

ABUNDANCE AND DISTRIBUTION PATTERNS OF INTERTIDAL FISHES AT
THREE SITES WITHIN REDWOOD NATIONAL AND STATE PARKS, 2004-05.

by

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ABSTRACT

Abundance and distribution patterns of intertidal fishes at three sites within Redwood National and State Parks, 2004-2005.

Karah N. Cox

The tidepool fishes of Redwood National and State Parks, California were sampled to access the community structure of intertidal fishes in this under-studied region. A total of 13 samplings, at three sites, took place from March 2004 to September 2005. Combined collections, at three rocky intertidal sites, yielded approximately 5,000 fish comprising 26 species from 11 families. The sites examined for this study, Enderts Beach, Damnation Creek, and False Klamath Cove, differed in both species richness and diversity. The sites also differed in habitat factors and tidepool characteristics. Damnation Creek, the larger, more heterogeneous habitat yielded the greatest number of fish species. False Klamath Cove, dominated by boulder substrate, had a greater number of species that are commonly associated with boulder substrata, including juvenile rockfish. Enderts Beach, the smallest area sampled, is surrounded by sandy beach which is unsuitable for most fish species. Although this site had the fewest species, fish abundances were more than double those of the other sites. Overall, patterns of fish abundances were driven largely by the family, Cottidae, which comprised 88% of the total fish sampled. Species diversity did not differ significantly over the time period sampled, although a greater abundance of fish and more species were found in summer compared to winter. This seasonal increase was in part due to the recruitment of young

cottids and the presence of summer seasonal species, such as juvenile black rockfish, *Sebastes melanops*. Mark-recapture methods suggested that tidepool sculpins exhibit high site fidelity. Of 1,399 marked sculpins, 309 out of the 314 recaptures were found in the pool of original collection. Habitat assessment showed that the three sites varied with regard to tidepool characteristics and patterns of fish abundances. Habitat-species relationships were examined and showed evidence of niche partitioning among some fish species, especially between the congeners *Oligocottus maculosus* and *O. snyderi*.

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1

INTRODUCTION

Arguably the most dynamic region of the marine environment is the rocky intertidal ecotone, the narrow band of shoreline subjected to both high and low tides. This transition zone between the marine and terrestrial habitats is a challenging environment for intertidal organisms. The flora and fauna found in these habitats must be able to withstand challenges such as wave turbulence, desiccation, and widely fluctuating temperature and salinity regimes. The community structure of intertidal fish assemblages is influenced by a physically complex and stressful environment (Griffiths et al. 2006).

A major influence on the distribution of marine intertidal organisms is the degree to which they are adapted to exposure (Doty 1946). The vertical distribution of organisms along the shore as well as the physical characteristics of the habitat (i.e. substrate complexity) determine the amount of exposure they will be subjected to during low tide. Many fish species find refuge in pools of water that become isolated from the ocean during low tide. These pools add another dimension to the distribution of intertidal fish. The vertical position/tidal height of pools determine the emersion time and subsequent environmental fluctuations (Huggett and Griffiths 1986).

Although tidepools provide refuge during low tide, isolated pools can have extreme daily fluctuations in pH, temperature and salinity. To withstand these pressures, intertidal fish have various mechanisms for maintaining internal osmotic and pH balance (Horn and Martin 2006). Many fish species have adapted to survive the stressful physico-chemical conditions of the intertidal habitat, with some having evolved the

ability to breathe air (Martin 1996). The special adaptations required to live in these habitats have resulted in unique assemblages of fish that inhabit the intertidal region.

The heterogeneous nature of the rocky intertidal zone makes these habitats ideal study sites for investigating the biological and physical factors that determine the distribution and abundance of species. Studies of community structure in the intertidal habitat have been the basis of several seminal developments in ecology (Connell 1972), including the intermediate disturbance hypothesis (Connell 1978), the concept of biogeographic boundaries (Dayton 1971, Menge and Sutherland 1976), keystone species (Paine 1966), and recruitment limitation (Dayton 1971, Underwood and Denley 1984, Roughgarden et al. 1988). Most of these studies have focused on sessile or slow moving invertebrate (i.e. snails and seastars) and algae species, probably because these organisms are relatively easy to observe, quantify, and manipulate. In contrast, relatively few studies have dealt with highly mobile species such as intertidal fish. The relative lack of attention given to intertidal fish may be largely due to their low abundances and cryptic nature (Horn et al. 1999). Despite these challenges, efforts have been made to examine the ecological role of fish in the intertidal ecosystem.

Several ecological characteristics of intertidal fish assemblages have been identified, including variation in temporal and spatial patterns of distribution and abundance. Variation in temporal patterns has been observed at the daily, seasonal, and long term (10+ years) scales. Daily changes in fish community structure can occur during the diel exposure and inundation of the low and high tides (Arakaki and Tokeshi 2006). Community structure of intertidal fish assemblages often exhibit strong seasonal

variability (Grossman 1982, Almada and Faria 2004). Species composition, abundance, recruitment timing and size class composition may all vary on seasonal or yearly time scales (Moring 1981, Griffiths 2003, Ritter and Priesler 2006). Although the majority of studies of intertidal fish have been done on a relatively short time scale (1-3 years), one long-term census (16 years) showed relatively little change in the numbers of recruits and adults of an intertidal fish assemblage (Pfister 2006). This suggests that temporal variation may be affected by scale and that when assessing a population the frequency and timing of sampling may affect results.

Scale may also play a role in spatial variation of intertidal fish assemblages. Variation in spatial patterns has been described within sites, between sites at the local scale and along a latitudinal gradient at a larger scale. Geology, wave exposure and nearshore oceanographic patterns may influence the community structure of intertidal fishes within an area (Green 1971, Gibson 1982). The dynamic nature of intertidal sites provides a multitude of variables that may affect the within-site variation of fish communities. For example, rocky intertidal fish distributions have been shown to vary within sites based on tidal height, tidepool size and habitat complexity (Nakamura 1976a, Griffiths 2003). Large-scale variation in intertidal fish communities is summarized along a latitudinal gradient by Prochazka et al. (1999).

At low tide, intertidal fish are often concentrated within tidepools making pools a convenient choice for sampling units within a site. These tidepools have certain characteristics, such as volume and algal cover, that can influence the structure of intertidal fish assemblages (Bennett and Griffiths 1984, Mahon and Mahon 1994). In

addition, several species of intertidal fish have been shown to exhibit homing behavior and return to the same pool when displaced (Green 1971, Khoo 1974, Yoshiyama et al. 1992). This suggests that individuals are selecting for certain habitat characteristics within a pool (Gibson and Yoshiyama 1999). Furthermore, tidepool fish have been shown to have affinities for various habitat characteristics that differ among species and age classes (Nakamura 1976a, Davis 2000). For example, the cottid *Oligocottus snyderi* has been shown to have increased adult abundances with increased tidepool algal cover (Ritter 2006). For the recruits of this species, in the presence of adults, the association with algal cover was negative. Thus, describing fish assemblages in intertidal areas requires observations of the specific habitat characteristics at a site, and assessment of the linkages of these factors in determining distribution and abundance (Nakamura 1976a).

In this project, a description of community structure of the tidepool fishes within the Redwood National and State Parks was performed by means of a broad scale, one-time inventory as well as repeated monitoring of species inhabiting discrete areas. The primary objectives of this study were to document patterns of abundance and distribution of intertidal fishes at three sites along the northern California coast and to determine the influence of habitat and environmental variables on these patterns. In addition, this study established a species list for each site and evaluated species richness and diversity within the region. Sampling methodology was utilized in a manner that allowed for comparisons with studies from locations throughout the Pacific Northwest coast.

5
STUDY SPECIES AND SITES

Study Species

Intertidal fishes may be categorized as primary residents, secondary or seasonal residents, or transient species depending on the duration of time spent in this environment (Thompson and Lehner 1976, Potts 1980). Primary residents spend most or all of their life in the rocky intertidal while secondary residents spend only part of their life history in this habitat (Gibson and Yoshiyama 1999). Transient species generally utilize rocky intertidal habitats during high tides and are sporadically trapped in tidepools on outgoing tides (Thompson and Lehner 1976). These species are mostly pelagic or sandy shore fish. Permanent residents are usually specialized for the highly variable and often harsh conditions present in this habitat. General adaptations of this group include a flattened or rounded body shape and lack of swim bladder making them negatively buoyant and demersal. Many resident intertidal species have evolved mechanisms for breathing air through modified skin or gill structures (Bridges 1988). Resident intertidal fish are usually small and cryptic which may explain the lack of attention given to these groups by monitoring agencies (Horn et al. 1999). Secondary or seasonal residents such as juvenile *Scorpaenichthys marmoratus* and *Sebastes spp.* are commonly observed in tidepools, however, adults of these species are rarely seen inhabiting intertidal areas (Studebaker 2006 and personal observations). Several seasonal and transient species were documented in this study and used for species richness comparisons, but focus was placed largely on resident species.

Sculpins of the Order Scorpaeniformes, family Cottidae, are the most abundant group of intertidal fishes in the Pacific Northwest, comprising as much as 98% of the fish species in the intertidal zone (Yoshiyama et al. 1986, Webster et al. in prep). The majority of sculpins found in temperate rocky intertidal habitats in the Pacific Northwest are from two genera, *Clinocottus* and *Oligocottus*. The most abundant sculpins in northern California are *Oligocottus snyderi*, the fluffy sculpin and *O. maculosus*, the tidepool sculpin (Moring 1972, Yoshiyama 1981). However, *Clinocottus acuticeps*, the sharpnose sculpin, and *C. globiceps*, the mosshead sculpin are also common in the rocky intertidal areas of northern California (Moring 1972, Miller and Lea 1976). The geographic distribution of these four sculpins is somewhat different. *Clinocottus acuticeps* are found from central California to the Aleutian Islands while *C. globiceps* are common from southern-central California to British Columbia. The range of *O. snyderi* extends from south-central California to British Columbia. Finally, *Oligocottus maculosus* is rarely noted in central California but is common from northern California to British Columbia (Miller and Lea 1972, Yoshiyama et al. 1986).

Throughout their ranges along the Pacific coast, intertidal sculpins have a protracted reproductive season extending from late autumn to early spring (Grossman and Devlaming 1984, Pfister 1997). Sculpins practice internal fertilization and females lay clutches of eggs that remain in the intertidal for approximately three weeks, before hatching (DeMartini 1999). The larvae then spend approximately one month (25-40 days) in the plankton, before settling into the rocky intertidal habitat (Washington et al. 1984, Blizard 2000). Intertidal sculpins recruit to tidepool habitats in spring and summer

(Grossman 1982, Pfister 1996, Ritter 2006). *Clinocottus globiceps*, and *O. snyderi* generally recruit to the rocky intertidal from March through August with peak recruitment noted in June for populations from Washington and central California (Pfister 1997, Blizard 2000, Ritter 2006). The recruitment peak for *O. maculosus* occurs between July and August for Washington and central California populations (Pfister 1997, Blizard 2000).

Other groups of intertidal fish commonly found in this region include the families Stichaeidae (pricklebacks) and Pholidae (gunnels). These taeniform, or ribbon-like fish, often reside beneath boulders or are associated with macroalgae and can breathe air for extended periods if out of water. The Northern clingfish, *Gobiesox maeandricus*, is the only species representing the Gobiesocidae family in the study region. Clingfishes are characterized by a large pelvic sucker that enables them to hold onto substrate and withstand strong waves. These families residing in the intertidal zone demonstrate a suite of morphological, physiological and behavioral adaptations for inhabiting this region. This study examines the abundance and distribution patterns of intertidal fish at three sites in northern California.

Study Region and Sites

This study was conducted in 2004-2005 at three sites in Redwood National and State Parks, Del Norte County, California: Enderts Beach, Damnation Creek and False Klamath Cove (Figure 1). Much of Redwood National and State Parks is underlain by rocks of the Franciscan assemblage (Bailey 1966). This assemblage consists of rock that

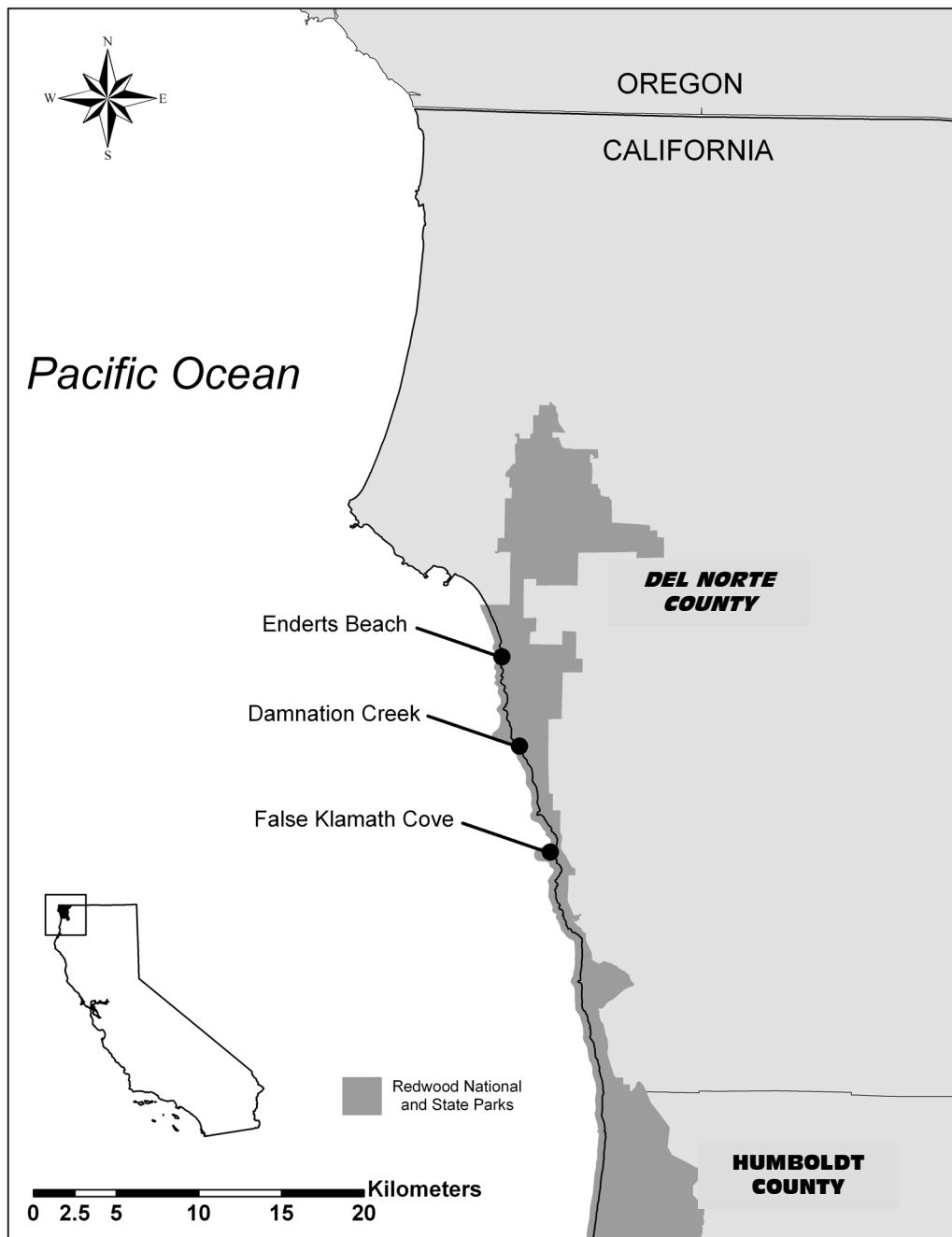


Figure 1. Map of northern Redwood National and State Parks, Del Norte County, California showing locations of intertidal fish study sites (Enderts Beach, Damnation Creek, and False Klamath Cove).

has been sheared and lifted from the ocean floor as a result of plate action along the Cascadia subduction zone. The rock along the Redwood National and State Parks coast from Enderts Beach to the mouth of Redwood Creek is primarily composed of sandstone and mudstone (Boyd and DeMartini 1977).

This coast is exposed to the open ocean with regular waves predominately striking the shore from the northwest. Wave height typically ranges from one to two meters, but occasional storms produce waves of greater than seven meters. The average significant wave height registered at the National Oceanic Atmospheric Association's (NOAA) Point St. George marine buoy, eight nautical miles west-northwest of Crescent City, California and 16 nautical miles from our Enderts Beach site, were 2.24 and 2.98 m for 2004 and 2005 respectively. The max wave height measured was 7.55 m for 2004 and 6.62 m for 2005 (data from NOAA marine buoy #46027).

Enderts Beach (N 41.69592, W 124.14245), the northern-most site surveyed is located just south of Crescent Beach and the town of Crescent City (Figure 2). The site is comprised of a gently sloping series of benches separated by rocky trenches. The rocky intertidal here is a narrow, 30 m wide, band spanning 50 m in length.

Damnation Creek (N 41.65249, W 124.12784), is located 6.5 kilometers north of False Klamath Cove and 5 kilometers south of Enderts Beach. The rocky intertidal here spans 175 meters in length and 65 meters in width and 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 (Figure 3). The site is near the mouth of Damnation Creek, but monitoring pools were established on the south side of the creek's



Figure 2. Site overview of the intertidal site Enderts Beach, Redwood National and State Parks, Del Norte County, California, used for tidepool fish studies in 2004-05. Panoramic photograph was taken at negative (<0.0 ft) low tide.



Figure 3. Site overview of the intertidal site False Klamath Cove, Redwood National and State Parks, Del Norte County, California, used for tidepool fish studies in 2004-05. Panoramic photograph was taken at negative (<0.0 ft) low tide.

outflow, far enough away to largely avoid direct freshwater input. Measurements of salinity revealed that some freshwater influence from the creek occurred during high flows.

False Klamath Cove (N 41.59377, W 124. 10773), is located just south of the mouth of Wilson Creek, about 5 miles north of the Klamath River mouth. It is the southern-most rocky intertidal site surveyed with variable substrate ranging from coarse sand to large boulders (Figure 4). This site is peninsula-like with ocean to the north and south, and a sea stack (approx. 75 m tall and 100 m wide) at the west end. The peninsula extends 250 meters in length and has a width of approximately 100 meters. It is a gently sloping field of boulders and small rock benches with potential for temporal variation in sand scour and boulder movement.



Figure 4. Site overview of the intertidal site False Klamath Cove, Redwood National and State Parks, Del Norte County, California, used for tidepool fish studies in 2004-05. Panoramic photograph was taken at negative (<0.0 ft) low tide.

Habitat Description

Distribution of tidepool fishes may be correlated with various biotic and abiotic factors (Nakamura 1976b, Davis 2000). In order to examine the habitat characteristics that may influence the tidepool fish community within Redwood National and State Parks, a number of factors were measured. Habitat characterization included describing the study sites and tidepools with respect to zonation and tidal height as well as assessing ocean conditions. In addition, the physical parameters measured within tidepools at each study site included volume, depth, surface area and rugosity. The amount of surfgrass and algae cover was also measured for each sampled tidepool.

Zonation and Tidal Heights

During periods of low tides, temperature, salinity, oxygen, and pH levels change with varying exposure levels along a vertical gradient. Organisms in the intertidal zone have specific distribution patterns that are correlated to exposure level (Connell 1972). Intertidal zonation into low, mid, and high regions can often be clearly delineated by assessing the assemblage of invertebrates and macrophytes present (Lubchenco 1980, Menge 2000). While dividing this habitat into tidal-height zones is readily accomplished with regard to exposed algae and invertebrates, these distinctions are more complicated with regard to submerged pools. Species assemblages within pools generally follow trends within the vertical gradient from high to low zones; however, pools in different zones may have similar species compositions due to varying pool depths and substrate

composition. Mussel beds commonly denote mid-intertidal pools, while low pools often contain surfgrass, *Phyllospadix sp.* (Dethier 1984). Determining clear borders for these zones is difficult because the depth of the pools adds another dimension. For example, a large, deep pool in the high intertidal zone may have similar physical characteristics and species composition as a shallower pool in the low-intertidal zone.

This study consisted of sampling intertidal fish using inventory and monitoring methods. In the inventory, entire areas were sampled while monitoring efforts only sampled individual tidepools within the sites. Zone assignments were slightly different for the inventory and monitoring portions of this study. Inventoried areas were divided into zones based on surrounding assemblages of organisms and relative to the mean tidal height. For the purpose of the inventory, the areas surveyed were divided into high and low zones for False Klamath Cove (Figure 5) with the addition of a middle zone for Damnation Creek (Figure 6). The mid zone was not surveyed at False Klamath Cove due to the configuration of this site. At low tide this site is surrounded on both sides by water with a narrow, central margin of exposed intertidal area. Due to the narrowness of the site only two zones could be adequately delineated for the inventory. Enderts Beach was not sampled for the inventory portion of this study.

For purposes of consistency, zone assignments for the monitoring study were based on relative tidal height. Relative tidal height served as a proxy for exposure time or the amount of time a tidepool was separated from the ocean during low tides. For the monitoring study, each sampled tidepool was categorized using tidal height measurements. Pools were assigned to the following zone categories based on

corresponding tidal height measurements: low between -0.2 and +0.2 feet, mid between +0.3 and +0.7 feet, and high greater than +0.7 feet. The Damnation Creek and False Klamath Cove site had monitored tidepools that fell into the low, mid and high zone categories. The monitored pools at Enderts Beach were all categorized as either mid or low as a result of the bench size and layout (Figure 7). There was not available high zone habitat at Enderts Beach since the rocky bench ended at approximately +0.2 feet.

Tidal heights were measured for each pool using a stadia rod and rotating laser leveler. The laser unit was placed on a level tripod several feet above the highest pool. A sensor that can detect the laser beam was run up and down a stadia rod (large ruler) that was held on the surface of each pool. When the sensor connected with the beam a relative height measurement for each pool was recorded. At low tide, a measurement was taken of ocean surface level (mean low, low water level) to calibrate the tidal height of the laser and the corresponding tidal height of each pool. The program Tides and Currents Version 2.1 (Nautical Software Inc. 1996) was used to determine the relative tidal height at the precise time and date the measurements were taken.

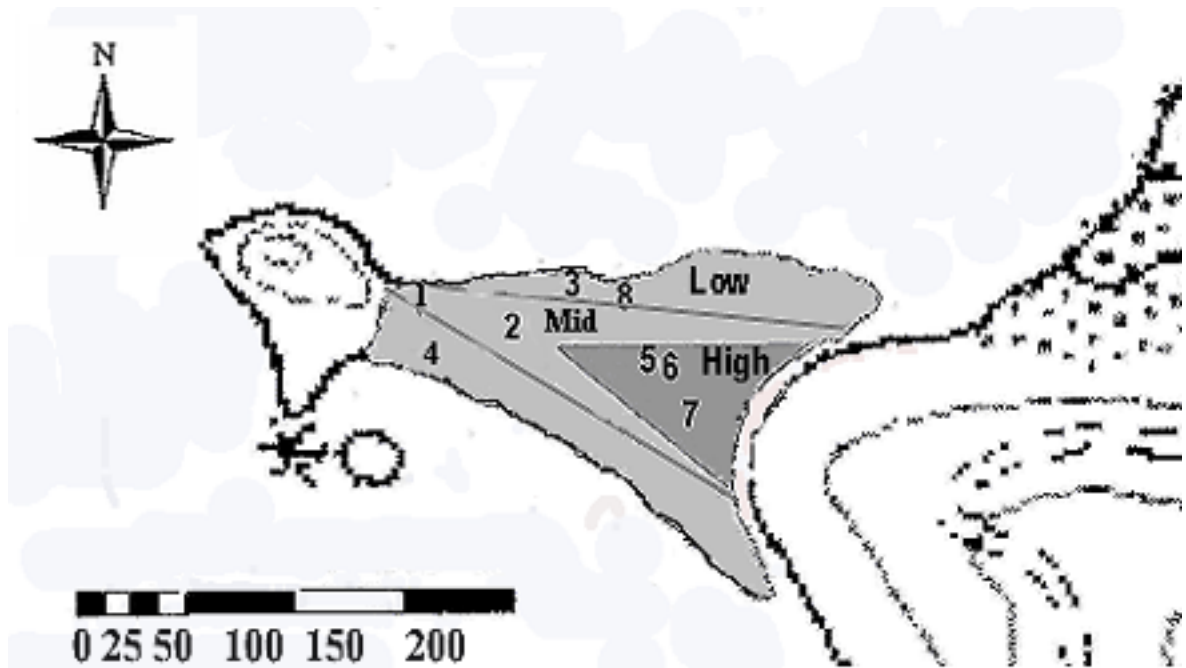


Figure 5. False Klamath Cove, Redwood National and State Parks intertidal area showing high (shaded dark grey), mid and low zones (shaded light grey). Tidal height zones were established for the intertidal fish monitoring and inventory studies. The low and high shaded areas were sampled for the inventory study while only specific pools were sampled for the monitoring study. Numbers indicate location of monitored pools within the designated low, mid and high zones. Site map created using Trimble Geoexplorer GPS.

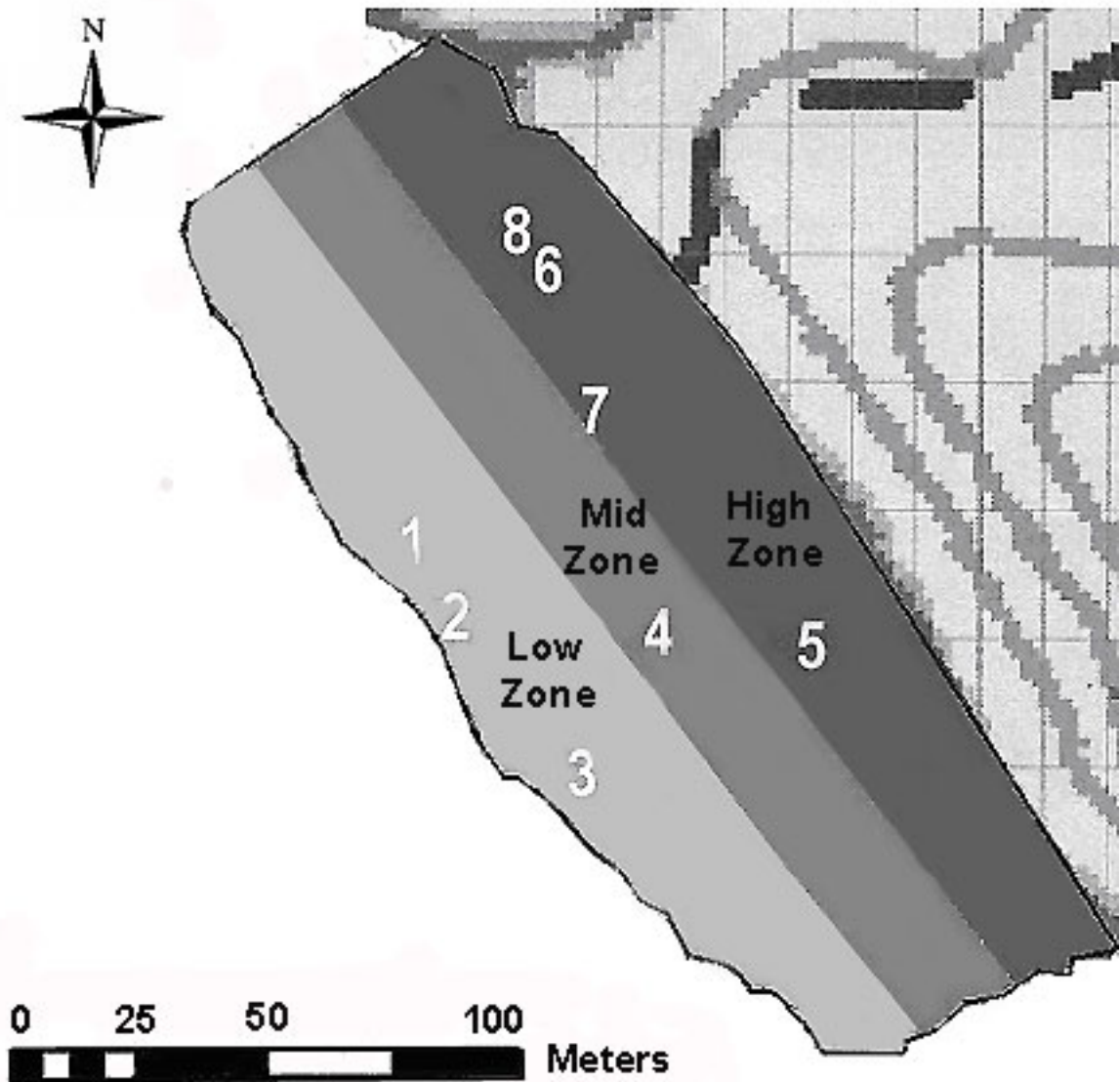


Figure 6. Damnation Creek, Redwood National and State Parks intertidal area showing high, mid and low zones (shaded). Tidal height zones were established for the intertidal fish monitoring and inventory studies. The shaded areas were sampled for the inventory study while only specific pools were sampled for the monitoring study. Numbers indicate location of monitored pools within the designated low, mid and high zones. Site map created using Trimble Geoexplorer GPS.

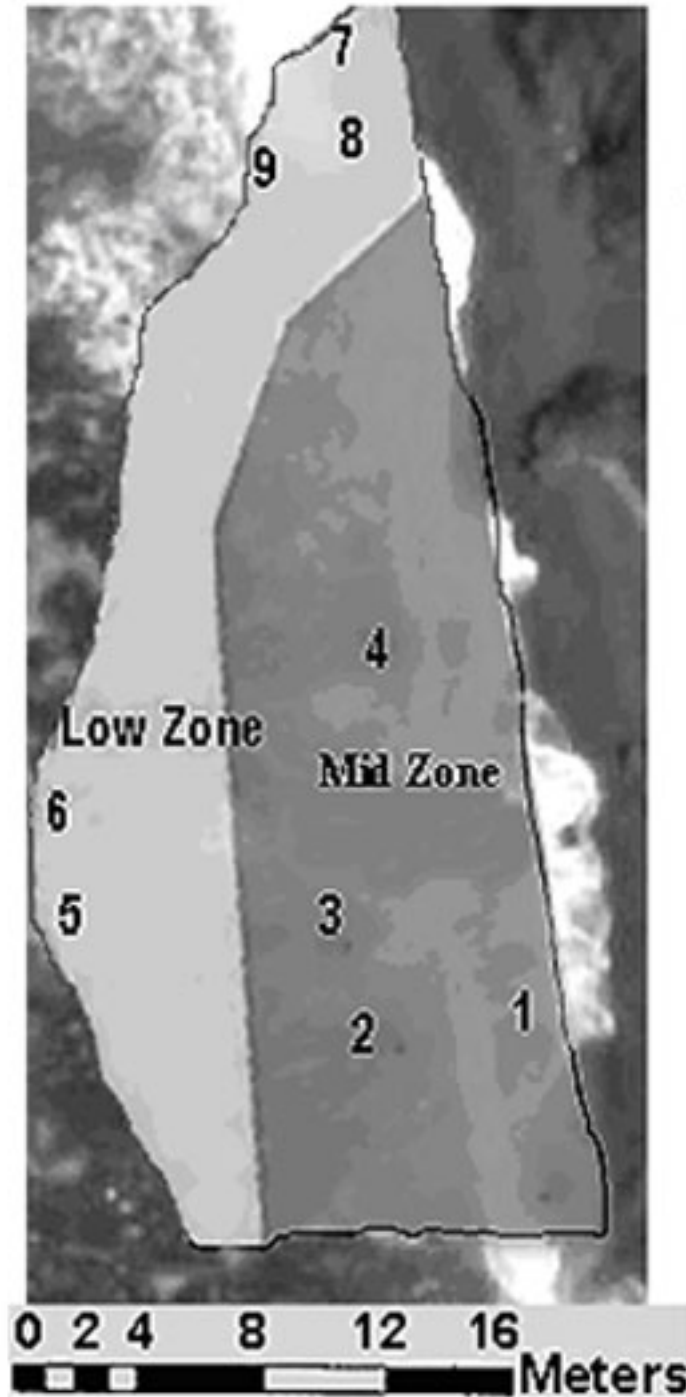


Figure 7. Enderts Beach, Redwood National and State Parks intertidal area showing mid and low zones (shaded). Tidal height zones were established for the intertidal fish monitoring study. Numbers indicate location of monitored pools within the designated low and mid zones. Site map created using Trimble Geoexplorer GPS.

Water Assessment

Data from the NOAA Point St. George marine buoy #46027 were used to approximate offshore, sea surface temperatures and upwelling indices. Onset brand, Tidbit temperature loggers were secured in the low zone at each site. The loggers recorded nearshore sea surface temperatures at hourly intervals throughout the study. Temperature readings were correlated with low-tide times using the program Tides and Currents 2.1 (Nautical Software Inc. 1996) and only the temperature readings corresponding to times when the loggers were covered with water, were used. Removing temperatures that were recorded during low tides when the loggers were not totally submerged, prevented air temperatures from being included in the water temperature measurements. This allowed for analysis of the average nearshore, high tide, ocean temperatures at each site. During each sampling event, prior to draining each pool, temperature and salinity measurements were recorded. Measurements for each sampled pool were made using a hand-held calibrated thermometer and salinity refractometer.

Abiotic Tidepool Parameters

Measurements of surface area, depth, volume and rugosity were collected for each tidepool surveyed. Pool surface area was assessed by taking a digital photo directly above each pool. The image analysis program ImageJ (Rasband 1997) was then used to draw a line around the outside of each pool to determine its circumference. This program was also used to calculate surface area for each pool. Depth of each tidepool was determined using the average of ten random measurements taken during low tide. Direct measurements of pool volume were made by draining the pools using bilge pumps and

buckets with volume increments. Analysis of the sampled pools was repeated during each season over the study to determine if substantial change in pool characteristics occurred over time. Two of the study pools (one each from False Klamath Cove and Damnation Creek) had an increase in sediment levels that caused significant differences in volume measurements over the study period. These pools and any corresponding data were removed from the study. The remaining pools did not show significant differences in surface area or volume calculations during the study period.

Rugosity measurements were taken in order to estimate the amount of relief in each pool. These measurements were estimated using a stadia rod and laser equipment (as described for tidal heights) to record relative elevations along length and width transects of each pool, at 10 centimeter increments. The slope between measurements was calculated and the standard deviation of all slopes was used as a measure of rugosity. Box plots were used to visualize the range of horizontal complexity (rugosity) for each site. Similar methodology is used for creating topographic profiles of shoreline (Lohse and Raimondi 2007, personal communication).

Biotic Tidepool Components

The proportion of tidepool surface area that was covered by macroalgae or surfgrass was estimated using a point-contact field method and from analysis of digital photographs. Algae and surfgrass species were identified and described as they related to potential fish cover (Abbott and Hollenberg 1976). These groups were collectively referred to as canopy cover to describe the total percentage cover of each pool. Because

fluctuations in certain algae and surfgrass species occur seasonally (Van Tamelen 1996) assessments were made in the spring of 2004 and during the winter of 2004.

In the field, a 50-square centimeter, 100-point grid was placed on the surface water of each pool and the cover (i.e. algae, rock, sand) below each point was identified and counted (Figure 8). The grid was moved to cover the entire pool, and the number of points necessary to cover the pool was used as a total surface area reference. This procedure established a description of the algae and surfgrass species present and percentage canopy cover. Digital photos were taken of the surface of each tidepool by standing directly above each pool. Digital photos were scored in the lab using the image analysis program ImageJ (Rasband 1997) to estimate cover relative to surface area (Figure 9). Image analysis involved establishing a scalar reference in the photograph then tracing the surface area of the pool. The surface area covered by algae and surfgrass was traced and the image program was used to determine the proportion of canopy cover. A 100-point grid, which was created in Adobe Photoshop, was layered over the photograph and used to score the percentage cover of algae and surfgrass species in a similar manner to the field estimates. Field estimates were made at the time the photos were taken to compare the two methods.

Sampling Methods

Species Inventory

The species inventory portion of this study included a broad census of the fish assemblages in the intertidal zone, including channels and crevices, boulders, and pools.

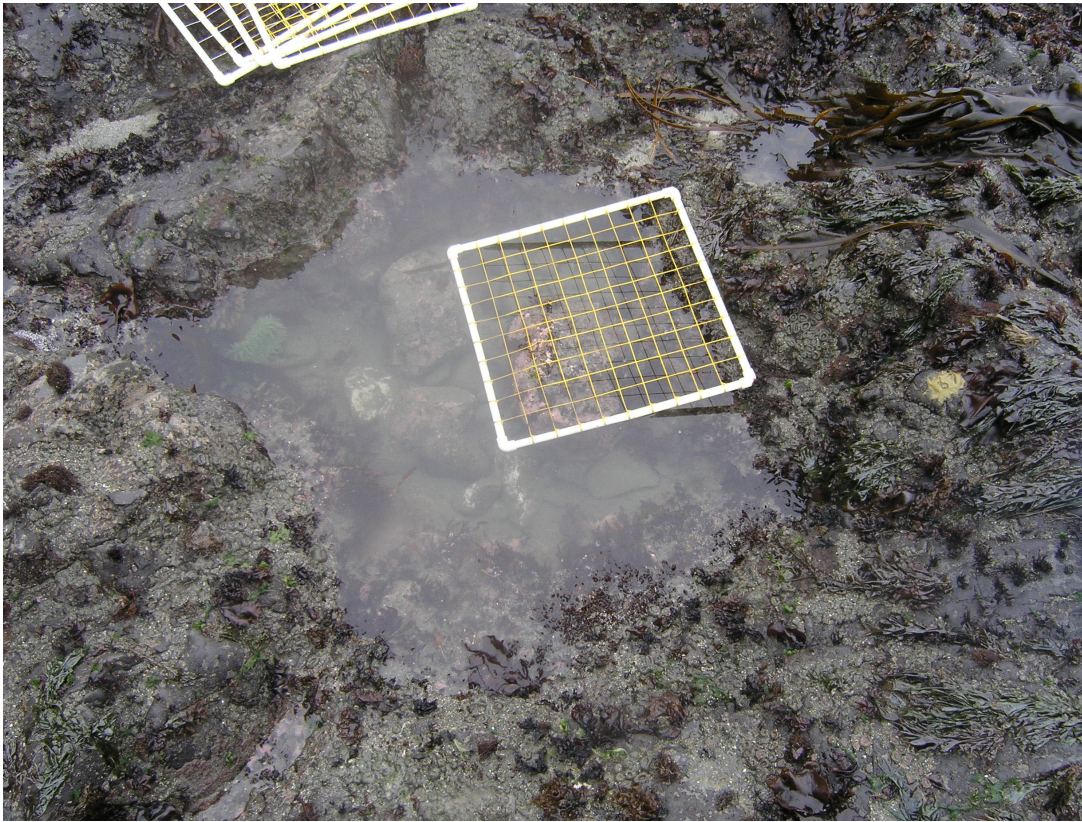


Figure 8. Field method for estimating canopy cover in rocky tidepools. Photograph shows 50 cm², 100-point grid placed on the surface of a tidepool in the field.

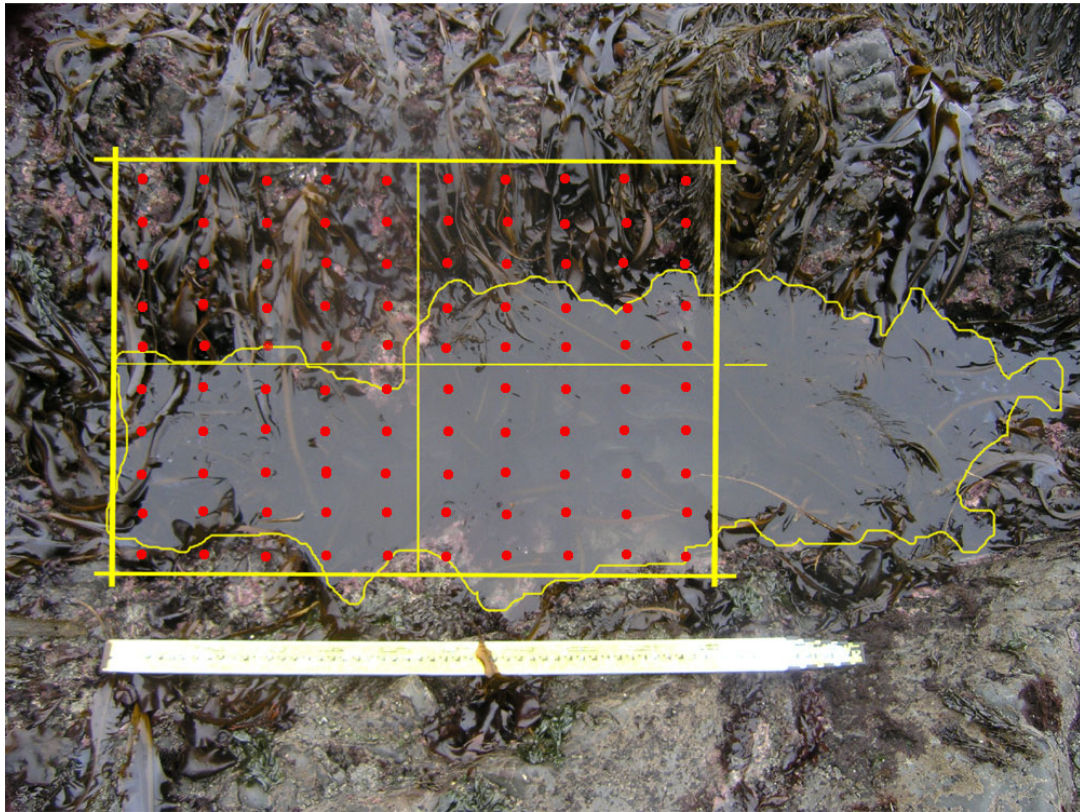


Figure 9. Method for estimating canopy cover in rocky tidepools. Photograph shows a 50 cm², 100-point grid generated in Adobe Photoshop layered over a tidepool image.

Rocky intertidal fish inventories were conducted on 5 February 2005 at Damnation Creek and 6 February 2005 at False Klamath Cove, Redwood National and State Parks. Enderts Beach was not included in the inventory because of the restricted size of its intertidal area. The coordinated efforts of approximately fifteen student assistants and several taxonomic experts provided an extensive range of effort for this survey. Multiple methods of collection were utilized to sample a wide range of species that inhabit various habitats within the intertidal zone. This sampling occurred during low tide when the mean low-low water level was between -1.2 and +1.0 feet. Collecting and handling of specimens followed an approved protocol from the Institutional Animal Care and Use Committee (#03/04.F.63-A).

The census for each site was conducted by dividing the site into tidal-height zones (see habitat methods section). Teams of five to eight samplers and at least one taxonomic expert sampled each zone for 30-minutes. Three teams of five samplers and one taxonomic expert sampled the low, mid, and high zones at Damnation Creek. At False Klamath Cove two teams of eight samplers and one taxonomic expert sampled the low and high zones. Teams were rotated so that all teams sampled each zone one time. This was done to ensure that sampling effort for each zone was the same and that each zone was thoroughly sampled. At the end of each time increment, collected fish were counted, identified (Miller and Lea 1976, Mecklenburg et al. 2002) and measured. A small subset of fish was collected for species verification while the remaining fish were returned to the area sampled.

Methods used for fish collection included bailing pools of various sizes with buckets and bilge pumps, poke poling, and hook and line fishing. Bailing tidepools required the cooperation of several people using buckets and manual bilge pumps to remove the water. This allowed for the easy and complete retrieval of all fish from emptied pools. Sampling included searching beneath large boulders and in crevices for species such as pricklebacks and gunnels. Moving boulders was accomplished by hand and with the aid of a crow bar for larger boulders. Poke poling is a modified hook and line method where a simple line with a hook is attached directly to a bamboo pole. The pole can then be stuck into rock crevices in the intertidal to catch more cryptic fish species, such as larger sculpin species and greenlings. Hook and line methods were carried out by experienced fishers just off the rocky shores and focused on nearshore species, such as surfperch.

Community Monitoring

The second part of this study was designed to monitor the change in diversity and abundance of intertidal fish species over approximately 18 months. Monitoring was conducted to allow for a quantitative comparison of fish species composition at the three rocky intertidal sites. Tidepools at all three sites were repeatedly sampled at regular intervals to ascertain whether the population structure of resident and seasonal fish species varied between and within sites, and over seasons. All of the pools were sampled during the same low-tide series. The sampling schedule depended on periodicity of low-tides causing study intervals to vary slightly (Table 1). The first eight samplings (March-

Table 1. Sampling schedule for Enderts Beach, Damnation Creek, and False Klamath Cove, Redwood National and State Parks rocky intertidal fish monitoring 2004-2005.

Sampling Period	Year	Month/Day
1	2004	13-16 March
2	2004	10-24 April
3	2004	9-11 May
4	2004	1-6 June
5	2004	2-4 July
6	2004	1-3 August
7	2004	28-30 August
8	2004	1-15 September
9	2004	10-12 December
10	2005	5-7 February
11	2005	24 April, 1 May
12	2005	5-9 June
13	2005	16-18 September

September 2004) occurred approximately monthly. Sampling occurred approximately every other month between September 2004 and September 2005.

Monitoring occurred during the periods of the most extreme low tides (lower low 'spring tides'). In the spring and summer these tides occurred in the morning, while in the fall and winter they occurred in the late afternoon. Air temperatures are higher in the afternoon, which may in turn affect tidepool water temperatures (Davis 2000).

Consequently, there is potential for diel variation in patterns of fish abundance.

However, in our study this variation was minimized because summer low tides, when air temperature would be expected to have the greatest influence on tidepool temperatures, occurred in the early morning. The air temperature during the afternoon winter tides was similar to the recorded tidepool temperatures.

A series of discrete tidepools was established at each site throughout the intertidal areas sampled. Eight pools were monitored at Damnation Creek and False Klamath Cove, and nine pools were monitored at Enderts Beach. The tidepools were selected based on their representation at the site and within designated tidal zones. Pool selection was also based on a set of criteria that included choosing pools with little or no connection to the sea during lower low 'spring tides', manageable volume (100-800 liters) and easy access. Selected tidepools were marked with marine epoxy and mapped to ensure that the same pools were sampled on each subsequent visit.

Community fish monitoring involved thoroughly draining the tidepools with buckets and bilge pumps to ensure that all fish were collected. The use of chemical methods for sampling fish was dismissed because of the necessity to return fish unharmed to pools,

and to avoid contamination of pools that might affect future fish abundances.

Furthermore, sampling intertidal fish after draining pools yields similar abundances to sampling methods using ichthyocides (Yoshiyama 1981). Sampling generally required five to eight researchers working four to six hours per site. Emptied pools were searched thoroughly. This included examining all exposed algae and looking under all movable rocks. Large boulders were not moved. Fish were gathered using handheld dip nets. Fish from each pool were identified and measured (total length to nearest 0.1 mm). Pools were then refilled and the fish replaced. Voucher specimens were collected and identified in the laboratory as needed.

A mark-recapture study was conducted to determine patterns of site fidelity and movement among cottid fish. During the six sampling events between April and September 2004, all cottid fish collected in the monitored tidepools were tagged. Colored silicone elastomer (Northwest Marine Technology) tags were injected subcutaneously to the cottids using a 3/10 cc gauge needle. Fish from each tidepool were given a unique batch tag. The location on the fish and color of the tag corresponded with a specific pool. For example, fish collected at Enderts Beach in pool three were tagged with a green mark under the left pectoral fin. Recapture of previously tagged fish provided data on pool fidelity and movement patterns of cottids at the Redwood National and State Parks rocky intertidal sites. Previous studies have indicated that elastomer tagging methods have no noticeable effect on growth and survival of cottids (Ritter 2006) or other small reef fishes (Malone et al. 1999)

Data Analysis

Habitat characteristics

The heterogeneous nature of the intertidal can lead to variation among tidepools in many of the measured habitat attributes (i.e. pool volume and tidal height). If tidepool characteristics are not significantly different among the three sites, then data can be lumped across sites to address the affect of pool characteristics on fish abundance and distribution patterns. Multivariate analysis of variance (MANOVA) was used to test for site differences of several tidepool habitat characteristics. Prior to analysis, percent cover data were arcsin-square-root transformed and other habitat variable data were square-root transformed.

To determine how well pool characteristics could be used to distinguish pools, between sites, a canonical discriminant analysis was performed. This analysis created a canonical discriminant score for each tidepool based on habitat variables and was used to determine which pool characteristics were associated with each of the sites sampled. The discriminant score determines whether groups (sites) differ in the mean of a variable (tidepool characteristic). Subsequently, variables are used to predict group (site) membership. This showed which habitat variables were contributing the most to the discrimination between sites. To normalize and linearize the data, transformations were performed on habitat variables. Percentage canopy cover was arcsin square-root transformed and all other habitat variables were square-root transformed

Fish Abundance and Distribution

Various methods are used to standardize fish abundances in intertidal studies, depending on the species and habitats sampled (Gibson 1999a). Attempts to standardize abundances include describing fish abundances per pool (Ritter 2006), per area (Craig and Pondella 2004), or as densities (per volume) (Mahon and Mahon 1994, Ritter 2006). Since intertidal fish are often patchily distributed and condensed within tidepools, a per-pool estimate of abundance may be useful in describing variation among sites. For the tidepool monitoring portion of this study, fish abundances are initially described per pool. The volume and surface area of the selected tidepools were used to describe the sites in the canonical discriminant analysis. For the repeated measures ANOVAs and Canonical Correspondence Analysis, densities (fish per cm³) were used to standardize abundances from all pools and sites.

Seasonality and site differences were tested for *O. maculocus* and *O. snyderi* densities using a repeated measures analysis of variance. Adult (>35mm), juvenile (26-35mm) and recruit (≤ 25) size classes were analyzed for both species. A Tukey's post-hoc test was then used to assess groupings of the results. Seasonality and site differences were tested for *Clinocottus globiceps* and *C. acuticeps* densities using a Kruskal-Wallis analysis. The non-parametric test was used for these species due to low numbers and nonnormal distribution of individuals. There were not enough individuals of these species to test for differences among life stages. A Spearman's Rank Correlation test was performed to test for size stratification within tidal heights and pool volumes for the four *Oligocottus* and *Clinocottus* species sampled. Spearman's Rank Correlation was

performed to test the direction and strength of relationships between variables, with R statistics between -1 and +1.

Canonical correspondence analysis (CCA) provides a graphical representation of correlated variables. This analysis was used to detect relationships between the habitat factors, sampling units (tidepools) and fish abundances. Canonical correspondence analysis was deemed appropriate for this study because intercorrelated environmental variables can be used and all factors determining species composition do not have to be known (Palmer 1993). This analysis was performed for fish species or groups that comprised at least 1% of the total fish sampled. The three species of *Artedius* were lumped into an *Artedius* spp. group and the seven species of Pholidae and Stichaidae were lumped into one group, in order to have enough individuals for the sample. The groupings were deemed appropriate because all species within each group were found to co-occur across all sampling periods. Densities (number of individuals per cm³) for nine of the most common fish species or groups were used in the CCA. Densities were calculated as average number of fish per pool, per volume of water (cm³). The habitat variables used in the CCA were pool tidal height, depth, surface area, rugosity and percent cover. Habitat characteristics and species densities were square-root transformed. A CCA provided a visualization of correlated variables for habitat factors, species densities and samples (pools).

Species Diversity and Richness

Species diversity and richness may be assessed utilizing various models and equations. This study utilized multiple models to describe the diversity and richness of intertidal fish species within the study sites. Species richness is simply the number of total species sampled. However, it is often more meaningful to take into consideration the evenness of species distribution when calculating richness indices. The Margalef species richness index takes evenness into account, and was used to assess species richness, with evenness, at each of the study sites (Margalef 1968). The equation used to calculate this index is:

$$R' = (S-1)/\ln N$$

where S= the number of species and N = the number of individuals of all species combined.

Generally, as species richness and evenness increase, diversity also increases. Several different indices are used to estimate diversity (Peet 1974). These indices are useful for comparing fish assemblages between sites, although no single index is ideal for describing seasonally fluctuating populations (Moring 1986). Two methods were used to examine the diversity of species, the Simpson's Index (D') and the Shannon Index, (H'). A combination of indices was used in order to take advantages of the strengths of each and develop a more complete understanding of community structure.

The Simpson's Index gives the probability that two individuals picked at random from a population are the same species (Simpson 1949). This index gives more weight to the more abundant species in a sample with the addition of rare species having only a small affect on the value. Therefore, a highly diverse site would have a lower probability

(D') of picking two individuals from the same species than a less diverse site. The bias corrected form of the Simpson's Index is:

$$D' = \sum n(n-1)/N(N-1)$$

where n = the total number of individuals of a particular species and N = the total number of individuals of all species.

The reciprocal of the Simpson's index ($1/D'$) gives a more intuitive value of diversity. The value of this index starts with one as the lowest possible figure. This figure would represent a community containing only one species, with higher values signifying greater sample diversity. This index was calculated for each sampling period, at each site, to examine if a seasonal or site difference in species diversity existed.

The Shannon Index (H') takes into account the distribution of individuals by species (Shannon and Weaver 1949). The equation used to calculate this index is:

$$H' = -\sum p_i(\ln p_i)$$

where p_i = proportion of species i .

Species diversity using both the Simpson's Index (D') and the Shannon Index (H') was calculated for fish assemblages at each site sampled for both the inventory and monitoring aspects of this study. One-way Analysis of Variance (ANOVA) was used to test for site and seasonal differences of species richness and diversity. Tukey post-hoc tests were used to assess groupings of significant results.

RESULTS

Habitat Characterization

The offshore NOAA buoy, #46027, registered average ocean temperatures for 2004 and 2005 as 11.2 and 11.7 °C, respectively. Ocean temperatures ranged between 7.6 and 17.2 °C for 2004 and 8.1 and 16.2 for 2005. Nearshore water temperatures recorded with ONSET tidbit© temperature loggers at the study sites fluctuated between 9 and 16 °C, with no significant temperature variation among sites (Figure 10). Temperatures at all three study sites showed seasonal trends with increased temperatures recorded in summer (June-September).

Increases in daily upwelling patterns usually correspond with decreased daily sea surface temperatures (Pacific Fisheries Environmental Laboratory daily upwelling indices). Although upwelling is associated with colder, nutrient rich waters, the average monthly peak upwelling times occurred in the spring and summer, when the average sea surface temperatures were also warmest (Figure 11). These corresponding peak upwelling (colder water) and sea surface temperatures (warmer water) counterbalance the overall sea surface temperature fluctuation in the study region. The rise in summer sea surface temperatures would be greater without upwelling. In 2005, upwelling in the northern California current, occurred later in the year than normal trends (Pacific Fisheries Environmental Laboratory annual upwelling anomaly, Barth et al. 2007)

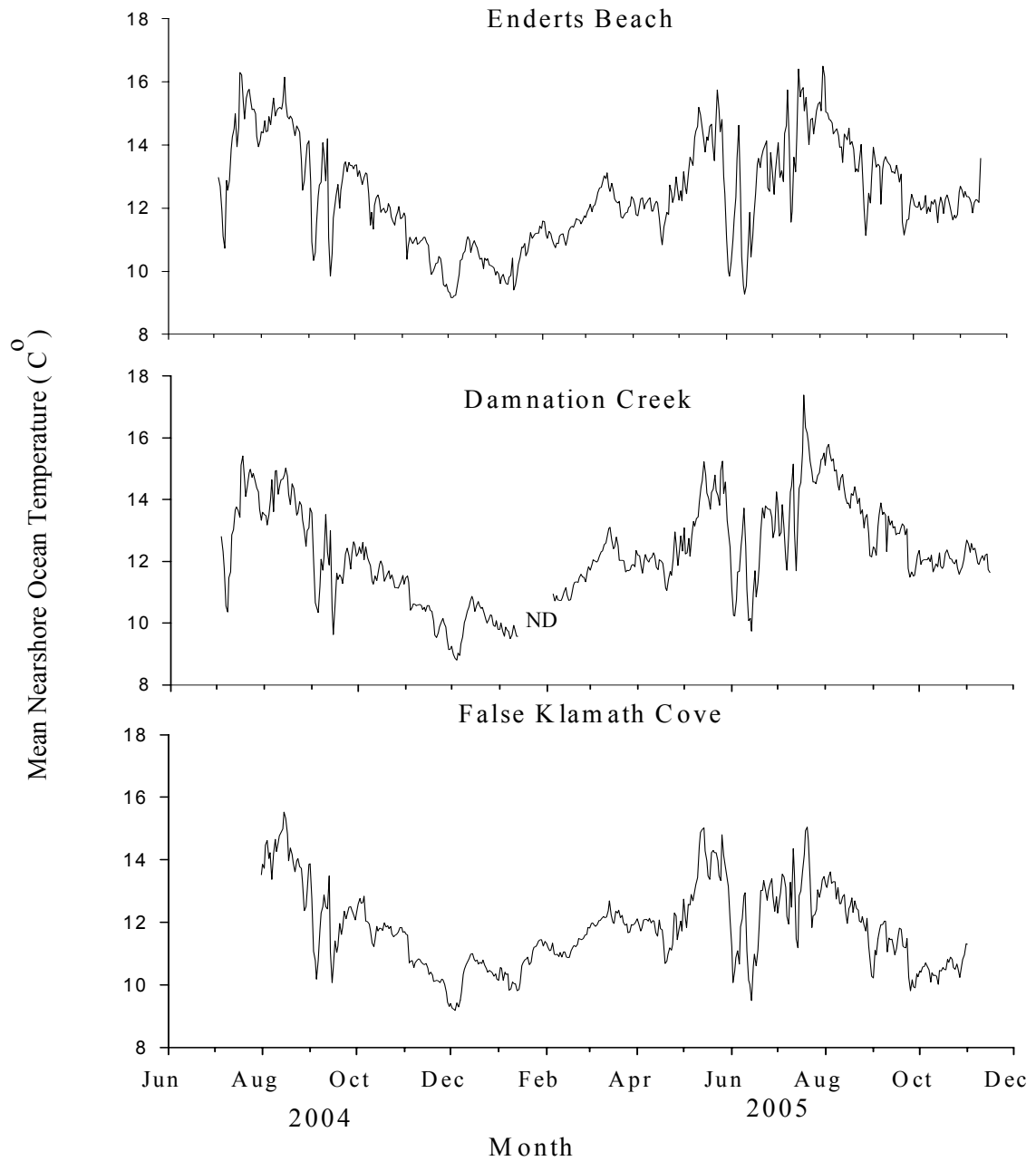


Figure 10. Average daily nearshore ocean temperatures (°C) for three rocky intertidal study sites within the Redwood National and State Parks for July 2004 to November 2005. Data from Onset temperature loggers analyzed to include only submersion temperatures. ND= No Data.

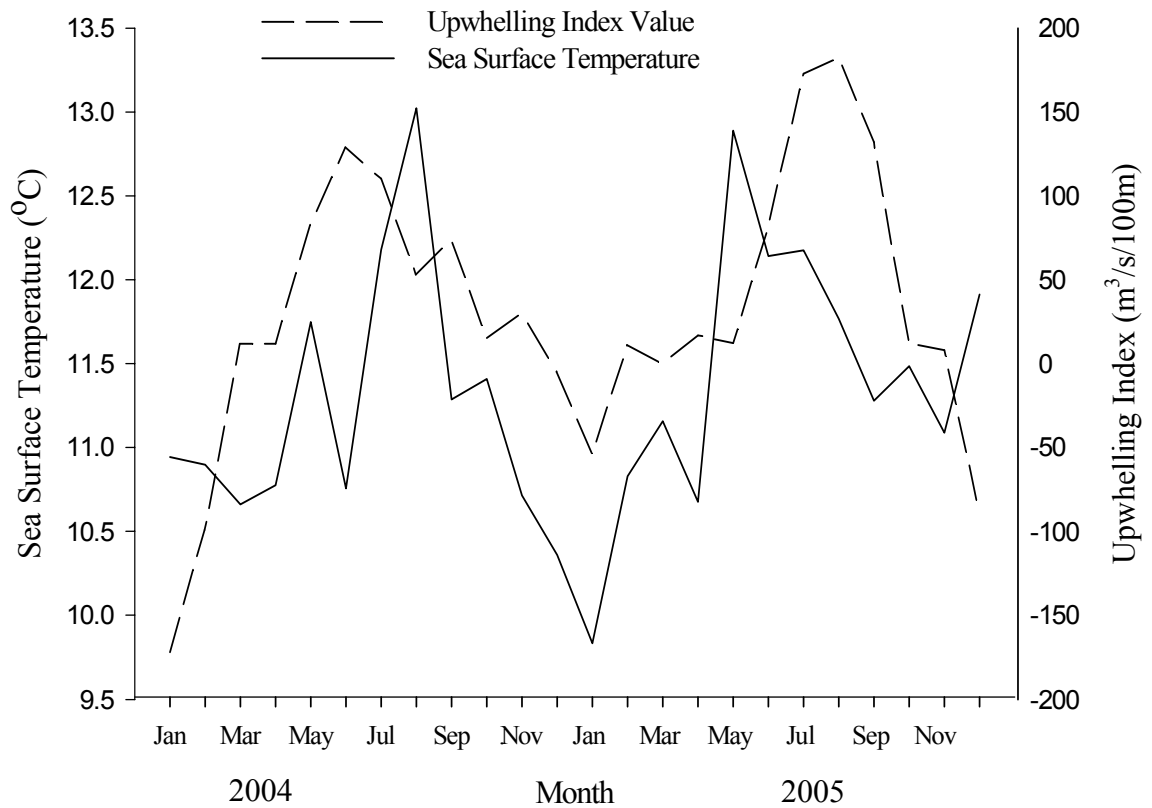


Figure 11. Upwelling and daily average sea surface temperatures were compiled from data collected by Pacific Fisheries Environmental Laboratory (NOAA) from the buoy (# 46027) located eight nautical miles northwest of Crescent City, California (N 41°51'06", W 124°22'54"). Data is from 2004-2005.

Temperatures taken in individual tidepools averaged 12.9 °C with a range of 9.8 to 17.2 °C. Tidepools had similar seasonal fluctuations as the recorded nearshore temperatures (Figure 10, Figure 12). Pool temperatures among sites were not significantly different when averaged across sampling periods. There was no consistent variation in temperature measurements among pools or tidal height zones within or among sites.

Tidepool salinity at the sites averaged 30 parts per thousand (ppt). Salinity was typically recorded between 26-34 ppt (Figure 12), with the exception of a few instances of decreased salinity after heavy rains, especially near creek mouths. Salinities showed some variation between sampling periods. The most evident deviation from the average salinity occurred in December 2004, when all sites had lower recorded salinities with overall averages of 22.1, 27.6, and 28.9 ppt for Damnation Creek, Enderts Beach, and False Klamath Cove, respectively. Damnation Creek, with the lowest average salinity had the closest freshwater input source (Damnation Creek) near the tidepools. Pools 1, 6 and 8 were located closest to the creek and had the lowest salinity readings of 16, 20 and 18 ppt, respectively. There was no significant difference in mean salinities between zones or pools within or among sites.

The other measured tidepool characteristics showed patterns of variation among pools and sites. Values for depth (m), surface area (m²), volume (m³), rugosity, and tidal height composition are shown in Table 2. Tidepools examined at Enderts Beach were, on average, larger in volume and depth than the other sites. Rugosity measurements are

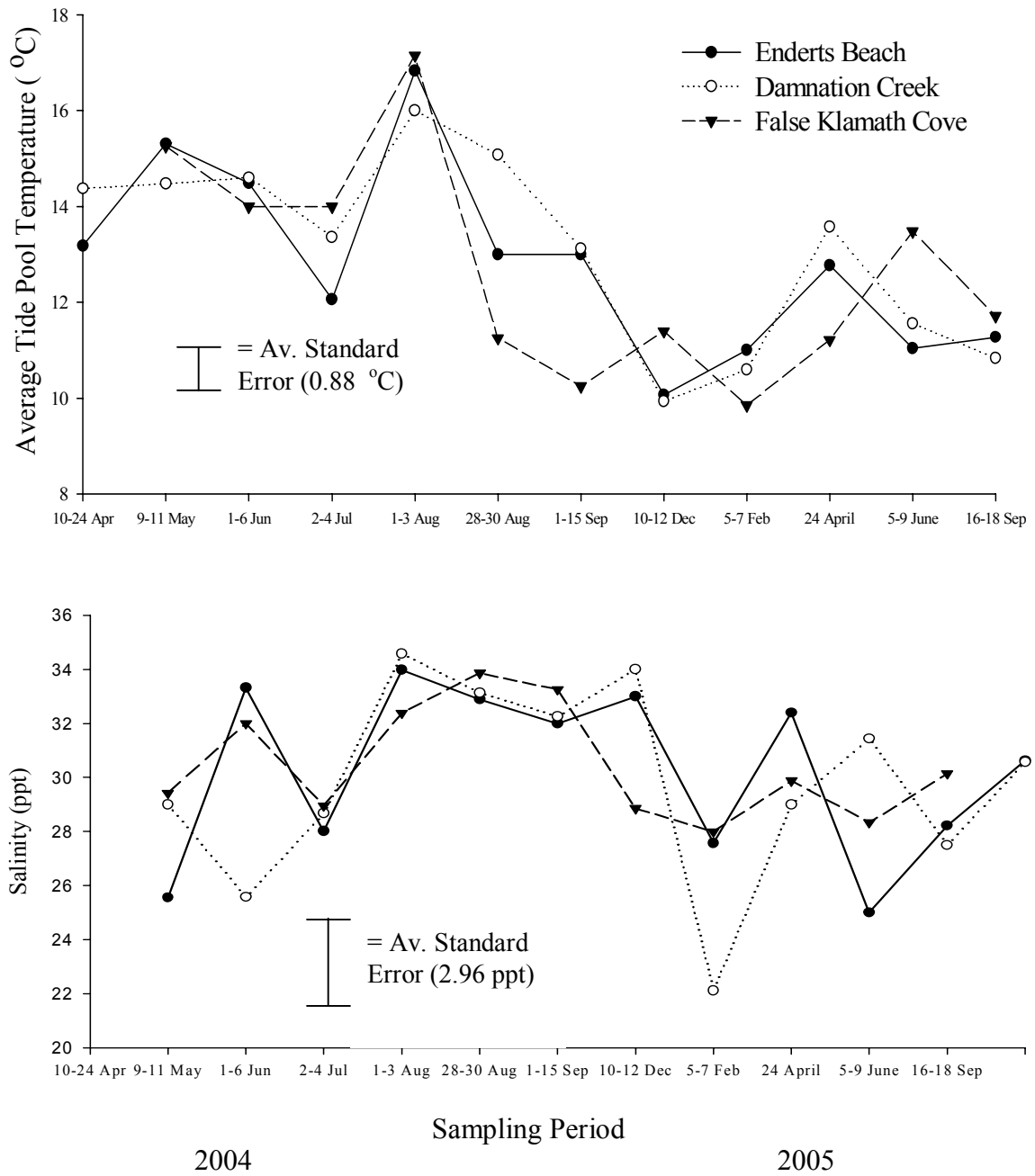


Figure 12. Average temperature (°C) (top) and salinity (ppt) (bottom) measurements for tidepools at three intertidal sites (Enderts Beach, Damnation Creek, and False Klamath Cove) within Redwood National and State Parks over 12 sampling periods from April 2004 to September 2005. Temperatures and salinities were averaged across all tidepools for each sampling period.

Table 2. Physical characteristics of three tidepool sites within Redwood National and State Parks. Average surface area, average depth, volume, surface area to volume ratio, tidal height and rugosity for each of the 25 pools sampled.

Site	Pool	Depth (m)	Surface Area (m ²)	Vol. (m ³)	Surface Area:Vol.	Tidal ht.(m)	Rugosity
Enderts Beach	1	0.16	2.17	0.30	7.26	0.60	0.33
	2	0.33	1.95	0.68	2.86	0.39	0.54
	3	0.32	2.85	0.85	3.34	0.04	0.59
	4	0.18	1.40	0.25	5.68	0.45	0.42
	5	0.19	1.01	0.19	5.46	-0.01	0.58
	6	0.20	1.10	0.16	6.90	-0.01	0.62
	7	0.18	1.34	0.18	7.58	-0.06	0.63
	8	0.22	0.72	0.14	5.20	0.03	0.67
	9	0.19	1.16	0.18	6.45	0.08	0.74
	Average	0.22	1.52	0.32	5.64	0.17	0.57
Standard Error		+/-0.02	+/-0.22	+/-0.09	+/-0.55	+/-0.08	+/-0.04
Damnation Creek	1	0.22	0.58	0.10	5.59	-0.01	0.83
	2	0.15	0.60	0.09	6.67	0.05	0.09
	3	0.20	0.55	0.15	3.65	-0.10	0.60
	4	0.19	0.88	0.22	4.03	0.70	0.59
	5	0.16	0.73	0.16	4.65	0.93	0.89
	6	0.13	0.75	0.09	7.95	1.00	0.48
	7	0.16	0.89	0.16	5.66	0.74	0.76
	8	0.13	2.85	0.38	7.48	1.31	0.14
	Average	0.17	0.98	0.17	5.71	0.58	0.55
Standard Error		+/-0.01	+/-0.27	+/-0.03	+/-0.56	+/-0.19	+/-0.11
False Klamath Cove	1	0.25	1.92	0.41	4.74	0.42	0.55
	2	0.14	0.69	0.11	6.37	0.18	1.74
	3	0.18	0.67	0.15	4.33	-0.23	0.99
	4	0.15	1.08	0.15	7.12	0.44	0.67
	5	0.21	3.02	0.45	6.64	0.85	0.45
	6	0.17	2.11	0.33	6.30	0.86	0.82
	7	0.18	1.95	0.35	5.52	0.89	0.49
	8	0.16	0.71	0.13	5.49	0.20	0.80
	Average	0.18	1.52	0.26	5.81	0.45	0.81
Standard Error		+/-0.01	+/-0.30	+/-0.05	+/-0.34	+/-0.14	+/-0.15

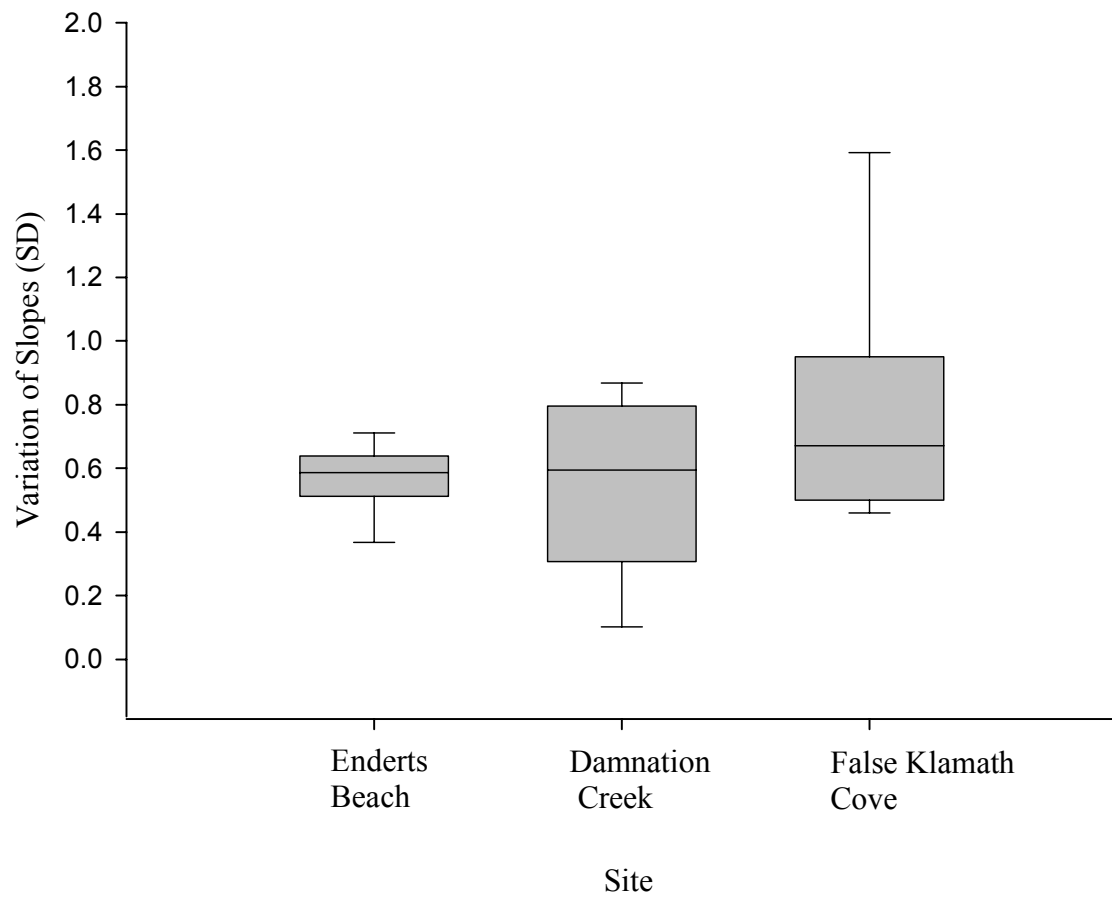


Figure 13. Box plots showing variation of slope (as estimate of rugosity) within tidepools at Enderts Beach, Damnation Creek, and False Klamath Cove, Redwood National and State Parks rocky intertidal sites. Slopes were calculated from tidal height measurements taken using a laser leveler and stadia rod. Data collected August 2004.

visualized with box plots showing the variation of slope within tidepools at each site (Figure 13). The tidepools at False Klamath Cove had the greatest rugosity or topographic complexity. The pools at Damnation Creek and Enderts Beach had intermediate rugosity levels. Enderts Beach had relatively little variation in rugosity levels among pools. In contrast, False Klamath Cove and Damnation Creek had pools with a greater range of rugosity levels. Average tidal heights of pools varied among sites. The tidepools at Enderts Beach were on average lower (+0.17 m) than pools at False Klamath Cove (+0.45) and Damnation Creek (+0.58). None of the abiotic tidepool parameters analyzed were significantly different among sites (Table 3).

The percentage canopy cover was significantly ($p=0.005$) different among sites. In a Tukey's post-hoc analysis, Damnation Creek tidepools had significantly greater average percentage cover (75%) than False Klamath Cove (54%) and Enderts Beach (31%), which were not significantly different ($p>0.05$) from each other (Figure 14, Table 3). *Egregia menziesii* and *Phyllospadix scouleri* were the greatest contributors to canopy cover. Seasonality differences in presence and abundance were observed in some algae/surfgrass species. However, seasonal variances in percent cover were similar across pools and not significant (Figure 14). This allowed for average percentage cover values to be compared among tidepools across multiple sampling periods.

Percentage canopy cover was the only significantly different tidepool habitat factor. Other variables were not significantly different between sites when analyzed individually. However, when combined in a forward stepwise discriminate analysis they contributed to an overall site difference between pools (Table 4). The habitat variables

Table 3. Results from a multivariate analysis of variance (MANOVA) testing for a site difference among tidepool characteristics. Data are pool averages from 13 sampling periods (2004-2005) comparing intertidal sites; Enderts Beach, Damnation Creek, and False Klamath Cove; Redwood National and State Parks. Significant p-value is underlined.

Dependent Variable	df	MS	F	P
% Canopy Cover ($\arcsin^{0.5}$)	2,22	0.491	6.829	<u>0.005*</u>
Volume ($x^{0.5}$)	2,22	0.043	1.790	0.190
Tidal Height ($x^{0.5}$)	2,22	0.116	1.732	0.200
Surface Area ($x^{0.5}$)	2,22	0.175	1.847	0.181
Temperature	2,22	0.190	0.688	0.513
Salinity	2,22	0.677	3.041	0.068
Depth ($x^{0.5}$)	2,22	0.007	2.889	0.077
Rugosity ($x^{0.5}$)	2,22	0.068	1.917	0.171

Multivariate Test Statistics				
Statistic	Value	F-Statistic	df	Prob
Wilks' Lambda	0.082	3.230	20, 26	0.003
Pillai Trace	1.360	2.974	20, 28	0.004
Hotelling-Lawley Trace	5.772	3.463	20, 24	0.002

*A Tukey's post-hoc test of percent canopy cover showed that Damnation Creek > False Klamath Cove = Enderts Beach.

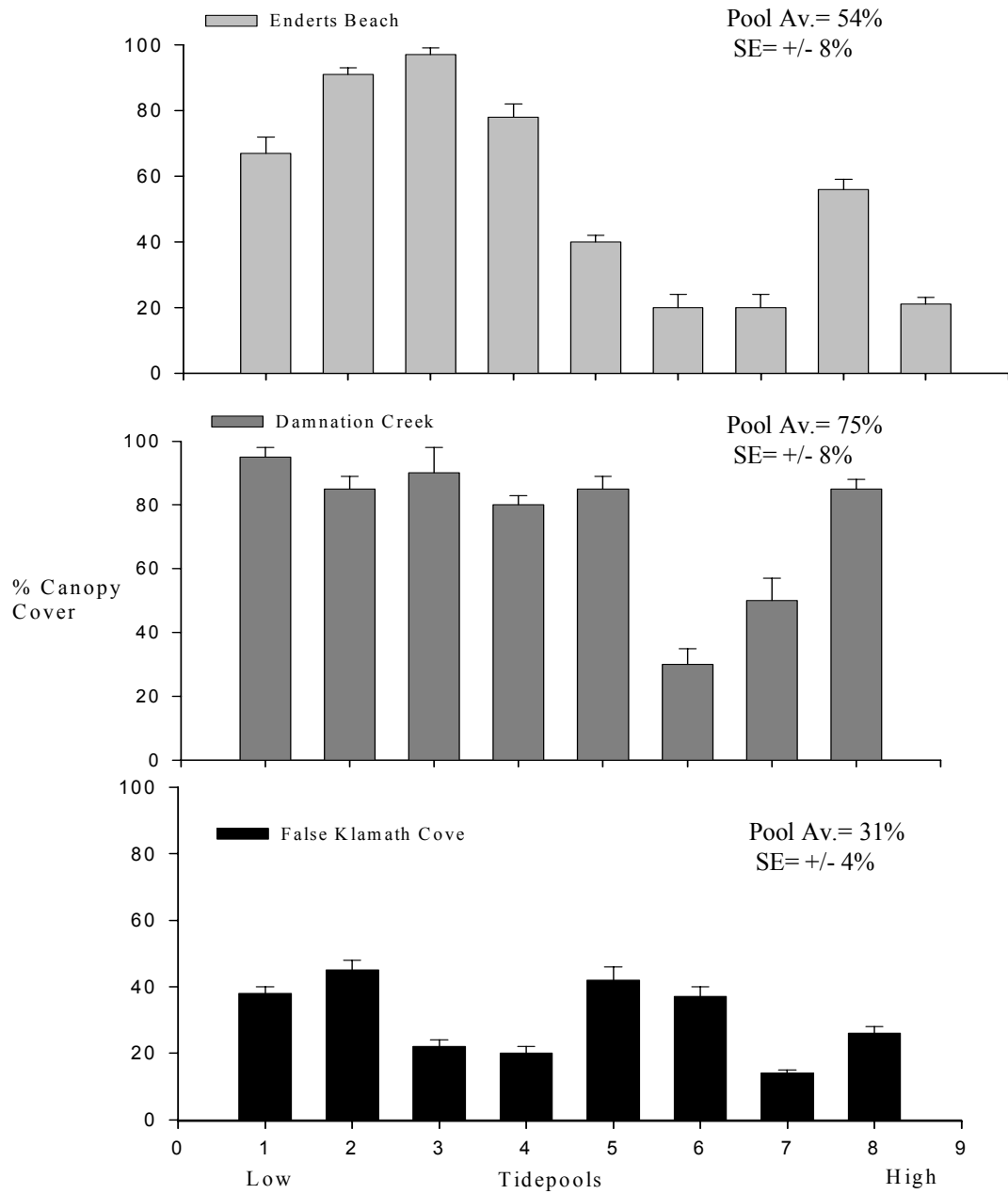


Figure 14. Average percent canopy cover in monitored tidepools at Enderts Beach, Damnation Creek, and False Klamath Cove, Redwood National and State Parks. Data were collected using point-contact methods in summer and winter 2004. Data are mean canopy cover for summer and winter samples with standard error bars.

Table 4. Canonical discriminate scores of pools within Redwood National and State Parks intertidal sites, Enderts Beach, Damnation Creek, and False Klamath Cove, determined by habitat variables. The canonical discriminant functions list the coefficients of the canonical variables computed for the data. Canonical discriminant functions are standardized by within variances.

Variable	Function	
	1	2
Volume	0.960	0.777
Tidal Height	1.388	-0.623
Depth	.	.
Surface Area	-1.637	0.026
Rugosity	.	.
% Canopy Cover	1.043	0.612
Temperature	.	.
Salinity	.	.

Statistic	Value	df	F-Statistic	Prob
Wilks' Lambda	0.241	8,38	4.926	0.0003

that were determined to drive each canonical discriminate function were surface area, percentage cover, tidal height and volume (Table 4). The Wilks' lambda test and associated probability ($p < 0.0005$) indicate a highly significant difference among the sites. Pool depth, rugosity, temperature and salinity did not contribute to site discrimination in the canonical discriminate analysis. The canonical scores created from these habitat variables successfully grouped all but two of the 25 sampled pools by site (92%) (Figure 15). All pools for False Klamath Cove and Damnation Creek were assigned correctly (100%) while 7 of the 9 (78%) pools at Enderts Beach were assigned correctly.

Species Inventory (February 2005)

A total of 23 fish species were identified from the Damnation Creek and False Klamath Cove intertidal sites during the February 2005 census (Table 5). The sites varied in both species composition and abundance. Damnation Creek yielded 21 species with a total of 148 fish. False Klamath Cove yielded 12 species and a total of 93 individuals. This computes to a species richness and abundance for False Klamath Cove of approximately 60% that found at Damnation Creek. The diversity index was slightly greater at False Klamath Cove compared to Damnation Creek, reflecting a higher number of rare species sampled at Damnation Creek (Table 5). The most abundant species found in the intertidal inventory were two sculpin species, *Oligocottus maculosus* and *O. snyderi*. This genus of the Cottidae comprised over half (51.0%) of the total number of fish sampled. Other genera of Cottidae, *Artedius* spp. and *Clinocottus* spp., also comprised a significant portion of the total fish inventoried (9.2% and 6.5%,

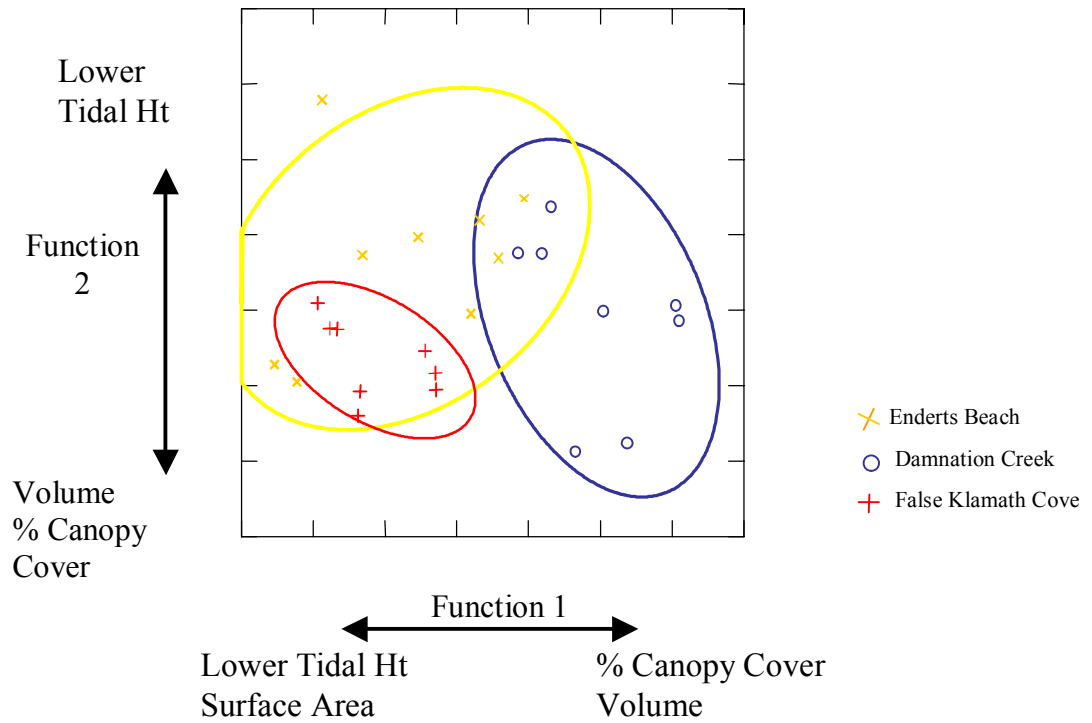


Figure 15. Plot of canonical discriminant scores of pools within Redwood National and State Parks intertidal sites; Enderts Beach, Damnation Creek, and False Klamath Cove, determined by four habitat variables. Pools within sites are separated based on tidal height, surface area, percent cover, and volume. Factor 1 separates pools with greater algae cover and volume from lower pools with greater surface area. Factor 2 separates pools with lower tidal height from pools with greater volume and percent algae cover. Data collected in 2004-2005.

Table 5. Fish abundances and corresponding size ranges from Damnation Creek and False Klamath Cove, Redwood National and State Parks during an inventory conducted 5-6 February 2005.

Genus Species	Common Name	Size Range (mm)	Damnation Creek	False Klamath Cove	Total	Relative Total %
<i>Oligocottus snyderi</i>	Fluffy sculpin	26-92	66	30	96	39.8
<i>Oligocottus maculosus</i>	Tidepool sculpin	28-87	7	20	27	11.2
<i>Artedius lateralis</i>	Smoothhead sculpin	54-140	18		18	7.5
<i>Clinocottus globiceps</i>	Mosshead sculpin	37-76	11	4	15	6.2
<i>Gobiesox maeandricus</i>	Northern clingfish	31-153	8	6	14	5.8
<i>Sebastes melanops</i>	Black rockfish	71-96	2	8	10	4.1
<i>Cebidichthys violaceus</i>	Monkeyface-eel	81-165	8	1	9	3.7
<i>Ascelichthys rhodorus</i>	Rosylip sculpin	76-155	4	4	8	3.3
<i>Hemilepidotus spinosus</i>	Brown Irish lord	62-68	2	5	7	2.9
<i>Scorpaenichthys marmoratus</i>	Cabezon	41-130	2	4	6	2.5
<i>Xiphister atropurpureus</i>	Black prickleback	51-111		6	6	2.5
<i>Artedius spp.</i>	Sculpin spp.	52-61		4	4	1.7
<i>Embiotoca lateralis</i>	Striped surfperch	310-340	4		4	1.7
<i>Hexagrammos decagrammus</i>	Kelp greenling	146-239	3	1	4	1.7
<i>Apodichthys flavidus</i>	Penpoint gunnel	89-112	2		2	0.8
<i>Enophrys bison</i>	Buffalo sculpin	105-179	2		2	0.8
<i>Liparis florae</i>	Tidepool snailfish	114-122	2		2	0.8
<i>Apodichthys fucorum</i>	Rockweed gunnel	91-175	2		2	0.8
<i>Anoplarchus purpureus</i>	High Cockscorb	108	1		1	0.4
<i>Bothragonus swanii</i>	Rockhead poacher	73	1		1	0.4
<i>Clinocottus acuticeps</i>	Sharpnose sculpin	50	1		1	0.4
<i>Hexagrammos superciliosus</i>	Rock greenling	315	1		1	0.4
<i>Pholis ornata</i>	Saddleback gunnel	61	1		1	0.4
Grand Total			148	93	241	100%
Species Richness			21	12	23	
Diversity Index (1/D)			4.43	5.97	5.32	

respectively). All cottids combined contributed 76.3% of the fish found in the inventory.

Tidal zonation influenced patterns of distribution and abundance of intertidal fish. The pattern of fish abundances within zones differed between Damnation Creek and False Klamath Cove (Figure 16). False Klamath Cove did not have a sampled mid zone but the high and low zones were sampled with the same effort at both sites. Damnation Creek had more fish species and greater abundances in the low zone (16 species and 55 individuals) than in the mid (5 species and 45 individuals) or high (7 species and 19 individuals) zones. This pattern was reversed at False Klamath Cove where the high zone had 55 total fish of 9 species. This is more than twice the 23 individuals and five species represented in the low zone at this site. The two most abundant species found at both sites had different distribution patterns within tidal zones and between sites (Figure 17). At both sites, *O. maculosus* was rarely collected in the low and mid zones while the abundances of *O. snyderi* varied between the sites. *Oligocottus snyderi* abundances were greater in the mid and lower zones at Damnation Creek, but equal between the high and low zones at False Klamath Cove (Figure 17).

Bailing of tidepools was by far the most successful method of catching fish, with 97% of the total fish collected using this method. The hook and line method, using shrimp as bait, collected two *Embiotica lateralis*, striped surfperch; one *Scorpaenictchys marmoratus*, cabezon; and one *Hexagrammos decagrammus*, kelp greenling. Poke poling was used to catch one *Artedius lateralis*, smoothhead sculpin; one *Embiotica lateralis*, striped surfperch and two *Enophrys bison*s, buffalo sculpin. This was the only method that captured *Enophrys bison*, demonstrating the importance of utilizing various methods in order to capture the greatest diversity of fish species.

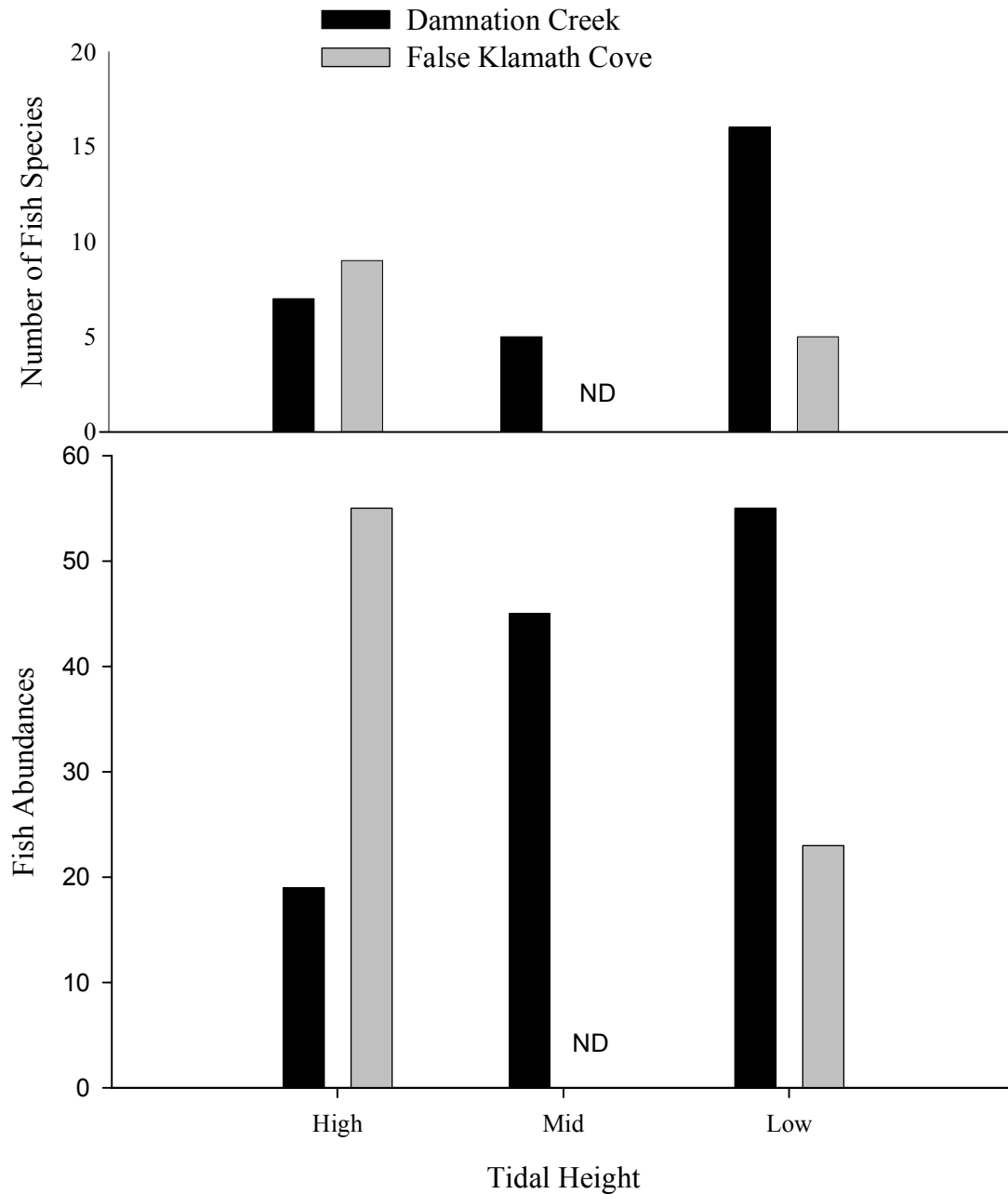


Figure 16. Total fish abundances (bottom) and number of species (top) collected at different tidal heights during intertidal fish inventories conducted on 5 February 2005 at Damnation Creek and 6 February 2005 at False Klamath Cove, Redwood National and State Parks. The mid intertidal zone was not sampled at False Klamath Cove so no data (ND) was recorded in the mid intertidal zone at this site.

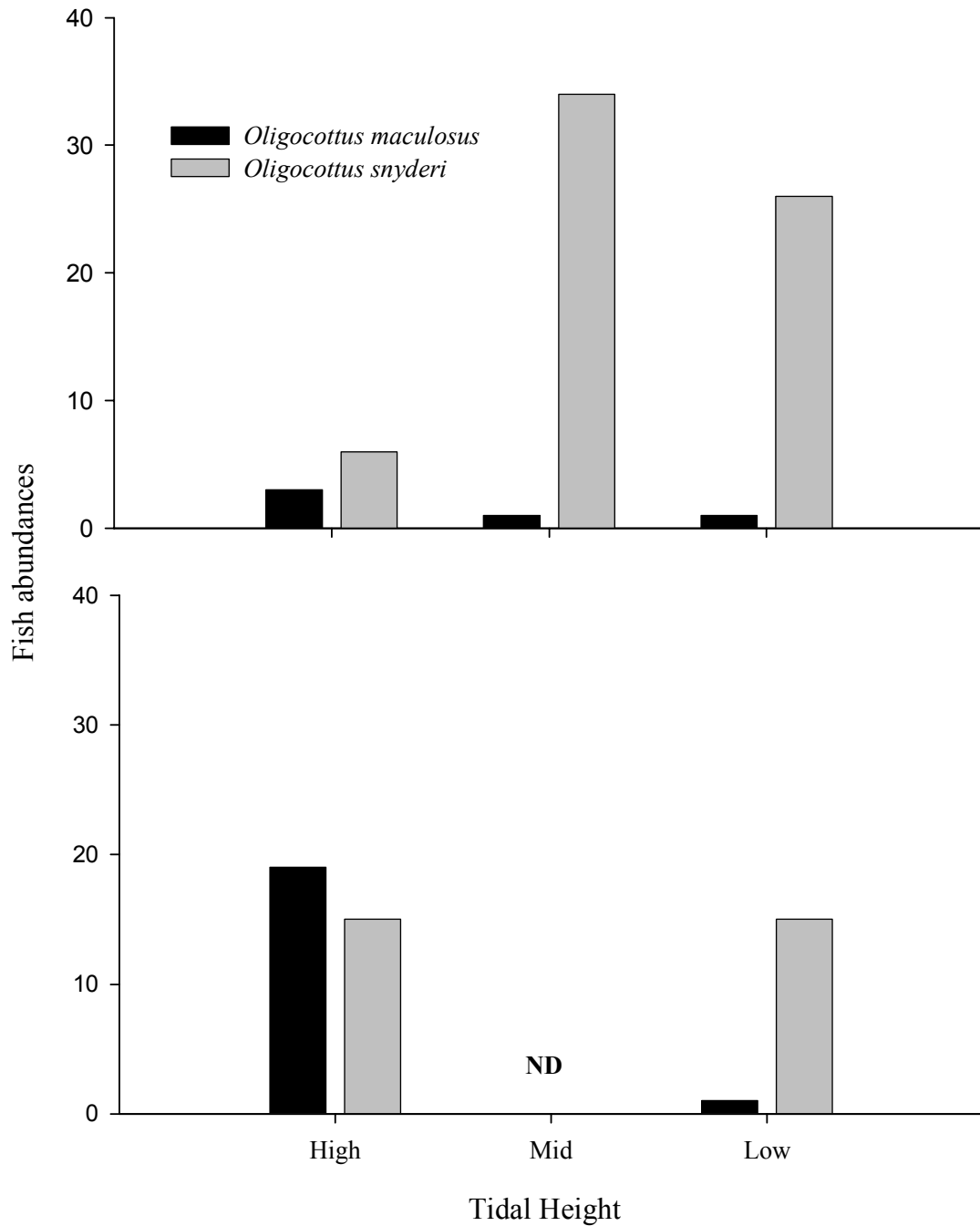


Figure 17. Total abundances of two sculpin species, *Oligocottus snyderi* and *Oligocottus maculosus*, during intertidal fish inventories conducted at Damnation Creek (top) on 5 February 2005 and at False Klamath Cove (bottom) on 6 February 2005, Redwood National and State Parks. The mid intertidal zone was not sampled at False Klamath Cove so no data (ND) was recorded in the mid intertidal zone at this site.

Community Monitoring

A total of 4,882 fish were sampled during 2004 and 2005 at Enderts Beach, Damnation Creek, and False Klamath Cove over 13 sampling periods (Table 6). The species composition and abundance varied between the sites sampled. The total number of fish collected at Enderts Beach was more than twice the abundance at either Damnation Creek or False Klamath Cove. In contrast, species richness was 25% less at Enderts Beach. Because fish may have been recaptured on one or more sampling occasions, these total counts should not be considered a population estimate.

The 24 species of fish noted during the tidepool monitoring of Redwood National and State Parks were grouped into 10 functional groups to simplify the summary of distribution patterns (Table 6). Groups were determined as a combination of taxonomic grouping and ecological niche utilization. For example, the seven species from the Stichaeidae and Pholidae (pricklebacks and gunnels) were grouped together due to their similar habitat utilization. These elongate, eel-like fish commonly reside beneath boulders or under algal cover. The early life history stages of this group are difficult to distinguish and were often identified only to group level. Larval fish of the genera *Clinocottus* and *Oligocottus* were also difficult to distinguish and in early sampling periods were lumped into the *Clinocottus/Oligocottus* complex. This complex was comprised of four common Cottidae species that have similar morphological characteristics (Mecklenburg et al. 2002). The most common genus of this complex will be described in greater detail in a following section.

Table 6. Total abundances of rocky intertidal fishes found in Redwood National and State Parks in 2004 -2005. Abundances given for Enderts Beach, Damnation Creek, and False Klamath Cove were summed for all sampling periods.

Species	Common Name	Functional Group	DMN	END	FKC	Total	Relative total %
<i>Atherinops californiensis</i> *	Jacksmelt*	Atheriniformes		1		1	0.02
<i>Clinidae spp.</i>	Kelpfish spp.	Clinidae			1	1	0.02
<i>Artedius corallinus</i>	Coralline sculpin	Artedius	4			4	0.08
<i>Artedius fenestralis</i>	Padded sculpin	Artedius	5	4	1	10	0.20
<i>Artedius lateralis</i>	Smoothhead sculpin	Artedius	35	13	15	63	1.29
<i>Oligocottus snyderi</i>	Fluffy sculpin	Clinocottus Oligocottus Complex	852	1564	722	3138	64.28
<i>Clinocottus aculiceps</i>	Sharpnose sculpin	Clinocottus Oligocottus Complex	13	84	10	107	2.19
<i>Clinocottus globiceps</i>	Mosshead sculpin	Clinocottus Oligocottus Complex	21	139	40	200	4.10
<i>Oligocottus maculosus</i>	Tidepool sculpin	Clinocottus Oligocottus Complex	80	525	183	788	16.14
<i>Clin./Olig. larvae spp.</i>	Sculpin larvae spp.	Clinocottus Oligocottus Complex	11	69	17	97	1.99
<i>Hemilepidotus spinosus</i>	Brown Irish lord	Other Cottidae	5		1	6	0.12
<i>Enophrys bison</i>	Buffalo sculpin	Other Cottidae			1	1	0.02
<i>Leptocottus armatus</i>	Staghorn sculpin	Other Cottidae		1		1	0.02
<i>Scorpaenichthys marmoratus</i> *	Cabezon*	Other Cottidae	12	36	26	74	1.52
<i>Gobiesox maeandricus</i>	Northern clingfish	Gobiesocidae	18	78	60	156	3.20
<i>Hexagrammos decagrammus</i>	Kelp greenling*	Hexagrammidae	3	6	3	12	0.25
<i>Liparis florum</i>	Tidepool Snailfish	Liparidae	1	2	4	7	0.14
<i>Apodichthys flavidus</i>	Penpoint gunnel	Pholidae Stichaeidae Complex	34	5	32	71	1.45
<i>Apodichthys fucorum</i>	Rockweed gunnel	Pholidae Stichaeidae Complex	1		4	5	0.10
<i>Pholis ornata</i>	Saddleback gunnel	Pholidae Stichaeidae Complex	1		3	4	0.08
<i>Xiphister atropurpureus</i>	Black prickleback	Pholidae Stichaeidae Complex	4	1	10	15	0.31
<i>Anoplarchus purpurascens</i>	High cockscomb	Pholidae Stichaeidae Complex	2		4	6	0.12
<i>Cebidichthys violaceus</i>	Monkeyface prickleback	Pholidae Stichaeidae Complex			3	3	0.06
<i>Xiphister mucosus</i>	Rock prickleback	Pholidae Stichaeidae Complex	2			2	0.04
<i>Pholidae/Stichaeidae larvae spp.</i>	Eel-like larvae spp.	Pholidae Stichaeidae Complex	4		7	11	0.23
<i>Sebastes melanops</i> *	Black rockfish*	Scorpaenidae	6	2	91	99	2.03
Total Abundance of Species			1114	2530	1238	4882	
Species Richness (# of Species)			19	15	20	24	

* Considered primarily seasonal or transient fish species

The *Artedius* group included three cottid species of the same genus that were grouped due to similar morphological and habitat characterizations (Table 6). The remaining species from this family were combined into the “Other Cottidae” group. This group consisted of four species of sculpins that commonly inhabit subtidal waters and are less frequently found in the intertidal. The Atherinidae, Liparidae, Gobisocidae, Clinidae, Hexagrammidae, and Scorpaenidae were each represented by only one species, all of which were easily identified and which inhabit distinct areas.

Most of the fish collected in this study were small (<100mm TL) (Table 7). Less than one percent of the fish collected were greater than 100 mm TL. The range of average lengths was 38-70 mm. The Scorpaenidae, Atheriniformes and Hexagrammids were represented only by the juvenile stage, as adults of these species are usually found in deeper offshore water.

Species abundance and distribution patterns differed between the sampled sites. Enderts Beach had the greatest overall abundance of fish, largely driven by the *Clinocottus/Oligocottus* group (Table 8). For all sites sampled, *Clinocottus* and *Oligocottus* sculpins comprised, by far, the greatest number of fish sampled (88.7% of total). Enderts Beach had at least twice the number of *Clinocottus/Oligocottus* species than the other sites. In contrast, this site had a much smaller number of Stichaeids and Pholids than the other sites. The majority of juvenile *Sebastes* (90%) recorded in this study were sampled in tidepools at False Klamath Cove.

The differences in fish patterns among sites were also affected by temporal variation. The highest abundance of total fish occurred during summer and early fall

Table 7. Abundance, size range (mm) and average total length (mm) for intertidal fish groups sampled at Enderts Beach, Damnation Creek, and False Klamath Cove, Redwood National and State Parks during 13 sampling periods in 2004-2005.

Fish Group	# of Species in Group	Total # of Fish	Total Length Range (mm)	Average Total Length (mm)
Artedius	3	77	17 - 134	66
Atheriniformes	1	1	84	--
Clinidae	1	1	68	--
<i>Clinocottus Oligocottus</i> Complex	4	4330	10 - 104	38
Other Cottidae	4	82	23 - 180	70
Gobiesocidae	1	156	12 - 80	43
Hexagrammidae	1	12	63 - 97	69
Liparidae	1	7	20 - 100	47
Pholidae Stichaeidae Complex	8	117	24 - 210	69
Scorpaenidae	1	99	35 - 77	57

Table 8. Abundances of intertidal fish sampled at Enderts Beach, Damnation Creek and False Klamath Cove, Redwood National and State Parks over 13 sampling periods, 2004-2005.

Fish Group	Damnation Creek	Enderts Beach	False Klamath Cove	Grand Total	Relative Total Abundance %
Artedius	44	17	16	77	1.58
Atheriniformes		1		1	0.02
Clinidae			1	1	0.02
<i>Clinocottus Oligocottus</i> Complex	977	2,381	972	4,330	88.69
Other Cottidae	17	37	28	82	1.68
Gobiesocidae	18	78	60	156	3.20
Hexagrammidae	3	6	3	12	0.25
Liparidae	1	2	4	7	0.14
Pholidae Stichaeidae Complex	48	6	63	117	2.40
Scorpaenidae	6	2	91	99	2.03
Grand Total	1114	2530	1238	4,882	100

sampling periods (Table 9). These patterns varied between sites, caused largely by high abundances of *Clinocottus* and *Oligocottus* recruits. Juvenile *Sebastes* were only recorded in tidepools during late spring and summer months (May-August).

Species composition was evaluated using several indices. The species diversity and richness values for each site within Redwood National and State Parks are given in Table 10. Species richness and diversity indices were also calculated for each sampling period at each of the three sites (Table 11). One-way Analysis of Variance (ANOVA) was used to test for seasonality in diversity and richness values. Tukey's post-hoc tests were used for individual seasonal comparisons (Table 12). There was not a significant seasonal relationship among any of the diversity values ($p > 0.05$) or the Margalef species richness index (R') ($p > 0.05$). There was a significant seasonal difference in number of species sampled, with more species noted in summer months than in the winter.

A one-way ANOVA was also used to test for significant differences of diversity and richness values among the three sites and a Tukey's post-hoc test was used for individual comparisons (Table 12). The sites differed in the number of species ($p < 0.01$) with a post-hoc comparison showing Enderts Beach as having fewer species (15) compared to Damnation Creek and False Klamath Cove (19 and 20 respectively). The calculated Margalef species richness indices (R') were significantly different among the sites ($p < 0.01$). Post-hoc comparisons showed that species richness was lower for Enderts Beach than the other two sites. The Shannon diversity index (H'), which describes the community structure, showed that the sites differed in overall species diversity (H') ($p < 0.01$). Simpson's reciprocal index of species diversity ($1/D'$) showed

Table 9. Total number of fish sampled during each sampling period in 2004-2005 at Enderts Beach, Damnation Creek and False Klamath Cove, Redwood National and State Parks. n/s=not sampled

		2004					2005									
Sampling Periods		1	2	3	4	5	6	7	8	9	10	11	12	13		
Date		3/04	4/04	5/04	6/04	7/04	8/1/04	8/28/04	9/04	12/04	2/05	5/05	6/05	10/05		
<u>False Klamath Cove</u>																
Fish Group																
Artedius		3	1	4	4	1	1	1		4			1	1		
Clinidae					1											
<i>Clinocottus/Oligocottus</i>		79	64	58	134	46	114	149	109	69	60	27	36	96		
Gobiesocidae		1	2	1	6	1	6	17	4	3	9	3	1	7		
Hexagrammidae				2	1											
Liparidae					2		1	1								
Other Cottidae		2	2	5	5	1	2	1	1		3	1	4	1		
Pholida/Stichaeidae		1	6	3	13	3	5	3	7	3	1	3	5	9		
Scorpaenidae				1	34	22	15						19			
<u>Damnation Creek</u>																
Fish Group																
Artedius		10	n/s		4	4	9	2	2	5	2	1		5		
<i>Clinocottus/Oligocottus</i>		46	64	n/s	50	137	127	88	129	110	62	44	40	126		
Gobiesocidae		1	2	n/s	1	2	2		1	6	2		1	1		
Hexagrammidae				n/s	2	1										
Liparidae				n/s	1											
Other Cottidae			2	n/s	3	2		3	5		2					
Pholidae/Stichaeidae		3	4	n/s	5	2	11	2	4	1	2	2	8	7		
Scorpaenidae						3							3			

Table 9 (Continued). Total number of fish sampled during each sampling period in 2004-2005 at Enderts Beach, Damnation Creek and False Klamath Cove, Redwood National and State Parks. n/s=not sampled

Sampling Periods Date	2004					2005									
	1	2	3	4	5	6	7	8	9	10	11	12	13		
3/04	4/04	5/04	6/04	7/04	8/1/04	8/28/04	9/04	12/04	2/05	5/05	6/05	10/05			
<u>Enderts Beach</u>															
Fish Group															
Artedius		2			3	1		4	4			1	2		
Atheriniformes		1													
<i>Clinocottus/Oligocottus</i>	61	93	176	347	548	318	259	49	42	44	75	179	190		
Gobiesocidae		5	12	17	12	6	10		7	3	2	3	1		
Hexagrammidae			3	2	1										
Liparidae			2												
Other Cottidae	1			12	9	8	5		1	1					
Pholidae/Stichaeidae		1		1		1						3			
Scorpaenidae					1							1			

Table 10. Intertidal fish species richness and diversity values for Redwood National and State Parks sites; Enderts Beach, Damnation Creek, and False Klamath Cove. Data is combined from 13 sampling periods between March 2004 and September 2005. Inventory data from a one time sampling event at Damnation Creek and False Klamath Cove, completed in February 2005, are noted in parenthesis.

	Enderts Beach (41.69 N)	Damnation Creek (41.65 N)	False Klamath Cove (41.59 N)	All Sites Combined
Number of specis (#)	15	19 (21)	20 (12)	24
Species Richness Index Margalef (R')	1.79	2.57 (4.00)	2.68 (2.43)	2.72
Species Diversity Shannon (H')	1.50	1.04	1.15	1.28
Species Diversity 1/Simpson's (1/D')	2.59	1.64 (4.43)	2.20 (5.97)	2.16
Pielou eveness	0.49	0.34	0.41	0.40

Table 11. Seasonal species diversity and richness indices for Enderts Beach, Damnation Creek, and False Klamath Cove, Redwood National and State Parks for intertidal fish sampling periods in 2004-2005. Diversity indices were calculated using Simpson's Reciprocal Index (1/D) and Shannon-Weiner index (H'). Also given are number of species collected (#) and Margalef's richness index (R').

	Enderts Beach				Damnation Creek				False Klamath Cove			
	1/D	H'	#	R'	1/D	H'	#	R'	1/D	H'	#	R'
2004												
13-16 March	2.07	0.82	4	0.74	1.24	0.47	5	1.03	2.55	1.14	6	1.21
10-24 April	2.18	1.00	6	1.12	1.82	1.06	9	1.83	1.77	0.99	7	1.39
9-11 May	2.28	0.98	5	0.76	2.35	1.27	9	1.85	2.25	1.22	9	1.90
1-6 June	1.84	0.87	6	0.84	2.50	1.38	10	2.18	2.97	1.47	10	1.95
2-4 July	1.84	0.81	8	1.10	1.61	0.88	10	1.83	3.03	1.42	10	1.89
1-3 August	1.72	0.76	6	0.86	1.62	0.88	8	1.45	2.24	1.25	11	2.03
28-30 August	1.60	0.71	5	0.72	1.42	0.65	5	0.90	1.59	0.80	7	1.17
1-15 September	3.57	1.28	4	0.76	1.62	0.90	9	1.65	1.66	0.97	9	1.67
2005												
10-12 December	4.14	1.56	7	1.50	1.54	0.80	7	1.29	3.24	1.47	8	1.60
5-7 February	2.78	1.15	5	1.03	1.40	0.67	6	1.23	3.86	1.53	7	1.40
24 April, 1May	2.57	1.12	5	0.94	1.41	0.62	5	1.06	2.00	1.10	7	1.70
5-9 June	2.37	1.10	7	1.15	1.85	0.98	6	1.29	4.66	1.67	8	1.66
16-18 September	2.31	1.01	5	0.77	1.51	0.80	7	1.29	2.19	1.25	11	2.12
Overall	2.59	1.50	15	1.79	1.64	1.04	19	2.57	2.20	1.15	20	2.68

Table 12. Analysis of variance of fish species diversity and richness indices from Enderts Beach, Damnation Creek, and False Klamath Cove, Redwood National and State Parks. Significant values are underlined and a Tukey's post-hoc analysis determined ranking of significant differences.

		<i>df</i>	<i>MS</i>	<i>F</i>	P-value	Post Hoc
No. of species	Site	2,24	26.85	18.42	<u>0.00</u>	EndertsBeach<False Klamath Cove
	Sampling Period	12,24	4.87	3.34	<u>0.01</u>	=Damnation Creek summer>winter
Margalef Species Richness (R')	Site	2,24	1.79	22.77	<u>0.00</u>	EndertsBeach False Klamath Cove
	Sampling Period	12,24	0.14	1.76	0.11	=Damnation Creek n.s.
Shannon Species Diversity (H')	Site	2,24	0.48	9.35	<u>0.00</u>	EndertsBeach<False Klamath Cove
	Sampling Period	12,24	0.08	1.61	0.16	=Damnation Creek n.s.
Simpson's species diversity (1/D')	Site	2,24	3.10	6.55	<u>0.01</u>	EndertsBeach<False Klamath Cove
	Sampling Period	12,24	0.56	1.18	0.35	=Damnation Creek n.s.

similar results to the Shannon diversity index with a significant difference in diversity values ($1/D'$) between sites ($p < 0.001$). Tukey's post-hoc examinations showed that Damnation Creek had significantly lower species diversity values than both Enderts Beach and False Klamath Cove, which were not significantly different from each other.

Abundance distributions within communities may be represented as rank-dominance curves, with one axis of the curve representing species rank in a community and the other representing logarithmic species abundance (Whittaker 1965). These plots are effective in analyzing types of abundance distributions in communities. A Whittaker plot of rank/dominance was used to visualize overall species abundance distributions (Figure 18). The plot is of the proportion of total number of individuals for each species in log scale against the species rank. The rank-abundance diagram shows the asymmetry in the abundance of intertidal fish species. Steep plots, as shown with the data, indicate assemblages with high dominance.

Size frequency distributions were determined for the two most abundant fish species, *Oligocottus maculosus* and *O. snyderi*, collected at the three intertidal sites from March 2004 to September 2005 (Figure 19). Both species had the greatest number of individuals in the 30-35 mm size range. Although more *O. snyderi* were collected, the size ranges for the two species were remarkably similar, 12.4-103.6 mm for *O. maculosus* and 11.2-98.7 mm for *O. snyderi*. Subsequently, size frequency distributions were examined for the two species at each site using the average number of individuals per pool (Figure 20). Enderts Beach had a much greater frequency of smaller individuals than the other two sites, indicating higher abundance of recruit and juvenile size classes.

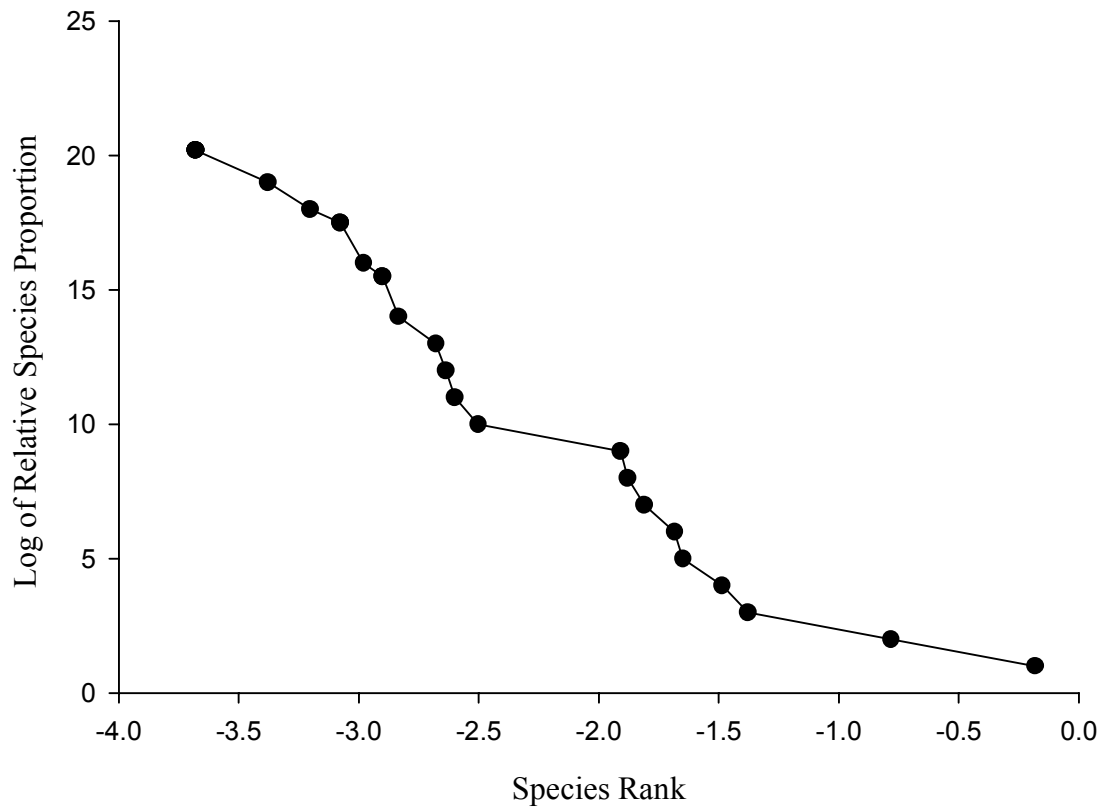


Figure 18. Whittaker plot of the relative intertidal fish species proportion verses species rank of abundance. Data from 13 sampling periods at Redwood National and State Parks sites (Damnation Creek, False Klamath Cove, and Enderts Beach) 2004-2005.

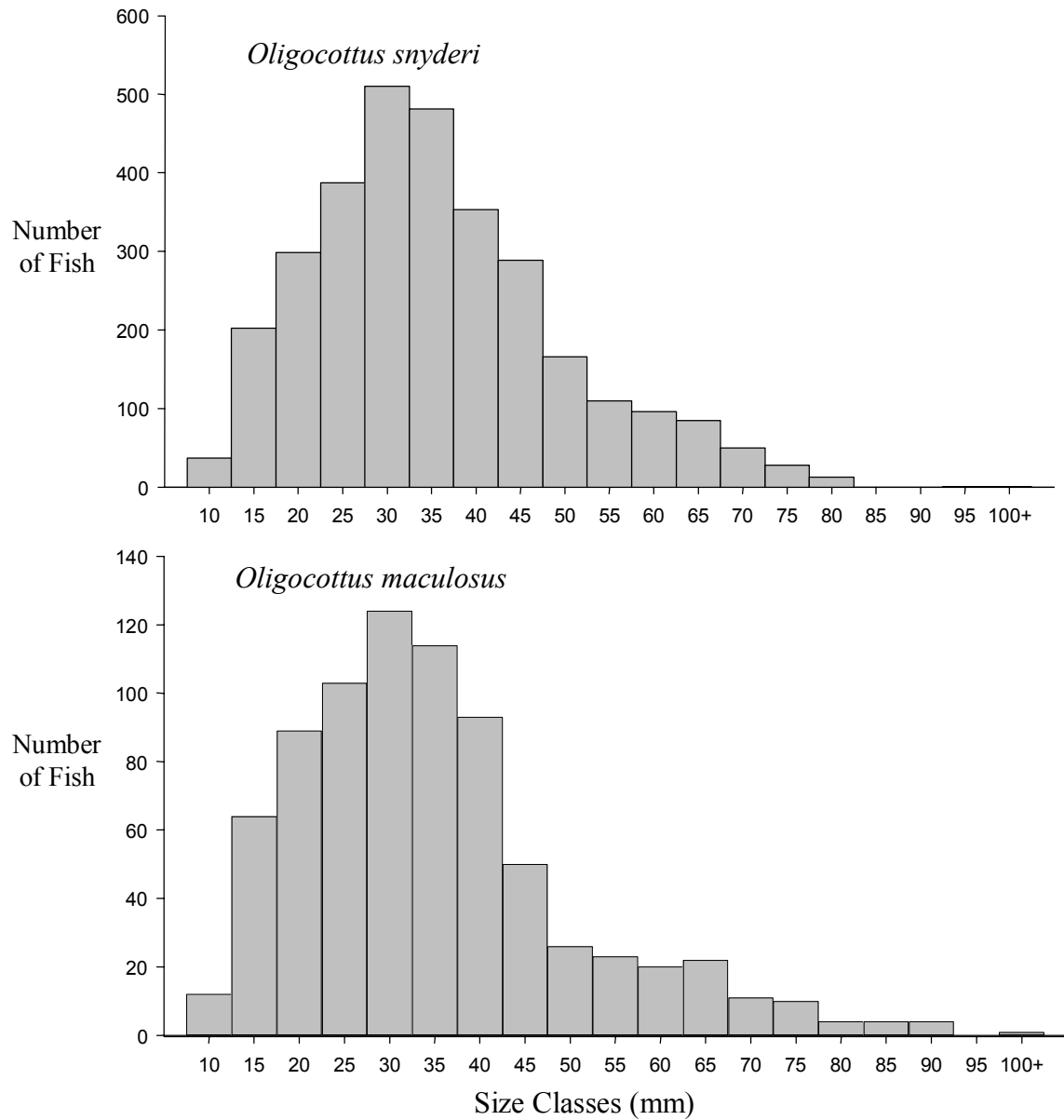


Figure 19. Size frequency distribution for *Oligocottus snyderi* (top) and *O. maculosus* (bottom) in combined sampling events from Enderts Beach, Damnation Creek, and False Klamath Cove, Redwood National and State Parks; 2004-2005.

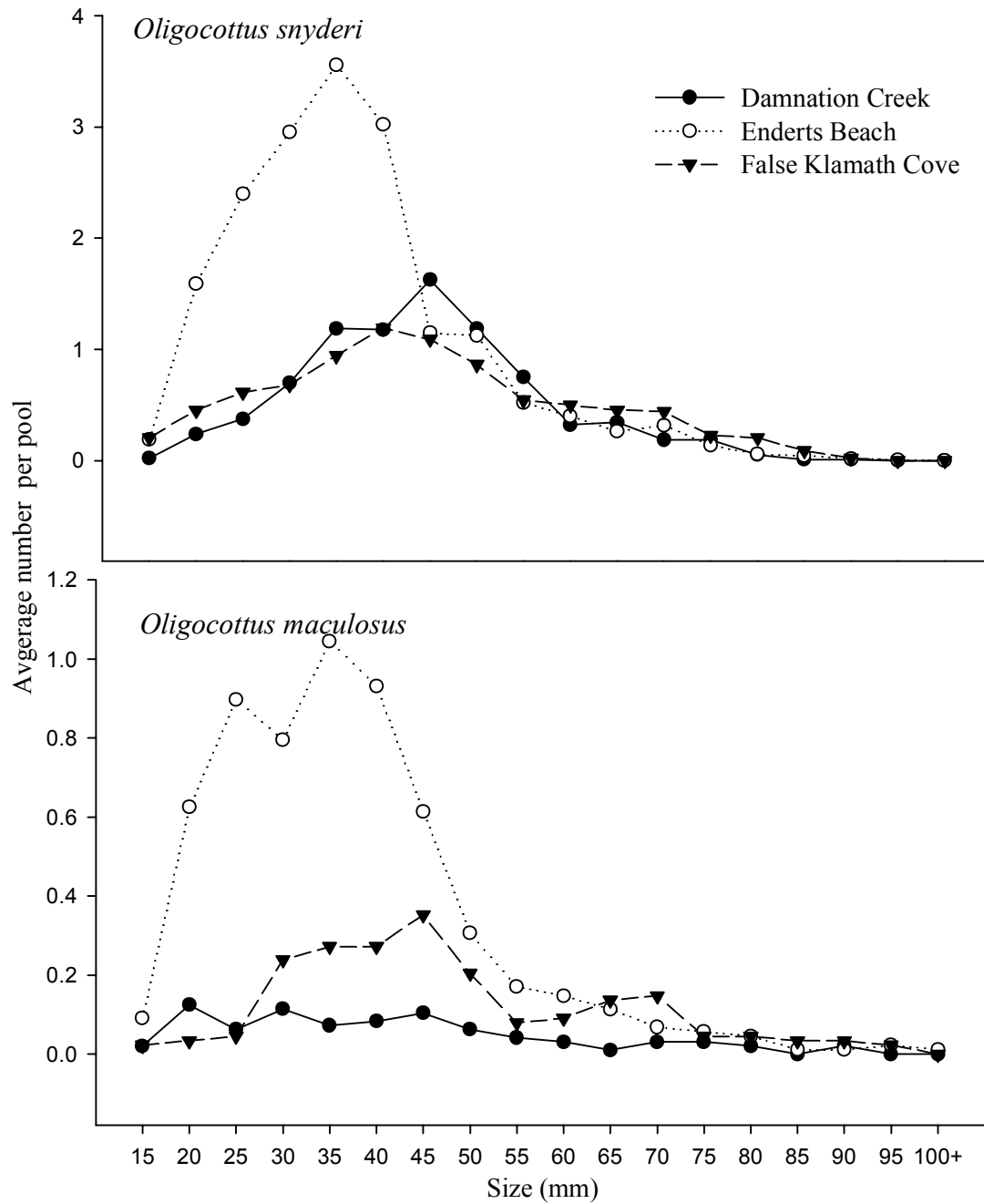


Figure 20. Size (mm) distribution of *O. snyderi* (top) and *O. maculosus* (bottom) for all sampling events combined from Enderts Beach, Damnation Creek, and False Klamath Cove, Redwood National and State Parks, 2004-2005.

Seasonal variation of both *O. snyderi* and *O. maculosus* was high for 2004, with peak abundances occurring in summer (Figure 21). In 2005, *O. snyderi* seemed to be following the same pattern of summer peak abundances, while *O. maculosus* abundances did not show a summer peak. Annual variation was seen in some data about the sites (Figure 22). To examine recruitment timing, fish were divided into three size-classes. Individuals less than and equal to 25 mm total length (TL) were considered to be new recruits (settlers within the last month), fish between 26-35 mm TL were placed into the juvenile category and all fish greater or equal to 36 mm TL were considered adults. The size class distribution patterns showed some temporal and spatial variation for both *O. snyderi* (Figure 23) and *O. maculosus* (Figure 24). The significance of this variation among sites and sampling periods was calculated using repeated measures analysis of variance (Table 13). Densities of recruits were significantly different between sites for both *Oligocottus snyderi* and *O. maculosus*, with Enderts Beach having a larger recruitment peak than the other sites. There was also a significant site difference in juvenile *O. snyderi* densities. The larger *O. snyderi* recruitment pulse at Enderts Beach supported higher juvenile abundances but this difference did not continue into the adult population. There was not a significant site difference in *O. maculosus* densities for the juvenile and adult life stages.

There were patterns of seasonal variation that differed between the three life stages of the cottid species examined. Densities of *Oligocottus snyderi* recruits were significantly different among sampling periods (Table 13). The significant pattern of

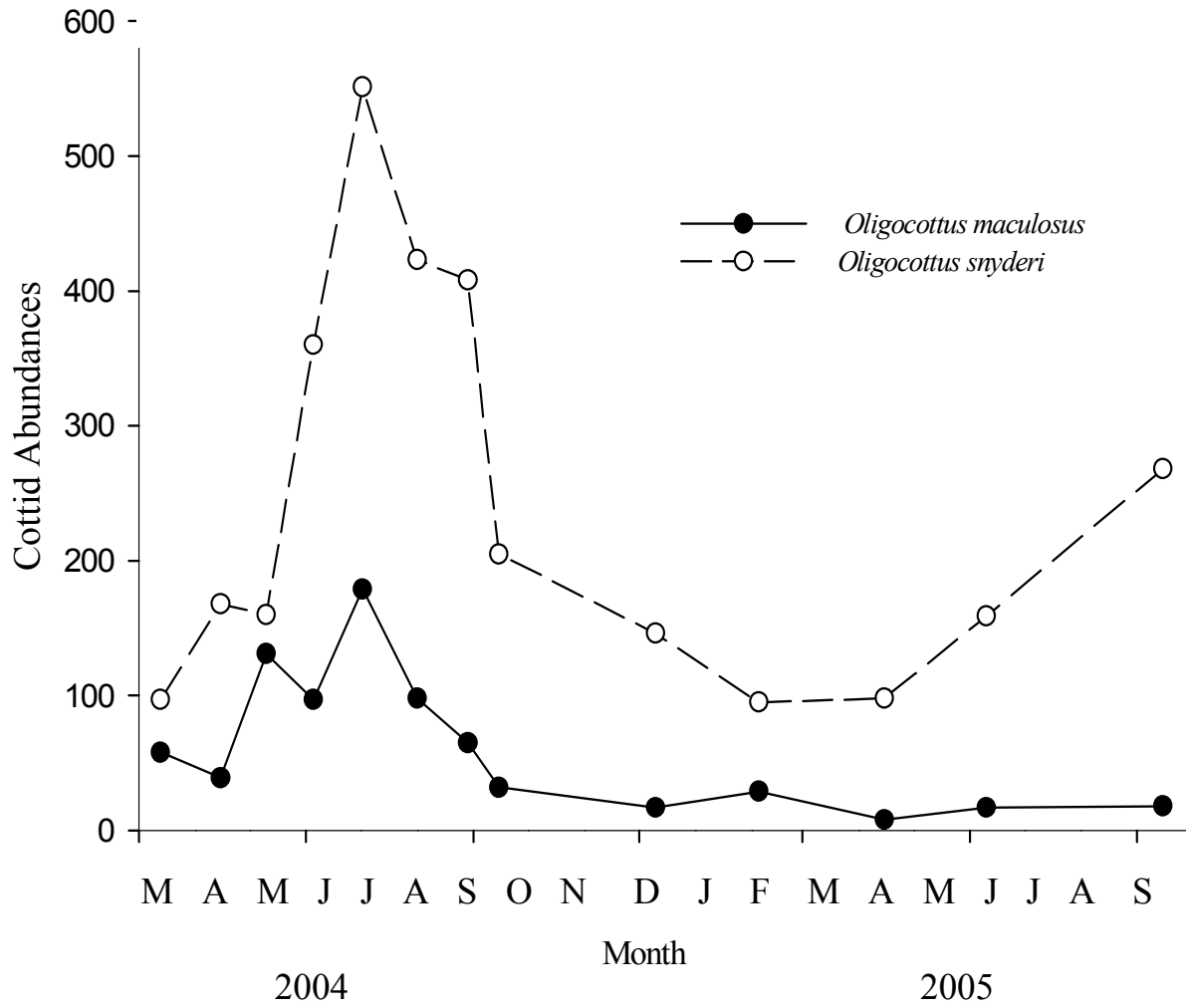


Figure 21. Total number of *Oligocottus maculosus* and *Oligocottus snyderi* from three sites within Redwood National and State Parks from 13 sampling periods in 2004-2005. Sampling periods were monthly for 2004 and bimonthly for 2005.

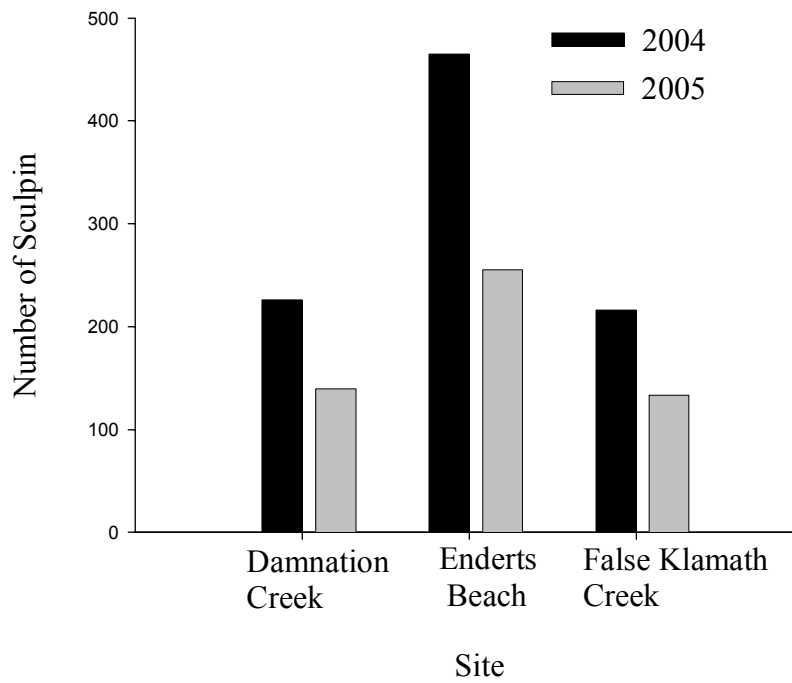


Figure 22. Average number of *Oligocottus* sculpins (*O. maculosus* and *O. snyderi* combined) per sampling period, per pool for 2004 and 2005. Data is combined for all sampled tidepools at rocky intertidal sites Damnation Creek, and Enderts Beach and False Klamath Cove, Redwood National and State Parks.

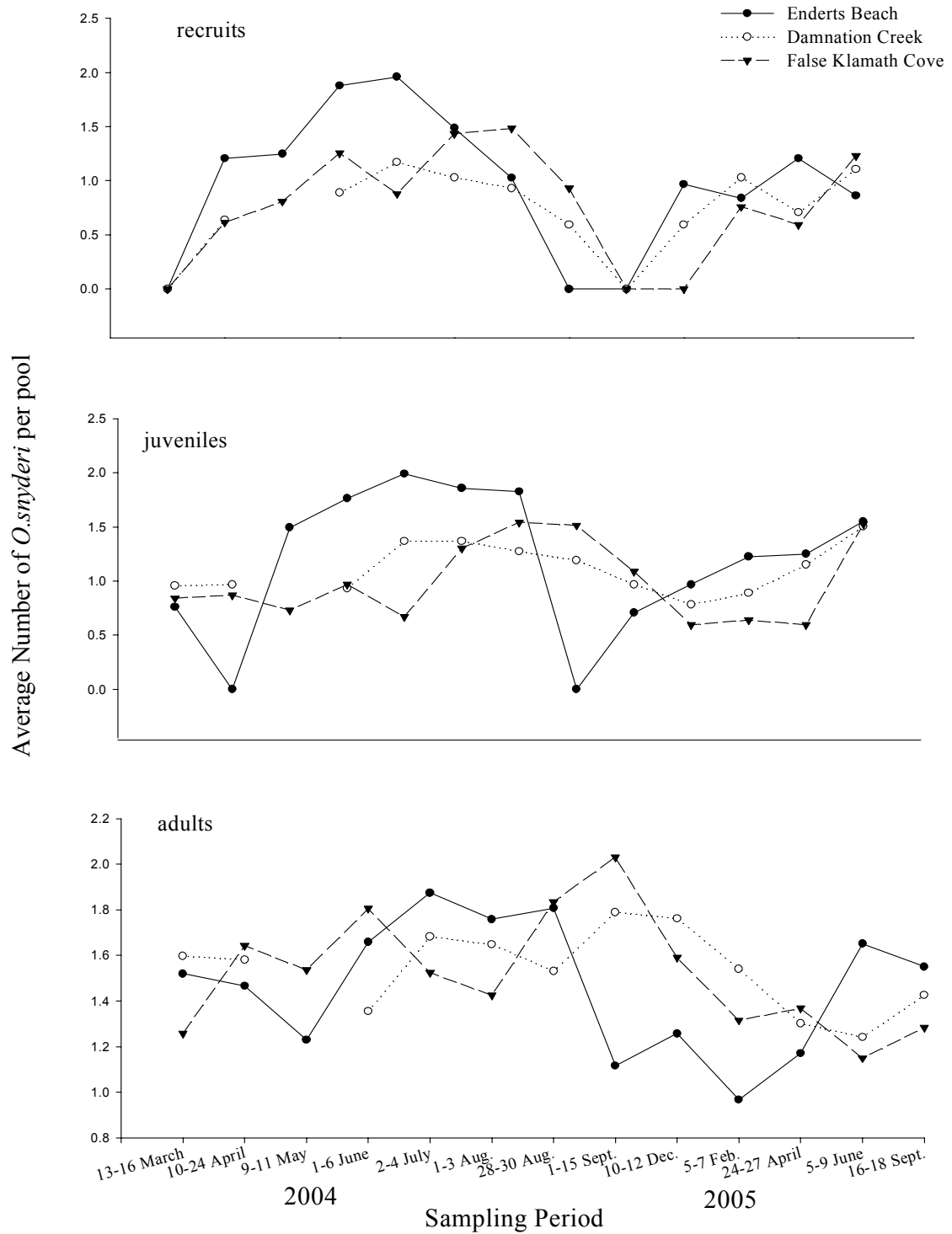


Figure 23. Average number of *Oligocottus snyderi* recruits(top), juveniles (middle), adults (bottom) per pool from three sites within Redwood National and State Parks from 13 sampling periods in 2004-2005. Data are square-root transformed.

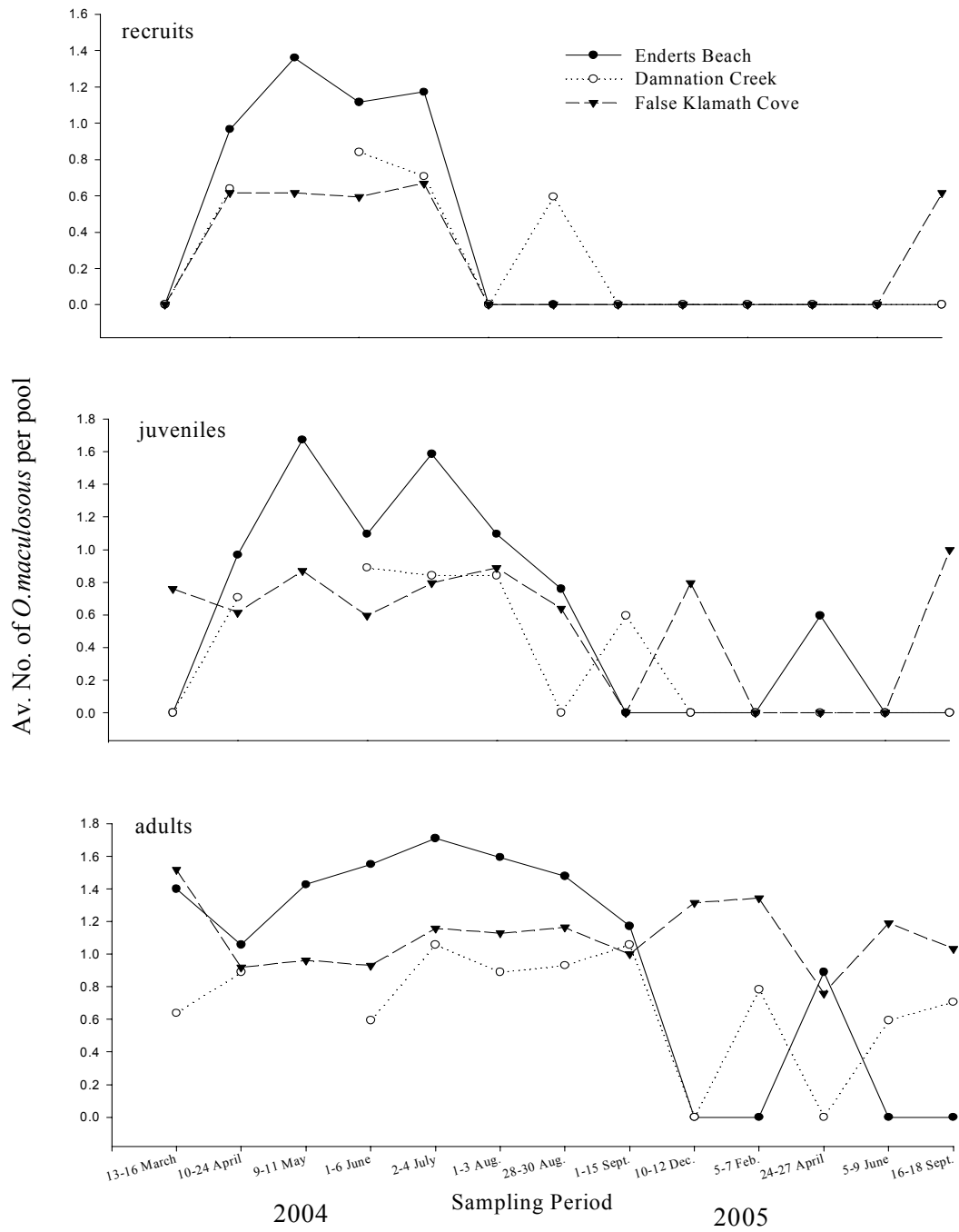


Figure 24. Average number of *Oligocottus maculosus* recruits (top), juveniles (middle), adults (bottom) per pool from three sites within Redwood National and State Parks from 13 sampling periods in 2004-2005. Data are square-root transformed.

Table 13. Comparison of site and sampling period on fish density (number of fish per cm³) using repeated-measures analysis. Fish density data for three different life stages of *Oligocottus snyderi* and *O. maculosus* from Enderts Beach, Damnation Creek and False Klamath Cove in 2004-2005. Fish densities are x[^]0.5 transformed. Significant (p <0.05) p-values are underlined. A Tukey's post-hoc analysis showed that, for all significant site differences, abundances were greater at Enderts Beach than False Klamath Cove and Damnation Creek.

Species	Source	df	Recruits (≤25mm TL)			Juveniles (26-35 mm TL)			Adults (≥ 36mm TL)		
			MS	F	p	MS	F	p	MS	F	p
<i>O. snyderi</i>	Sampling Period	12	36.66	12.35	0.000						
	Site	2	24.93	8.40	0.000	51.95	15.55	0.000	23.61	6.31	0.000
	(Pool) Site	24	12.24	4.12	0.000	63.00	18.85	0.000	42.09	11.2	0.000
	SP *Site	22	5.56	1.87	0.012	15.03	4.50	0.000	11.30	3.02	0.000
	Error	229	2.96			13.26	3.97	0.000	38.48	10.2	0.000
Test using MS for nested (Pool) Site error term											
<i>O. maculosus</i>	Site	12	36.66	6.58	<u>0.000</u>	51.95	3.91	<u>0.003</u>	23.61	0.61	0.801
	SP	2	24.93	4.48	<u>0.023</u>	63.00	4.74	<u>0.019</u>	42.09	1.09	0.353
	SP * Site	24	12.24	2.20	<u>0.034</u>	15.03	1.13	0.386	11.30	0.29	0.991
	Sampling Period	12	4.37	6.17	0.000	7.87	6.17	0.000	11.99	4.07	0.000
	Site	2	3.01	4.25	0.015	9.47	7.42	0.001	32.96	11.1	0.000
<i>O. maculosus</i>	(Pool)Site	24	1.22	1.72	0.022	3.97	3.11	0.000	7.726	2.62	0.000
	SP *Site	22	1.50	2.12	0.003	5.31	4.17	0.000	13.85	4.70	0.000
	Error	229	0.70			1.27			2.94		
	Test using MS for nested (Pool) Site error term										
	Site	12	4.37	2.90	<u>0.015</u>	7.87	1.48	0.203	11.99	0.86	0.593
<i>O. maculosus</i>	SP	2	3.01	1.99	0.160	9.47	1.78	0.192	32.96	2.38	0.111
	SP * Site	24	1.22	0.81	0.694	3.97	0.74	0.751	7.72	0.55	0.914

seasonal recruitment is clearly seen with peak abundances for both species in early summer (Figure 23 and Figure 24). Juvenile densities had a similar pattern of seasonal variation as the earlier age class; however, the difference was only significant for *Oligocottus snyderi*. Adult populations did not vary significantly between the sampling periods for *O. snyderi* or *O. maculosus* populations ($p > 0.5$). The interaction between sampling period and site was significant for *O. snyderi* recruits (Table 13). This reveals that the site differences were not consistent across sampling periods. The larger summer *O. snyderi* recruitment peak at Enderts Beach is probably causing the inconsistency in the interaction. The interaction term was not significant for any other life stage.

A Kruskal-Wallis analysis was used to test for site and seasonal differences in total *Clinocottus globiceps* and *C. acuticeps* densities (Table 14). The non-parametric test was used for these species due to the low numbers and nonnormal distribution of individuals. There were not enough individuals of these species to test for differences among life stages. The combined life stages of *Clinocottus globiceps* and *C. acuticeps* showed significant differences ($p < 0.001$) in densities among sites. A Tukey's post-hoc comparison test showed that both species had greater densities at Enderts Beach than False Klamath Cove and Damnation Creek. Both species also showed significant differences ($p < 0.05$) in densities among sampling periods.

Fish from the family Cottidae were injected with elastomer tags over six sampling periods between April and September 2004. Tagging data from this study suggested pool fidelity with very little evidence of movement between pools. A total of 1399 fish were

Table 14. Kruskal-Wallis one-way Analysis of Variance test of site and sampling period differences in fish densities of *Clinocottus acuticeps* and *C. globiceps* from Enderts Beach, Damnation Creek and False Klamath Cove in 2004-2005. Fish densities are average number of fish per cm³ ($x^{0.5}$ transformed). Significant ($p < 0.05$) p-values are underlined. A Tukey's post-hoc multiple comparison tested for between site differences.

<i>Species</i>	Source	Test statistic	p	Post-hoc comparison
<i>C. acuticeps</i>	Site	15.337	<u>0.000</u>	Enderts Beach > Damnation Creek = False Klamath Cove
	Sampling Period	11.199	<u>0.048</u>	
<i>C. globiceps</i>	Site	11.768	<u>0.003</u>	Enderts Beach > Damnation Creek = False Klamath Cove
	Sampling Period	35.566	<u>0.000</u>	

Table 15. Summary of mark recapture data for intertidal fish collected at three sites (Enderts Beach, Damnation Creek, and False Klamath Cove) within Redwood National and State Parks from April 2004 to September 2005.

Sampling Period	Date	Number of Fish Marked	Marked Fish at Large	Recaptures
2	Apr-04	30		
3	May-04	111	30	10
4	Jun-04	303	141	22
5	Jul-04	358	444	67
6	Aug-04	292	802	67
7	Aug-04	305	1094	93
8	Sep-04	0	1399	44
9	Dec-04	0	1399	7
10	Feb-05	0	1399	3
11	May-05	0	1399	0
12	Jun-05	0	1399	1
13	Sep-05	0	1399	0
Total		1399	1399	314

tagged over the six monthly sampling periods (Table 15). Of these, a total of 314 recaptures were recorded with only six individuals recaptured outside of their original tagging location. In four of these instances the fish were recaptured in pools very close (<5m) to the original pool of marking. The other two recaptures showed movement between pools that were approximately 5-10 meters apart. Twenty-two percent of cottids were recaptured and less than 2% of fish were recaptured in a different tidepool from their original capture location.

Habitat Factors and Fish Patterns

Zonation patterns of fish abundances varied greatly among sites and pools. The species present, their abundances, and size structure all varied among tidal height zones with a trend toward greater fish abundance in lower pools. The seasonal influx of juvenile cottids during summer into higher pools tended to lessen the degree of variation among zones.

Zonation patterns for the four most abundant cottid species (*O. snyderi*, *O. maculosus*, *C. acuticeps*, *C. globiceps*) were examined at each of the three intertidal sites (Figure 25). Pools higher on the shore (high and medium tidal heights) had greater densities of *O. maculosus*, *C. acuticeps* and *C. globiceps* at all three sites than lower pools. This pattern was opposite at all sites for *O. snyderi*. These abundance patterns were lumped across all cottid age classes and partly driven by high abundances of recruits in the higher pools. A Spearman's rank correlation test was used to examine the size distribution of cottids within tidal height. Spearman's statistic r-values indicated *C.*

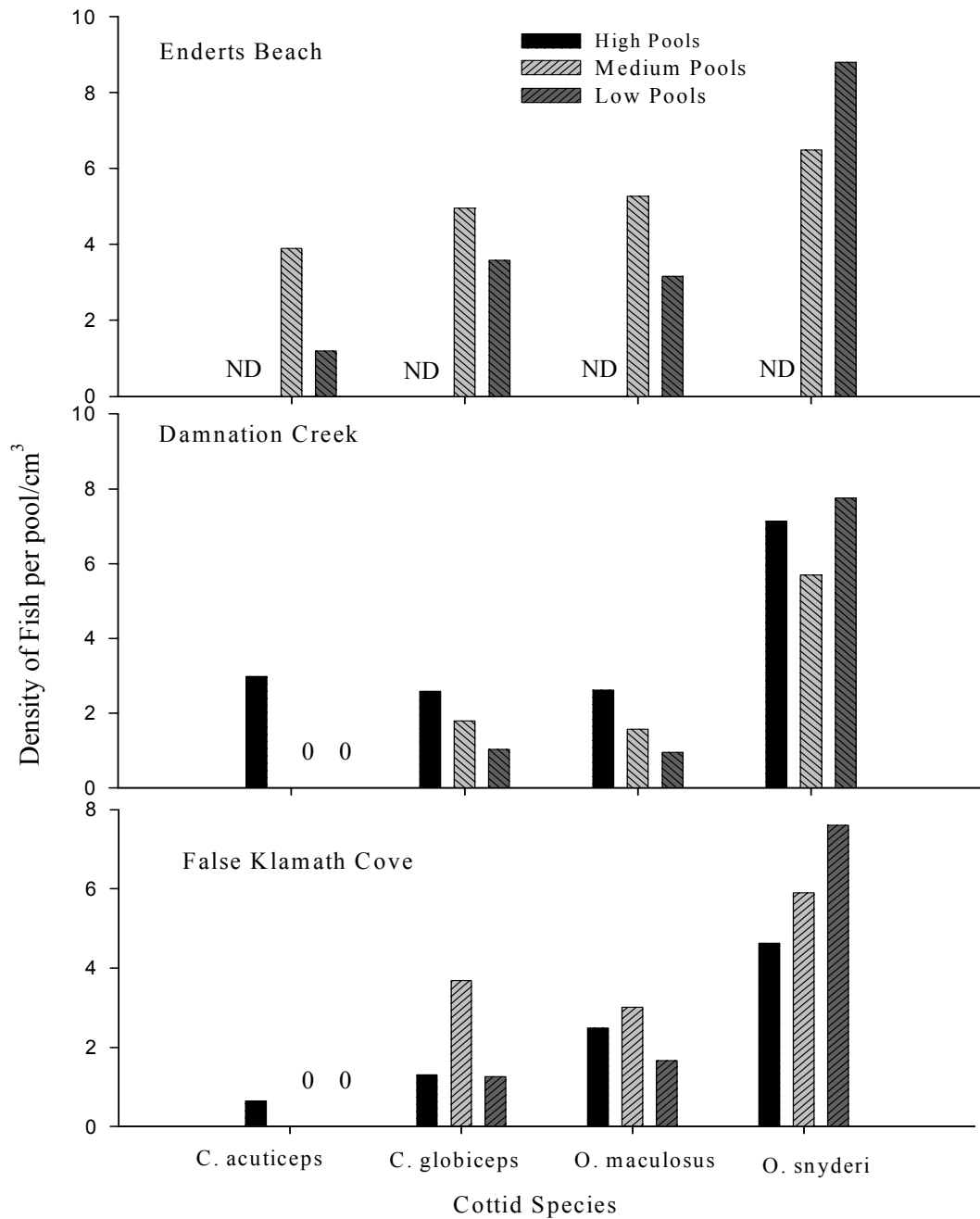


Figure 25. Tidal height distribution (high, medium and low) of four cottid species *Oligocottus maculosus*, *O. snyderi*, *Clinocottus globiceps*, and *C. acuticeps* at intertidal sites Enderts Beach (top), Damnation Creek (middle) and False Klamath Cove (bottom). Densities are number per pool/cm³. Data are square-root transformed. ND= no data collected for zone. 0= zero fish found.

globiceps ($r=-0.351$), *O. maculosus* ($r= -0.061$) and *O. snyderi* ($r=-0.008$) size increased with decreasing tidepool height above mean low water. However, the r -values are only indicative of very weak correlations between fish size and tidal height. *Clinocottus acuticeps* showed a weak positive ($+0.090$) correlation with increased size and tidal height.

A canonical correspondence analysis (CCA) attempted to detect relationships between the pool habitat factors and species group abundances (Figure 26). The habitat factors used for this analysis were tidal height, rugosity, surface area, depth, and percentage canopy cover. Pool temperature and salinity were initially put into the CCA, but showed no effect on the results. Consequently, pool temperatures and salinity were not included in the final canonical correspondence factor analysis. The CCA of fish assemblages and habitat characteristics showed the nine groups and 25 tidepools loaded on axis 1 and 2. Lines pointing in the same direction indicate that the corresponding habitat variables are positively correlated with each other. For example, rugosity and depth were correlated. Long lines are more important than the short ones. Lines pointing in opposite directions are negatively correlated, exemplified by, the lines for tidal height and percentage canopy cover. This would be interpreted as lower pools being more highly associated with greater canopy cover. Lines with an angle of 90 degrees indicate that the two variables are uncorrelated. An example is pool depth and tidal height. The same interpretation holds for species. For example, *Clinocottus globiceps* and *O. maculosus* are near each other in the CCA which is interpreted as the two species being closely associated with regard to pools and habitat factors. Sampled pools are removed

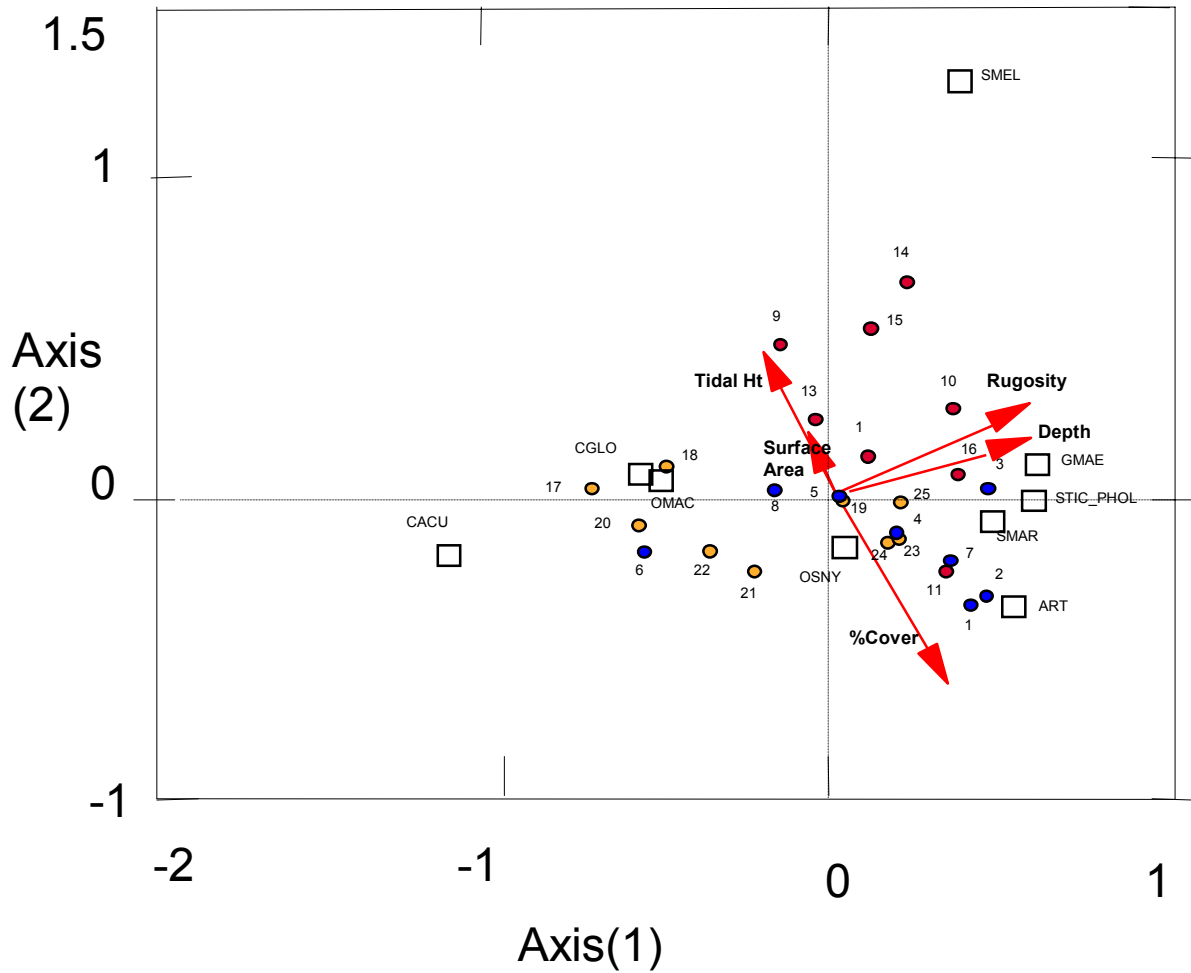


Figure 26. Canonical Correspondence Analysis (CCA) of fish assemblages and habitat variables. Red arrows denote the habitat variables: Tidal height, Surface Area, Rugosity, Depth, and Percent (%) canopy cover. (species =□; ●=Enderts Beach, ●=Damnation Creek, ●=False Klamath Cove sampled pools). Species included in the above figure are coded as follows: *Sebastes melanops* (SMEL), *Gobiesox maeandricus*(GMAE), *Oligocottus snyderi* (OSNY), *O. maculosus* (OMAC), *Artedius* 3 spp. (ART), *Clinocottus globiceps* (CGLO), *C. acuticeps* (CACU), *Scorpaenichthys marmoratus*(SMAR), Stichaeidae/ Pholidae 7 spp (STIC_PHOL).

from the CCA in Figure 27 to simplify the visualization of species and habitat factors.

The cottid species, *Clinocottus globiceps*, *C. acuticeps*, and *O. maculosus*, are on the left side of the plot with a weak positive association with tidal height and surface area and a

negative association with rugosity and depth. *Gobiesox maeandricus* and the

Pholidae/Stichaeidae fall on the positive side of Axis 1 and are positively correlated with

rugosity and depth. *Oligocottus snyderi* falls near the center of the plot meaning it was

distributed in most of the pools, but it does show a positive association with percent cover

and negative association with tidal height and surface area. *Artedius* spp. were also

positively associated with percentage cover and negative tidal height and surface area.

Sebastes melanops was not associated with the other fish species and correlated with

negative percent cover and positively with the other habitat factors.

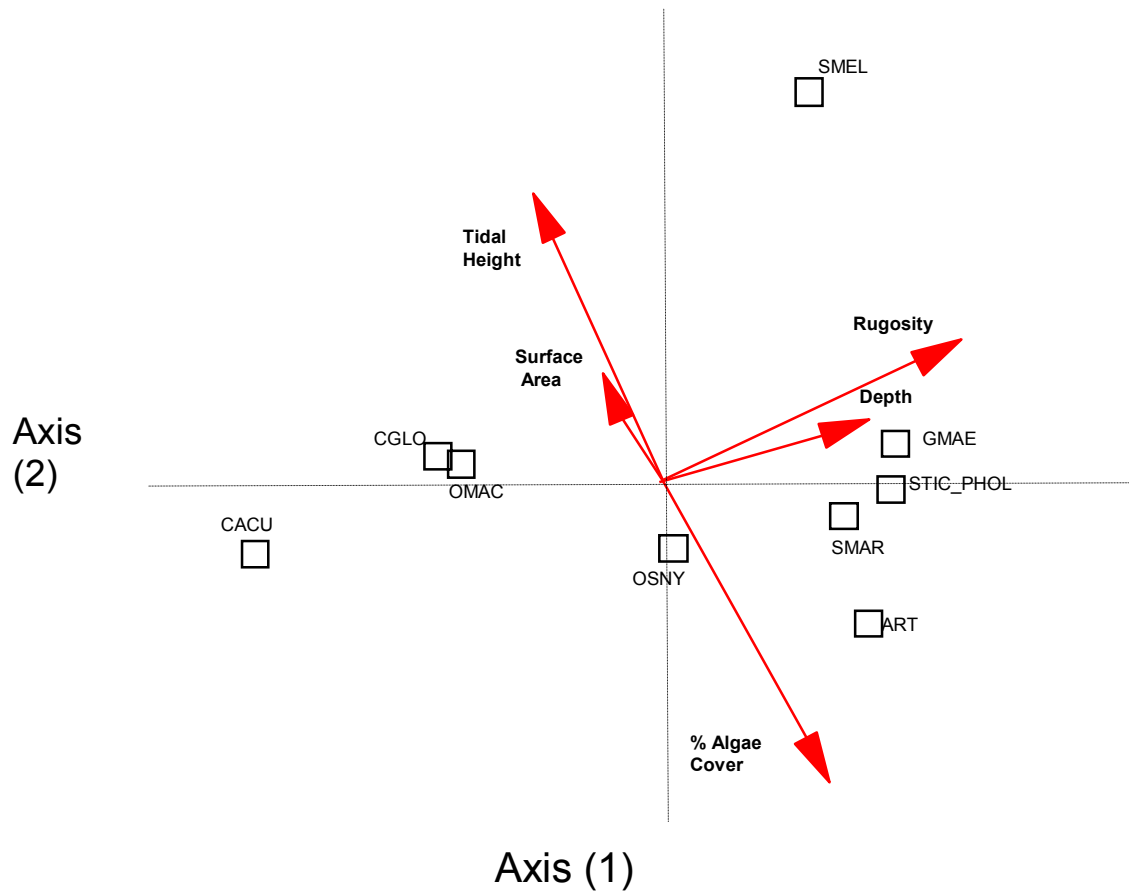


Figure 27. Canonical Correspondence Analysis (CCA) of fish assemblages and habitat variables. Red arrows denote the habitat variables: Tidal height, Surface Area, Rugosity, Depth, and Percent (%) canopy cover. (species = □). Species included in the above figure are coded as follows: *Sebastes melanops* (SMEL), *Gobiesox maeandricus* (GMAE), *Oligocottus snyderi* (OSNY), *O. maculosus* (OMAC), *Artedius* 3 spp. (ART), *Clinocottus globiceps* (CGLO), *C. acuticeps* (CACU), *Scorpaenichthys marmoratus* (SMAR), Stichaeidae/ Pholidae 7 spp (STIC_PHOL).

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DISCUSSION

This study described the intertidal fish assemblages at three sites within Redwood National and State Parks in northern California. Twenty-six species were identified in the rocky intertidal sites sampled from March 2004 to September 2005 (Appendix A). Similar numbers and species have been found in intertidal studies conducted in other parts of northern California (Grossman 1982, Yoshiyama et al. 1986) and Oregon (Chadwick 1976, Yoshiyama et al. 1986) (Appendix B). The geographically closest species assessment to this study occurred in Trinidad Bay, California (Moring 1986), approximately 70 kilometers to the south of the Redwood National and State Parks study sites. A total of 20 intertidal fish species were sampled in Trinidad Bay from 1965-70. Moring's study found similar values of species diversity and richness (Table 10, Table 16), but had some differences in species composition (Appendix B) as compared to this study. Most notably, Moring reported a greater abundance of *O. maculosus* (68%) than *O. snyderi* (13%), compared to this study's findings of *O. snyderi* (66%) and *O. maculosus* (17%) abundances. He described 7% of his total sampled fish as being seasonal or transient intertidal fish species. He noted 4% of the fish sampled to be seasonal species (Appendix B, Table 6).

In contrast to northern California; southern California rocky intertidal fish communities are relatively species poor. Southern California sites had fewer species and lower diversity than the northern California sites (Table 16). A study at six sites within the Southern California Bight found a total of 10 fish species (Adams 2006) while studies at different sites in San Diego reported between 12 (Craig and Pondella 2004) and 15

Table 16. Intertidal fish species richness and diversity values for three studies conducted in northern and southern California. Current data is from three intertidal sites within Redwood National and State Parks, northern California sampled from 2004-2005 and for six sites (averaged) from the Southern California Bight sampled from 2004-2005. Historical data is from Trinidad Bay, northern California sampled from 1965 to 1970.

	Trinidad 41.31 N Moring ¹ (1986)	So. Cal Bight 33.55-34.04 N Adams ² (2006)	Redwood NSP Sites Combined
Number of specis (#)	20	5 - 8	24
Species Richness Index Margalef (R')	2.57	1.12 (Avg)	2.72
Species Diversity Shannon (H')	1.21	0.76 (Avg)	1.28
Species index 1/Simpson's (1/D')	2.02		2.16

¹ Moring, J.R. 1986. Seasonal presence of tidepool fish species in a rocky intertidal zone of northern California, USA. *Hydrobiologia* 134: 21-27.

² Adams, Stevie L. 2006. Seasonal distribution and abundance of tidepool fishes at six locations within the Southern California bight, 2004-2005. M.S. Thesis, California State University, Northridge. 64pgs. 6 Sites included: Leo Carrillo State Park, Malibu; Paradise Cove, Malibu; Resort Point, Palos Verdes; White's Point, San Pedro; Little Corona, Corona del Mar; and Shaw's Cove, Laguna Beach

species (Davis 2000). In all of these studies, a few species dominated the total fish abundances. Therefore, regional patterns of species richness may vary due to increased numbers of rare species. The most common fish species found in rocky intertidal sites from California to Alaska belong to the Cottidae (Moring 1972, Yoshiyama 1980). Along a latitudinal gradient, of the California coast, the percentage of total fish abundances made up by Cottids decreases from north to south. They represent 89% of the total fish abundances in this study, 74% in the Southern California Bight (Adams 2006) and 50% in San Diego (Craig and Pondella 2004).

Overall species richness may be similar within geographic regions (i.e. northern California and Oregon) and across large temporal scales, but the species composition may vary among sites. For example, *O. snyderi* (Cottidae) was the most abundant fish in this study (Table 6) as well as in a study done in Cape Mendocino, California and Cape Arago, Oregon (Yoshiyama et al. 1986). However, studies done closer to the Redwood National and State Parks sites, found that *O. maculosus* replaced *O. snyderi* as the predominant intertidal fish resident (Moring 1972, Yoshiyama et al. 1986). The variation in species composition between these studies may be due to several factors. The various studies noted above occurred at different times and lacked long term data, so it is difficult to know how the populations fluctuate over time. Within a region, fish distributions are likely to be affected by small scale variations that occur within a site. These small scale differences, such as tidepool size and tidal height, may change the suitability of a site to various intertidal fish species. Projecting the community structure patterns of a single site

to the surrounding region may be in error if the region cannot be shown to be homogeneous.

Habitat characterization among study sites

The three rocky intertidal sites studied in Redwood National and State Parks were all within 11 km of one another which would suggest that habitat differences would be minimal. However, site analysis for this study showed that rocky intertidal sites may vary with regards to habitat factors and tidepool characteristics even when geographically close together (Table 2, Figure 15). These small scale differences may provide insight into the patterns of fish distribution and abundance characteristics between sites and between pools. This study also showed differences in intertidal fish community structure among the sites that were geographically close together (Figure 26).

Damnation Creek, the larger, more heterogeneous intertidal habitat yielded a greater number of total fish species compared to the other sites (Tables 5 and 6). This site had significantly greater percentage canopy cover within the sampled pools (Table 3). False Klamath Cove consisted of more boulder type substrate, and had a greater number of fish generally associated with this habitat. Enderts Beach, the smallest rocky intertidal area sampled, is surrounded by sandy beach unsuitable for most rocky intertidal fish species. Tidepools at Enderts Beach had a pattern of lower average tidal heights and greater volume than the other sites. These patterns of variation within tidepool characteristics were not significant by themselves. However, when combined in a discriminate analysis they contributed to an overall site difference between pools (Figure 15). Enderts Beach had fewer species, but greater overall fish abundances than the other

two sites sampled. These increased abundances were mostly due to large numbers of newly recruited cottids (Figure 20). The relationships between habitat characteristics and fish abundances suggest that different sites may offer more suitable habitat for certain species and life stages. To determine how different species were associated with various habitat factors, this study examined these relationships within specific tidepools.

Habitat partitioning among intertidal species

Because fish are capable of moving between pools during flood tides, allowing them to exert some site selection, many studies have examined correlations of certain tidepool characteristics with patterns of intertidal fish distribution (Horn and Martin 2006). Several habitat characteristics, such as algal cover or depth, may determine the suitability of a tidepool for resident fish species (Gibson and Yoshiyama 1999). Certain advantages are linked with specific tidepool characteristics, suggesting that some pools could provide more optimal habitats for various species of fish. If fish have some ability to select for these optimal habitats then an association would be expected between the fish present and favorable habitat characteristics.

Mark-recapture studies are often used to infer habitat selection and site fidelity (Ritter 2006). In this study, only six of 314 tagged cottids were recaptured outside of their original “home” pools. This suggests that recaptured resident cottid species exhibited site fidelity to individual pools within the study sites (Table 15). The mark-recapture study included a small subset of pools at each site and did not address the degree of localization of inter-tidepool movement. However, recaptures outside the

“home” pools were rare even in pools that were very close to one another. Studies that have repeatedly sampled series of adjacent pools suggest that many intertidal species have small home ranges centered around one tidepool (Richkus 1978). Even if several pools made up an individual's home range there may be an increased probability of recapture in tidepools with more favorable habitat characteristics (i.e. amount of canopy cover) (Gibson 1999b). Green (1971) found that adult *O. maculosus* permanently inhabited specific pools for a period of up to one year. Other studies on homing behavior have shown several species of intertidal cottids to be repeatedly collected in the same tidepool and even returning to home pools after displacement of up to 100 m (Moring 1976, Richkus 1978, Yoshiyama et al. 1992).

Specific tidepools were monitored to determine how different species were associated with various habitat factors. A greater abundance of fish associated with certain tidepool characteristics may suggest selection for these ‘optimal’ traits. The relative importance of tidepool characteristics varied among fish species sampled. For example, variable vertical distribution patterns have been commonly noted in different species of cottids (Green 1971, Mgaya 1992). *Oligocottus snyderi* have been shown to dominant lower pools and *O. maculosus* are often distributed in mid to higher pools (Mgaya 1992). This study showed that greater abundances of *O. snyderi* occupied areas and pools of lower tidal height, although this species was found in all pools (Figure 25). The opposite pattern was described for *O. maculosus* and *Clinocottus* species, with more fish sampled in medium to high zones. The tidepool characteristics driving these patterns of distribution may be a result of physiological tolerance differences or competition for

space. This intertidal zone partitioning may be influenced by different thermal tolerances between the two species (Nakano and Iwama 2002). Experiments have shown, for instance, that *O. maculosus* has a tolerance for higher temperatures than *O. snyderi* (Nakamura 1976a). Several studies have shown that within intertidal fish species, smaller individuals are often more abundant in higher, less optimal pools (Green 1971, Mgaya 1992, Davis 2000). In this study there was a slight increase in fish size with decreasing tidal height for three of the abundant cottid species, but this association was not significant. Newly settled fish may not be associated with the same habitat qualities as adults due to parameters such as different food requirements, habitat needs, or competitive interactions with larger fish (Zander et al. 1999).

Canopy cover in a pool may be beneficial to resident fish by reducing predation risk and by providing shade to the pool (Gibson and Yoshiyama 1999). Canopy cover may also play an important role in prey availability. Diet studies indicate that amphipods, copepods, isopods, and annelids are the main contributors to cottid diets (Nakamura 1971), and a positive correlation between these prey abundances and algae has been shown (Hacker and Steneck 1990). Other studies have shown associations between canopy cover and nearshore fish species such as, *Oligocottus maculosus*, *Apodichthys flavidus* and *O. snyderi* (Ritter 2006, Romanuk and Levings 2006). In this study, a canonical correspondence analysis (CCA) showed an association between *O. snyderi* and the *Artedius* group with increased percentage canopy cover (Figure 26). Percentage canopy cover between the study sites differed, but this could not be directly correlated with site specific differences in fish abundances.

Other patterns of habitat factors differed among the study sites and may have contributed to patterns of fish distributions. Patterns of rugosity varied among the study sites, although not significantly. These patterns showed that tidepools at False Klamath Cove had greater rugosity or topographic complexity than tidepools at Damnation Creek and Enderts Beach (Figure 13). Enderts Beach pools had lower variation in rugosity levels than the other sites. This site was comprised of a relatively flat bedrock bench and the pools were depressions that lacked topographic complexity or boulders. In the CCA, rugosity was positively associated with *Gobiesox maeandricus* and the Pholidae/Stichaidae group (Figure 26). Very few fish from either the Pholidae or Stichaidae were associated with pools at Enderts Beach, which may have been due to these fishes' preference for more complex, boulder habitats. Tidepool depth contributed to the cottid distribution and habitat association patterns in the rocky intertidal. The CCA showed that *Oligocottus maculosus*, *C. acuticeps*, and *C. globiceps* were associated with shallower pools while *O. snyderi* abundance did not vary by depth. Similar segregation of pools by depth, for the two *Oligocottus* species, was noted by Nakamura (1976a).

The affect of tidepool size (surface area and volume) on fish abundances varies across studies. Tidepool volume may explain a significant amount of the variation in the abundance of tidepool fishes (Pfister 1995) or it may be used as one of many correlated habitat variables to describe patterns of fish distribution (Adams 2006). Pools of approximately the same size were selected for this study and the measured volume and surface area of the monitored tidepools was not significantly different between the sites and pools (Table 2). These factors were used to describe the study sites in the canonical

discriminant analysis. For the CCA fish densities were used to standardize fish abundances across all pools. In the CCA surface area did not have strong associations with any of the fish species. However, there was a weak negative association between *O. snyderi* and surface area.

The differences in patterns of habitat utilization between species, suggest selective niche partitioning. For *O. snyderi* the CCA suggested that overall ‘optimal’ traits were low intertidal pools that had higher percent canopy cover while, for *O. maculosus* the CCA suggested association with shallower, less rugose pools. Partitioning of habitat may serve to decrease the density dependent interactions between intertidal fish. This is not to discount the existence of species interactions, such as competition and predation, although few studies have examined these processes in intertidal fish. Studies examining competition between species of intertidal fish have shown little evidence supporting its role in shaping community structure (Faria and Almada 2001). However, intraspecific competition may be more common within intertidal fish (Almada and Faria 2004, Ritter 2006). Szabo (2002) suggested that, within *O. maculosus*, smaller fish may be limited to higher, less optimal pools by intercohort competition.

Temporal affects on intertidal fish species

Seasonality is also an important factor in species distribution and composition. The affects of seasonality may increase with latitude, in part, due to the greater degree of temperature variation (Gibson and Yoshiyama 1999). In contrast, Adams (2006) determined that seasonality was not playing a significant role in the composition of

ichthyofaunal assemblages in southern California. An absence of seasonal variation has also been shown in some tropical studies. This may be attributed to more constant temperatures and in some areas, a decrease or absence of transient species (Chang et al. 1973, Prochazka 1996). In this study, there was no significant seasonal difference in species diversity (Table 12). However, the number of species (Tables 11 and 12) and abundance of cottid fish (Figure 21) was greater in summer than in winter.

The seasonal fluctuation of fish abundances observed in this study was strongly impacted by an increased number of cottids in the summer (Figure 21). Recruitment pulses were observed in resident *Oligocottus* sculpin species in the summer (June-August). Peaks in recruitment were evident at all sampled sites for both 2004 and 2005. This was consistent with recruitment patterns noted for *Oligocottus* species studied previously in California (Grossman and Devlaming 1984, Pfister 1996). No clear recruitment periods for other fish species were determined, with the exception of *Sebastes melanops*. *Sebastes melanops* was the only completely seasonal species found in this study (Table 11). Juveniles of this species were only present in tidepools from May to August, which is consistent with previous studies (Moring 1986, Studebaker 2006). This suggests that the rocky intertidal may serve as important nursery habitat for *S. melanops* (Studebaker 2006).

Seasonal upwelling, which increases primary productivity, is thought to contribute to some of the variability in the annual recruitment of many intertidal species (Bosman et al. 1987). For example, a significant correlation between *Oligocottus snyderi* recruitment and productivity has been described in central California (Grossman and

Devlaming 1984). The reproduction of this species seems to be timed to insure that the larvae metamorphose during upwelling. Upwelling for the study region typically peaks in late spring to early summer (NOAA PFEL indices). A typical upwelling pattern occurred in 2004 and coincided with peaks in *Oligocottus snyderi* and *O. maculosus* recruitment (Figure 28). In 2005, peak upwelling occurred much later than normal (NOAA PFEL anomalies). *Oligocottus snyderi* recruitment had a reduced peak that coincided with the late-summer peak in upwelling. In contrast, there were no recorded *O. maculosus* recruits in 2005. This may have represented a weakened recruitment year for this species. It is also possible that this species recruited later in 2005, outside the timing of this study. Consequently, longer-term sampling efforts may be necessary to understand the normal levels of recruitment timing and strength for these species.

Spatial affects on recruitment.

Oligocottus recruitment varied among sites sampled. Recruitment levels of both *O. snyderi* and *O. maculosus* were significantly greater at Enderts Beach than at the other two study sites (Figure 20, Table 13). The previously discussed differences in tidepool characteristics may explain some of this variation. Larger-scale habitat factors may also have affected patterns of recruitment in this study. The intertidal area at Enderts Beach is smaller than at False Klamath Cove and Damnation Creek. Also, Enderts Beach is surrounded by long stretches of sandy beach, unsuitable habitat for sculpins. Thus, recruits may be more concentrated at Enderts Beach due to a lack of surrounding

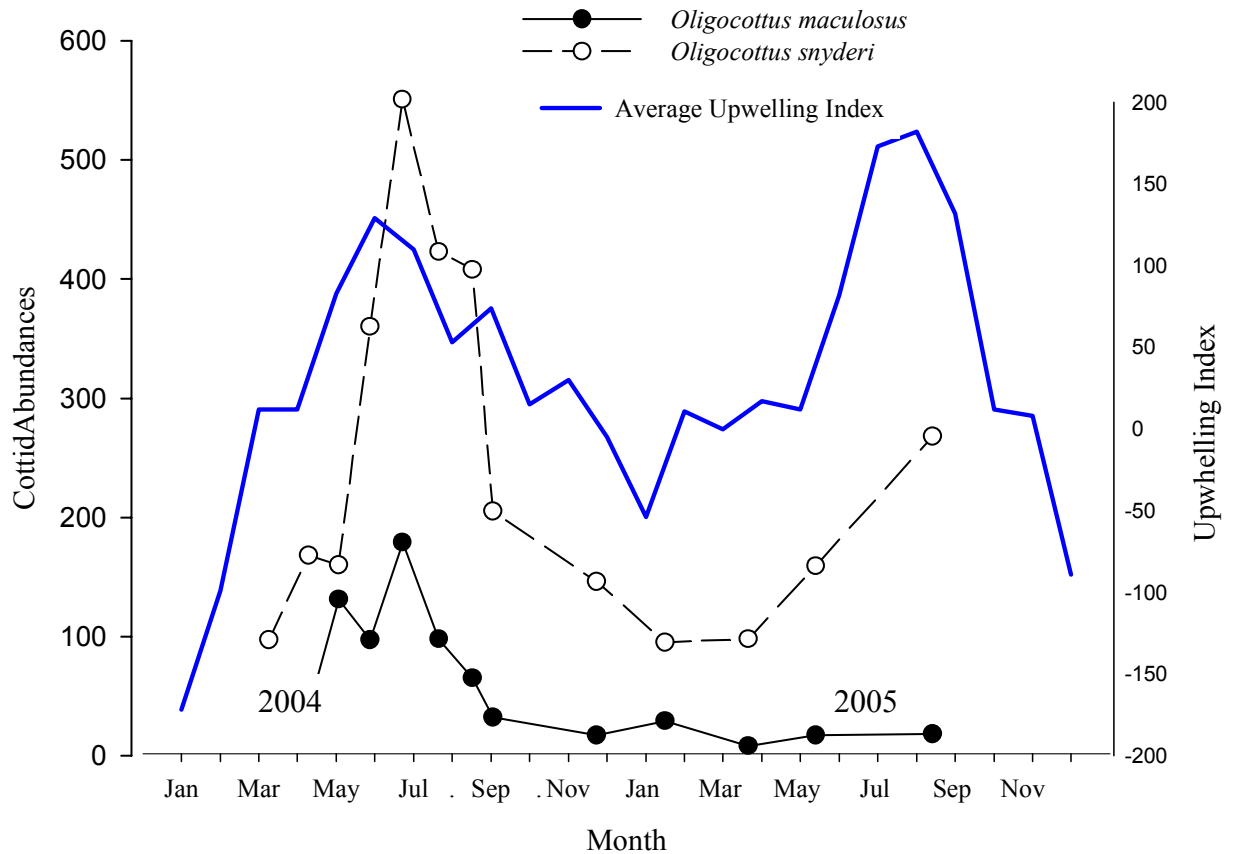


Figure 28. Total number of *O. maculosus* and *O. snyderi* recruits (<25mm TL) from three sites within Redwood National and State Parks from 13 sampling periods in 2004-2005. Sampling periods were monthly for 2004 and bimonthly for 2005. Upwelling values (blue line) were compiled from data collected by Pacific Fisheries Environmental Laboratory (NOAA) from the buoy (# 46027) located eight nautical miles northwest of Crescent City, California (N 41°51'06", W 124°22'54"). Data is from 2004-2005.

settlement habitat. This suggests that the level of isolation of intertidal sites may also play a role in recruitment variation.

There were also significantly greater numbers of juvenile (25-36mm) *Oligocottus snyderi* at Enderts Beach. However, there was no significant site difference between adult (>35 mm) densities for these species. Two studies have noted the incongruence between recruitment levels and adult abundances in the intertidal sculpin, *Clinocottus globiceps* (Pfister 1996, 2006, Webster et al. personal communication). These results suggest that some populations may not be recruitment limited, but may be more influenced by post-recruitment processes. Determining the processes affecting the study populations would require not only longer term study, but also a larger spatial understanding of factors affecting recruitment success.

Many physical and ecological factors can influence the population dynamics of tidepool fishes. Physical factors such as ocean currents, upwelling regimes and wave exposure exert various levels of influence over nearshore fish populations (Green 1971). Upwelling can influence larval exchange by affecting the along-shore dispersal rate (Ritter 2006). This influence may be important in this study region, since the peak in upwelling coincides with peak recruitment timing of intertidal cottid species.

Dispersing larvae, of most marine species, are subject to offshore transport by ocean currents before settling into the benthic habitat. This leads to the inference that local populations are mostly or even entirely replenished from more distant populations (Roughgarden et al. 1985, Caley et al 1996). Marine populations are generally characterized as having these “open” model characteristics (Caswell 1978) and by

definition are not affected by local recruitment levels. However, recent studies also have argued that for many nearshore and temperate reef species, larval retention may be playing a greater role in population structure than could be explained by a completely open model (Swearer et al. 1999, Cowen 2002). The planktonic larval dispersal that most fish species undergo is affected by planktonic duration as well as strength and direction of oceanic currents. The reproductive strategies of most intertidal fish species may be adapted for larval retention. For example, sculpin species lay demersal, negatively buoyant eggs and have a relatively short larval planktonic stage. Accordingly, nearshore surveys have found that 80% of intertidal sculpin larvae were found within 30 meters of shore (Marliave 1986).

Methods and significance of intertidal fish sampling.

When trying to describe an intertidal fish assemblage, sampling methodology may greatly affect the results (Horn et al. 1999). For example, certain crevice dwelling species, such as pricklebacks, may be underestimated when only sampling tidepools. In this study, data from an intertidal inventory and from repeated tidepool monitoring were collected to represent as many of the intertidal fish species as possible. Both methods were useful in assessing and describing the taxonomic structure within the study sites in Redwood National and State Parks. Monitoring provided insight into seasonal differences that are common both in recruitment timing and in presence of transient fish species. The inventory was aimed at sampling habitat that may be under-represented in the repeated tide-pool monitoring. The overall species lists and relative abundances of

common species, determined from the inventory and monitoring, were similar (Tables 5 and 6). However, two rare species were found only during the inventory and four uncommon species were sampled only during the monitoring. By combining the methods, greater species richness was described for the sites sampled.

The number of species and the distribution patterns observed at Damnation Creek were similar for both sampling methods. However, the species distribution patterns at False Klamath Cove differed between the inventory and monitoring studies with fewer fish species found in the inventory than the monitoring (Table 10). The inventory further showed an atypical zonation pattern of species distribution within False Klamath Cove, with a greater number of fish and fish species sampled in the high zone than the low zone. The habitat at False Klamath Cove has larger boulders in the high zone that have deep pockets of water around them during low tide. These oversized pools were only sampled during the inventory and yielded a greater number of fish than smaller pools in the low zone. Sampling effort may have been concentrated in these large pools during the inventory, decreasing the range of habitat niches searched and resulted in the decreased overall species richness. This demonstrates that within site differences in abundance and distribution may be affected by the specific habitat sampled and by the sampling method utilized. More fish species were found with the repeated monitoring method at the same sites, suggesting that the increased effort and longer term monitoring of specific pools did a better job of representing the fish assemblage at the sites.

Monitoring of intertidal communities is critical to the ecological understanding and protection of these sensitive areas. A baseline assessment of habitat structure and

corresponding biota is necessary to build a guideline from which to monitor change.

This study was an extension of a monitoring project that included establishing a descriptive analysis of intertidal sites within the park (Cox et al. 2006). The program to monitor intertidal communities of the Redwood National and State Parks incorporated inventorying and monitoring the intertidal and nearshore fish. This study attempted to find linkages between intertidal habitat characteristics, seasonality and fish abundance and distribution patterns.

The ultimate goal of a monitoring program is to understand and predict how environmental changes, including those resulting from human impacts, influence ecological processes and how communities respond to such changes. For example, if an oil spill were to happen off the northern California coast, pre-spill, baseline data about the health of the community would be necessary to assess impacts from the spill and to monitor future restoration efforts. Marine communities may also be altered by human or naturally occurring events such as trampling, sewage outfall (Littler and Murray 1975) or sea surface temperature increases (Barry et al. 1995, Sagarin et al. 1999). Intertidal fish may serve as biomonitors, indicating relative health of the intertidal area (Horn et al. 1999). Finally, understanding their response to environmental disturbances may provide insights for managers facing issues such as global climate change and increased pollution.

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Appendix A. List of all fish families and species found within Redwood National and State Parks, 2004-2005. Combined list for inventory and monitoring methods.

Family	Species	Common Name
Agonidae	<i>Bothragonus swanii</i> *	Rockhead poacher*
Atherinidae	<i>Atherinops californiensis</i> *	Jacksmelt*
Clinidae	<i>Clinidae spp.</i>	Kelpfish spp.
Cottidae	<i>Artedius corallinus</i>	Coralline sculpin
Cottidae	<i>Artedius fenestralis</i>	Padded sculpin
Cottidae	<i>Artedius lateralis</i>	Smoothhead sculpin
Cottidae	<i>Oligocottus snyderi</i>	Fluffy sculpin
Cottidae	<i>Clinocottus acuticeps</i>	Sharpnose sculpin
Cottidae	<i>Clinocottus globiceps</i>	Mosshead sculpin
Cottidae	<i>Oligocottus maculosus</i>	Tidepool sculpin
Cottidae	<i>Hemileptidotus spinosus</i>	Brown Irish lord
Cottidae	<i>Enophrys bison</i>	Buffalo sculpin
Cottidae	<i>Leptocottus armatus</i>	Staghorn sculpin
Cottidae	<i>Scorpaenichthys marmoratus</i> *	Cabezon*
Gobiesocidae	<i>Gobiesox maendricus</i>	Northern clingfish
Embiotocidae	<i>Embiotoca lateralis</i> *	Striped surfperch*
Hexagrammidae	<i>Hexagrammos decagrammus</i> *	Kelp greenling*
Liparidae	<i>Liparis florae</i>	Tidepool Snailfish
Pholidae	<i>Apodichthys flavidus</i>	Penpoint gunnel
Pholidae	<i>Apodichthys fucorum</i>	Rockweed gunnel
Pholidae	<i>Pholis ornata</i>	Saddleback gunnel
Stichaeidae	<i>Xiphister atropurpureus</i>	Black prickleback
Stichaeidae	<i>Anoplarchus purpureus</i>	High cockscomb
Stichaeidae	<i>Cebidichthys violaceus</i>	Monkeyface prickleback
Stichaeidae	<i>Xiphister mucosus</i>	Rock prickleback
Scorpaenidae	<i>Sebastes melanops</i> *	Black rockfish*

* Considered primarily seasonal or transient intertidal fish species

Appendix B. Intertidal fish species composition (abundances and proportion of total in parenthesis) comparison between studies conducted in Northern California and Oregon. Some species were not included in the counts (nc). *are primarily seasonal residents

Species	Bruels Point, CA July 1973 39°35' N (Chadwick 1976)	Cape Mendo, CA Aug, 1982 40°25' N (Yoshiyama et al 1986)	Brookings,OR May+Aug, 1982 42°5' N	Cape Arago, OR May+Aug, 1982 43°18' N	Trinidad Bay, CA May 1965-May 1970 41°31' N (Moring 1986)
<i>Oligocottus snyderi</i>	22 (.16)	91 (.41)	57 (.27)	150 (.45)	195 (.13)
<i>Oligocottus maculosus</i>	54 (.40)	44 (.20)	63 (.30)	67 (.20)	1102 (.68)
<i>Artedius lateralis</i>	1 (.01)	9 (.04)	3 (.01)	22 (.07)	2
<i>Artedius fenestralis</i>	0	0	0	0	1
<i>Scorpaenichthys marmoratus*</i>	6 (.04)	7 (.03)	8 (.04)	4 (.01)	25 (.02)
<i>Oligocottus rimensis</i>	0	0	13 (.06)	0	
<i>Clinocottus analis</i>	2 (.01)	2 (.01)	0	0	
<i>Clinocottus globiceps</i>	11 (.08)	22 (.10)	3 (.01)	11 (.03)	6
<i>Clinocottus acuticeps</i>	2 (.01)	2 (.01)	8 (.04)	5 (.02)	5
<i>Hemilepidotus</i> spp.	0	4 (.02)	0	15 (.05)	2
<i>Aselichthys rhodorus</i>	0	0	0	11 (.03)	
<i>Enophrys bison</i>	0	0	0	1	
<i>Apodichthys flavidus</i>	1 (.01)	24 (.11)	45 (.21)	13 (.04)	11 (.01)
<i>Apodichthys(Xeropes) fucorum</i>	3 (.02)	nc	nc	nc	15 (.01)
<i>Xiphister mucosus</i>	5 (.04)	nc	nc	nc	
<i>Xiphister atropurpureus</i>		nc	nc	nc	38(.03)
<i>Anoplarchus purpureus</i>	4 (.04)	nc	nc	nc	21(.01)
<i>Cebidichthys violaceus</i>	0	nc	nc	nc	1
<i>Pholis</i> spp.	0	13 (.06)			1
<i>Sebastes</i> spp.*	20 (.15)	nc	nc	nc	78 (.05)