites. The plots at Enderts and False Klamath Cove had mostly recovered by the end of 2009, but the plots at Damnation Creek had not yet recovered by 2013. Consequently, the only site to show a decline over the course of the study was Damnation Creek ($r= -0.73$, $df=17$, $p<0.001$). When turfweed cover dropped, the plots became dominated by mostly open space and the opportunistic alga *Porphyra* (Figure 9). It is worth noting that the timing of the decline seems to correspond to the period of colder than normal sea surface temperatures previously discussed (Figure 5). The extent to which changing oceanographic conditions drives the dynamics of this species deserves further consideration. Also interesting is that *Endocladia* cover was usually lower in the fall than during the summer; this difference was significant at Enderts ($t=-3.286$, $df=8$, $p=0.01$) and False Klamath Cove ($t=-3.751$, $df=8$, $p=0.006$) and almost significant at Damnation Creek ($t=-2.131$, $df=8$, $p=0.066$).

Rockweed (Fucus gardneri) and Dwarf Rockweed (Pelvetiopsis limitata) photoplots

In both sets of rockweed plots, the dominant species was the targeted rockweed. Specifically, cover of *Fucus gardneri* varied between 60 and 95% at Damnation Creek and between 50 and 90% at False Klamath Cove (Figure 10). Cover of *Pelvetiopsis limitata* at False Klamath varied between 50 and 90% but between 30 and 70% at Enderts (Figure 11). Except for *Fucus* at Damnation Creek, declines in rockweed cover appeared correlate to higher barnacle cover, while increases in rockweed cover correlated to fewer barnacles. Since rockweeds are canopy forming species, it is unclear whether barnacle abundances truly changed or just became more/less visible in response to changes in rockweed cover. At Enderts, changes in rockweed cover were correlated with changes in open space. While rockweed cover appeared to be slightly higher during the summer surveys, this difference was only significant in Damnation *Fucus* plots ($t=-2.358$, $df=8$, $p=0.05$).

California Mussel (Mytilus californianus) photoplots

Overall, mussel (*Mytilus californianus*) cover in these plots was high (and remained little changed) during the survey period (Figure 12). There were several periods of slightly lower mussel cover at Enderts Beach, and these were mainly due to the virtual absence of mussels from one of the five replicate photoplots (Figure 7b). For example, from fall 2009 to fall 2011 mussel cover was below 80%, open space (rock) around 5%, and barnacles making up the remaining 15%. An examination of the panoramic photographs from these periods revealed that these declines were not site wide but due to a localized loss of mussels. There was no evidence of seasonality in mussel cover.

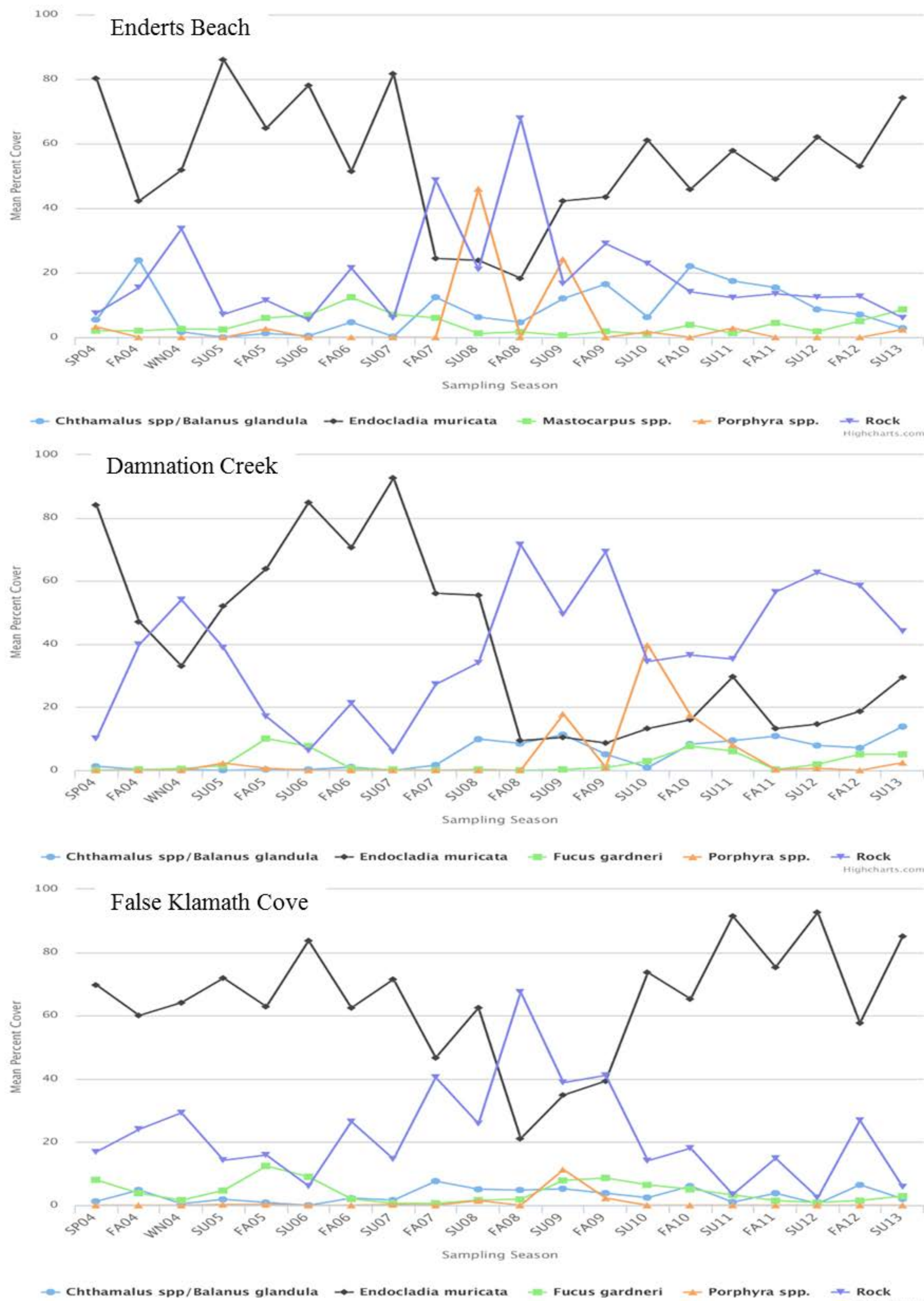


Figure 9. Mean percent cover of taxa in turfweed (*Endocladia muricata*) photoplots. Note that the same color line may represent different taxa in the three plots.

Enderts Beach

No Plots

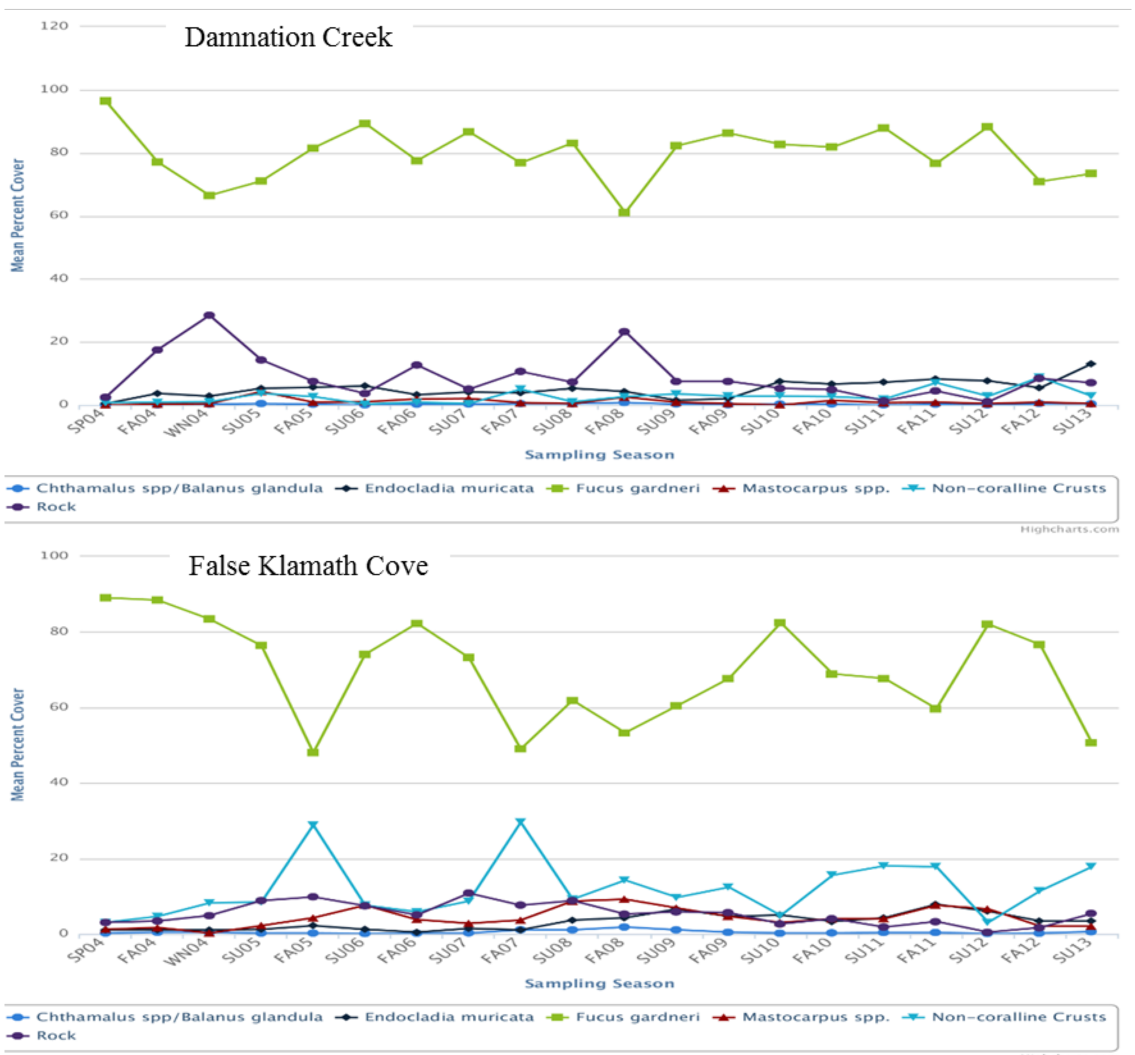
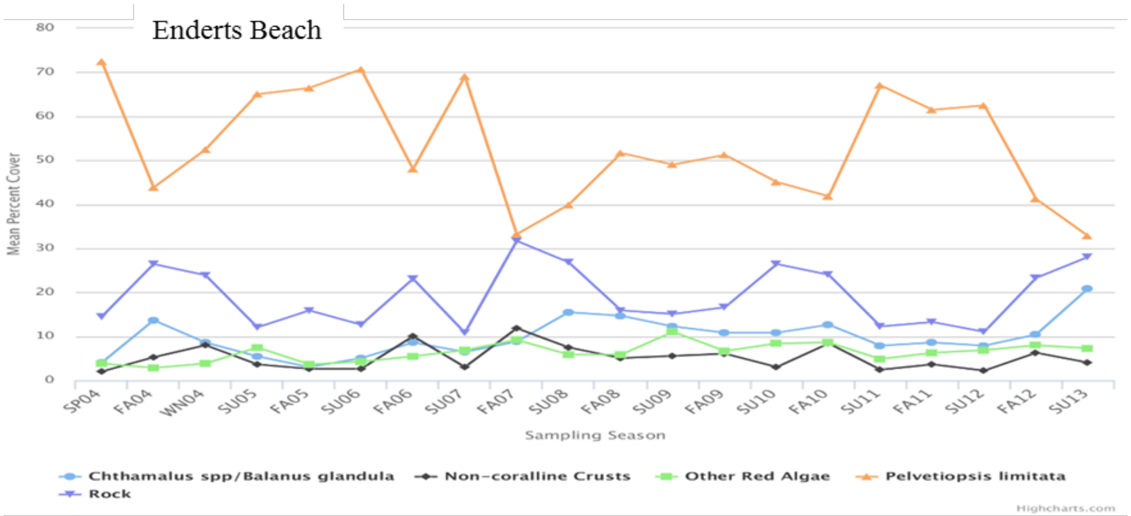


Figure 10. Mean abundance of taxa in the rockweed (*Fucus gardneri*) photoplots. Note the different scales on the y axes.



Damnation Creek

No Plots

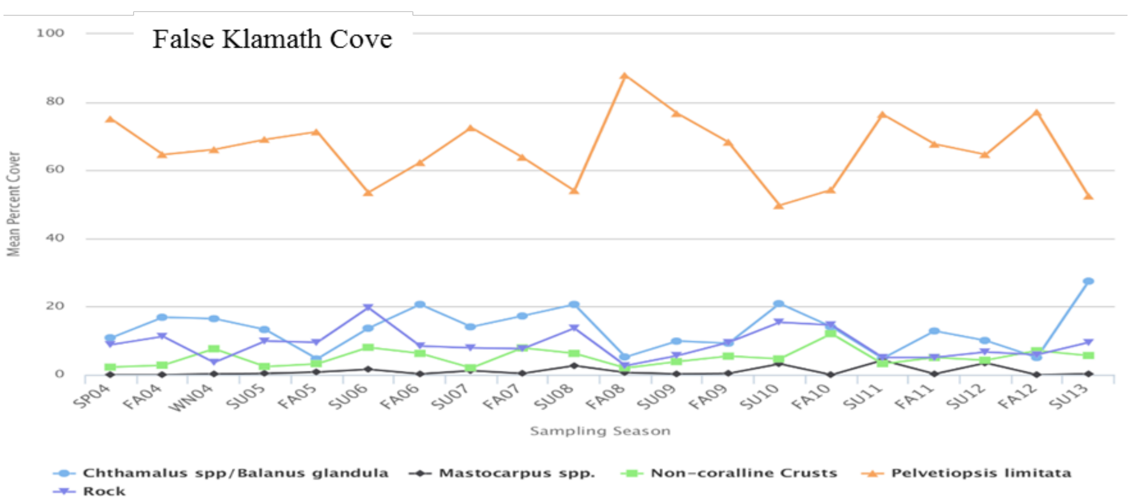


Figure 11. Mean abundance of taxa in dwarf rockweed (*Pelvetiopsis*) photoplots. Note that the same color line may represent different taxa in the three plots. Also note the different scales on the y axes.

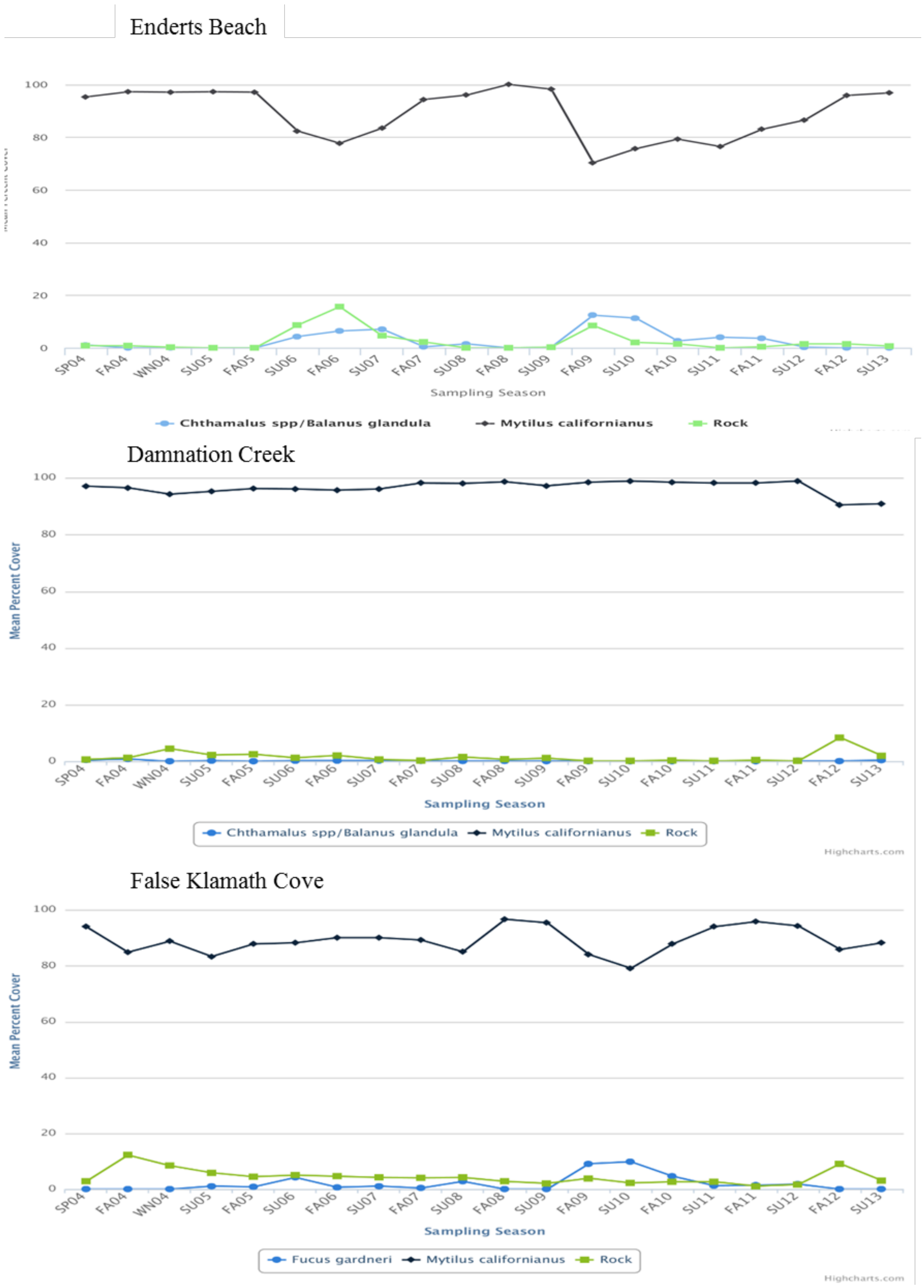


Figure 12. Mean abundance of taxa in mussel (*Mytilus californianus*) photoplots. Note that the same color line may represent different taxa in the three plots. Also note the different scales on the y axes.

Power Analysis

Power analysis was used to estimate the change in abundance that could be statistically measured following a disturbance for the target sessile species in each photoplot (Figure 13). In general, the smaller the amount of spatial variation among plots, the smaller the MDD. Consequently, the two methods (1 and 3) that calculated MDD utilizing data from the entire study period yielded slightly better results than method 2, which only used the data from the summer 2013 survey (Figure 13). Specifically, method 1 yielded MDDs mostly in the range of 5 to 10% (mean=6.4%), method 2 mostly in the range of 10-20% (mean=14.1%), and method 3 mostly in the range of 10-15% (mean=10.8%).

Because few intertidal species are distributed uniformly across the intertidal zone, the number of individuals found in replicate quadrats likely varies depending upon their location. Such spatial variation means that any estimate of abundance has an error (=variance) term associated with it. Since one of the goals of any monitoring program is to detect temporal changes in abundances, the design of the program should be robust enough to detect such changes in spite of this error term (=spatial variation). Using power analysis it is possible to estimate the MDD, a metric of the amount temporal variation that can be detected.

The results of the power analysis on the focal species in each photoplot suggest that the design of the RNSP monitoring program can detect a change in abundance (% cover) on the order of 5-15%. To put this in context, over the course of the study the barnacle % cover varied by over 60%, turfweed cover by 60%, rockweed cover by about 40%, and mussel cover by 20%. A decline of 15% would mean the loss of approximately 15-40% of these populations, depending upon the taxa and the site (Table 9).

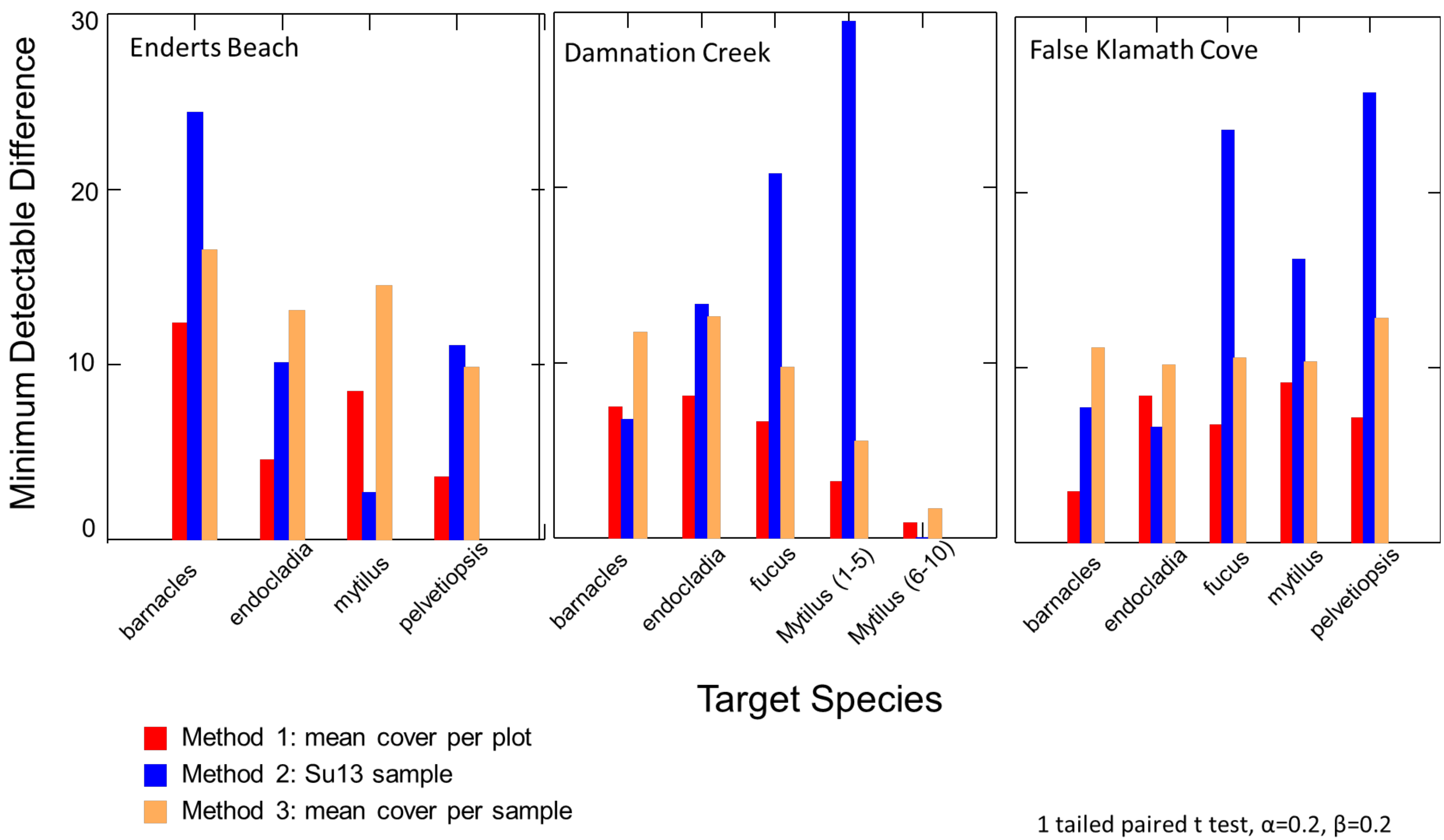


Figure 13. Power analysis of sessile species within photoplots at Redwood National and State Parks intertidal sites. Minimum Detectable Difference (MDD) represents the actual change in abundance.

Table 9. Estimated loss of the population assuming a decline in cover of 15%. Mean cover is the average abundance over the study period (2004-2013).

Focal Taxa	Site	Mean cover	% loss
Chthamalus/Balanus	Enderts	46	33
	Damnation	36	42
	False Klamath	57	26
Endocladia	Enderts	55	27
	Damnation	41	37
	False Klamath	65	23
Fucus	Damnation	81	19
	False Klamath	69	22
Mytilus	Enderts	89	17
	Damnation	96	16
	False Klamath	89	17
Pelvetiopsis	Enderts	97	28
	False Klamath	53	23

Mobile Invertebrates

A total of 36 taxa of mobile invertebrates were found within the photoplots at the three sites, but most of these were rare (Table 10, Figures 14-16). While the results of the MDS analysis suggest that the assemblages in each of the photoplot types are fairly distinct (Figure 17), the results of the SIMPER analysis suggests that this is due mostly to different abundances of limpets (*Lottia* spp.) and periwinkle snails (*Littorina* spp.), and to a much lesser extent the striped dog winkle (*Nucella emarginata*) and black turban snail (Chlorostoma (=*Tegula*) *funebralis*), not the presence of different taxa (Table 11). Abundances for these top four mobile species are presented in the plot types where they were most abundant (Figures 18-19). These graphs can be created for any mobile species in any plot type with the interactive graphing tool found at http://data.piscoweb.org/marine1/intertidalmap.html.

Table 10. Mobile invertebrate taxa found in photoplots at all Redwood National and State Park sites during 2006-2013 surveys.

Taxa	Common Name	Code for Figures
Mollusks		
Unidentified limpet spp.	limpets	LIMPET
Acanthiucella spp.	unicorn snail	ACASPP

Table 10 (continued). Mobile invertebrate taxa found in photoplots at all Redwood National and State Park sites during 2006-2013 surveys.

Taxa	Common Name	Code for Figures
Mollusks (continued)		
Alia carinata	carinate dovesnail	ALICAR
Amphissa spp.	wrinkled/ variegated amphissa	AMPSPP
Bittium eschrichtii	bittium snail	BITSPP
Epitonium tinctum	white wentletrap	EPITIN
Fissurella volcano	volcano key-hole limpet	FISVOL
Lacuna spp.	chink shell	LACSPP
Littorina spp.	periwinkle	LITTSPP
Homolopoma/Margarites spp.	dwarf turban complex	HOMMAR
Nucella canaliculata	channelled dog winkle	NUCCAN
Nucella emarginata/ostrina	striped dog winkle	NUCEMA
Nucella lamellosa	frilled dog winkle	NUCLAM
Oceanebra circumtexta	circled rocksnail	OCECIR
Onchidella borealis	leather limpet	ONCBOR
Chlorostoma (=*Tegula*) *funebralis*	black turban	CHLFUN
Chitons		
Kathrina tunicata	black Katy chiton	KATTUN
Lepidochitona dentiens	Gould's baby chiton	LEPDEN
Lepidozona spp.	Lepidozona spp.	LEPSPP
Mopalia spp.	hairy chiton	MOPSPP
Nuttallina spp.	California spiny chiton	NUTSPP
Crustaceans		
Hemigrapsus nudus	purple shore crab	HEMNUD
Idotea spp.	Vosnesesensky's isopod	IDOSPP
Pachycheles spp.	thick-clawed porcelain crab	PACSPP
Pachygrapsis crassipes	striped shore crab	PACCRA
Pagurus beringanus	Bering hermit	PAGBER
Pagurus granosimanos	grainy hand hermit	PAGGRA
Pagurus hirsutisculus	hairy hermit	PAGHIR
Pagurus samuelis	blueband hermit	PAGSAM

Table 10 (continued). Mobile invertebrate taxa found in photoplots at all Redwood National and State Park sites during 2006-2013 surveys.

Taxa	Common Name	Code for Figures
Crustaceans (continued)		
Petrolisthes spp.	flat porcelain crab	PETSPP
Pugettia spp.	kelp crab	PUGSPP
Echinoderms		
Cucumaria spp.	sea cucumber	CUCSPP
Leptasterias hexactis	six-rayed star	LEPHEX
Pisaster ochraceus	ochre star	PISOCH
Ophiurida spp.	brittle stars	OPHSPP
Platyhelminthes	flat worms	FLATWO

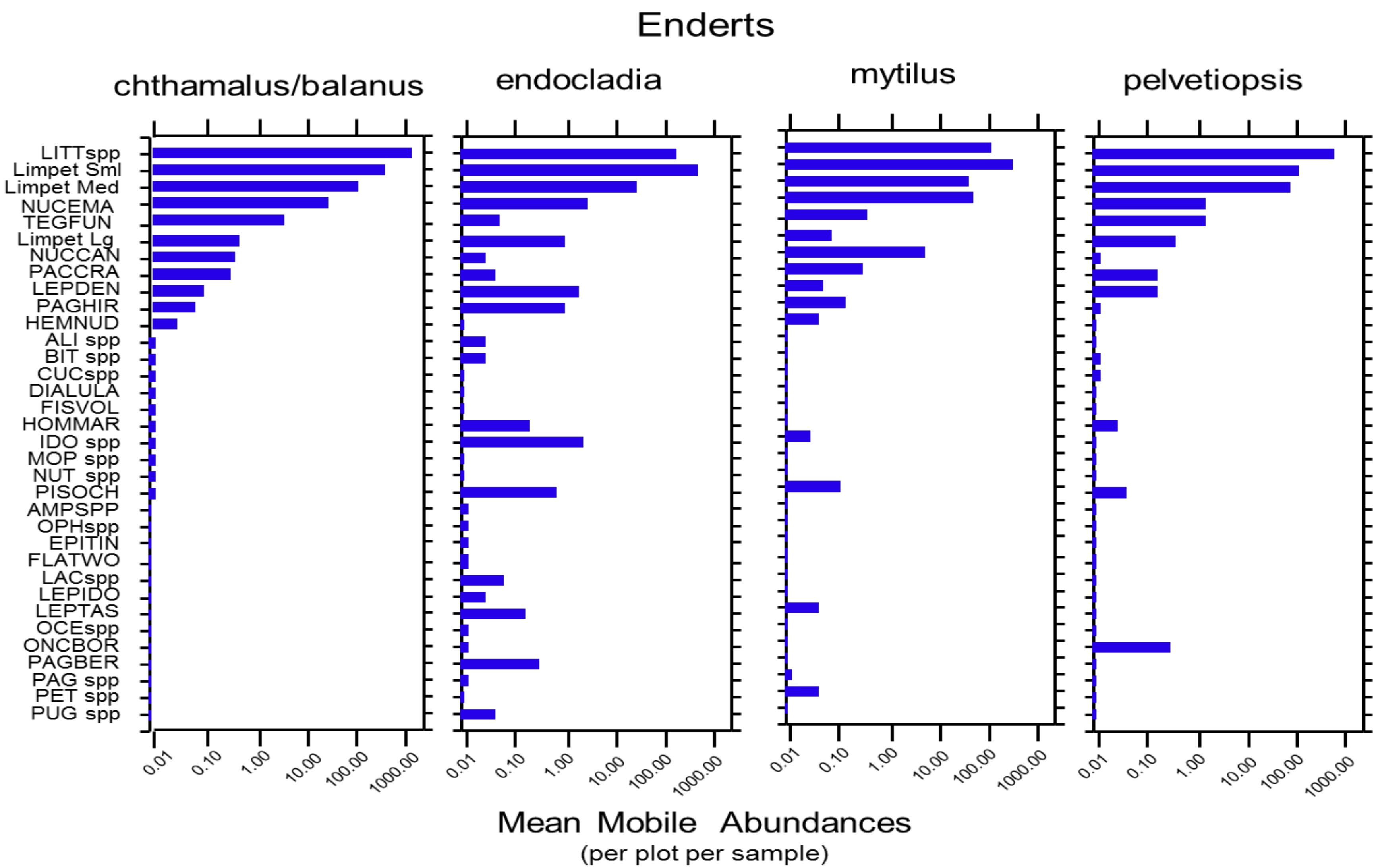


Figure 14. Mean abundances per plot per sample (2006-2013) of mobile invertebrate species found in the different plot types at Enderts Beach.

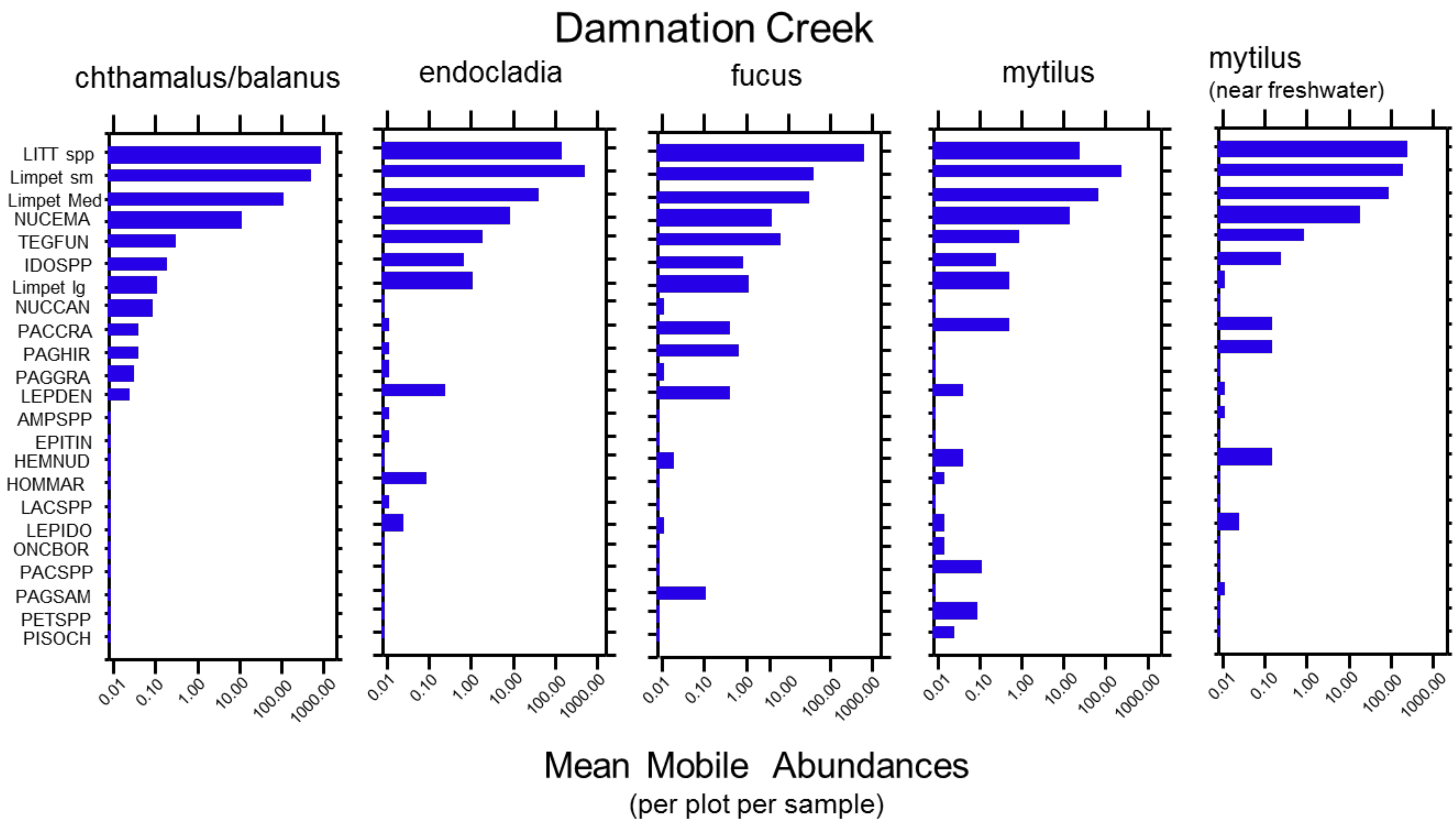


Figure 15. Mean abundances per plot per sample (2006-2013) of mobile invertebrate species found in the different plot types at Damnation Creek.

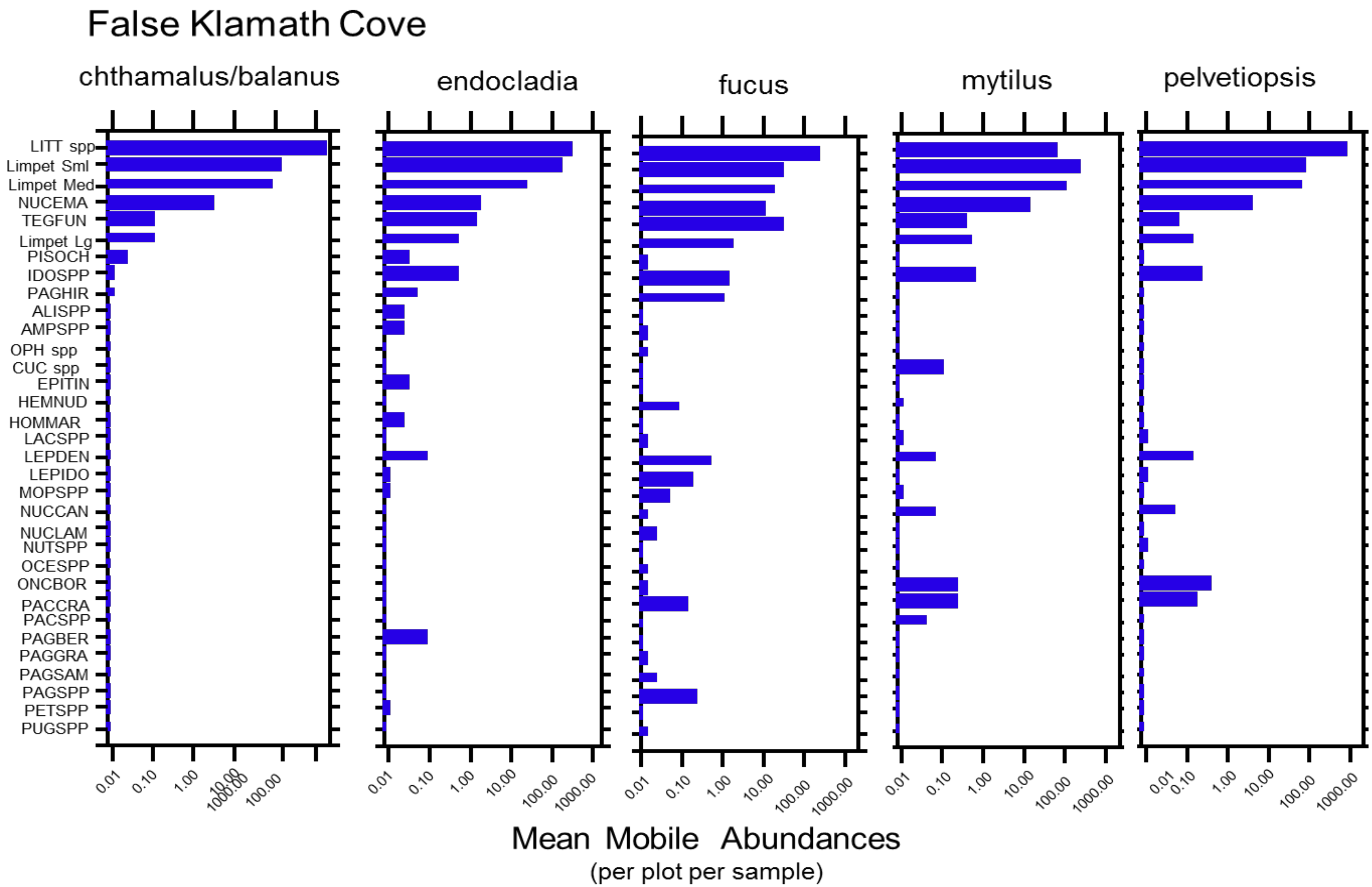


Figure 16. Mean abundances per plot per sample (2006-2013) of mobile invertebrate species found in the different plot types at False Klamath Cove.

Table 11. Results of SIMPER analysis showing the contribution of species to the similarity of mobile invertebrate assemblages in the photoplots.

Photoplot	**Species**	**Avg. similarity**	**Limpet**	***Littorina spp.***	***Nucella canaliculata***	***Nucella emarginata***	***Tegula funebralis***
Enderts		**Contribution to similarity (%)**					
	Chthamalus/Balanus	66.2	32.8	66.0	–	1.1	–
	Endocladia	60	95.4	3.5	–	0.3	–
	Mytilus	62	81.5	8.1	0.9	9.4	–
	Pelvetiopsis	73.1	30.3	69.4	–	–	–
		Rank contribution					
	Chthamalus/Balanus	–	2	1	–	3	–
	Endocladia	–	1	2	–	3	–
	Mytilus	–	1	3	4	2	–
	Pelvetiopsis	–	2	1	–	–	–
Damnation Creek		**Contribution to similarity (%)**					
	Chthamalus/Balanus	57.8	46.3	53.1	–	–	–
	Endocladia	54.5	88.7	10.1	–	1.1	–
	Fucus	70.1	10.9	87.8	–	–	0.6
	Mytilus (plot 1-5)	59.4	90.9	4.6	–	4.1	–
	Mytilus (plot 6-10)	57.8	58.9	36.9	–	4.0	–

Table 11 (continued). Results of SIMPER analysis showing the contribution of species to the similarity of mobile invertebrate assemblages in the photoplots.

Photoplot	Species	Avg. similarity	Limpet	*Littorina spp.*	*Nucella canaliculata*	*Nucella emarginata*	*Tegula funebralis*
Damnation Creek (continued)	**Rank contribution**						
	Chthamalus/Balanus	–	2	1	–	–	–
	Endocladia	–	1	2	–	3	–
	Fucus	–	2	1	–	–	3
	Mytilus (plot 1-5)	–	1	2	–	3	–
	Mytilus (plot 6-10)	–	1	2	–	3	–
False Klamath Cove	**Contribution to similarity (%)**						
	Chthamalus/Balanus	64.5	9.6	90.3	–	–	–
	Endocladia	67.2	33.1	66.5	–	–	–
	Fucus	62	19.9	63.1	–	4.3	12.2
	Mytilus	64.1	94.6	2.1	–	3.2	–
	Pelvetiopsis	67.8	16.7	83.1	–	–	–
	Rank contribution						
	Chthamalus/Balanus	–	2	1	–	–	–
	Endocladia	–	2	1	–	–	–
	Fucus	–	2	1	–	4	3
	Mytilus	–	1	3	–	2	–
	Pelvetiopsis	–	2	1	–	–	–

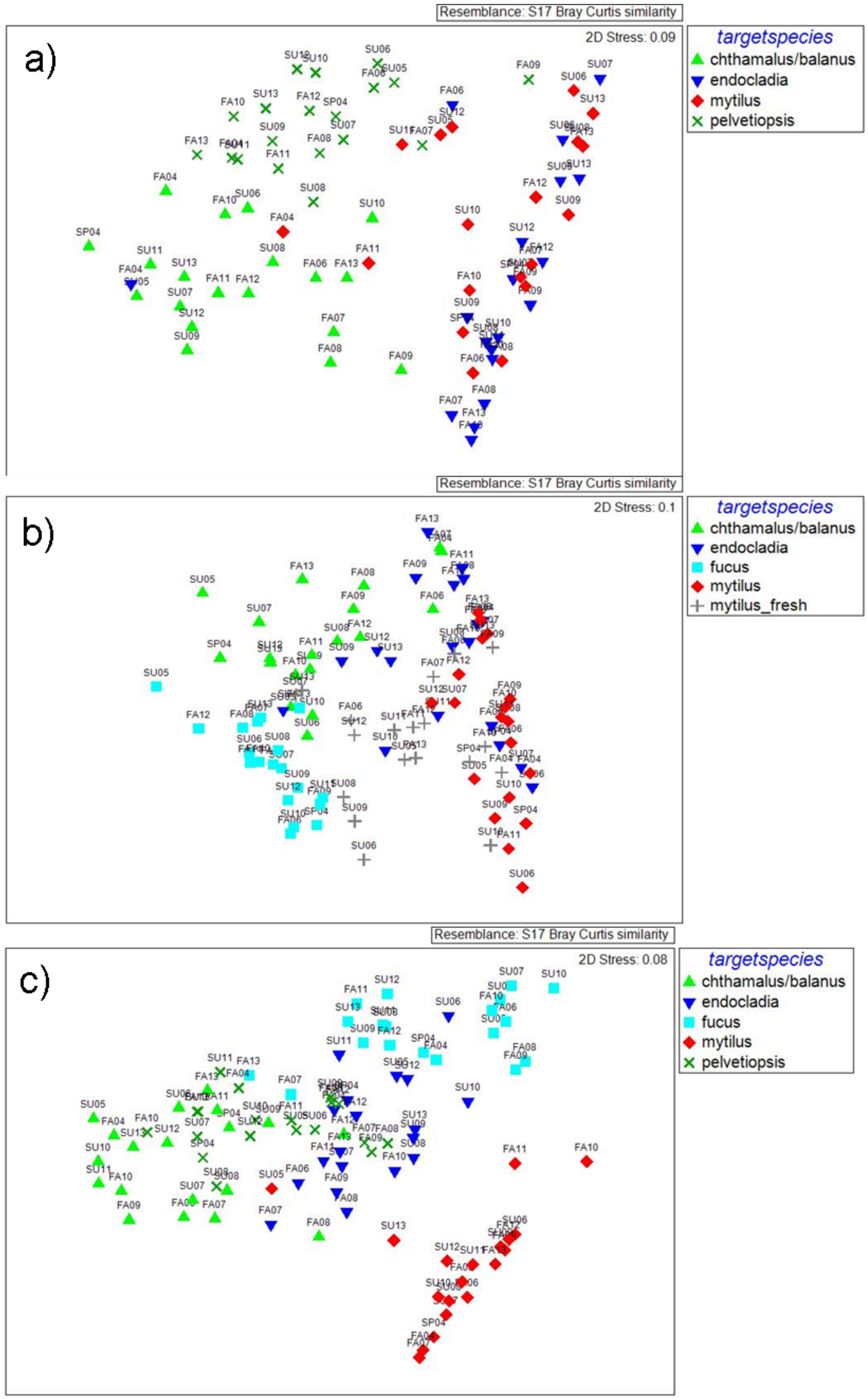


Figure 17. Multi-dimensional scaling (MDS) plots showing the similarity of the mobile invertebrate assemblages with mussel, barnacle, turfweed, dwarf rockweed, and rockweed photoplots for a) Enderts Beach, b) Damnation Creek, and c) False Klamath Creek during surveys conducted from 2004-2013.

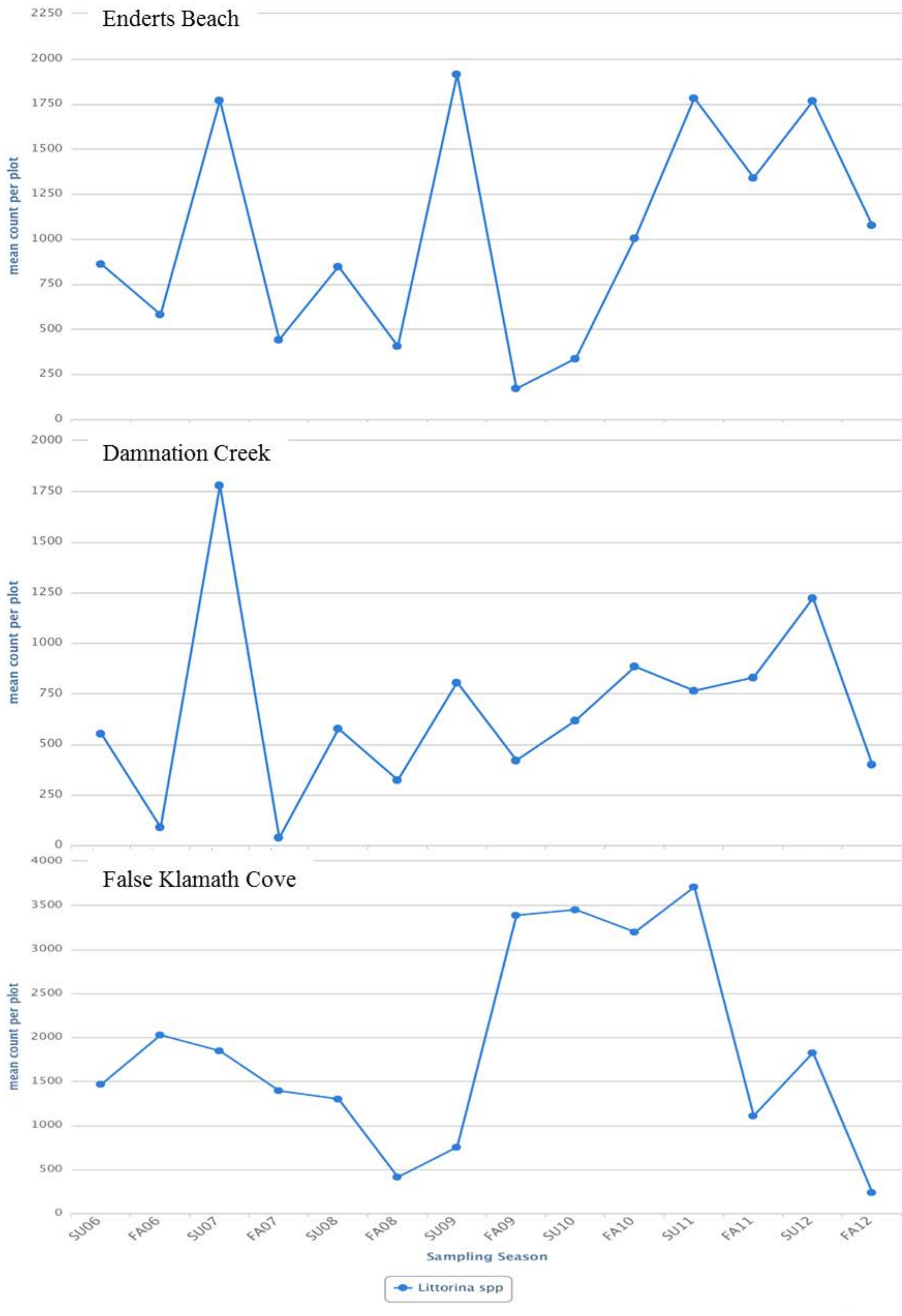


Figure 18. Mean abundance of littorines in the barnacle photoplots during the 2006-2012 sampling periods. Note different scales on y axes.

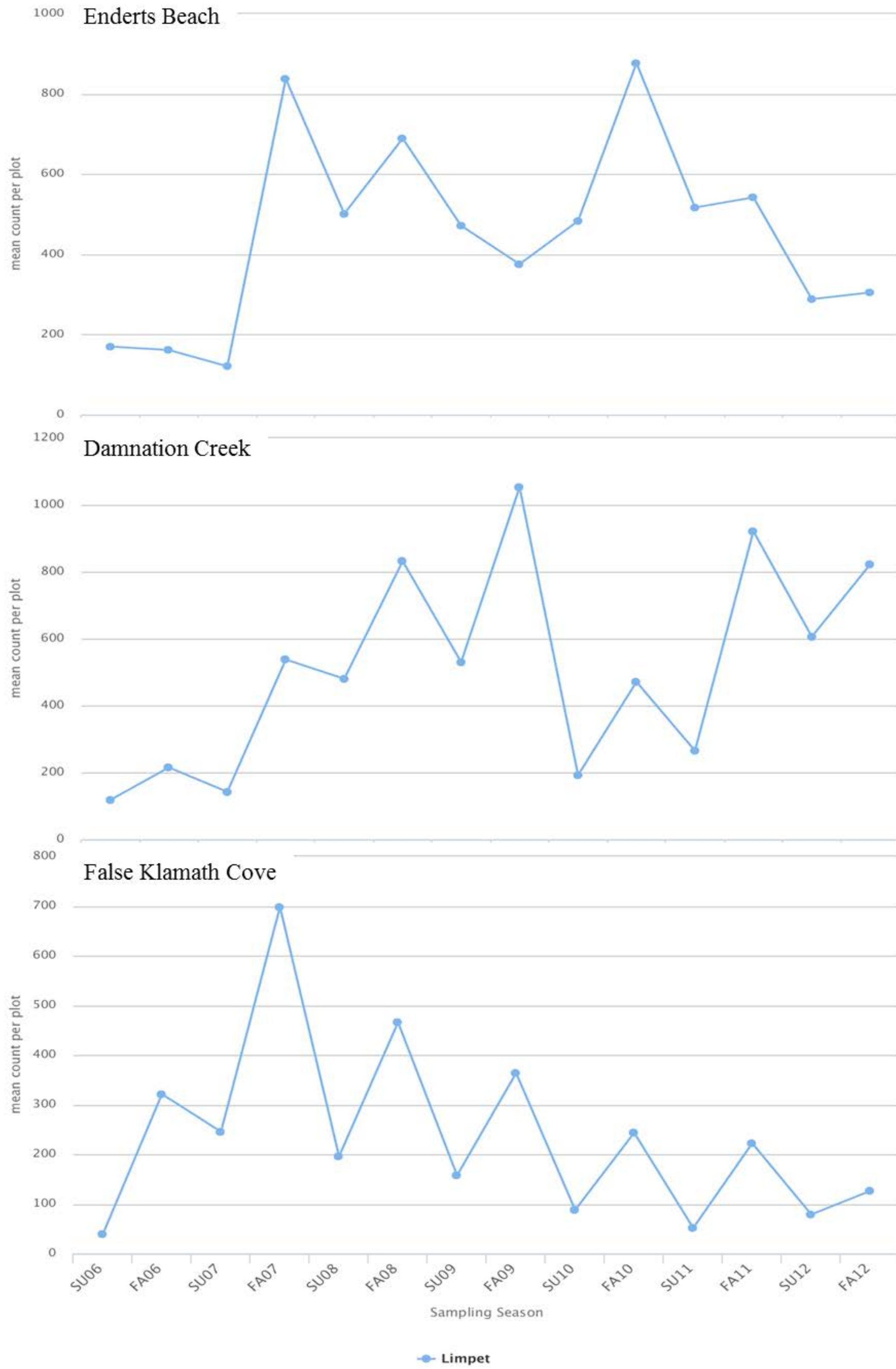


Figure 19. Mean abundance of limpets in the turfweed (*Endocladia muricata*) during the 2006-2012 sampling periods. Note different scales on y-axes.

The predatory striped dog winkle (*Nucella emarginata*) was commonly found in the mussel plots at all three sites, where it achieved densities of between 2-8 individuals per plot at Damnation Creek and False Klamath Cove, but between 5-25 individuals per plot at Enderts (Figure 20). While abundances appeared to vary seasonally at Damnation Creek (runs test, n=19, p=0.01) and perhaps at Enderts (runs test, n=19, p=0.08), they did not at False Klamath Cove (runs test, n=19, p=0.15). Interestingly, the populations at Enderts and Damnation Creek appeared to be comprised of larger individuals in the summer than in the fall (Figure 22) In contrast, there appeared to be little variation in the size distributions at False Klamath Cove. Fluctuations in juvenile dog whelks (2-10mm) abundances was compared to adult populations (>10mm) in Figure 24.

The black turban snail (*Chlorostoma funebralis*), a grazer commonly found in the rockweed (*Fucus gardneri*) plots, initially achieved densities of between 5-25 individuals per plot at Damnation Creek and between 25-45 individuals per plot at False Klamath Cove (Figure 21). However, numbers in the rockweed plots at False Klamath Cove have declined over the course of the study period (r=0.48, df=17, p=0.04). Although the numbers at Damnation Creek also dropped, this trend was not significant (r=0.26, df=17, p=0.29). While there did not appear to be any seasonal variation in numbers at either site (runs test, n=19, p=0.35 for Damnation Creek and p=0.47 for False Klamath Cove), at Damnation Creek the populations appeared to be comprised of larger individuals during the fall sample (Figure 23). This did not appear to be true at False Klamath Cove (Figure 23). Fluctuations in juvenile turban snails (2-10mm) abundances was compared to adult populations (>10mm) in Figure 24.

The periwinkle snail (*Littorina* spp.), which was by far the most common taxon, was particularly abundant in the barnacle plots where it often exceeded 1000 individuals per plot (>2500 per m^2, Figure 18). Abundances were particularly high at Enderts from late 2009 and 2011 (Figure 18). Abundances varied seasonally at Damnation Creek (runs test, n=19, p=0.005) and to a lesser extent at Enderts (runs test, n=19, p=0.07), but not at False Klamath Cove (runs test, n=19, p=0.2).

In comparison, limpets (*Lottia* spp.), which tended to be more evenly distributed across plot types but were slightly more common in the turfweed (*Endocladia*) plots, achieved densities of between 200-800 individuals per plot at Enderts and Damnation Creek and between 100-500 individuals per plot at False Klamath Cove (Figure 19). Abundances appeared to vary seasonally at Damnation Creek (runs test, n=19, p=0.0002) and False Klamath Cove (runs test, n=19, p=0.003), but not at Enderts (runs test, n=19, p=0.15). Interestingly, limpet abundances at Damnation Creek increased over the study period (r=0.58, df=17, p=0.01), perhaps in response to the decline in turfweed cover in these plots previously discussed (see photoplot results section).

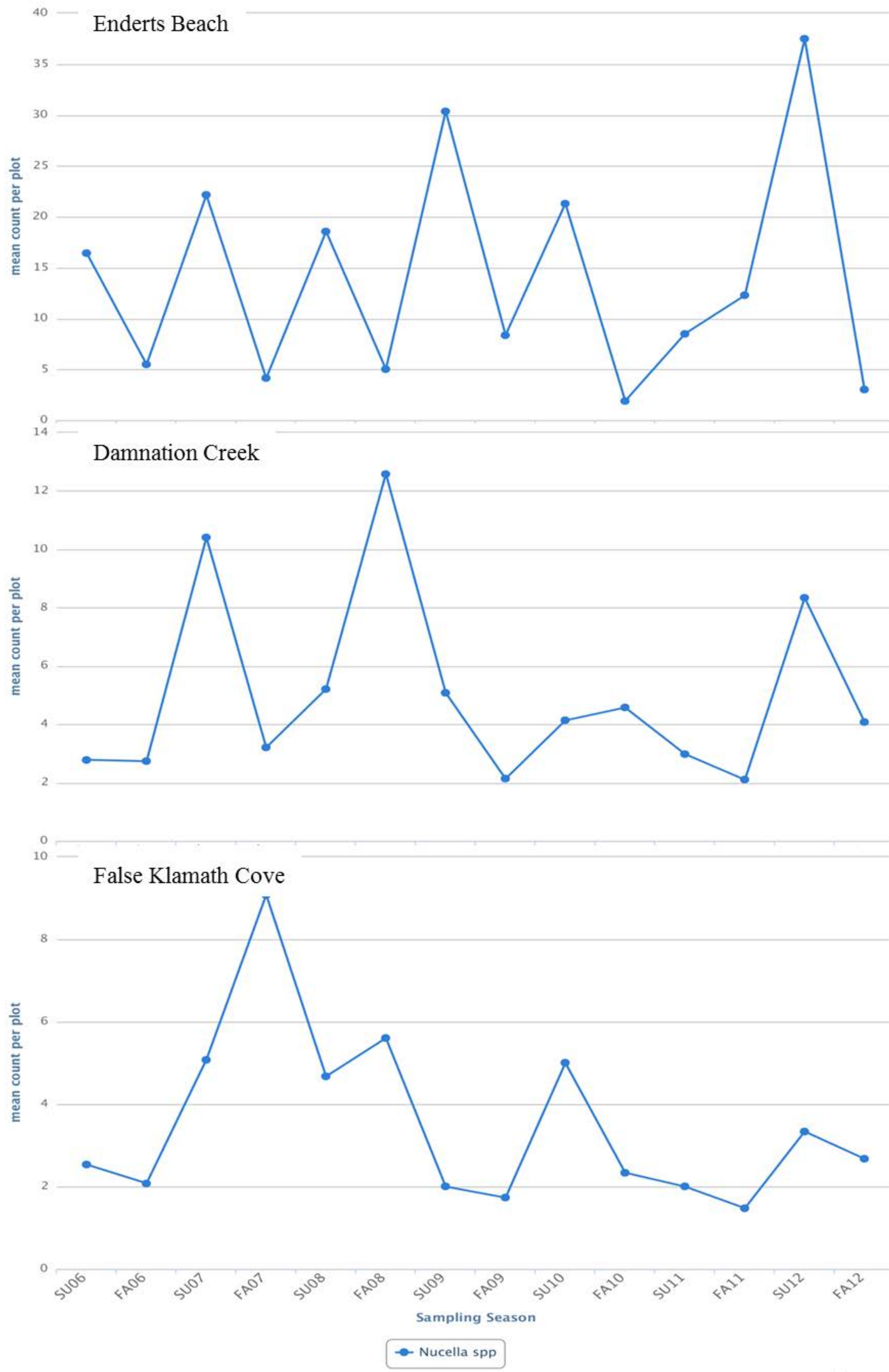


Figure 20. Mean abundances of dog winkle (*Nucella* spp.) in mussel (*Mytilus*) photoplots during the 2006-2012 sampling periods. Note different scales on y-axes.

Enderts Beach

No Plots

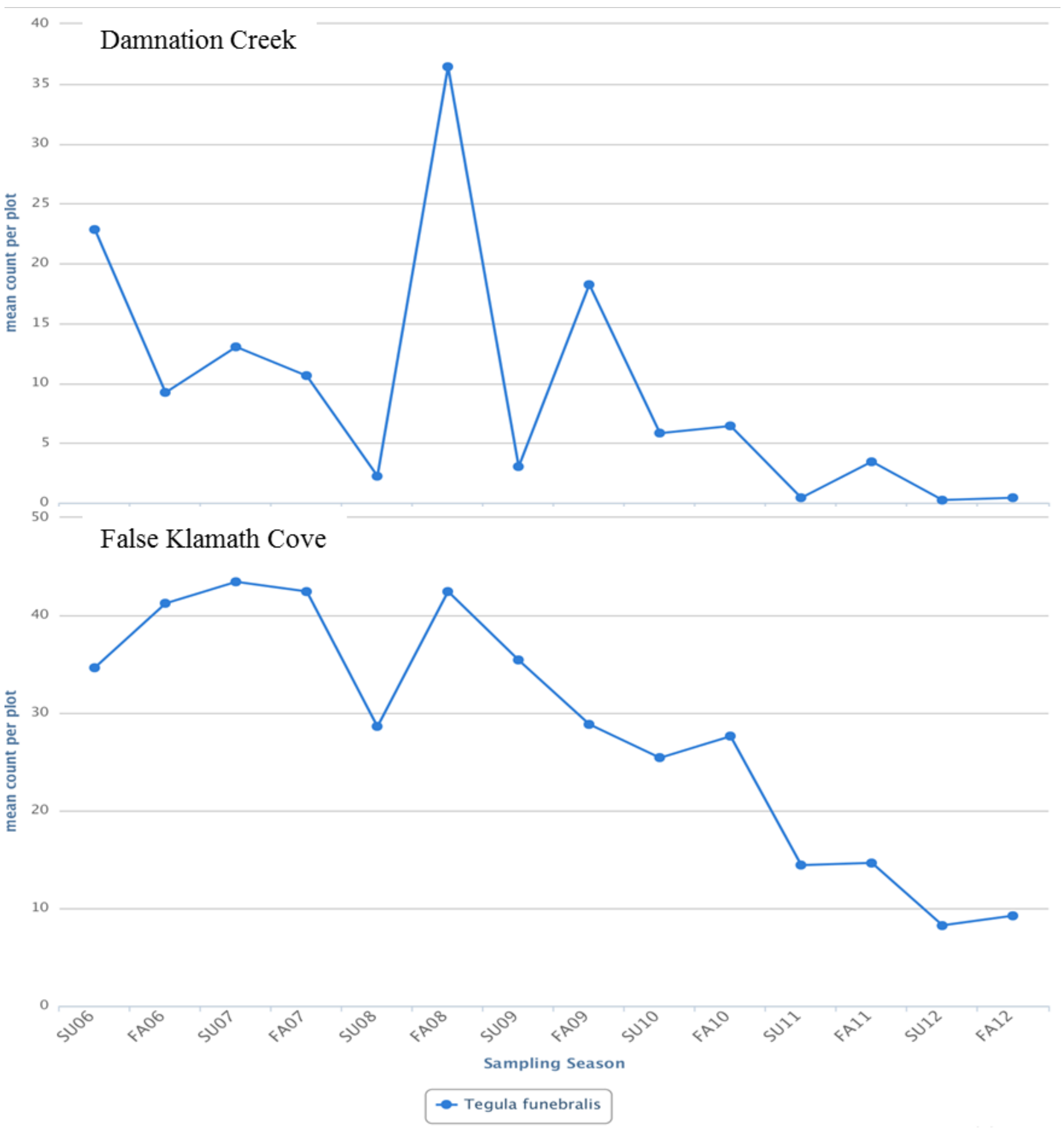


Figure 21. Mean abundances of black turban snails (*Chlorostoma* (=*Tegula*) *funebralis*) in rockweed (*Fucus gardneri*) photoplots during the 2006-2012 sampling periods. Note different scales on y-axes.

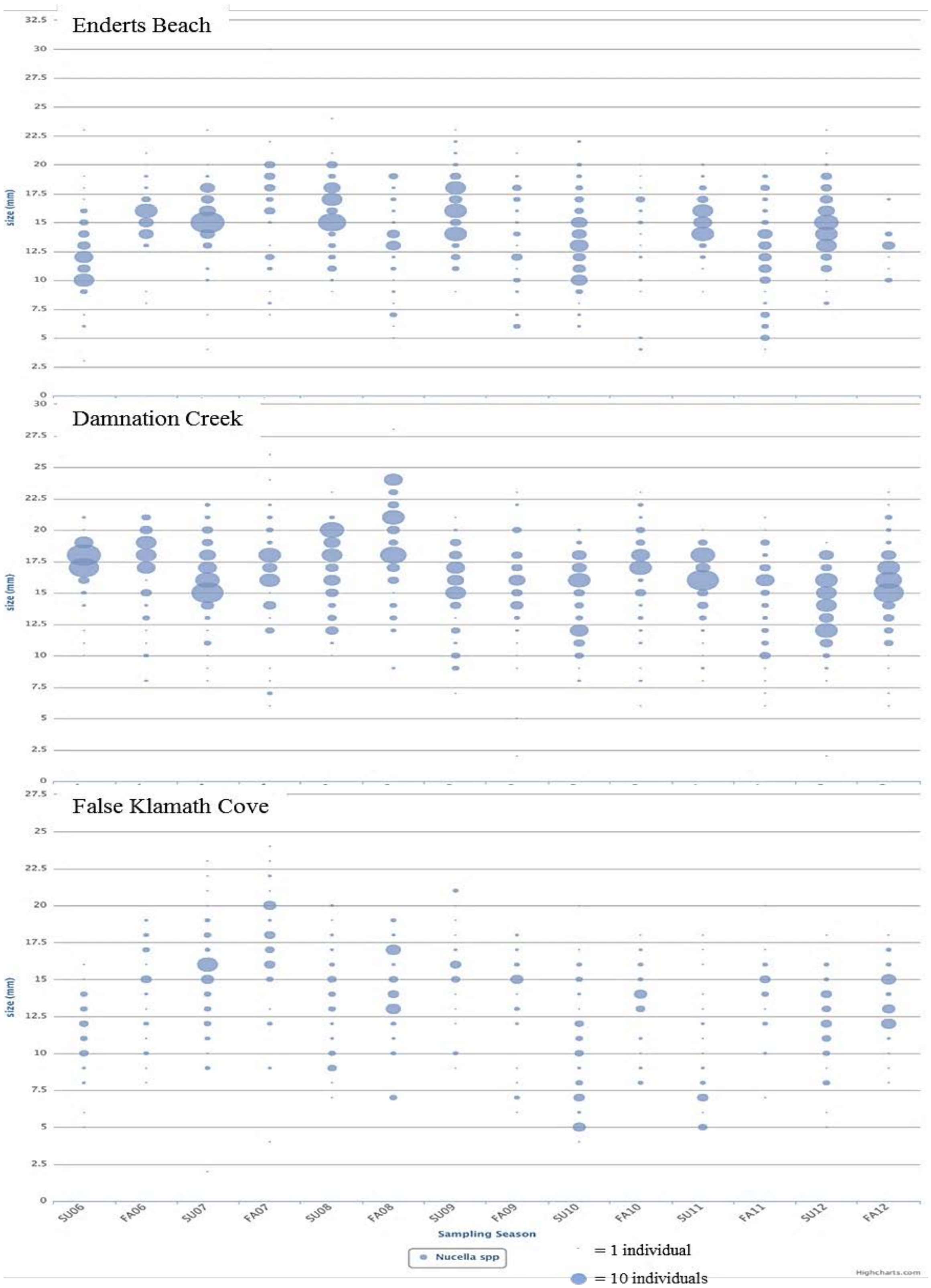


Figure 22. Size frequency distributions of dog winkles (*Nucella* spp.) in mussel (*Mytilus*) photoplots during 2006-2012 sampling periods. The larger the circle the more abundant the size. Note different scales on y-axes.

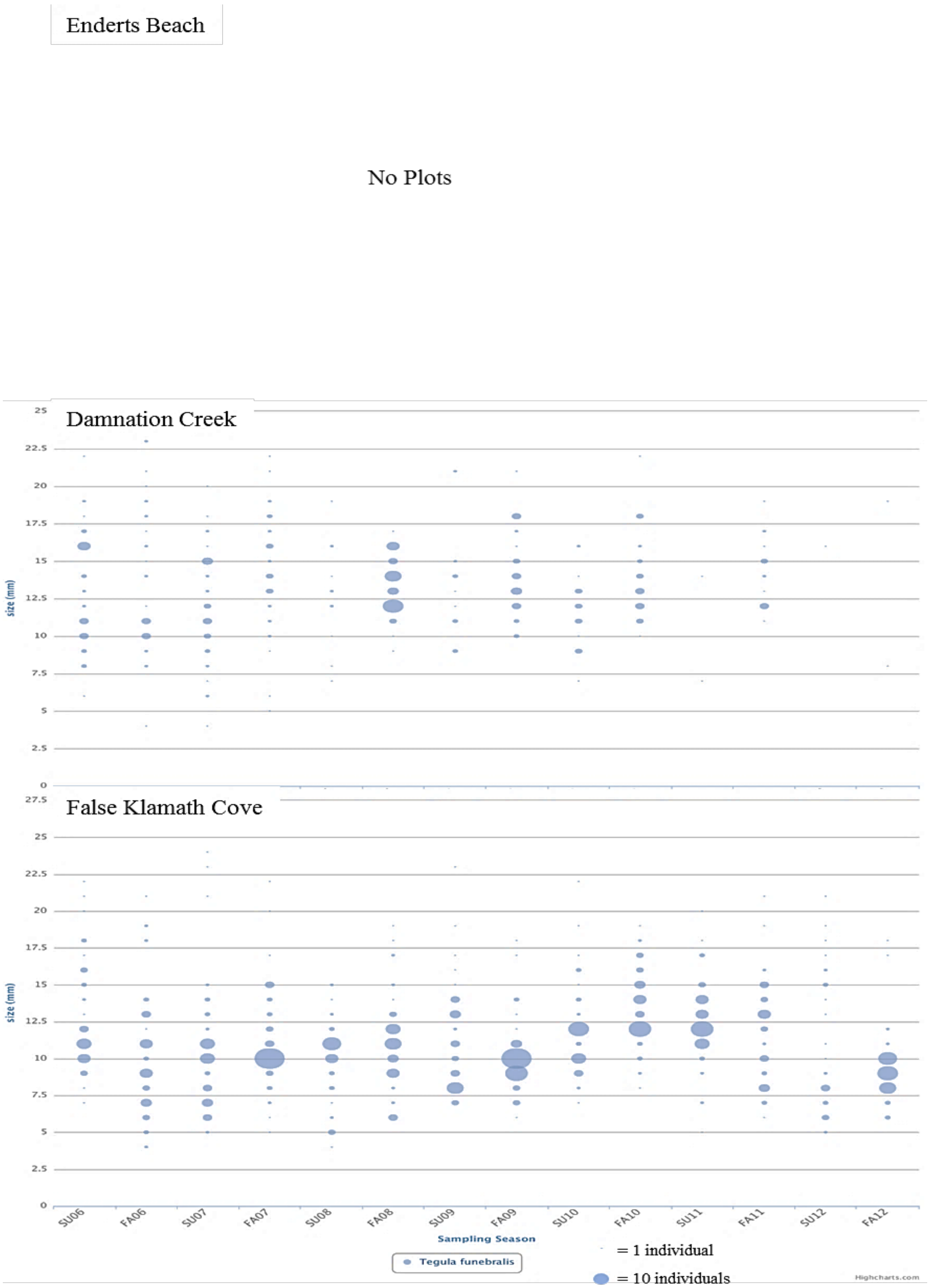


Figure 23. Size frequency distributions black turban snails (*Chlorostoma* (=*Tegula*) *funebralis*) in rockweed (*Fucus gardneri*) photoplots during the 2006-2012 sampling periods. Note different scales on y-axes. The larger the circle the more abundant the size. Note different scales on y-axis.

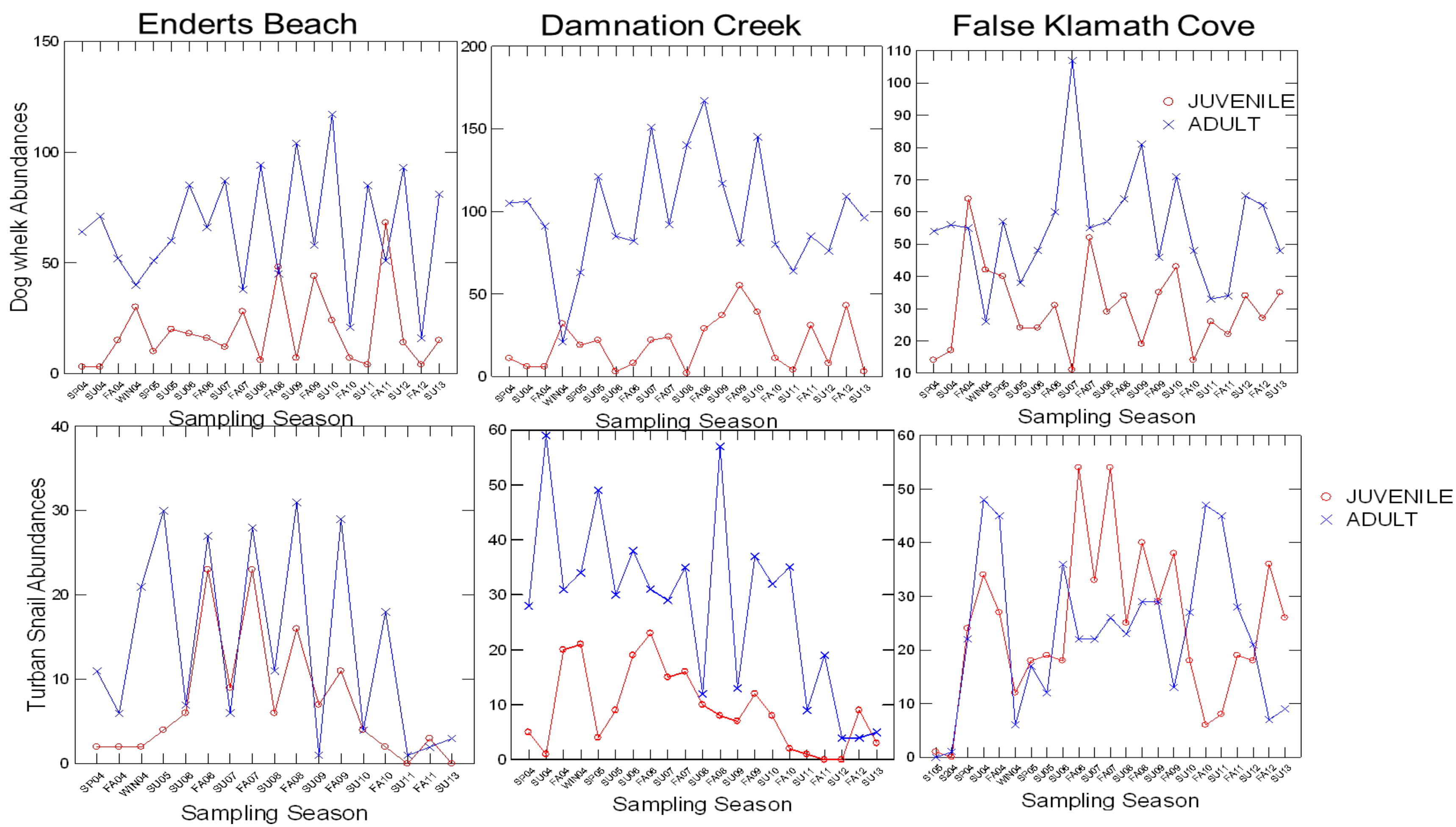


Figure 24. Juvenile (2-10mm) and adult (>10mm) abundances of dog winkle and turban snails over study period.

Barnacle Clearings

Although the number of new barnacles in the clearings varied both among sites and over time, in general there were between 200 and 400 new individuals in the clearings when they were sampled (Figure 25). In five of the seven surveys at Enderts the number of new *Balanus* appeared to exceed the number of new *Chthamalus*, while in six of the seven samples at Damnation Creek the number of new *Chthamalus* appeared to exceed the number of new *Balanus*. At False Klamath there was no consistent difference. Interestingly, the number of barnacles in the clearings when they were sampled was a predictor of the abundance of barnacles in the photoplots during the same sampling period at Enderts ($r=0.338$, $n=32$, $p=0.058$) and False Klamath Cove ($r=0.337$, $n=34$, $p= 0.051$), but not at Damnation Creek ($r=0.06$, $n=35$, $p=0.73$). However, there was no relationship with population size at any future time periods. This suggests that the population in the photoplots during the early summer at Enderts and False Klamath Cove was comprised mostly of one cohort, and that initial post-settlement mortality was density independent.

Results of a stepwise multiple regression analysis also suggested that the number of new barnacles in the clearings was influenced by a number of factors, including sea surface temperature and the abundances of limpets, littorines, and the predatory dog winkle *(Nucella emarginata*) (Table 12). Potential variables in the model included average Sea Surface Temperature for the previous 6-, 8-, 10-, and 12-month periods, and the abundances of periwinkles (*Littorina* spp.), small and medium limpets (*Lottia* spp.), and dog winkles (*Nucella emarginata*) measured in the photoplots at the time the clearings were sampled (summer), the previous sample (fall), and the mean of these two values.

Table 12. Results of stepwise regression comparing the number of barnacles in clearings to various environmental parameters at three Redwood National and State Parks sites.

Site	Variable	Coefficient	t	p
Enderts r = 0.80, N = 7, p = 0.030	Constant	718.6	7.54	0.0007
	Sea surface temperature (6 mo.)	-571.3	-3.00	0.030
Damnation Creek r = 0.99, N = 7, p = 0.003	Constant	742.3	22.6	0.002
	Sea surface temperature (6 mo.)	-245.0	-15.2	0.004
	Littorina (fall)	0.4	11.6	0.007
	N. emarginata (mean)	-25.7	-29.1	0.001
	Small limpets (mean)	-0.19	-3.82	0.062
False Klamath Cove r = 0.85, N = 7, p = 0.015	Constant	617.2	13.4	0.00004
	N. emarginata (mean)	-38.2	-3.61	0.015

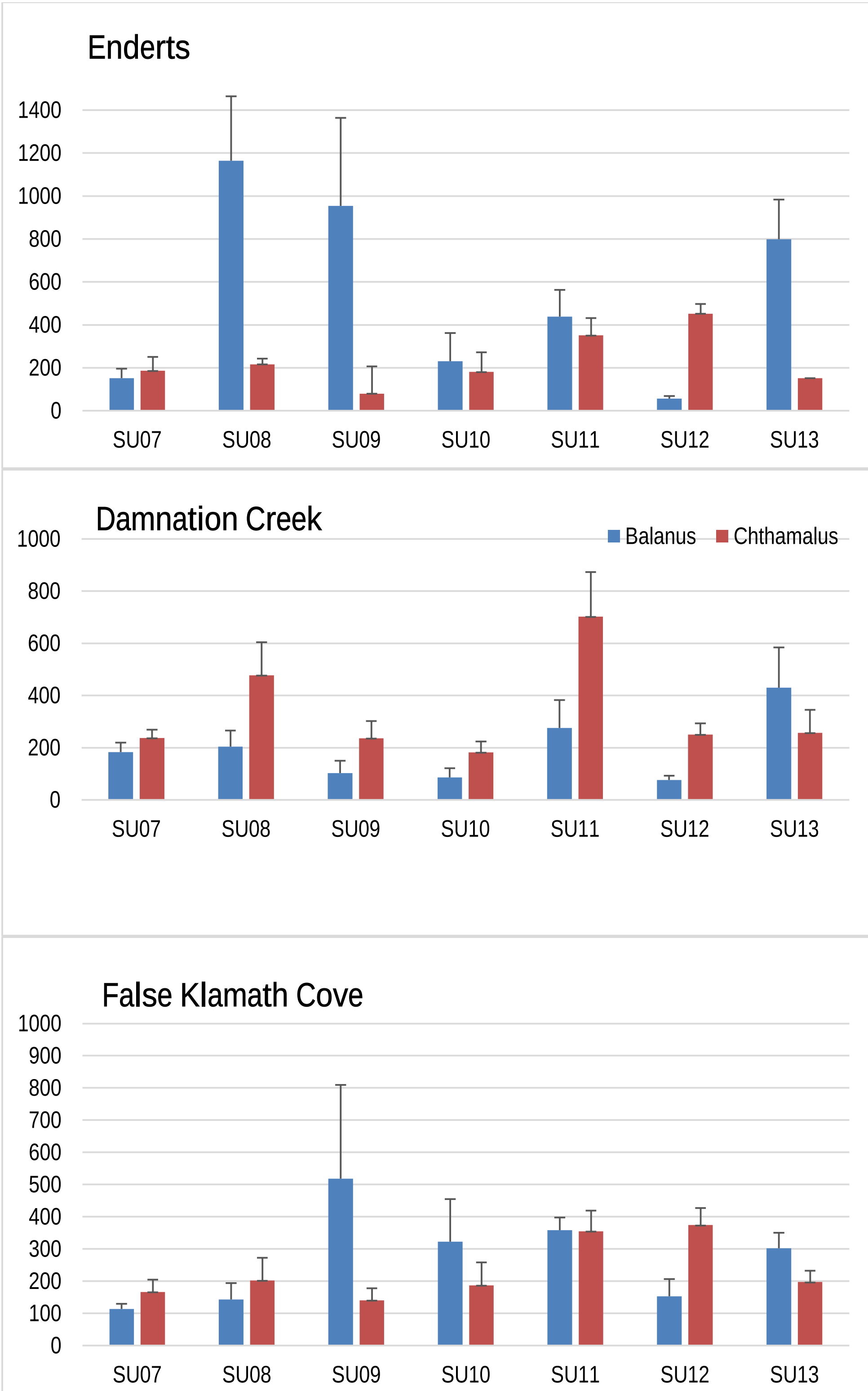


Figure 25. Mean number (± 1SE) of barnacles in the clearings sampled in the summer at Redwood National and State Parks sites from May 2007 to May 2013. Note different scales on y-axis. Enderts (top), Damnation Creek (middle), and False Klamath Cover (bottom).

Sea Star Plots

Because the sea star plots are irregularly shaped and vary in size, sea star abundances should not be compared across sites. At both Enderts and Damnation Creek, the number of ochre sea stars declined from 2004 to 2008, after which they mostly remained in this “reduced” state (Figure 26). This decline was not evident at False Klamath Cove. Interestingly, as has been previously suggested (see Sanford 1999) that some of the variation in numbers observed at the sites can be explained by variations in sea surface temperature. Specifically, there was a significant positive correlation between sea surface temperature and abundances at Enderts and Damnation Creek but not at False Klamath Cove (Figure 27).

During the first part of the study period the populations of ochre sea stars at all three sites were dominated by smaller (<50mm) individuals, including many below 20mm in size (Figures 28-30). The growth of these individuals and the observation of no recruitment led the populations later in the study period at Damnation Creek and False Klamath Cove to be dominated by individuals between 50 and 100 mm in size. While this was also true at Enderts (Figure 28), there was no indication that a recruitment failure occurred at this site. Interestingly, while at both Damnation Creek and False Klamath Cove there were few large (>100mm) individuals, at Enderts a considerable proportion of the population was comprised of these larger individuals (Figures 28-30).

During the fall 2013 survey, sea stars exhibiting symptoms of sea star wasting syndrome were observed at all three RNSP sites, but not in large numbers. Specifically, seven of 397 *Pisaster ochraceus* sampled at Enderts, six of 147 at Damnation Creek, and one of 337 at False Klamath Cove exhibited some signs of the disease (note that sea star wasting syndrome can be observed even on smaller size classes of sea stars). At Damnation Creek, one *Pycnopodia helianthoides* exhibiting symptoms of wasting syndrome was also found. Perhaps because of these low levels of incidence, there was no evidence that population sizes were down within monitoring plots. Preliminary data from summer 2014 sampling showed more evidence of sea star wasting syndrome within RNSP. See discussion for more information on sea star wasting disease and mortality in RNSP.

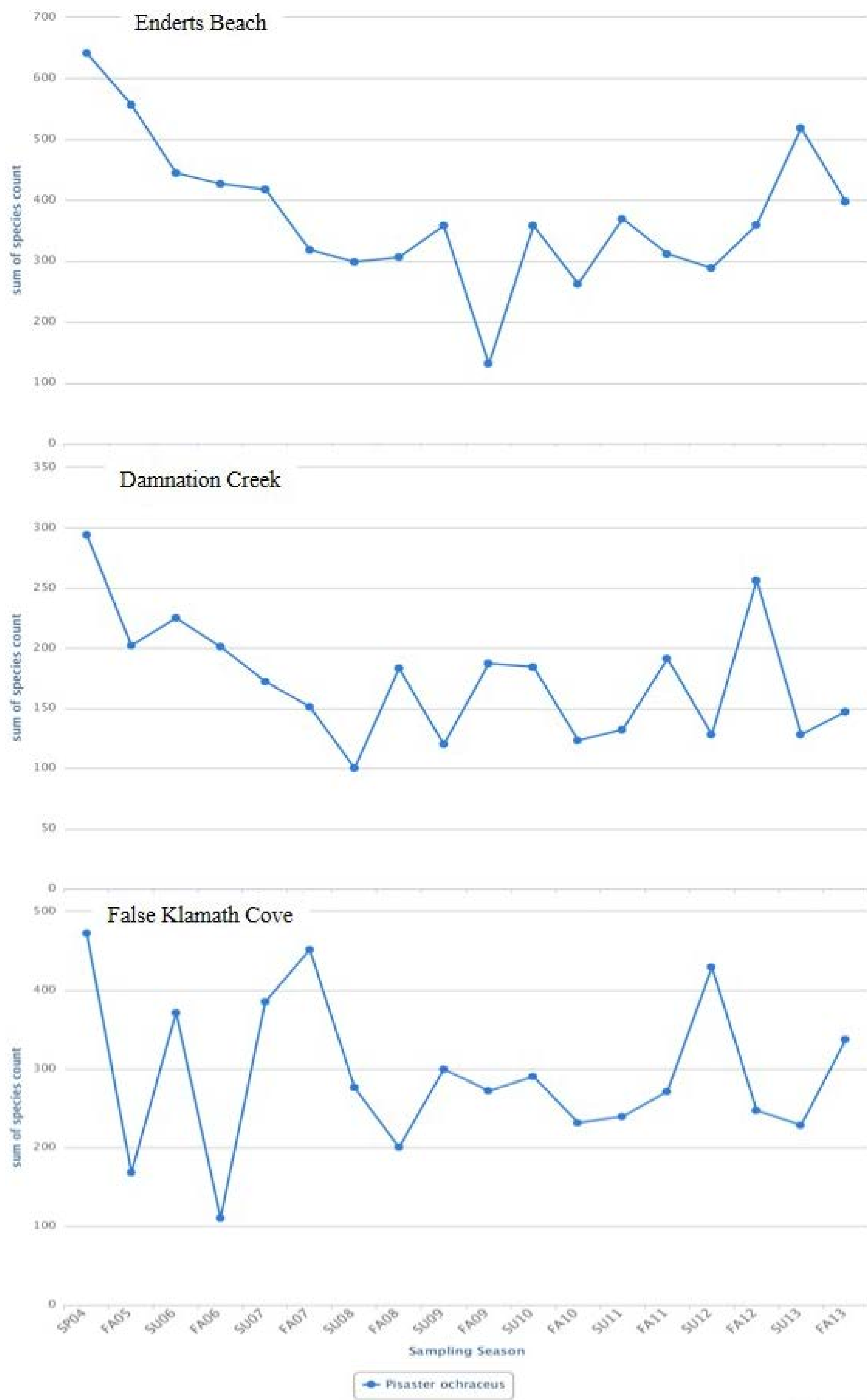


Figure 26. Total number of ochre sea stars (*Pisaster ochraceus*) per plot at three sites within the Redwood National and State Parks during sampling periods in 2004-2013. Note different scales on y-axis.

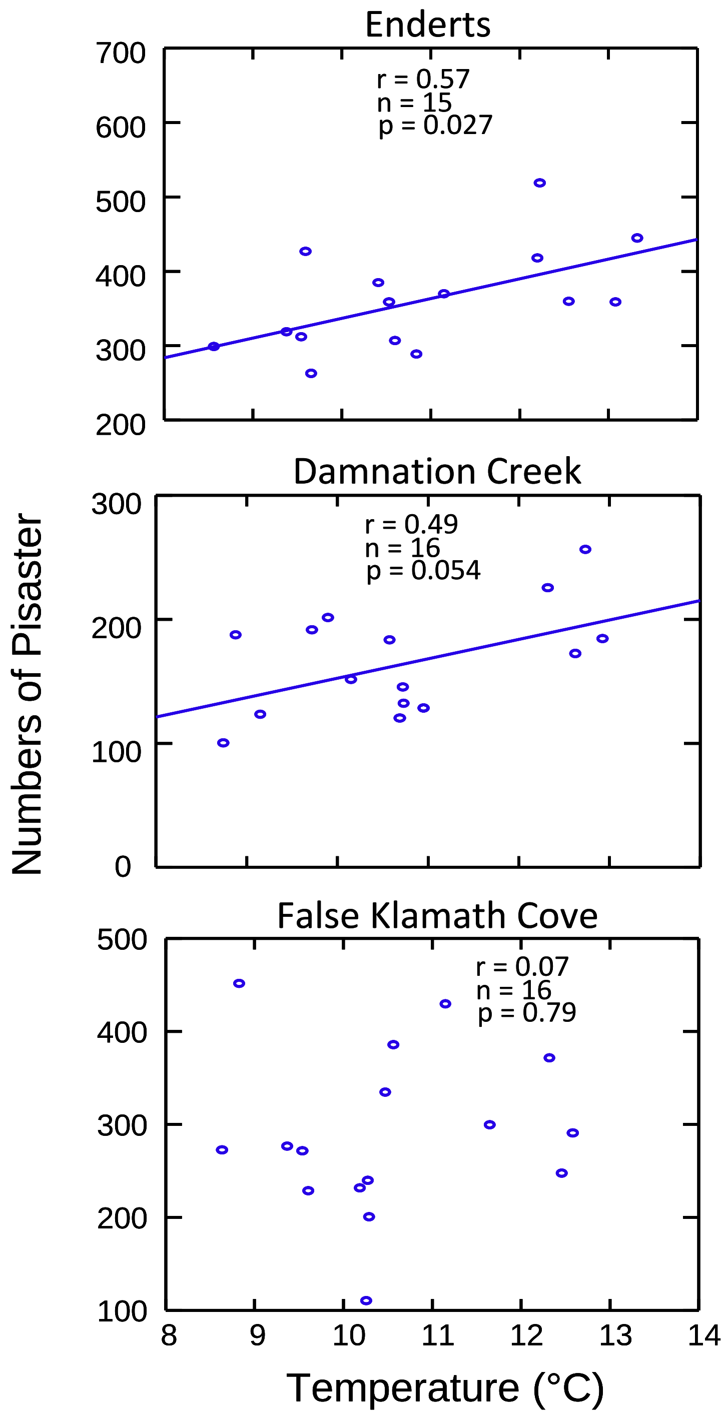


Figure 27. Regression plots for ochre sea star (*Pisaster ochraceous*) abundances and average temperatures at the Redwood National and State Parks intertidal sites from surveys conducted 2004-2013. Note the different scales on the y axes.

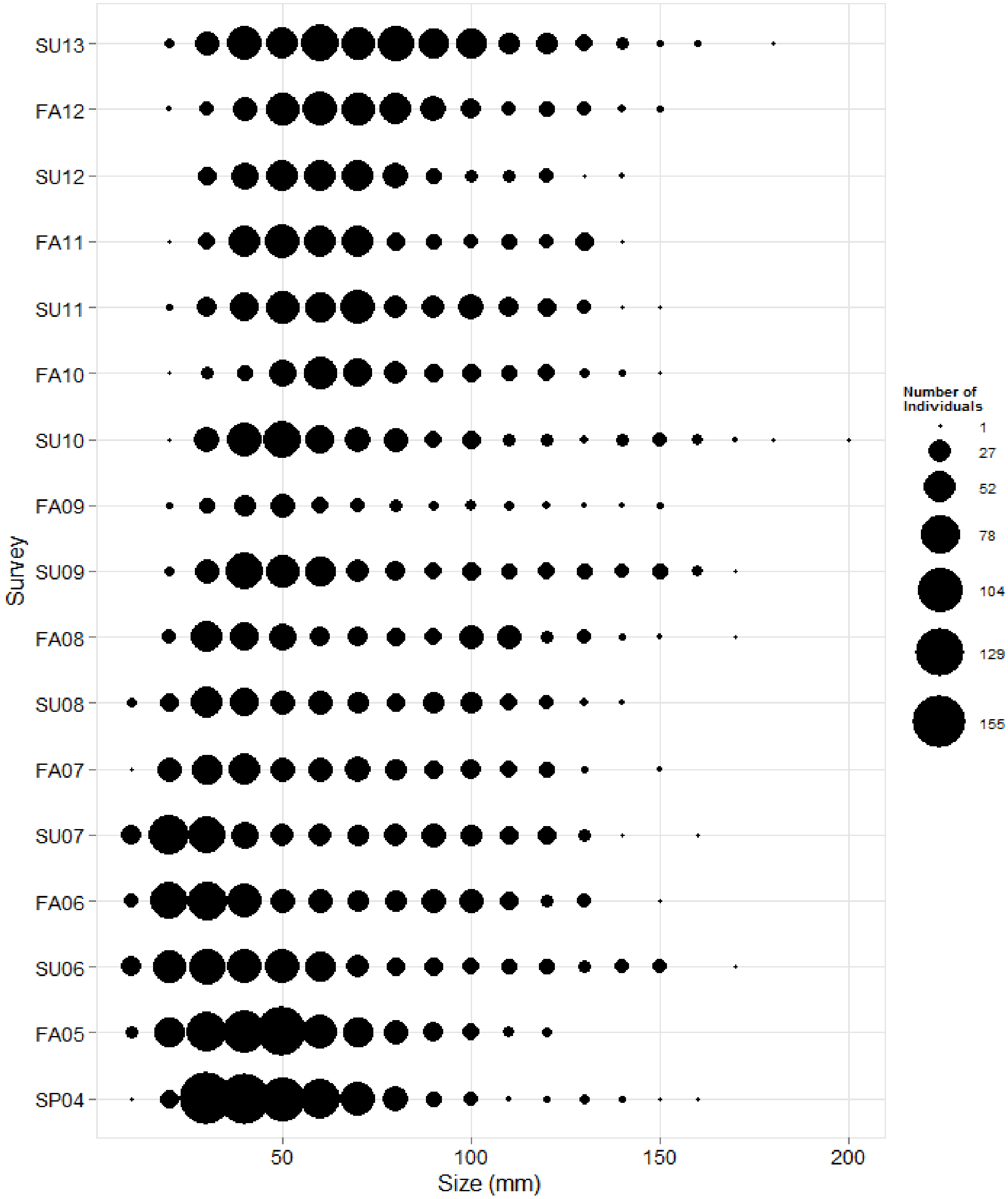


Figure 28. Size distributions of ochre sea stars (*Pisaster ochraceous*) at Enderts Beach during sampling periods in 2004-2013.

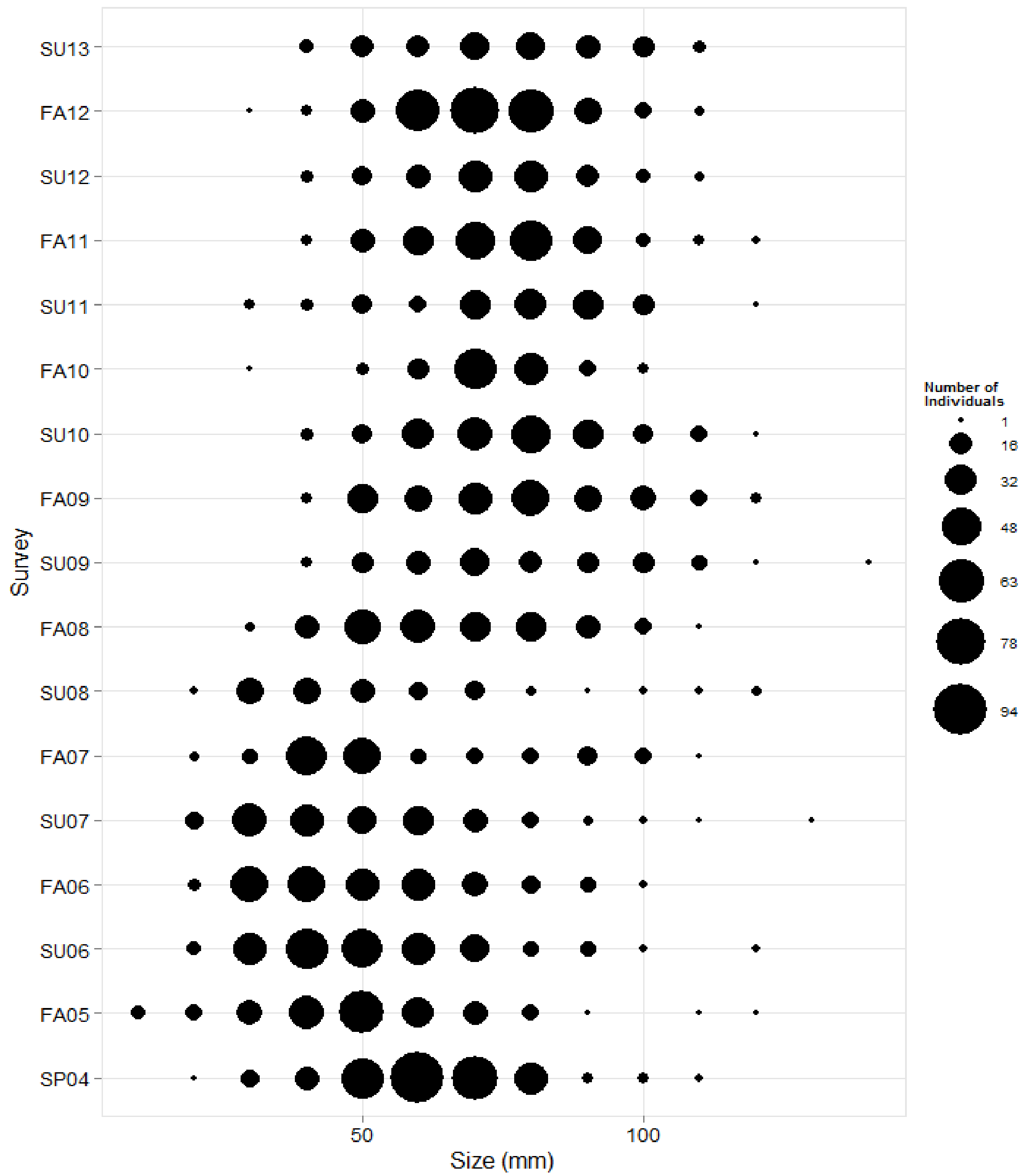


Figure 29. Size distributions of ochre sea stars (*Pisaster ochraceous*) at Damnation Creek during sampling periods in 2004-2013.

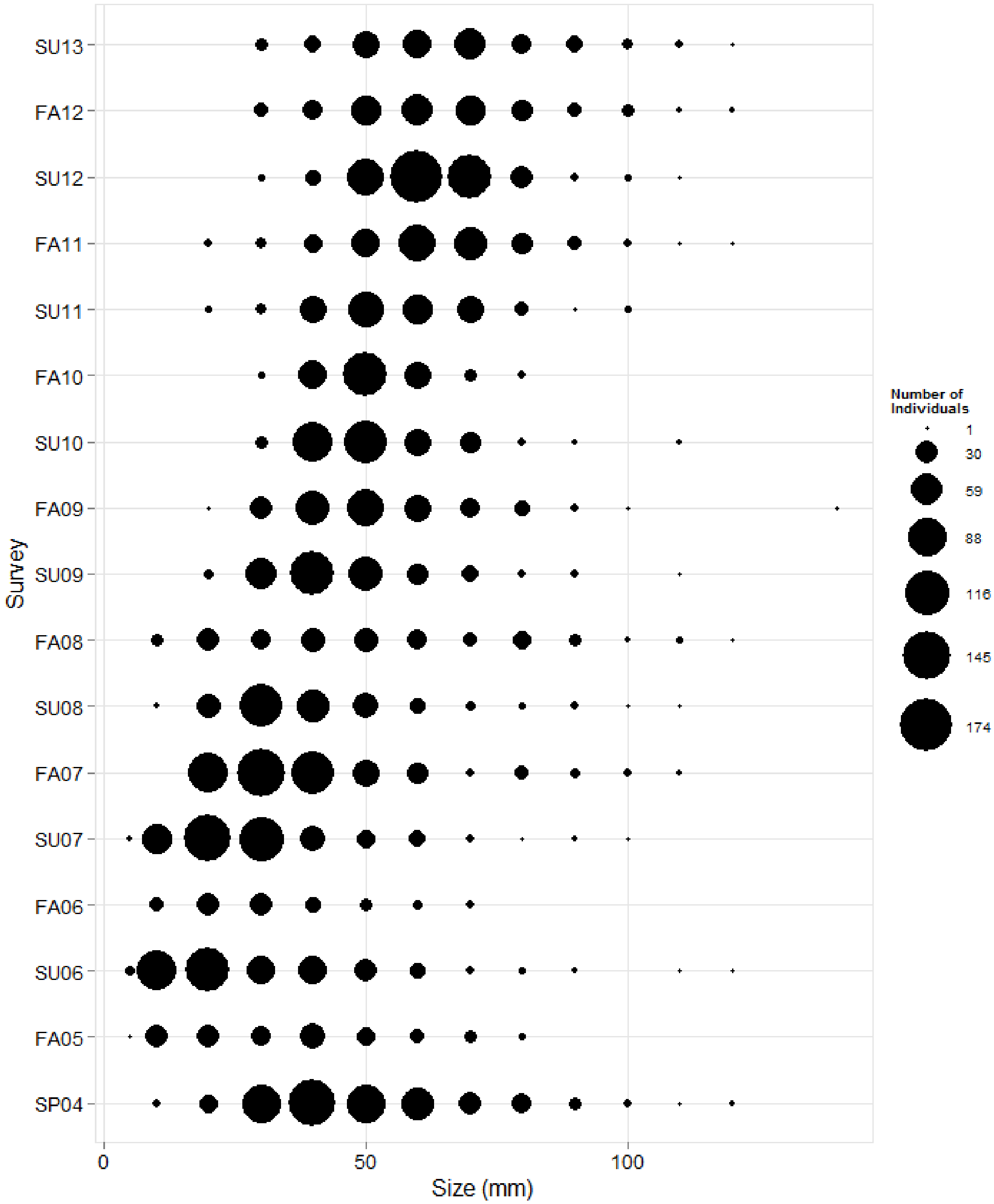


Figure 30. Size distributions of ochre sea stars (*Pisaster ochraceous*) at False Klamath Cove during sampling periods in 2004-2013.

Black Katy Chiton

Abundances of the black Katy chiton (*Katharina tunicata*) are monitored within the sea star plots which, as noted above, vary in sizes. Therefore, abundances of this chiton should not be compared across sites. At Enderts, abundances of the black Katy chiton declined over the course of the study (Figure 31, r=0.68, n=15, p=0.005). Although few black Katy chitons were ever present at Damnation Creek, abundances at this site also dropped over time (r=0.62, n=15, p=0.011). In comparison, at False Klamath Cove the numbers of black Katy chitons dropped from 2004 to 2008, but their numbers soon began to increase (Figure 31).

Mussel Measurements

There were slight differences in size structure of the mussels among the three sites (Figure 32). Specifically, while the populations at False Klamath Cove and Damnation Creek (plots 1-5) consisted mostly of individuals from 20-60 mm in length, those at Enderts and Damnation Creek (plots 6-10) included individuals up to 120 mm in length. When bed depth measurements (Figure 33) were compared to average mussel size, in all cases the ratios were greater than 1 (Figure 33), which indicates that the beds at these sites were comprised of more than one layer of mussels. This suggests that any measure of mussel abundance based on the visible layer (e.g. Figure 12) underestimates the true population size of the mussels. For example, while mussel cover did not change (Figure 12), in summer 2012 the depth:length ratio decreased dramatically at Damnation Creek (Figure 33). This suggests that despite a lack of change in cover, there was still a loss of mussels. The addition of mussel measurements to the sampling protocols in 2010 was in response to an increasing concern for baseline data necessary to mitigate after an oil spill through the NRDA (Natural Resource Damage Assessment) process.

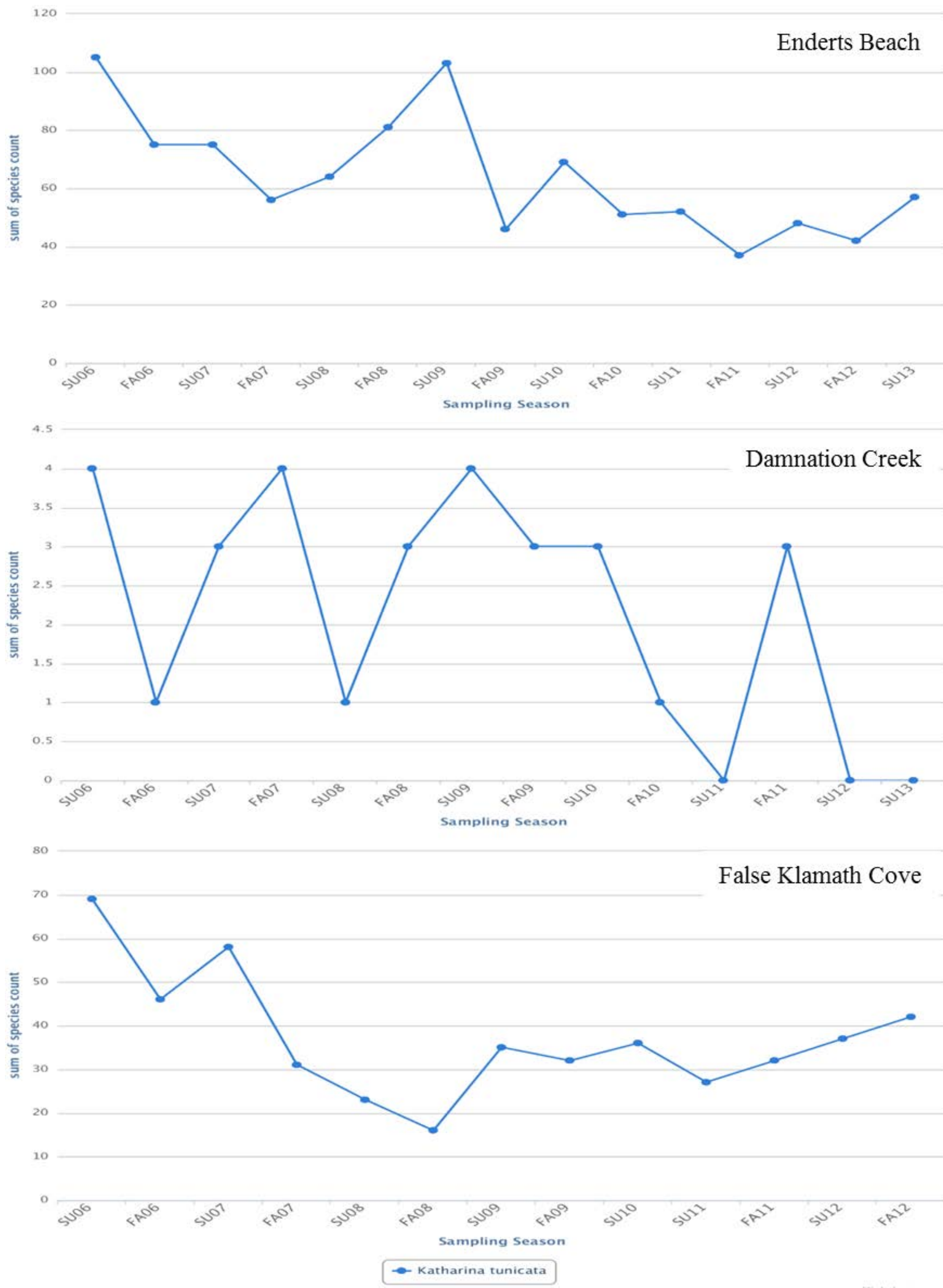


Figure 31. Total number of black Katy chiton (*Katharina tunicata*) in the sea star plots at three Redwood National and State Park sites from 2006-2013. Note different scales on y-axis.

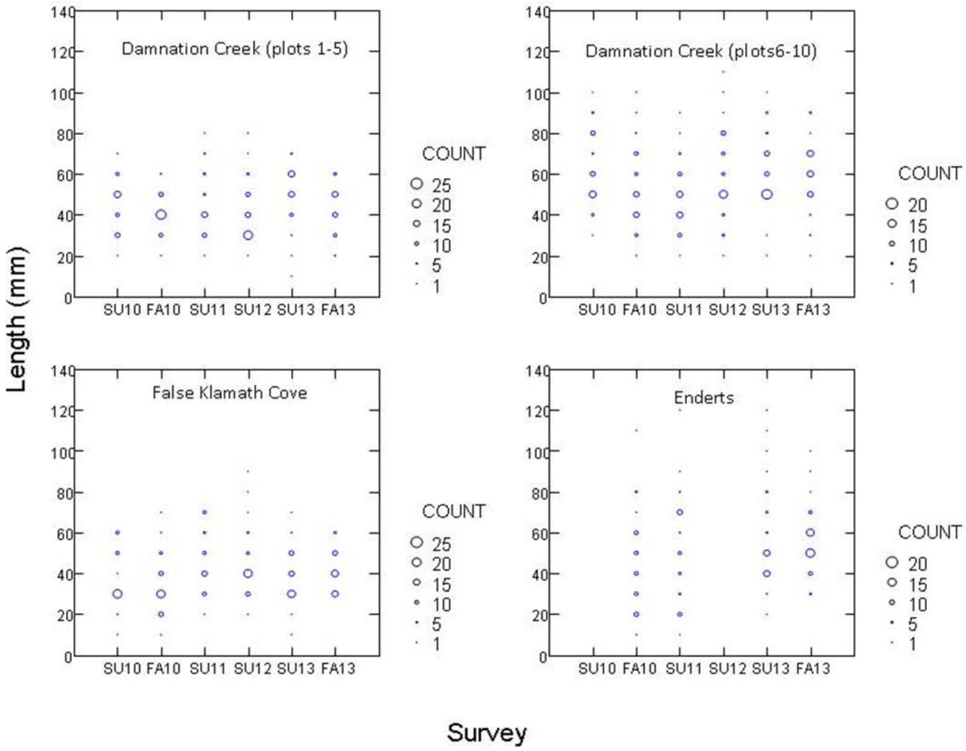


Figure 32. Size distributions of mussels (*Mytilus californianus*) at three sites within the Redwood National and State Parks during sampling periods in 2010-2013. Note: Some dates were not sampled at Enderts.

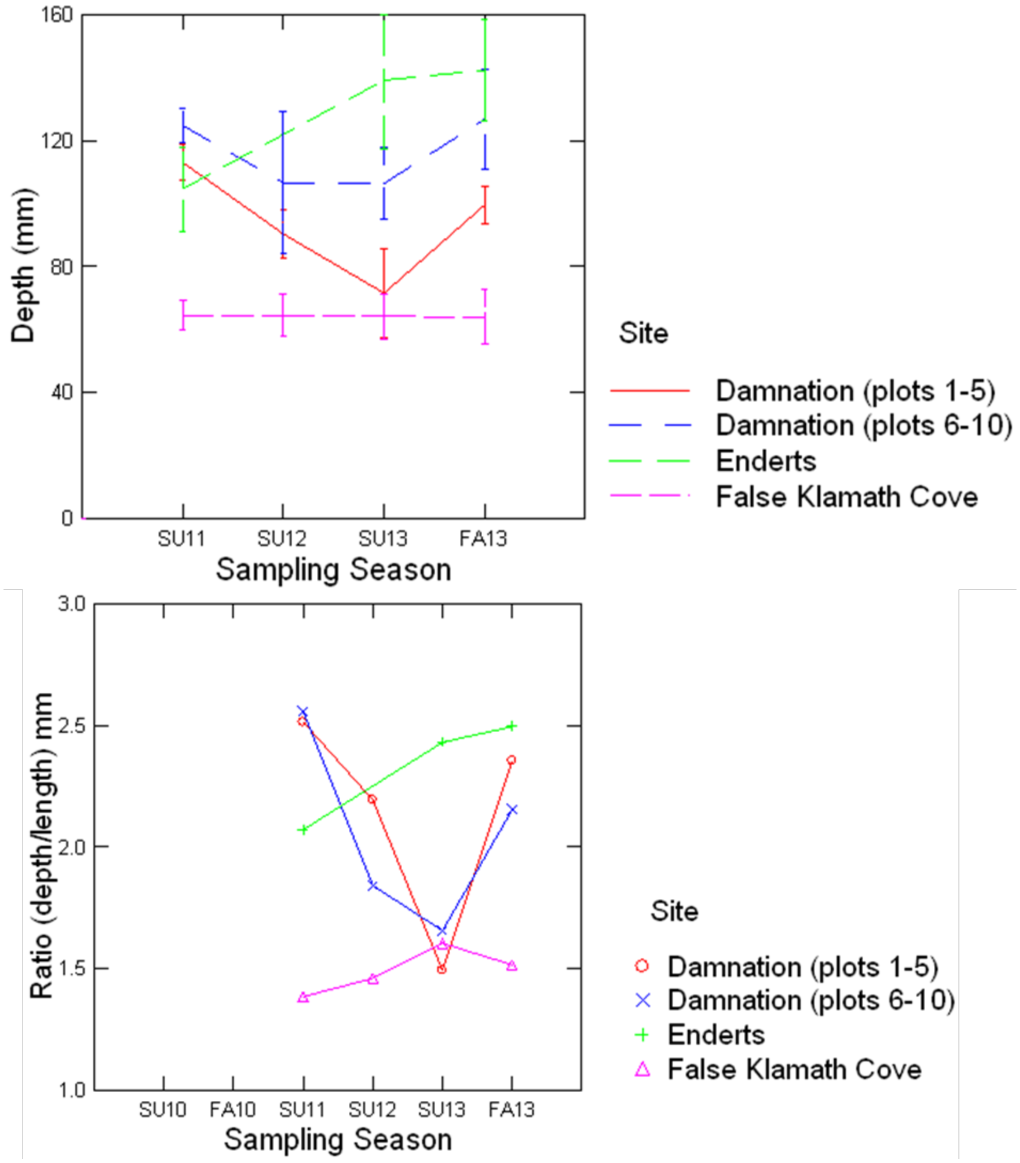


Figure 33. Measurements of depth (mm) of mussel (*Mytilus californianus*) beds and ratio of depth to length (mm) for Redwood National and State Parks sites from 2010-2013. Note: depth measurements were not taken in 2010.

Surfgrass and Sea Palm Transects

Over the course of the study, surfgrass abundance usually varied from 80 to 95% (Figure 34). The high cover of surfgrass throughout the study period suggests little disturbance to these sensitive areas. Recovery from small disturbances that leave most of the bed in tact has been shown to be rapid, and this was the case in the surfgrass transects at Damnation Creek that bounced back from a 20% dip in cover in 2010 to 95% cover by 2012. Because these plots were often inaccessible during the fall sample, it is unknown whether surfgrass abundances vary seasonally. Surfgrasses are major primary producers and support many species of invertebrates, algae, and fish. They are also sensitive to many types of disturbance such as sewage outflow and oiling (see Appendix B, *Phyllospadix* Natural History) which has led to their protection under US federal law.

Sea palm (*Postelsia palmaeformis)* transects at False Klamath Cove were established in 2013. Total numbers and densities for plot 1 decreased from 330 individuals (density of 27.5/m^2) in summer 2013 to 139 individuals (density of 11.6/m^2) in summer 2014. Plot 2 was only sampled in 2014 and had 363 individuals (density of 30.3/m^2). The sea palm is a protected species with limited commercial harvest allowed in California. Monitoring it within the RNSP will provide some baseline information and allow us to track the population within our plots.

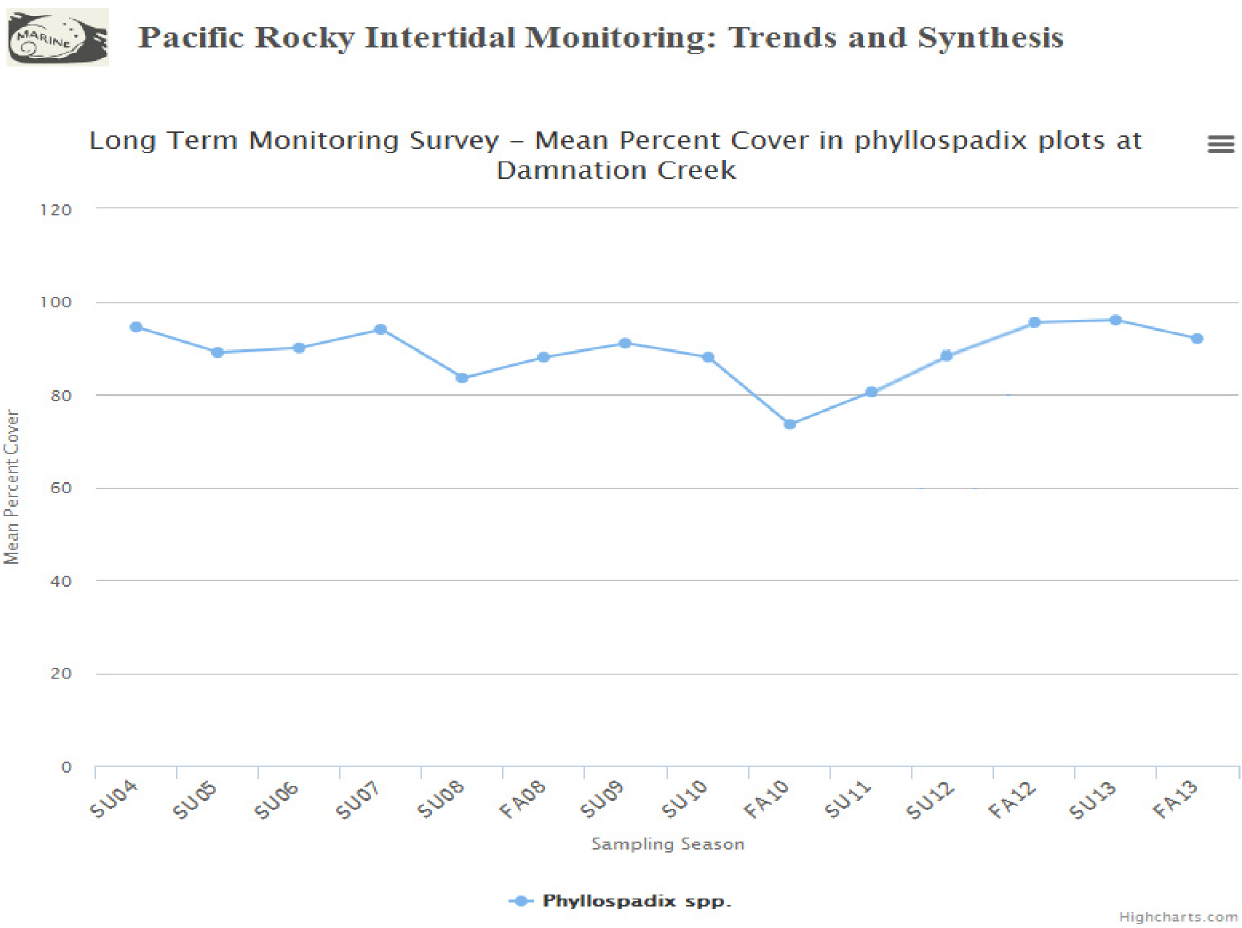


Figure 34. Mean percent cover of surfgrass at Damnation Creek within the Redwood National and State Parks during sampling periods in 2004-2013. During some fall sampling periods surveys could not be conducted.

Regional Comparisons

Broad scale spatial patterns that include RNSP sites can be seen at http://www.eeb.ucsc.edu/pacificrockyintertidal/broad-scale/index.html.

Biodiversity Surveys

The biodiversity survey conducted at Damnation Creek in 2004 found a total of 115 different taxa (Appendix D-2), approximately twice the number found during the 9 years of sampling community structure at this site (see Table 7 and Table 10). Although turfweed (*Endocladia*) and surfgrass (*Phyllospaddix* spp.) were the most common alga taxa found during the survey, there was also lot of open (unoccupied) space on the rock (Figure 35). The most common mobile invertebrate taxa found were the periwinkle snail (*Littorina* spp.), chink snail (*Lacuna* spp.), and limpet (*Lottia paradigitalis/strigatella*) (Figure 36). Although five taxa of sea star were found in the sea star swaths, by far the most common was the ochre sea star (Figure 37). A topographic map for Damnation Creek showing the general rugosity of the site is shown in Figure 38.

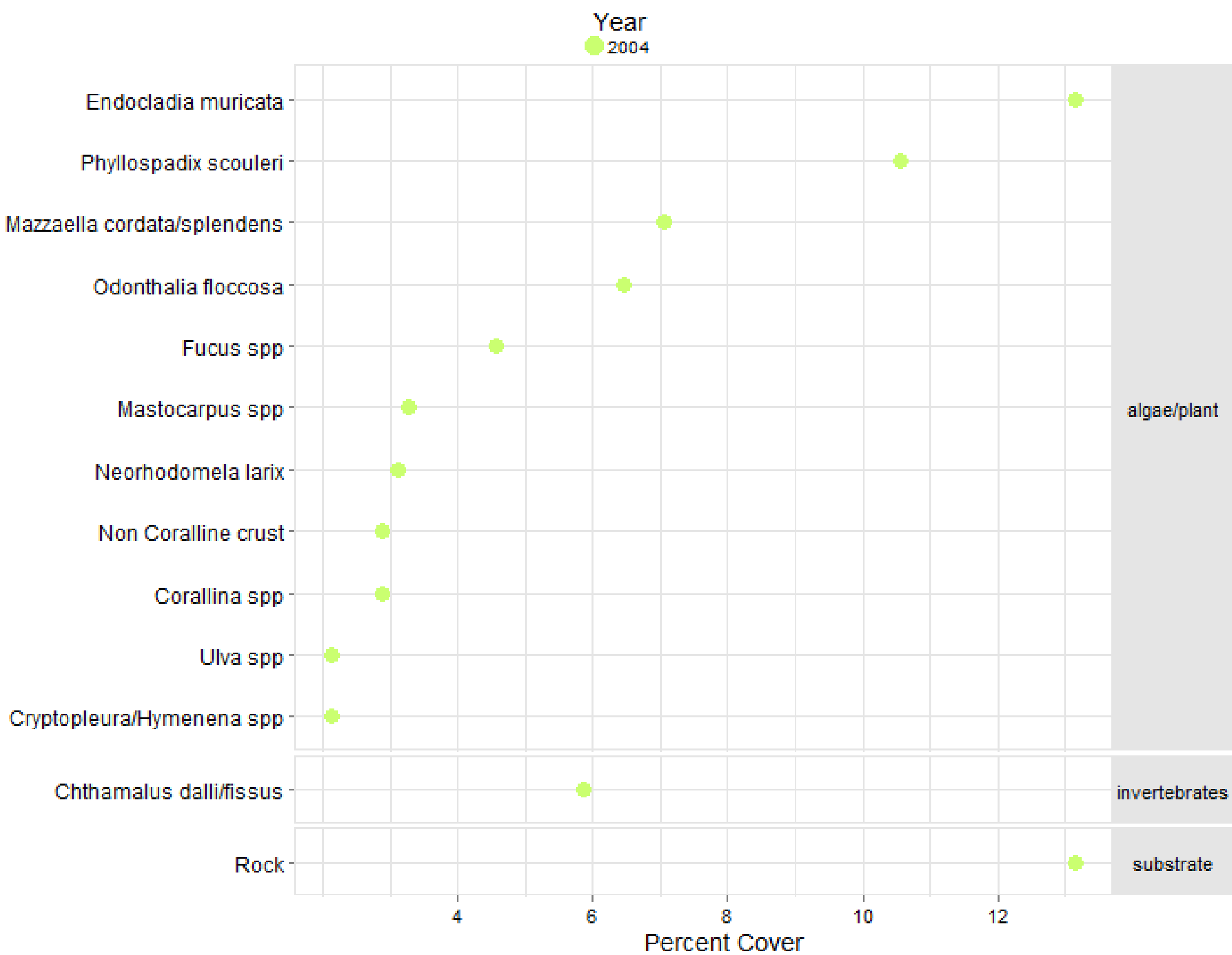


Figure 35. Percent cover of the most common species/substrate found during the point contact biodiversity survey at Damnation Creek in 2004.

Figure 36. Average density of mobile invertebrate species found during the biodiversity survey at Damnation Creek in 2004.

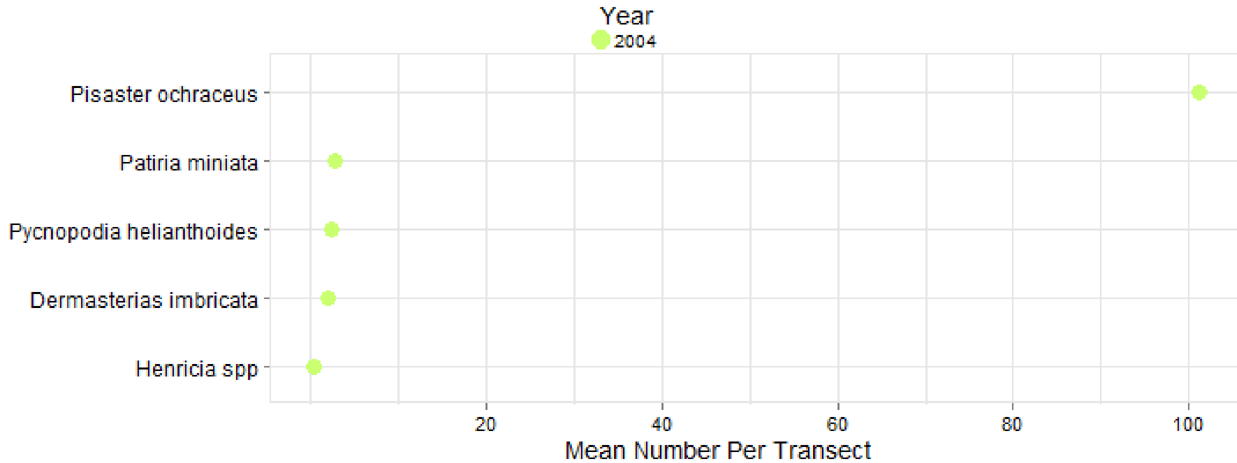


Figure 37. Sea star abundances for species found during the biodiversity survey at Damnation Creek in 2004.

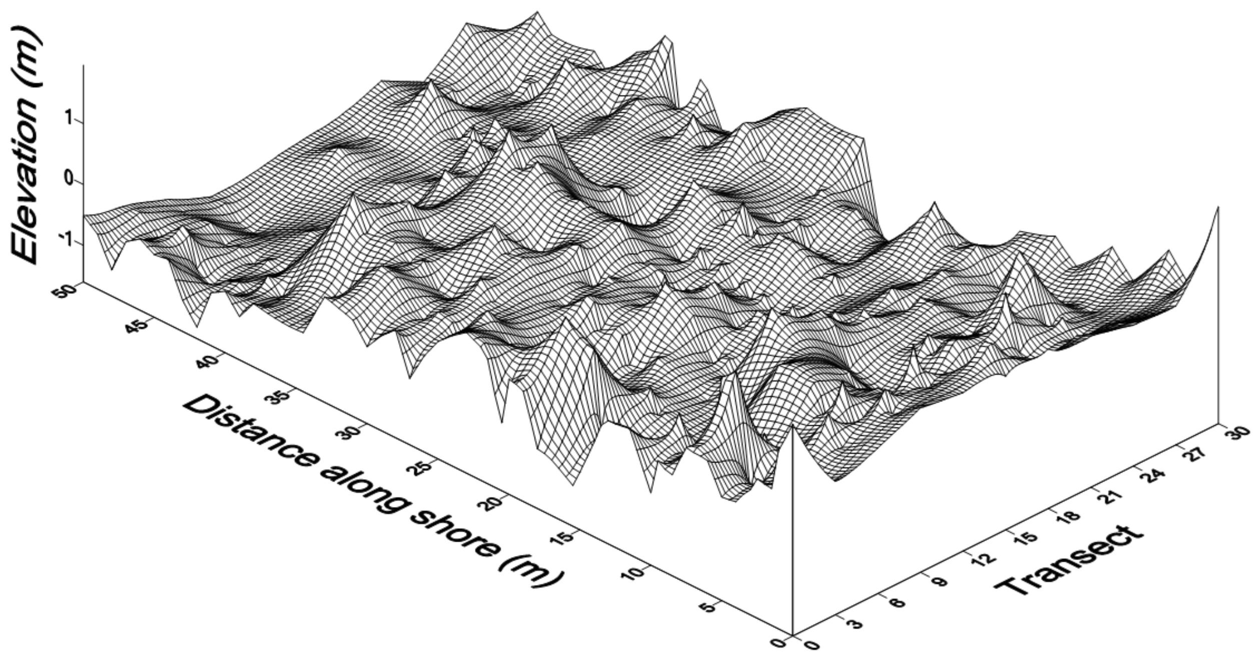


Figure 38. Topographic map of biodiversity survey grid at Damnation Creek. On the y-axis (distance along the shore) the high zone is at 0m, the low zone at 50m.

Through MPA funding, biodiversity sampling occurred in 2014-15 at the other sites within the RNSP. Combined with the panoramic photographs, these surveys provide information on a broader site-wide scale that can be used in conjunction with the long-term monitored permanent plots to provide a temporal and spatial assessment of intertidal community structure. The goals of these surveys are to detect trends and address fundamental questions related to biogeography, effects of human use, management of coastal resources, and conservation at a relevant spatial scale (the temperate west coast of North America).

Discussion

Because the intertidal area represents the transition zone between the terrestrial and marine environments, intertidal organisms spend part of their time immersed in water and part of their time exposed to air. Although dealing with this disparate set of environmental conditions can be challenging, rocky shore communities are highly diverse and include many species only found in this narrow band of coastal habitat. Rocky shores are one of the most accessible marine habitats which, while fostering a strong public appreciation of these communities, also makes them vulnerable to degradation via human activities (Smith et al. 2008). Natural temporal variation in rocky intertidal systems can be quite high and can occur on the scale of months (seasonal), years, and even decades, so long-term monitoring is essential for separating natural change from human-induced.

A primary objective of the RNSP monitoring program is to track changes in the structure of the intertidal community over time. To accomplish this, data on the distribution, abundance, and sizes of species found at several sites within RNSP are being collected. When collected over long periods of time, such data not only help our understanding of the processes that affect intertidal communities, they provide a baseline picture of the natural condition of the community. In the event of some type of larger-scale disturbance, either anthropogenic (i.e. oil spill, introduction of non-native species (Carlton and Geller 1993), climate change (Barry et al. 1995, Sagarin et al. 1999, Helmuth et al. 2006) or natural (i.e. disease, El Niño), this baseline can help managers assess the effects of this event on the structure of the intertidal community (Raimondi et al. 1999).

Although the data from the RNSP monitoring program show that the populations of both sessile and mobile intertidal species varied over time, with a few exceptions (declines in turban snails at False Klamath Creek, black Katy chitons at Enderts, and black Katy chitons and turfweed at Damnation Creek, and increases in limpets at Damnation Creek) there were no other significant long-term trends over the 9 years of this study. The few exceptions were not particularly drastic or noteworthy. Thus, to date there appears to have been little change to the structure of the intertidal communities in the plots at the three study sites, a result supported by the temporal consistency evident in the MDS analyses.

Although what caused the populations at the RNSP sites to vary over time was not directly investigated, since most intertidal species are either sessile or have limited mobility, it was probably not due to the immigration/emigration of individuals. Instead, it was likely due to variations in recruitment, mortality, or both. For example, it seems likely that the seasonal differences in abundance observed in some of the populations are due, in part, to the fact that they only recruit during certain parts of the year. The observed seasonal differences in size structure of the dog winkle *Nucella emarginata* supports this idea. The fact that the abundance of barnacles in the photoplots was positively correlated with the number of new barnacles in the clearings suggests that temporal variation in recruitment can also explain some of the longer-term differences in population size observed at the RNSP sites.

There is also evidence that temporal variation in disturbance, which can be an important source of mortality, can explain some of the variations in numbers of individuals at the RNSP sites. For example, small scale disturbances periodically caused the decline of mussels at Enderts by removing all of the mussels from one of the photoplots. Since this photoplot was soon filled in either by the encroachment of the surrounding mussels or by recruitment, in this case it did not take long for the community to "recover". Similarly, periodic disturbances also appear to eliminate large fractions of barnacle populations at the three sites. This may, in part, be due to the fact that when barnacles get crowded, they form hummocks (Barnes and Powell 1950, Wu 1980, Bertness et al 1998), a growth form that is highly unstable and susceptible to large waves/disturbances. Such hummocking has been observed at the RNSP sites.

Some of the variations in abundances at the RNSP sites might also be explained by temporal variations in oceanographic/environmental conditions. For example, at both Enderts and Damnation Creek, the number of sea stars was positively correlated, and the number of new barnacles in the clearings negatively correlated, to sea surface temperature. In the case of the sea stars, evidence suggests that colder water temperatures cause intertidal individuals to stop foraging and either seek places of refuge or move subtidally (Sanford 1999). Since the barnacles *Balanus glandula* and *Chthamalus* spp. both have planktonic larvae, the fact that barnacle recruitment was correlated with sea surface temperature most likely indicates that the amount of onshore larval transport depends upon oceanographic conditions. Interestingly, the decline in abundance of the turfweed *Endocladia muricata* at all three sites during the first part of this study appeared to coincide with a period of lower than normal water temperatures. Therefore, the population size of this alga may also be affected by changes in oceanographic/environmental conditions. Although abundances soon recovered at Enderts and False Klamath Cove, they have remained low at Damnation Creek, perhaps due to a lack of recruitment.

Comparisons between the current state of the RNSP intertidal community and previous observations made by Boyd and DeMartini (1977) indicate a shift from a highly disturbed, early successional community, to a more stable, late successional community. Variations in abundance due to small-scale spatial clearance have also decreased since the earlier study periods. Although such changes may be attributed to decreased sediment loads and lower quantities of driftwood due to decreases in logging activity (e.g. McGary 2005), without long-term monitoring data it is not possible to directly link the changes in community structure to the impacts of logging at these sites. The response and recovery rates of intertidal assemblages, similar to those studied in this report, after disturbances such as logging, oil spills and/or cleanup efforts such as power washing have been shown to vary by taxa as well as by biogeographic regions (Conway-Cranos 2012). This variability highlights the importance of long-term monitoring across a broad geographic range in order to successfully manage resources.

When disturbances such as oil spills occur, the NRDA process has requirements for detecting effects of the disturbance on ecosystems. In order to determine if the sampling framework utilized in the long-term monitoring program at RNSP would be useful in detecting a disturbance in the organisms monitored, a power analysis was performed on the existing data. The ability of this analysis to distinguish a situation (disturbance) different from the null hypothesis (natural variation) is the power. Given a power of 80%, we determined the level of change the photoplots could detect (Figure

13). For example, the MDDs over the study period in mussel plots is between 2-12 %, so if an unexpected disturbance (e.g. oil spill) wiped out 25 % of mussels, our sample design would allow us to detect that change. For all of the plot types at all three of the sites, the MDDs fell below 30% (below 15% for all surveys- method 1 and 2). That can be restated as, with a power of 80%, the monitoring protocols can detect an actual change in abundance of the target species >15%.

Since its inception in the early 1990's, the MARINe monitoring program has provided a wealth of information about the structure and dynamics of rocky intertidal communities along the western coast of North America. The data from the ongoing RNSP monitoring program have been vital to our understanding of the dynamics of the MARINe sites in northern California. The RNSP findings have and will continue to inform managers and policymakers and facilitate marine conservation through public outreach. For example, the data from the RNSP monitoring program have been used to help design the Marine Protected Area (MPA) network in the northern California region, and the protocols are used as the template for the monitoring program to assess the effectiveness of these reserves. As of December 2012, the MPAs for the northern coast of California have been designated, and the monitoring plan is underway. An important component of this monitoring plan was conducting biodiversity surveys at the existing RNSP sites between 2014-2015.

Following the recommendations of the US Commission on Ocean Policy, the Pew Commission Report, and the California Ocean Protection Act, California is rapidly moving towards a new era of marine resource management aimed at dealing with the impacts of humans on marine ecosystems (Raimondi 2009, 2011, Smith et al. 2008). Long-term monitoring programs, like the one in RNSP, are vital to this endeavor because they provide important information not only about the current state of populations and communities, but also about whether and how much they change over time.

Sea Star Wasting Disease

The largest sea star wasting syndrome event ever recorded has been devastating sea star populations at many sites along the west coast of North America (Stokstad 2014). This syndrome is characterized by the formation of white lesions in the ectoderm of the star, decay of tissue surrounding the lesions, fragmentation of the body, and death. The disease can appear and progress rapidly and has been observed in several sea star species including *Pisaster ochraceus*. Since *P. ochraceus* is considered a keystone species (Paine 1966), population declines have the potential to greatly alter the structure of the intertidal community. Previous incidences of this disease in southern California are thought have been associated with warmer than normal water temperatures and coincided with the 1982-1984 and 1997-1998 El Nino events (Eckert et al. 2000). The current wasting syndrome event is unique and puzzling due to its large spatial scale and the absence of El Nino conditions. Researchers are currently working to identify a potential pathogen as the causative agent, but the underlying cause remains unknown.

In June 2013, MARINe researchers observed *Pisaster ochraceus* affected by this disease at several sites in Washington. Since then it has been found at sites all along the western coast of North America, from Alaska to Baja California. At some sites, numbers of *P. ochraceus* have declined by more than 90% in monitoring plots (Ammann et al. 2014). At other sites, such as Enderts Beach and False Klamath Cove in RNSP, the disease is present but a noticeable decline has yet to be observed.

Preliminary assessments suggest a decline in sea stars has become apparent in many Northern California sites including all RNSP sites. As of 2014, Damnation Creek appears to have experienced greater than 50% loss of sea stars in the sampled plots, with 40% of the remaining stars showing signs of wasting. Although Enderts and False Klamath Cove numbers had not yet shown a significant decline, 8% and 40% of the ochre sea stars had some level of wasting disease. More information and current data are available at seastarwasting.org.

Continued monitoring at RNSP and other MARINe sites will allow researchers to further track the progression of the disease and its effects on both sea star populations and rocky intertidal communities as a whole. Furthermore, researchers have observed potential signs of recovery, such as high levels of recruitment and tissue regrowth in surviving stars, at some sites. Continued monitoring will allow the progression of the disease and its effects on both sea star populations and rocky intertidal communities as a whole to be determined at the three RNSP sites. Visit seastarwasting.org for updated information and data.

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Appendix A: Species Monitored

Target, Core and Optional Species Defined

The definitions of monitored species are adapted from the MARINe handbook (Engle 2005).

Target Species: “Target” species (also called key or indicator species) are species or species groups specifically chosen for long-term monitoring. They dominate particular zones or biotic assemblages in rocky intertidal habitats. The criteria for selecting target species include the following:

- Species ecologically important in structuring intertidal communities.
- Species that are competitive dominants or major predators.
- Species that are abundant, conspicuous or large.
- Species whose presence provides numerous microhabitats for other organisms.
- Species that are slow growing and long-lived.
- Species that have interesting distributions along California coasts.
- Species found throughout California shores.
- Species characteristic of discrete intertidal heights.
- Species that are rare, unique, or found only in a particular intertidal habitat.
- Species approaching their biogeographic limits in California.
- Species that have been well studied, with extensive literature available.
- Species of special human interest.
- Species vulnerable and/or sensitive to human impacts, especially from oil spills.
- Species with special legal status.
- Introduced or invasive species.
- Species harvested by sport or commercial activities.
- Practical species for long-term monitoring.
- Readily identifiable, non-cryptic species.
- Sessile or sedentary species of reasonable size.
- Species located high enough in the intertidal to permit sufficient time to sample.

Currently, there are **18 designated target species monitored by MARINe***:

Egregia menziezii

Fucus gardneri

Hedophyllum sessile

Hesperophycus californicus

Pelvetiopsis limitata

Silvetia compressa

Endocladia muricata

Neorhodomela larix

Phyllospadix scouleri/torreyi

Anthopleura elegantissima/sola

Mytilus californianus

Lottia gigantea

Haliotis cracherodii

Chthamalus dalli/fissus/Balanus glandula

Semibalanus cariosus

Tetraclita rubescens

Pollicipes polymerus

Pisaster ochraceus

*underlined species are currently monitored at RNSP sites.

Designated target species have the highest priority for monitoring. They are monitored at as many sites as possible. If the species is present in sufficient numbers and it is logistically possible, plots or transects are established to monitor it. More information on target species (e.g., photos and how to identify) can be found on the MARINe public website.

Core Species: "Core" species are those **species, species groups, or substrates that are scored using one or more survey methods by everyone in MARINe**. Core species must be reasonably and consistently identifiable using the designated scoring protocol (e.g., from labscored photos of fixed plots possibly supplemented by plot sketches/notes). They also must be important enough to warrant scoring for abundance trends. Some of these species only occur at northern sites, or conversely, southern sites, yet to ensure that we notice if they expand their range, we must score everywhere. All target species are core species. It is important that **scorers in all monitoring groups be able to identify and record all core species. Data sheets must include all core species**, though core species that are absent or rarely occur at a site can be deemphasized. Entries for all core species will be required for data submission to the MARINe database.

Optional Species: “Optional” species are **non-core species or species groups that one or more monitoring groups choose to score at their sites; however, for various reasons, are not appropriate or feasible for all groups to score**. Since optional species will not be scored by everyone, coast-wide comparisons of trends for these species will be limited or not possible. However, all groups sampling MARINe north sites (NorCal, RNSP and Oregon) use the same list of optional species.

Appendix B: Natural History of Target Species

These brief descriptions provide context for the selection of these target species by including information on life history, ecological importance, and sensitivity to anthropogenic activities. Descriptions of the natural history of the target species monitored in this study have been adapted with permission from the Pacific Rocky Intertidal Website http://www.eeb.ucsc.edu/pacificrockyintertidal/target/index.html#target-list

Endocladia muricata (Turfweed)

Description

Thalli are densely bushy, dark red to blackish brown tufts, 4-8 cm tall. Branches are cylindrical throughout, covered with small conical spines (Abbott and Hollenberg 1976).

Natural History

Endocladia is common north of Point Conception and one of the most common algae in central California, forming distinctive dark bands along the upper shoreline. *Endocladia* abundance fades in warmer waters to the south, being largely replaced in lower portions of its zone by other small red algae (e.g. *Gelidium* spp.) *Endocladia* often grows with other small reds (e.g. *Mastocarpus papillatus*, *Gelidium* spp.) to form a low, tight turf that traps sediment and moisture, and provides a sheltered microhabitat for a host of small organisms. Glynn (1965) found over 90 species associated with *Endocladia* clumps in Monterey.

Endocladia has been shown to facilitate recruitment of *Silvetia compressa*, possibly by providing propagules protection from dislodgement, grazing, and/or desiccation (Johnson and Brawley 1998). Turfweed also can provide habitat for attachment of young mussels. Expanding mussel patches may displace *Endocladia*, but it can then grow on the mussel shells, creating a layered assemblage. Some *Endocladia* clumps appear donut- or crescent-shaped; this condition may be caused by storms tearing out center areas possibly weakened by accumulated anoxic sediment.

Endocladia is hardy and quite resistant to desiccation, yet vulnerable to oiling from spills due to its location in the high intertidal. Recovery from natural or human disturbances may vary from 1 to more than 6 years (see Kinnetics 1992).

Phyllospadix spp. (Surfgrass)

Description

Surfgrass is an angiosperm with true leaves, stems, and rootstocks; not an alga.

P. scouleri leaf blades are characteristically flat and wide (2-4 mm) reaching no longer than 3 feet in length. Leaves arise from a congested rhizotomous base and flowers are found near the base on short stalks (1-6 cm). *P. torreyi* leaves are characteristically less than 2 mm wide and are generally more firm, cylindrical, and wiry than *P. scouleri*. Leaf blades can reach up to 10ft long. The leaves arise from a congested rhizotomous base with flowers on elongate stalks (>10 cm long). (Adams 2006).

Natural History

Surf grasses grow as perennials and adult plants are reproductively dioecious with male and female flowers on different adult plants. Surf grasses can pollinate both underwater and at the surface in sea water. Surfgrass ranks amongst the most productive of the marine primary producers (Duarte and Chiscano 1999), with these habitats providing shelter for many invertebrates and supporting many species of algae (Stewart and Myers 1980). The red algae *Smithora naiadum* and *Melobesia mediocris* are exclusively epiphytic on sea grasses (Abbott and Hollenberg 1976). Surfgrass also provides nursery habitat for fishes and invertebrates, some of which are commercially important, such as the California spiny lobster (Engle 1979).

Surfgrass beds increase water clarity by filtering water and trapping sediments and can stabilize the sediment, preventing erosion. Surfgrass metabolism changes the concentration of carbon and oxygen in water by sequestering carbon dioxide and respiring oxygen. Surfgrass forests can modify the severity of water currents, making near shore habitats relatively protected from big surf. The structure of surfgrass canopies modifies water current velocity and waves, enhancing sedimentation of suspended particles and preventing sediment resuspension (Garcia and Duarte 2001).

Phyllospadix is susceptible to desiccation and heat stress during low midday tides (Raimondi et al. 1999). It is also sensitive to sewage (Littler and Murray 1975) and oiling (Foster et al. 1988). If the rhizome systems remain viable, recovery following disturbance can be fairly rapid; however, if the entire bed is lost recovery is slow because recruitment is sporadic and restoration projects have thus far been unsuccessful (Turner 1983, 1985). Other threats to surfgrasses include coastal development, thermal pollution (power plants), invasion of non-natives (e.g. *Caulerpa taxifolia*), and dislodgement caused by anchors. The sensitivity of surfgrass habitats to declines in ecosystem health, coupled with their fundamental role in sheltering countless other species (many of which have commercial value), has led to their protection at the United States federal level under Section 404 of the Clean Water Act as well as in Section 10 of the Rivers and Harbors Act. The Environmental Protection Agency holds the responsibility of enforcing these pieces of legislation which aim to protect these habitats from unpermitted dredging and filling activities (Green 2003).

Chthamalus dalli **and** ***Balanus glandula*** **(Acorn Barnacles)**

Description

C. fissus/dalli: small barnacle, up to 8 mm in diameter. Shell is brown-grey in color and smooth. Operculum is oval. These species are virtually indistinguishable in the field.

B. glandula: bigger barnacle than *C. fissus/dalli*, up to 22 mm in diameter. Shell is white to gray in color. Operculum is white and diamond-shaped. Plates are deeply ridged (Morris et al. 1980).

Natural History

Acorn barnacles, *Chthamalus fissus/dalli* and *Balanus glandula*, typically dominate the high intertidal zone along the western coast of North America. Acorn barnacle species can be difficult to identify in photographic monitoring, but *B. glandula* can be distinguished from *C. fissus/dalli* by its larger size (to 22 mm), whiter color, and diamond-shaped operculum. The configurations of their exoskeletal plates also differ. To distinguish *C. fissus* from *C. dalli* requires dissection and microscopic examination of the opercular plates. A bent morph of *C. fissus*, similar to that seen in the Gulf of California species *Chthamalus anisopoma*, has been documented at several Long-Term Monitoring sites (Miner et al. 2005).

Acorn barnacles are hermaphroditic as adults and spawn often, at variable times throughout the year (Hines 1978). The planktonic larvae can settle in incredible densities (to 70,000/m^2), forming a distinct band along the upper intertidal that contain few other invertebrates except littorines and the heartiest limpets. *Balanus glandula* can out-compete *Chthamalus fissus/dalli* by crowding or smothering, but *C. fissus/dalli* can occupy higher tide levels than *B. glandula* because it is more resistant to desiccation. Lower on the shore, acorn barnacles mix in with the *Endocladia* (Turfweed) assemblage, and are also common on mussel shells.

Chthamalus fissus/dalli grows rapidly, but only survives a few months to a few years. *Balanus glandula* can live longer (to 10 years), but its larger size and lower tidal position subject it to higher levels of mortality from predatory gastropods and ochre sea stars. Acorn barnacles (particularly *B. glandula*) facilitate the recruitment of *Endocladia* and fucoid algae by reducing the grazing pressure of limpets (Farrell 1991). Long-Term monitoring data have shown this facilitation at several sites, where barnacle plots have become slowly inundated by *Endocladia, Pelvetiopsis*, and *Silvetia* (Miner et al. 2005).

Acorn barnacles are highly vulnerable to smothering from oil spills because floating oil often sticks along the uppermost tidal levels. Significant, widespread barnacle impacts were reported after the 1969 Santa Barbara oil platform blow-out (Foster et al.1971) and the 1971 collision of two tankers off San Francisco (Chan 1973). However, high recruitment rates may promote relatively rapid recovery of acorn barnacles; disturbance recovery times ranging from several months to several years have been reported (see Vesco and Gillard 1980).

A condition referred to as "hummocking" is observed in acorn barnacles at several monitoring sites. Hummocking occurs in response to high recruitment densities and growth rates, which intensify competition for primary substrate space (Bertness et. al. 1998). This condition causes crowded barnacles to grow up instead of out until they eventually grow so high that they are susceptible to removal by wave action. Evidence of hummocking was observed at all three monitored sites within RNSP. Frequently, large patches of barnacles would be entirely removed from one sampling period to the next.

Mytilus californianus (California Mussel)

Description
Mussel shell to about 130 mm long. Shell is a bluish-black color, often with eroded white valves and darker at margins. Anterior end of shell is sharply pointed. Prominent radial ribbing but also concentric growth lines present (Morris 1980).

Natural History

The California mussel forms extensive beds, which may be multi-layered (usually in the northern part of its range). Mussels attach to hard substrate by secreting byssal threads at the base of the foot (Morris et al. 1980). Byssal thread production appears to be possible only when water flow is <50 cm/s. Although wave action in the intertidal results in flow rates much higher than this, mussel aggregations greatly reduce water flow within the beds and make possible the production of byssal threads (Carrington et al. 2008). Thick (20 cm) beds of California mussels trap water, sediment, and detritus that provide food and shelter for an incredible diversity of plants and animals, including cryptic forms inhabiting spaces between mussels as well as biota attached to mussel shells (Paine 1966, MacGinitie and MacGinitie 1968, Suchanek 1979, Kanter 1980, Lohse 1993). For example, MacGinitie and MacGinitie (1968) counted 625 mussels and 4,096 other invertebrates in a single 25 cm^2 clump, and Kanter (1980) identified 610 species of animals and 141 species of algae from mussel beds at the Channel Islands. Kinnetics (1992) documented locational differences in the composition and abundance of mussel bed species. Northern sites had densely packed, multi-layered beds, but the more open southern sites had higher species diversity.

The California mussel spawns all year but spawning peaks in July and December in California. Young mussels settle preferentially into existing beds at irregular intervals, grow at variable rates depending on environmental conditions and eventually reach ages of 8 years or more (see Morris et al. 1980, Ricketts et al. 1985). *M. californianus* is a filter feeder, and is quarantined from collection/consumption from late spring to early autumn because the toxin from a dinoflagellate accumulates in the tissue (Kozloff 1983). This toxin can cause paralysis and death.

While mussels can tolerate typical rigors of intertidal life quite successfully, desiccation likely limits the upper extent of mussel beds, storms tear out various-sized mussel patches and sea stars prey especially on lower zone mussels. Beds that are already patchy or thinned by human disturbance (e.g. via trampling or collection for bait) have increased susceptibility to wave damage. Mussels have also been found to be adversely affected by oil spills (Chan 1973, Foster et al. 1971). Recovery from disturbance varies from fairly rapid (if clearings are small and surrounded by mussels that can move in) to periods greater than 10 years (if clearings are large and recruitment is necessary for recolonization) (Vesco and Gillard 1980, Kinnetics 1992).

Pisaster ochraceus (Ochre sea star)

Description
Highly variable in color; most commonly purple, but can also be orange, orange-ochre, yellow, reddish, or shades of brown. A "brilliant purple" morph is common in the inland waters of Washington and British Columbia. Average arm radius in California/Oregon is around 9 cm (Harley et al. 2006, Raimondi et al. 2012) but can reach 3x this size. Individuals usually have 5 arms but this can vary from 4 to 7. Aboral surfaces have many small white spines arranged in detached groups or in a reticulate pattern, generally forming a star-shaped design on central part of disk (Morris et al. 1980). Tube feet on the undersides of arms have suckers that allow them to remain attached to rock in high wave energy shores.

Natural History
Pisaster ochraceus sea stars have long been referred to as keystone species in the rocky intertidal (Paine 1966, Menge 2004) and, while they are known to have a wide diet (including barnacles, snails, limpets, and chitons), mussels are their primary prey items on the open coast (Morris et al. 1980, Harley et al 2006). In the protected inland waters of Washington and British Columbia, mussels are often rare and *P. ochraceus* feeds primarily on barnacles and whelks (Harley et al. 2006). Using their tube feet to pull the valves apart, *P. ochraceus* are able to evert their stomachs and insert them between the valves of a mussel (Morris et al. 1980). Interactions between ochre stars and their prey have been well researched, especially the role of *P. ochraceus* in determining the lower limit of northern mussel beds (Paine 1966, 1974; Dayton 1971). Motile prey have been shown to exhibit escape responses to the chemical presence of *P. ochraceus* (Morris et al. 1980). A study examining the effect of low tide body temperature of *P. ochraceus* on feeding rates showed that aerial body temperatures experienced by *P. ochraceus* can have profound effects on predation rates (Pincebourde et al. 2008).

Ochre sea stars stand out in the intertidal due to their vibrantly contrasting color differences, ranging from bright orange to purple. Data from long-term monitoring has shown a consistent color frequency of approximately 20% orange stars across a large geographic range of exposed coast

(Raimondi et al. 2007). The underlying cause of color polymorphism in *Pisaster ochraceus* is not fully understood, but it has been suggested that diet may play a key role (Harley et al. 2006).

Pisaster ochraceus is a broadcast spawner, with fertilization occurring in the water and development resulting in a free-swimming, feeding larva (Morris et al. 1980). These sea stars are able to regenerate arms that are lost and are thought to live up to 20 years (Morris et al. 1980). Ochre sea stars have few predators, but seagulls and sea otters occasionally eat them, and they are often collected by curious tidepool visitors due to their striking colors. Throughout southern California, severe declines of *P. ochraceus* (and other sea star) populations have been documented in association with warm-water periods since 1978, with greatest losses during El Niño events such as occurred in 1982-1984 and 1997-1998 (Eckert et al. 2000). The causative agent for this sea star wasting disease (see http://www.eeb.ucsc.edu/pacificrockyintertidal/data-products/sea-star-wasting/index.html) has not been confirmed, but may be a *Vibrio* bacterium (Eckert et al. 2000). Population recovery, apparently due to cooler-water conditions and large recruitment events, has been documented in many, but not all areas (Blanchette et al. 2006, Raimondi et al. 2012). *P. ochraceus* wasting disease has recently been recorded as far north as British Columbia, also associated with high water temperatures (Bates et al. 2009). Sensitivity to oil spills is not well known, but Chan (1973) saw no obvious effects from a San Francisco oil spill.

***Pelvetiopsis limitata* (Dwarf Rockweed)**

Description

This perennial brown alga stands between 4-8cm tall and is light tan to olive in color arising from a small discoid holdfast. The densely branched thallus is cylindrical at the base, becoming flattened to cylindrical in the upper fronds. The dichotomously divided branches tend to arch inward and lack midribs (Abbott and Hollenberg 1976).

Natural History

Pelvetiopsis limitata is considered a good indicator organism of exposed rocky coasts. It forms extensive zones in the high intertidal region and is fed on by limpets and other invertebrate grazers. *Pelvetiopsis* is most closely related to *Hesperophycus* (Serrão et al. 1999), with both genera producing one large egg per oogonium. Two species of *Pelvetiopsis* occur in California, *P. limitata* and *P. arborescens*. The former species more closely resembles a dwarf *Fucus*, whereas the latter is similar in appearance to a small *Silvetia* due to its more cylindrical branches (Abott and Hollenberg 1976). In central California, *P. limitata* can co-occur with *Silvetia compressa* although *P. limitata* is generally found at higher tidal elevations. When identification is in doubt, specimens can be examined microscopically to determine the number of eggs per oogonium. *P. limitata* has only one egg per oogonium while *Silvetia* has two and *Fucus* eight.

Little scientific attention has been given to *Pelvetiopsis limitata* leaving much of its reproductive periodicity, longevity, and ecology unknown. *P. limitata* may be an indicator species of human traffic. A study on human trampling effects showed that *P. limitata* was markedly absent from the most heavily trampled sites and suggested that it may be highly susceptible to breakage especially when growing on the edges of rocks (Beauchamp and Gowing 1982). *P. limitata* also becomes detached from the substrate during winter storms which are predicted to increase in intensity and frequency due to climate change. Recruitment and survival of *P. limitata* embryos are higher under the canopy of adults especially in higher tidal elevations (Skene 2009). Predicted effects of climate change and the resulting sea level rises on this high zone species include increased rates of adult mortality and limited ability to shift its distribution to higher elevations (Skene 2009).

Fucus gardneri **(Northern Rockweed)**

Description

This olive-brown thallus can reach up to 50 cm tall and 15-25 mm wide. Individuals in protected sites are often larger than those at exposed ones. Branches are flattened and dichotomously branched with a distinct midrib. Reproductive conceptacles are concentrated at branch tips (swollen when mature).

Natural History

Fucus gardneri forms broad, dense canopies in the mid intertidal zone and can extend well into the high zone, with plants becoming smaller and less dense at the upper edge of its tidal range. This fucoid is tolerant of a wide range of salinities, and occurs on the outer coast, on protected inland shores, and even in areas inundated by freshwater (O'Clair and Lindstrom 2000). *F. gardneri* canopies are important for providing protection from desiccation to a suite of other algae and invertebrates. Some grazers inhabiting the *F. gardneri* understory have been shown to facilitate the persistence of the rockweed by selectively grazing other algae that compete with *F. gardneri* for space. For example, the littorine,*Littorina sitkana* aids in the succession of *F. gardneri* by preferentially consuming more ephemeral algae like *Ulva lactuca* and *Enteromorpha* (Lubchenco 1983).

The life history of this algal species is diplontic, with a diploid thallus and gamete formation via meiosis (Searles 1980). When mature, receptacles (swollen, yellowish bumps) on the blade tips release gametes at low tide. Eggs are fertilized with the incoming tide, and the resulting zygotes secrete adhesive and attach to the substratum (O'Clair and Lindstrom 2000). Individuals are thought to live approximately 2-3 years at exposed sites, and approximately 4-5 years in protected areas (O'Clair and Lindstrom 2000).

It has been shown that desiccation, which affects this upper-intertidal species, can weaken *Fucus gardneri* thalli and thereby increase mortality from water motion via stipe breakage (Haring et al. 2002). However, *F. gardneri* is able to recover rapidly from desiccation when submerged; the same study showed that it is capable of recouping enough water within in 30 seconds to be able to withstand a dynamic load which broke experimentally desiccated stipes. In addition to desiccation, this alga is highly sensitive to oil contamination as shown by the documented dramatic population collapse following the Cosco Busan oil spill in 2007 (Cosco Busan Oil Spill Trustees 2012). However, it appears to be even more sensitive to heat, as was demonstrated by the increased *F. gardneri* mortality in hot water cleaned areas versus un-treated rocks following the Exxon Valdez oil spill in 1989 (De Vogelaere and Foster 1994). Despite high initial mortality rates following the Exxon Valdez spill, *F. gardneri* cover increased to match levels in reference areas by 1992; however, the uniform age structure of the cohort that recruited post-spill created an unstable population that precluded full recovery for more than seven years after the spill (Driskell et al. 2001).

Appendix C: Raw Data of Field Conditions

Table C-1. Raw Data of field conditions for sampling trips in 2004-2013 at three intertidal sites within RNSP. Codes for levels indicated are 0=Zero, L = Low levels or relatively few, M = Medium or moderate levels, H = High numbers or high levels, ND = No Data. Tide level is relative to Mean Low Low Water (MLLW).

Site ID	Season Code	Start Time	End Time	Low Tide Level (ft)	Low Tide Time	Swell Surge	Wind	Rain	Recent Rain	Sedi-ment Level	Scour	Rock Move-ment	Plant Wrack	Drift-wood	Shell Debris	Dead Animals	Trash
DMN	SP04	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
END	SP04	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FKC	SP04	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
END	SU04	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FKC	SU04	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DMN	SU04	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FKC	FA04	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DMN	FA04	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
END	FA04	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
END	WN04	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FKC	WN04	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DMN	WN04	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FKC	SP05	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
END	SU05	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DMN	SU05	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FKC	FA05	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DMN	FA05	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
END	FA05	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
END	SU06	5:30	10:30	-1.9	7:23	L	L	ND	H	M	L	L	L	M	H	0	0
FKC	SU06	5:45	12:00	-1.6	8:07	L	L	0	L	H	0	M	L	H	M	0	L
DMN	SU06	6:00	12:30	-1.2	8:50	L	L	0	L	M	L	L	L	M	L	0	L
FKC	FA06	13:30	18:00	-0.4	16:30	M	L	0	M	M	L	M	L	H	L	0	0
DMN	FA06	13:30	18:30	-0.9	17:15	H	L	0	M	M	L	M	L	M	L	0	0
END	FA06	14:00	18:15	-0.9	18:10	M	H	L	M	L	L	L	ND	L	L	ND	ND

Site ID	Season Code	Start Time	End Time	Low Tide Level (ft)	Low Tide Time	Swell Surge	Wind	Rain	Recent Rain	Sedi-ment Level	Scour	Rock Move-ment	Plant Wrack	Drift-wood	Shell Debris	Dead Animals	Trash
END	SU07	6:00	11:45	-1.2	8:15	L	M	0	0	L	L	L	L	L	L	0	L
DMN	SU07	6:50	12:00	-1.1	8:55	M	L	L	0	H	L	M	L	L	L	0	L
FKC	SU07	6:30	12:30	-0.9	9:38	L	L	L	L	H	L	L	L	M	L	L	L
DMN	FA07	13:00	17:30	-0.1	16:30	M	M	0	H	M	L	0	0	L	L	0	0
END	FA07	13:30	17:30	-0.4	17:15	M	M	0	H	L	0	0	M	M	L	0	0
FKC	FA07	14:30	18:15	-0.5	17:45	M	L	0	H	M	L	L	L	M	L	L	L
FKC	SU08	4:30	10:00	-0.9	7:28	M	M	0	L	L	L	M	L	L	L	L	L
DMN	SU08	4:15	10:30	-0.9	8:05	L	M	0	0	M	L	H	L	L	L	0	0
END	SU08	5:00	10:00	-0.7	8:44	L	M	0	0	L	L	M	L	L	L	0	0
DMN	FA08	12:45	18:00	-1.0	15:53	L	L	0	ND	M	M	L	L	M	L	0	L
END	FA08	13:00	17:00	-1.6	16:41	M	L	0	0	L	M	L	L	M	L	0	L
FKC	FA08	13:45	18:00	-2.0	17:30	M	L	M	0	M	M	M	L	L	L	L	L
END	SU09	6:00	10:30	-2.2	7:55	L	L	0	0	L	L	L	L	M	M	0	L
DMN	SU09	6:20	11:00	-2.0	8:45	L	L	0	0	M	M	M	L	L	L	L	0
FKC	SU09	6:15	11:00	-1.6	9:36	L	L	0	0	M	M	M	L	M	L	0	L
FKC	FA09	13:00	17:15	-0.5	15:49	M	L	0	H	M	H	M	L	L	L	0	L
DMN	FA09	13:15	17:20	-0.7	16:31	M	M	M	M	M	M	M	L	L	L	0	L
END	FA09	13:30	18:15	-0.8	17:11	M	M	H	H	L	M	M	L	L	L	0	L
END	SU10	5:15	8:00	-1.6	6:05	L	L	L	M	L	M	L	L	L	L	0	0
FKC	SU10	5:15	10:20	-1.6	6:48	L	L	L	H	M	L	M	L	L	M	L	L
DMN	SU10	6:00	10:45	-1.5	7:29	L	L	0	M	M	M	M	L	L	L	0	M
FKC	FA10	12:45	16:30	-0.4	15:08	H	L	L	H	L	M	M	L	L	L	0	L
DMN	FA10	13:15	16:40	-1.0	15:57	L	L	0	M	M	M	L	L	L	L	L	M
END	FA10	13:40	16:40	-1.3	16:43	L	L	L	M	L	L	L	L	M	M	0	L
FKC	SU11	5:30	11:00	-2.0	7:51	M	L	0	L	M	L	L	L	M	L	0	0
DMN	SU11	6:30	11:45	-1.6	8:39	M	L	0	0	M	L	L	L	L	L	0	L
END	SU11	7:20	12:00	-1.1	9:27	M	L	0	L	L	L	L	L	L	L	0	0
DMN	FA11	14:00	17:15	-0.2	16:36	L	L	0	0	M	M	0	L	L	L	L	L
FKC	FA11	14:15	17:15	-0.4	17:09	M	L	0	0	H	L	M	L	L	L	L	L
END	FA11	14:45	17:30	-0.6	17:44	M	L	0	0	L	L	L	L	L	L	0	L

Site ID	Season Code	Start Time	End Time	Low Tide Level (ft)	Low Tide Time	Swell Surge	Wind	Rain	Recent Rain	Sedi-ment Level	Scour	Rock Move-ment	Plant Wrack	Drift-wood	Shell Debris	Dead Animals	Trash
FKC	SU12	5:30	9:30	-0.8	7:28	L	L	L	L	M	L	L	L	0	L	L	0
DMN	SU12	6:00	9:45	-0.8	8:05	L	L	L	L	L	L	L	L	M	L	0	0
END	SU12	6:15	10:00	-0.7	8:42	L	M	M	L	L	L	L	L	0	L	0	L
FKC	FA12	13:30	16:45	-1.2	16:04	H	L	M	L	M	M	L	L	L	L	0	L
DMN	FA12	14:00	17:10	-1.7	16:53	H	M	0	M	L	L	L	L	L	L	0	L
END	FA12	14:45	17:30	-1.9	17:44	M	L	0	L	L	L	L	L	L	L	0	L

Appendix D. Species list created from biodiversity sampling at Damnation Creek, Del Norte County, California June 2, 2004.

Please note: We ask that you please contact the SWAT Team (swat@biology.ucsc.edu) prior to using this information for any purpose. We make this request to: 1. Reduce redundancy; we may be currently working on projects that involve this information. 2. We would like to be informed of and involved in projects developed using this information. We have been careful to voucher any organisms that were difficult to identify in the field so that more detailed evaluation could be done in the lab. We are therefore confident that the identification of organisms listed below is reliable with the caveat that some sponges and tunicates are very difficult to identify to species without detailed histological evaluation, which we have not done. The number of cases where this could have been a problem is very small. For more information please visit our website above or link directly to our protocols at: http://cbsurveys.ucsc.edu/sampling/images/dataprotocols.pdf

Species list:

Acmaea mitra

Acrosiphonia spp.

Ahnfeltia spp.

Alaria marginata

Alia spp.

Amphissa versicolor

Anthopleura elegantissima

Anthopleura xanthogrammica

Balanus glandula

Bossiella spp.

Bugula spp.

Calliarthron spp.

Callithamnion pikeanum

Cancer oregonensis

Centroceras/Ceramium/Corall-ophila spp.

Chlorostoma funebralis

Chondracanthus canaliculatus

Chthamalus spp.

Cirolana spp.

Cladophora columbiana

Colpomenia/Leathesia spp.

Constantinea simplex

Corallina spp.

Cryptochiton stelleri

Cryptopleura/Hymenena spp.

Cryptosiphonia woodii

Dermasterias imbricata

Desmarestia ligulata

Diatoms

Diaulula sandigensis

Dilsea californica

Dirona picta

Ectocarpales

Egregia menziesii

Encrusting coralline

Endocladia muricata

Farlowia/Pikea spp.

Fucus spp.

Gelidium coulteri

Gelidium coulteri/pusillum

Grateloupia doryphora

Halichondria spp.

Halosaccion glandiforme

Halymenia/Schizymenia spp.

Henricia spp.

Hermissenda crassicornis

Hildenbrandia/Peyssonnelia spp.

Homalopoma baculum/luridum

Idotea spp.

Kalypso paleacea

Katharina tunicata

Lacuna spp.

Laminaria setchellii

Laminaria sinclairii

Lepidochitona dentiens

Lepidozona spp.

Leptasterias spp.

Littorina keenae

Littorina plena/scutulata

Lottia austrodigitalis/digitalis

Lottia limatula

Lottia paradigitalis/strigatella

Lottia pelta

Lottia scutum

Mastocarpus jardinii

Mastocarpus papillatus

Mazzaella spp.

Membranipora spp.

Microcladia borealis

Microcladia coulteri

Mytilus californianus

Neoptilota/Ptilota spp.

Neorhodomela larix

Neorhodomela oregona

Nucella emarginata/ostrina

Odonthalia floccosa

Osmundea spectabilis

Pachygrapsus crassipes

Pagurus granosimanus

Pagurus hirsutiusculus

Pagurus samuelis

Patiria miniata

Pelvetiopsis spp.

Petrocelis spp.

Phyllospadix scouleri

Pisaster ochraceus

Pista spp.

Plocamium cartilagineum

Plocamium violaceum

Pollicipes polymerus

Polysiphonia spp.

Porphyra spp.

Prionitis lanceolata

Prionitis lyallii

Prionitis spp.

Pterosiphonia bipinnata

Pterosiphonia dendroidea/pennata

Pugettia producta

Pycnopodia helianthoides

Ralfsiaceae

Saccharina sessilis

Sculpin

Searlesia dira

Semibalanus cariosus

Styela montereyensis

Tiffaniella snyderiae

Tonicella lineata

Ulva spp.

Ulva taeniata

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National Park Service
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