THE ECOLOGY OF SURF ZONE FAUNA OF DISSIPATIVE SANDY BEACHES IN SOUTHERN OREGON U.S.A.

by

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The surf zone fauna of three dissipative sandy beaches in southern Oregon were sampled and the community composition was compared to environmental variables. Samples were collected throughout the summer of 2006 using a beach seine, hyperbenthic sledge, and sediment core during high, mid and low tides, spring and neap tides, and day and night. Sledge samples contained 49,363 individuals (92 species), most of which were the mysid *Archaeomysis grebnitzkii*. We caught 2,059 individuals (19 species) in the beach seine, most of which were the smooth bay shrimp *Lissocrangon stylirostris*. The fauna was composed of species that are typically inhabitants of the open ocean, rocky intertidal and sandy beach. The biggest influence on catch was the date on which the fauna were sampled. Juvenile Chinook salmon and ghost shrimp larvae, species that had not been previously reported as inhabitants of the surf zone of sandy beach, were observed.

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To my parents, who taught me to think and to dream.

TABLE OF CONTENTS

Chapter Page

I. GENERAL INTRODUCTION 1

II. THE ECOLOGY OF THE SURF-ZONE FAUNA OF THREE DISSIPATIVE SANDY BEACHES IN SOUTHERN OREGON 3
- Introduction 3
- Materials and Methods 5
- Results 13
- Discussion 32
- Bridge 42

III. THE ECOLOGY OF SURF-ZONE FISH AND MACROCRUSTACEANS OF DISSIPATIVE SANDY BEACHES IN SOUTHERN OREGON, 43
- Introduction 43
- Materials and Methods 45
- Results 54
- Discussion 64
- Bridge 70

IV. NEW HABITAT OF SUB-YEARLING CHINOOK SALMON DISCOVERED: THE SURF-ZONE OF A SANDY BEACH 71
- Introduction 71
- Materials and Methods 73
- Results 77
- Discussion 84
- Bridge 89

Chapter Page

V. THE POPULATION ECOLOGY OF THE SMOOTH BAY SHRIMP, *LISSOCRANGON STYLIROSTRIS* (DECAPODA, CRANGONIDAE), AT A DISSIPATIVE SANDY BEACH IN SOUTHERN OREGON, WITH NOTES ON THE OCCURRENCE AND BIOLOGY OF ITS PARASITE, *ARGEIA PUGETTENSIS* (ISOPODA, BOPYRIDAE) 90

Introduction 90

Materials and Methods 92

Results 100

Discussion 112

VI. CONCLUDING SUMMARY 120

APPENDIX A: RAW DATA OBTAINED FROM SAMPLINGS OF THE SURF ZONE OF THREE DISSIPATIVE SANDY BEACHES AND STOMACH CONTENT ANALYSIS OF TWO SPECES OF FISH 123

BIBLIOGRAPHY 132

LIST OF FIGURES

CHAPTER II Page

1. Study area with location of the three dissipative sandy beaches 6
2. Time during which the surf zone fauna was sampled 7
3. Flow chart explaining how the surf zone fauna was separated based on the number of sampling dates each species was present, the life stage, and the environment they have been cited as inhabiting. 18
4. Cluster Analysis of surf-zone fauna 21
5. Cluster Analysis of adult sandy beach species 25
6. Positive linear correlations between both diversity and evenness values with wave height. 27
7. Positive linear correlation between the dry weights of detached macrophytes and the number of species 28
8. Cluster analysis of species present as meroplankton in surf-zone fauna 29
9. Negative linear correlation between densities of all zoea stages of *Neotrypaea californiensis* and salinity.. 30
10. Negative linear correlation between densities of *Neotrypaea californiensis* zoea stages I and II and salinity 31

CHAPTER III

1. Study area with location of three dissipative sandy beaches......................... 46
2. Positive correlation between the diversity and total swimming macrofauna densities minus *Lissocrangon stylirostris* with the weight of detached macrophytes... 57
3. Positive linear correlation between *Lissocrangon stylirostris* densities and the densities of the mysid *Archaeomysis grebnitzkii* 58
4. Non-parametric Multi-Dimensional Scaling of surf zone macrofauna 59
5. Size-frequency distribution of juvenile English sole 60
6. Mean standard lengths of English sole correlated to the Julian date on which they were caught 61
7. Linear correlations between Julian date towards both the feeding selectivity of English sole, and the densities of *Archaeomysis grebnitzkii*.... 62

CHAPTER IV

1. Study area with location of Bastendorff Beach 73
2. Non Parametric Multi-Dimensional Scaling of 48 Chinook salmon stomach contents sampled in the surf-zone of a sandy beach........................ 80
3. Species Richness of the stomach contents of 48 sub-yearling Chinook salmon correlated to standard length 82

CHAPTER IV (Continued.) Page

4. Mean percentage of invertebrate and fish prey items in stomach contents of Chinook salmon compared to their size class 83

CHAPTER V

1. Study area with location of Bastendorff Beach 93
2. Mean monthly day time densities of parasitized and non-parasitized *L. stylirostris* observed during the four months sampled.................................. 101
3. Mean densities of parasitized and non-parasitized male and female *L. stylirostris* observed during day and night and spring and neap tides........... 102
4. Mean densities of brooding non-parasitized *L. stylirostris* observed during four different times.. 104
5. Size frequency distribution of *L. stylirostris* in the summer 2006 105
6. Size frequency distribution of *L. stylirostris* for (a) males and females, (b) Parasitized females, Non-parasitized females, and (c) Parasitized males and Non-parasitized males... 107
7. Dry weight comparison by size class between parasitized and non-parasitized *L. stylirostris*... 109
8. Linear correlation between lengths of *L. stylirostris* and its parasite, *A. pugettensis*... 110

LIST OF TABLES

CHAPTER II Page

1. Date of sampling and environmental variables measured at three sandy beaches in southern Oregon during the summer of 2006 14
2. List of species present in three dissipative sandy beaches sampled during the summer of 2006 16
3. Total and mean densities, species richness, diversity, and evenness values of the surf-zone fauna present in three dissipative sandy beaches in southern Oregon during the summer of 2006 20
4. Similarity Percentage analysis showing the species contributing to similarity of each cluster formed by the analysis presented in Fig. 2, Fig. 5 and Fig 6 23
5. Results of two-way ANOVA test for differences in *Excirolana chiltoni* densities 24

CHAPTER III

1. Location and time of sampling during which the swimming macrofauna community of Southern Oregon was sampled 48
2. Mean biological values of the swimming macrofauna observed during different times of day, tides and lunar tides 49
3. Results of two-way ANOVA test for differences in surf-zone macrofauna densities at low tide 55
4. Similarity Percentage analysis showing species contributing to similarity of each cluster formed by nMDS in Fig. 4 59
5. Fish species present in the swimming macrofauna community.................... 63

CHAPTER IV

1. Dates on which we sampled for sub-yearling Chinook in the surf-zone of a sandy beach 78
2. Frequency of occurrence (%F) and selectivity index (Sel) of the 11 most common prey species present in the stomachs of 48 sub-yearling Chinook salmon 79
3. Similarity Percentage Analysis (SIMPER) showing the prey items contributing to similarity of each cluster formed by nMDS presented in Fig. 2 81

CHAPTER V

1. Time of sampling and biological values obtained from an *L. stylirostris* population present at Bastendorff, a dissipative sandy beach....................... 95
2. Results of two-way ANOVA test for differences in *Lissocrangon stylirostris* densities at low tide.. 103

APPENDIX A

1. Surf zone fauna densities observed at three dissipative sandy beaches......... 124
2. Swimming surf zone macrofauna densities observed at three dissipative sandy beaches of southern Oregon during the summer of 2006. 128
3. Stomach contents of 48 juvenile Chinook salmon... 129
4. Stomach Content Analysis of 61 juvenile English sole caught at three dissipative sandy beaches 131

CHAPTER I

GENERAL INTRODUCTION

In the past, the sandy beach surf zone fauna has been characterized as structurally homogeneous and were thought to offer little variability in terms of habitat diversity, cover or productivity (Pearse et al. 1942, Hedgpeth 1957). However, several studies have suggested fluctuations in physical variables (wave height, turbidity, sand grain size, beach slope, temperature and salinity) and temporal scales (seasons, tidal level, moon stage, time of day) may alter the composition and species richness of surf zone assemblages (e.g. Watkin 1941, Colman and Segrove 1955, Boysen 1975, Hamerlynck and Mees 1991, Clark et al. 1996, Mees and Jones 1997, Lock et al. 1999, Beyst et al. 2001, Dominguez Granda et al. 2004, McLachlan 2006).

This fauna is almost entirely of marine origin and consists almost completely of crustaceans (McLachlan 2006). These species can be present as adults or as one or more of its developmental stages (Mees and Jones 1997, Beyst et al. 2001, Dominguez Granda et al. 2004, McLachlan 2006). McLachlan (2006) categorized these species as residents, non-residents and immigrants. In which, resident species may be planktonic or benthoplanktonic species while non-residents may be holo- (adult stages) or meroplanktonic species (development stages). Immigrants are those species categorized as temporary visitors.

In Oregon very little if any work has been done on this community or the variables that influence it, despite the fact that more than two-thirds of the coastline is comprised by sandy beach (ODFW 2006) and that the surf zone fauna is considered important ecologically and economically (Moran and Fishelson 1971, Murison et al. 1984, Beyst et al. 1999, Mauchline 1982, Laughlin and Linden 1983, Brandt et al 1993, Mees and Jones 1997, Cockroft et al. 1998). Several studies have been conducted on individual species that inhabit the area (Barnard 1954, Bosworth 1973, Hoeman 1982, Hughes 1982, Llewellyn 1983). This will be the first work that attempts to document the entire community and analyze the factors that influence it. The primary objectives of this thesis were to (1) describe the community present in the surf zone of three sandy beaches of southern Oregon, U.S.A. and to (2) analyze the environmental variables that influence this community. The surf zone fauna was separated due to its size. Chapter II analyzed the ecology of the smaller swimming surf zone fauna (~ 1 mm in length). Chapter III analyzed the ecology of the surf zone fish and macrocrustaceans (≥ 5 mm in length). Because of the abundance of Chinook salmon (*Oncorhynchus tshawytscha*) and smooth bay shrimp (*Lissocrangon stylirostris*) in the samples, their ecology was analyzed in a separate chapter. Chapter IV estimated the time of residency and the feeding habits of sub-yearling Chinook salmon in a dissipative sandy beach of southern Oregon. Finally, Chapter V documented the ecology of *L. stylirostris* present in a dissipative sandy beach of Southern Oregon.

CHAPTER II

THE ECOLOGY OF THE SURF-ZONE FAUNA OF THREE DISSIPATIVE SANDY BEACHES IN SOUTHERN OREGON

Introduction

The sandy beach surf-zone fauna has been characterized as structurally homogeneous and the surf-zone has been considered to provide habitat, cover or productivity (Pearse et al. 1942, Hedgpeth 1957). However, a number of studies have found that fluctuations in physical variables (wave height, turbidity, sand grain size, beach slope, temperature and salinity) and temporal scales (seasons, tidal level, moon stage, time of day) can alter the composition and species richness of surf-zone assemblages (e.g. Watkin 1941, Colman & Segrove 1955, Boysen 1975, Hamerlynck & Mees 1991, Clark et al, 1996, Mees & Jones 1997, Lock et al 1999, Beyst et al. 2001, Dominguez Granda et al. 2004, McLachlan 2006).

The sandy beach surf-zone fauna is composed primarily of crustaceans (McLachlan 2006). These species can be present as adults, juveniles, larvae or eggs (Mees & Jones 1997, Beyst et al. 2001, Dominguez Granda et al 2004, McLachlan 2006). McLachlan (2006) categorized the surf-zone fauna as residents and non-residents; resident species are present regularly in the surf-zone while non-residents are present sporadically or irregularly. Within the resident forms, benthoplanktonic forms, also known as hyperbenthic forms (Mees & Jones 1997), are species that occur both in the benthos and in the plankton. Within the non-resident group, several of its species have been known to be inhabitants of other environments, actively or passively migrating to the sandy beach. Tully and Céidigh (1987) stated that the possible functions of migration could be classified into three categories: non-interactive (those associated with life cycle events such as feeding, searching for mates, mating and moulting), interactive (brought about through competition and disturbance, including crowding, interference, predation and deterioration of habitat quality) and catastrophic (non-behavioural) drift.

Despite the fact that more than two-thirds of the Oregon coastline is sandy beach (ODFW 2006) and that in other regions the surf-zone fauna is considered important ecologically and economically (Moran & Fishelson 1971, Murison et al. 1984, Beyst et al. 1999, Mauchline 1982, Laughlin & Linden 1983, Brandt et al 1993, Mees & Jones 1997, Cockroft et al. 1998), little work has been done on the surf-zone community present in the water column or the variables that influence it. On the west coast of North America, several studies have been conducted on individual species that inhabit the surf-zone (Barnard 1954, Bosworth 1973, Hoeman 1982, Hughes 1982, Llewellyn 1983) but this will be the first study that attempts to document the entire community and analyze the variables that influence it. The specific aims of this study were to (1) describe the surf-zone community present at three sandy beaches in Oregon and to (2) investigate the environmental variables that may influence this community.

Materials and Methods

Study Area

The Oregon coast is characterized by mixed semidiurnal tides, with maximum daily amplitude of 3.6 m and a mean of 2 m. Wave action is severe in winter and moderate in summer, with average wave heights of 4-5 m and 1-2 m, respectively (Komar et al. 1976). This study was conducted in southern Oregon at the sandy beaches of Bastendorff (43°35'N, 124°35'W), Whisky Run (43°18'N, 124°40'W) and Horsfall Beach (43°27'N, 124°16'W) (Fig. 1). Bastendorff and Whisky Run are approximately 3 Km long and Horsfall is over 15 Km long. Bastendorff is located immediately south of the mouth of Coos Bay and is bordered by a rocky shore on the south and a rock jetty at the mouth of the Coos Estuary to the north. Whisky Run and Horsfall are located approximately 15 Km south and north of Coos Bay, respectively, and are bordered by other sandy beaches or sandflats. Bastendorff is semi-exposed, and Whisky Run and Horsfall are exposed beaches. The three beaches are dissipative beaches, which are flat beaches in which the wave energy is dissipated in the surf-zone rather than reflected from the beach face, which is what occurs on reflective beaches (McLachlan 1980, Masselink & Short 1983). Oregon beach sands typically range from 200-300 µm, which corresponds to modally dissipative beaches that may become intermediate in midsummer (McLachlan 1990). Intermediate beaches are those that may exhibit physical characteristics of dissipative and reflective beaches. These three beaches were chosen due to their accessibility, similar physical characteristics and their positioning with respect to the Coos River.

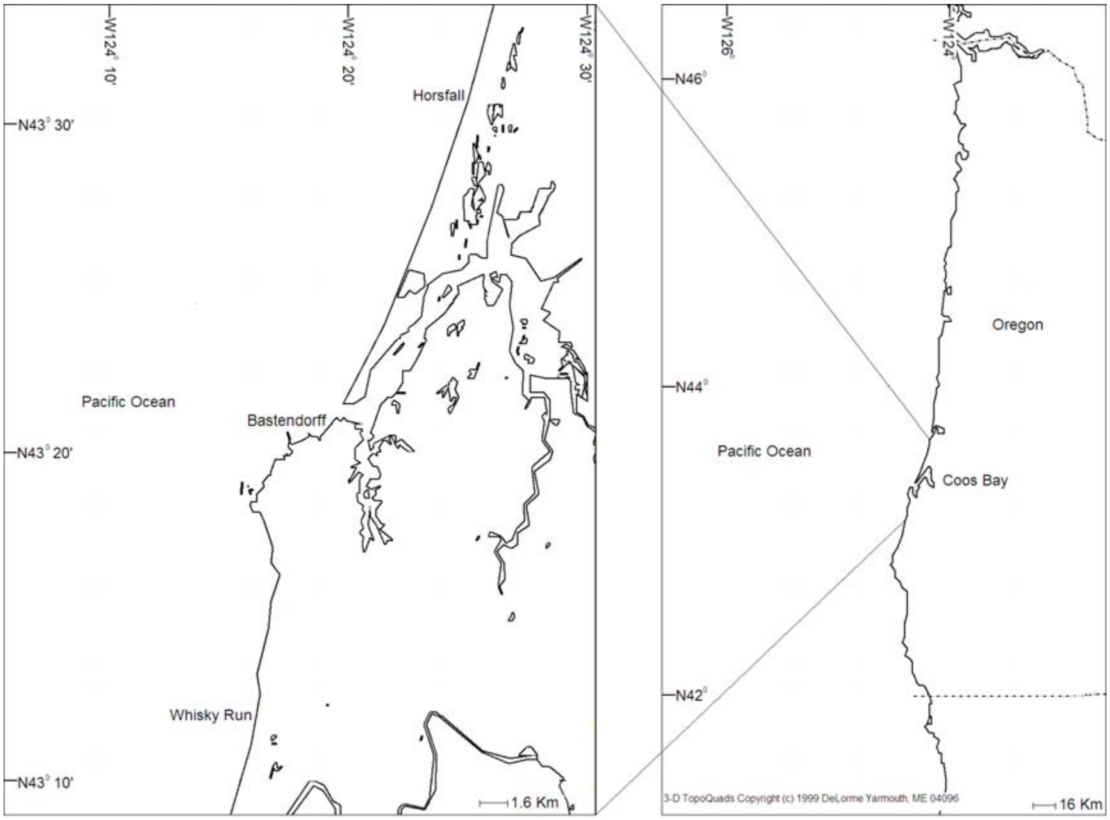

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Figure 1. Study area with location of the three dissipative sandy beaches sampled in southern Oregon during the summer of 2006.

Sampling

The three beaches were sampled in summer 2006. Bastendorff was sampled on six dates during high, mid and low tides, neap and spring tides, and day and night (Fig. 2). Night samples were taken only during low tide for safety reasons. Horsfall and Whisky Run were sampled once each during the day on a low neap tide.

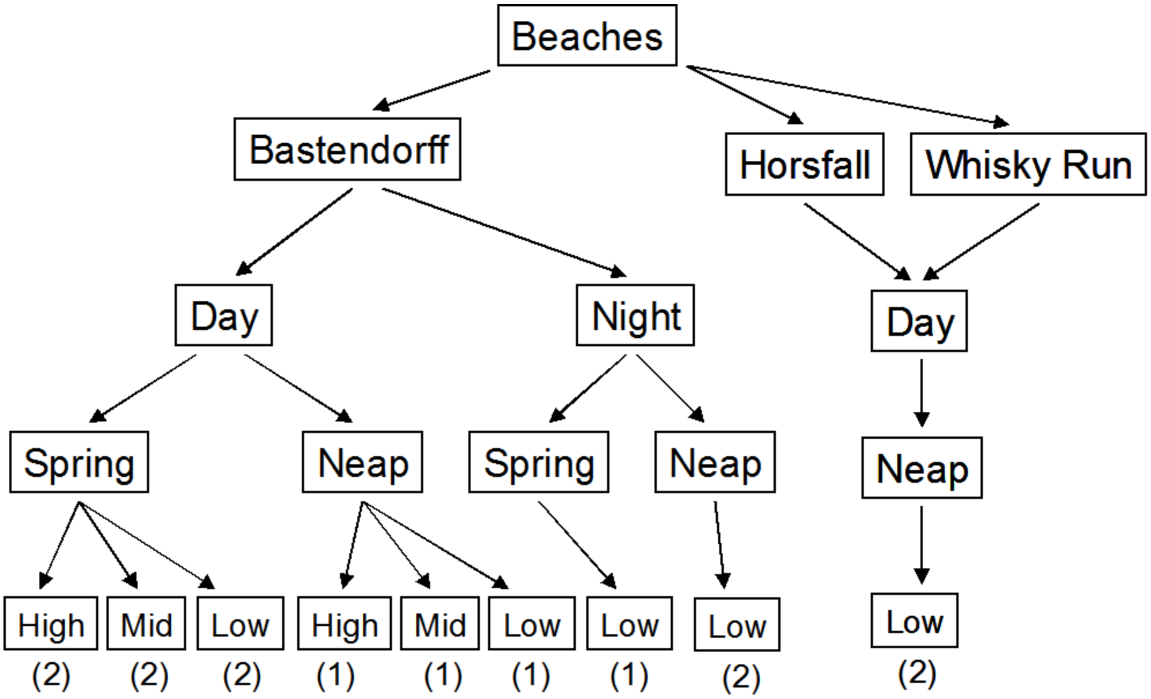

Figure 2. Time during which the surf zone fauna of dissipative sandy beaches was sampled with a hyperbenthic sledge. ( ) = number of samples.

The surf-zone fauna was sampled using a hyperbenthic sledge (Hamerlynck & Mees 1991) and the macrobenthic fauna with sediment cores. Sampling took place where the shallow surf-zone borders the swash zone (McLachlan and Brown, 2006). The hyperbenthic sledge sampled the swimming surf-zone fauna present in the whole water column at an approximate depth of 50 cm. Two zooplankton nets were mounted, one above the other, on the mouth of the sledge. The net had a 25 cm tall and 70 cm wide mouth and was 4 m long with a 1 mm mesh. The sledge was hand towed by two people parallel to the shoreline for 400 m in total (200 m one way and back). Because of how much time it takes to obtain a sample with the sledge, we considered it impossible to take replicates, a conclusion also reached in previous works (Watkin 1941). Therefore the tows were made sufficiently long for them to account for possible variance in the fauna due to the different areas present in the surf-zone of sandy beaches and to the patchy distribution that species may present (Mees & Jones 1997, Lock et al. 1999). The base of the lower net was 5 cm above the sea floor to avoid the collection of large quantities of sand (Mees & Jones 1997).

To determine if the species present in the water column were also present in the sediment, the benthic fauna was sampled with a sediment core. We took three samples of the sediment present in the surf-zone at approximately 50 cm in water depth in conjunction with the sledge samples. The samples were taken using a 10 cm diameter plastic core, which sampled approximately the top 15 cm of sediment. Each sediment sample consisted of the fauna present in ten sediment cores. Samples were passed through a 1-mm sieve and preserved in 10% buffered formalin.

Environmental Variables

To be able to test correlations between the fauna and several environmental variables that have been known to influence the fauna (Watkin 1941, Colman & Segrove 1955, Boysen 1975, Hamerlynck & Mees 1991, Clark et al, 1996, Mees & Jones 1997, Lock et al 1999, Beyst et al. 2001, Dominguez Granda et al. 2004, McLachlan 2006), sand grain size, beach profile, temperature, salinity, chlorophyll a, turbidity, the abundance of detached macrophytes, wave height and wind speed were measured. To measure sediment grain size (µm), three sediment samples were taken with the core at 50 cm water depth to measure sediment grain size. Sand grain size (% and mode) was determined by drying, sieving and weighing the sediment samples. Grain size distributions were statistically compared between pairs of beaches and tides using a Kolmogorov-Smirnov test (K-S test) (Sokal and Rohlf, 1995). The beach profile was determined using standard surveying techniques (Kavanagh 1992). Temperature (°C), salinity, chlorophyll *a* (Chla, mg/m^3) and optical back-scatter (OBS, NTU) data were obtained with a Sea Bird model 19-Conductivity-Temperature-Depth (CTD). The CTD was equipped with a Wet Star TD-700 fluorometer and an OBS. The CTD was carried into the surf-zone and placed in the water at approximately one meter in depth for two minutes. Because of mechanical problems, this particular CTD was only available for the first and last sample taken at Bastendorff and the samples taken at Horsfall and Whisky Run. On the other four dates on which Bastendorff was sampled, a CTD without a fluorometer and OBS was used. On these dates, in order to measure chlorophyll a and turbidity, three 250 to 1000 ml water samples were taken to measure each of these two variables. These water samples were analyzed following standard method (Parsons et al. 1984). The chlorophyll a and turbidity values obtained from the water samples were standardized to the CTD values using data obtained at the same time using the two methods. The detached macrophytes present in the hyperbenthic sledge samples were separated, dried and weighed ($g/100m^2$). Wind wave height (m) and wind speed (m/s) were obtained from the NOAA Station

46015, which is located 16 nautical miles west of Port Orford, OR (42°45'24"N, 124°49'45"W).

Sample Processing and Data Analysis

In the laboratory, the organisms were identified to the lowest taxonomic level with a dissecting scope and using Rudy Jr. & Rudy (1983), Kathman et al. (1986), Kozloff (1987), Smith & Carlton (1989), Brusca et al. (2001), Shanks (2001) and Chapman (2007). Crustacean species were further categorized by developmental stage (Lock et al. 1999, Beyst et al. 2001, Dominguez Granda et al. 2004). A distinction was made between the surf-zone water column species that were considered regular or sporadic. Species were considered Regulars if they were present on three or more sampling dates. Among Regular species, a distinction was also made between species that were present only as adults or only as developmental stages (juvenile, larvae or eggs). Species present only as a developmental stage were grouped as meroplankton. Based on their reported habitat (Rudy Jr. & Rudy 1983, Kathman et al. 1986, Kozloff 1987, Smith & Carlton 1989, Brusca et al. 2001, Shanks 2001 and Chapman 2007), adults were also separated into three groups, planktonic, rocky intertidal and sandy beach. The planktonic group consisted of species that have been reported from the coastal ocean. The rocky intertidal group consisted of species that have been reported on rocky shores or on the macrophytes present on rocky shores. The sandy beach group consisted of species that have been reported as inhabitants of sandy beaches.

A non-Parametric Cluster Analysis was conducted to observed similarities between samples. Clusters are a group of samples with high similarity, and were determined by a visual cut off at a resemblance or similarity level. An Analysis of Similarity (ANOSIM) was conducted to determine significant differences between beaches, between the clusters and between samples taken with the top and bottom net. To determine what species contributed to the formation of each cluster, a Similarity Percentage Analysis (SIMPER) was conducted. Prior to the analysis the data were $\log_{10}$ (x+1) transformed to reduce the influence of dominating species and the resemblance was obtained using the Bray-Curtis Index. To determine the environmental variables that best explained community pattern, a Biota-Environment matching analysis (BIOENV) was conducted. The environmental variables tested were temperature, salinity, chlorophyll a, OBS, wave height, wind speed and sand grain size, Julian date, stage of tide, lunar tide and time of day. Data were normalized and the resemblance obtained using the Eucledian distance. These four statistical programs are present in the PRIMER 6 package (Clarke & Gorley 2001).

Densities of organisms were calculated for the surf-zone and benthic samples. Species richness (S), diversity (H'), evenness (J') and dominance (d) were calculated only for the surf-zone fauna. Surf-zone densities (ind./100 m^2) were calculated using the total area sampled by the sledge (280 m^2), which was obtained by multiplying the length of the tow and the width of the sledge. Mean benthic densities (ind./100 m^2) were calculated using the area sampled with the sediment core (314 cm^2). Species richness was determined by the number of species per sample, and the Shannon Index was used as a measurement of diversity (Ludwig & Reynolds 1988). Equitability between species or evenness was measured with Pielou's evenness function (J') (Pielou 1977). Dominance, or the impact of dominant species, was analyzed with the Berger-Parker index (d) (Berger & Parker 1970). Values are presented with standard deviation (±) wherever possible. We were not able to use a three-way ANOVA to analyze density variances due to tides, lunar tides and time of day because we did not sample during all three tides at night. Instead, densities were compared among samples taken with the sledge and core, top and bottom net, three tidal tides, two lunar tides or day and night separately using one-way ANOVAs (5 separate tests). Pair-wise comparisons were conducted using Tukey's test. We tested for significant effects of changes in lunar tide and time of day on density using a partially nested mixed model two-way ANOVA, with lunar tide and time of day as fixed factors. We were able to use two-way ANOVAs despite the fact that we sampled only once during the spring/night low tide because we did obtain replicates for spring/day low tide, neap/night low tide and neap/day low tide. However, because of the lack of spring/night low tide replicates we were not able to do any further statistical comparison. All of the assumptions for the analysis of variance were met, except for the homogeneity of variances. To meet this assumption, the data were $\log_{10}(x+1)$ transformed and then tested with an F max test. Dominance of the community by specific species was also analyzed using one-way ANOVAs and the data were arc sin transformed to meet the homogeneity of variances assumption, which was tested using an F max test (Sokal & Rohlf 1995). Because of difficulties meeting ANOVA assumptions, differences in S, H' and J' were analyzed using a Kruskal-Wallis non-parametric test (Sokal & Rohlf 1995).

Linear correlations between the biological data (Density, S, H’ and J’) of the five groups (planktonic, rocky/macrophyte, sandy beach, meroplankton, sporadic) and wind speed, wave height, chlorophyll a, OBS, temperature, salinity, detached macrophytes, sand grain size and Julian date were made. These analyses were conducted on the whole community, the three adult groups and the development stage group separately. Finally within the sandy beach and meroplankton groups, the densities of several species were analyzed with one-way ANOVAs and were correlated to the measured environmental variables.

Results

Environmental Variables

The wind was mostly from the Northwest at speeds of approximately 4.3±1.4 m/s, producing waves that varied between 1 and 2.7 m, with significantly larger waves during spring tides ($n = 5$, $F = 59.93$, $p < 0.001$) (Table 1). The dry weight of detached macrophytes varied between 0.5 g to almost 40 g /100 m^2. The slope at Bastendorff varied between 1:36 (06/07/06) and 1:59 (07/22/06), and was 1:74 at Whisky Run and 1:33 at Horsfall. The sand grain size varied at the three beaches, with finer sand present at Whisky Run (Table 1).

Table 1. Date of sampling and environmental variables measured at three sandy beaches in southern Oregon during the summer of 2006. Bast. = Bastendorff, Hors. = Horsfall, Whis. = Whisky Run. W. dir. = wind direction (degrees), W. sp. = wind speed (m/s), Wave = wave height (m), Chla = chlorophyll a (mg/m^3), OBS = optical back scatter (NTU), Sal = salinity, Temp = temperature (ºC), Macro = weight of detached macrophytes (g), Sand = % of sand grains with sizes ≤ 381 µm. * Samples in which detached macrophyte values were not available. ** Values were considered outliers and therefore not presented.

Beach	Date	W. dir.	W. Sp.	Wave	Chla	OBS	Sal	Temp	Macro	Sand
Bast.	6/7	15	5.7	1.7	0.3	10.0	32.2	14.0	*	71.4
Bast.	6/7	16	5.3	1.7	0.3	5.2	32.1	14.2	*	67.1
Bast.	6/7	19	4.9	1.5	0.3	4.8	32.0	14.7	*	37.0
Bast.	7/22	45	3.2	2.3	0.1	6.1	33.8	10.8	0.5	78.4
Bast.	7/22	32	3.0	2.3	0.1	1.1	34.0	10.7	5.1	66.3
Bast.	7/22	43	3.1	2.3	0.1	2.1	33.6	10.7	4.1	75.9
Bast.	7/27	40	4.9	2.7	0.1	6.3	33.1	9.9	20.2	64.0
Bast.	7/27	28	5.7	2.9	0.2	2.1	33.6	9.6	19.2	49.1
Bast.	7/27	21	5.8	2.8	0.1	2.1	33.4	9.7	38.5	43.3
Bast.	7/30	204	1.3	1.1	0.4	3.6	33.7	11.1	15.9	69.8
Bast.	8/2	21	3.4	1.1	0.2	1.5	33.6	11.9	1.7	40.4
Bast.	8/13	18	5.9	2.7	**	13.6	29.5	15.7	3.9	41.5
Hors.	6/30	18	4.0	1.6	0.3	9.3	33.7	9.4	0.7	14.6
Whis.	7/1	24	4.2	1.6	3.2	181.0	33.6	9.4	1.0	65.4

At Bastendorff, the mean sand grain size was significantly finer high than at low tide (n = 3, D = 0.19, p = 0.01) but there was no significant difference between high and mid or low and mid tide.

Faunal Composition

A total of 49,363 individuals belonging to 92 species were identified from the 14 samples with a mean of 3,526±6,578 ind./100 m^2 (±S.D.) (Table 2). *Upogebia pugettensis* and

Nereis vexillosa were present in more than one developmental stage. The most abundant and common species was the mysid *Archaeomysis grebnitzkii* (91% or 3,201±6,904 ind./100m^2). Of the 94 species, 51 were considered Regulars and 43 were considered Sporadic (Table 2). Of the 51 regulars, 34 were present as adults only and 17 were present as meroplankton only. Finally of the 34 adults, 13 were sandy beach species, 8 planktonkic, and 13 rocky intertidal (Fig. 3). Of the three beaches, Bastendorff had the highest mean density and species richness but lowest diversity and evenness (Table 3). The mean densities observed in Bastendorff were 15 times greater than those observed at Horsfall and Whisky Run, however diversity and evenness values observed in Horsfall and Whisky Run were higher than those observed at Bastendorff.

Table 2. List of species present in three dissipative sandy beaches sampled during the summer of 2006. Taxa = higher taxa, Stage = life stage, Density = total densities (ind./100m^2), Beach, 1 = Bastendorff, 2 = Horsfall, 3 = Whisky Run.

Table 3. Total and mean densities (ind./100 m^2 ± S.D), species richness, diversity, (Shannon Index), and evenness (Pielou's function) values of the surf-zone fauna present in three dissipative sandy beaches in southern Oregon during the summer of 2006. HW, MW, LW = high, mid and low tide respectively. Day and Night = Time of day. Spring and Neap = lunar tides.

Species	Stage	Taxa	Density	Beach
Planktonic Group				
Sagitta sp.	adult	Chaetognatha	28	1,2,3
Muggiaea atlantica	adult	Cnidaria	18	1,2,3
Obelia sp.*	adult	Cnidaria	537	1,2,3
Calanus marshallae	adult	Crustacea	248	1,2,3
Eucalanus bungii	adult	Crustacea	7	1,2
Lycaeopsis themistoides	adult	Crustacea	12	1,2,3
Pleurobrachia sp.	adult	Ctenophora	4	1,2,3
Insect	adult	Insect	4	1,2,3
Rocky Intertidal Group				
Caprella equilibra	adult	Crustacea	38	1
Caprella verrucosa	adult	Crustacea	5	1
Caprella incisa	adult	Crustacea	84	1,3
Exosphaeroma amplicauda	adult	Crustacea	8	1
Gnathopleusteus sp.	adult	Crustacea	100	1
Gnorimosphaeroma oregonensis	adult	Crustacea	3	1,2
Holmesimysis costata	adult	Crustacea	72	1,2
Idotea fewkesi	adult	Crustacea	18	1,2,3
Jassa shawi	adult	Crustacea	511	1
Laniropsis derjugini	adult	Crustacea	8	1
Metacaprella anomala	adult	Crustacea	12	1
Pontongenia rostrata	adult	Crustacea	30	1
Stenothoides burkanki	adult	Crustacea	3	1,2,3
Allorchestes bellabella	adult	Crustacea	83	1,2,3
Sandy Beach Group				
*Archaeomysis grebnitzkii**	adult	Crustacea	44,819	1,2,3,
*Atylus tridens**	adult	Crustacea	890	1,2,3
Diastylis sp.	adult	Crustacea	18	1
Dogielinotus loquax	adult	Crustacea	12	1
*Eohaustorius washingtonianus**	adult	Crustacea	26	1,2,3
Excirolana kincaidi	adult	Crustacea	89	1
Hartmanodes hartmanae	adult	Crustacea	40	1,2,3
*Lissocrangon stylirostris**	adult	Crustacea	308	1,2,3
Mandilophoxus sp.*	adult	Crustacea	41	1,2,3

Table 2. Continued.

*Nephtys californiensis**	adult	Polychaeta	2	1,2
Spionidae sp.*	adult	Polychaeta	8	1,2
Achelia spinoseta	adult	Pycnogonida	22	1,2
Meroplankton Group				
Mytilus sp.	juvenile	Bivalvia	143	1
Cancer gracilis or antennarius	megalopa	Crustacea	5	1,2
*Cancer magister**	megalopa	Crustacea	22	1
Crangonidae sp. 1	megalopa	Crustacea	53	1,2,3
Crangonidae sp. 1	zoea	Crustacea	7	1,2,3
Crangonidae sp. 2	megalopa	Crustacea	18	1
Fabia subquatra	zoea	Crustacea	14	1
Hemigrapsus orogenensis	megalopa	Crustacea	44	1
Lophopanopeus bellus	megalopa	Crustacea	60	1,2,3
Neotrypaea californiensis	zoea	Crustacea	62	1,2,3
Pachycheles sp.	zoea	Crustacea	99	1,2,3
Upogebia pugettensis	megalopa	Crustacea	6	1
*Littorina plena**	egg	Gastropoda	580	1,2,3
Lacuna sp.	juvenile	Gastropoda	28	1
Leptocottus armatus	postlarva	Osteichthies	4	1
Pleuronectes vetulus	egg	Osteichthies	20	1
Nereis vexillosa	postlarva	Polychaeta	17	1
Sporadic Group				
Siliqua patula	juvenile	Bivalvia	1	1
Cephalopoda sp.	egg	Cephalopoda	1	1
Polyorchis penicillatus	adult	Cnidaria	1	1
Aequorea aequorea	adult	Cnidaria	1	1,2,3
Sarsia sp.	adullt	Cnidaria	1	1
Scrippsia pacifica	adult	Cnidaria	0.4	1
Atylus sp.	adult	Crustacea	11	1
Balanus glandula	nauplii	Crustacea	0.4	1
Cancer oregenesis/productus	megalopa	Crustacea	10	1
Cancer sp.	zoea	Crustacea	1	1
Corophium sp.	adult	Crustacea	1	1
Crangonidae sp. 2	zoea	Crustacea	2	1
Crangonidae sp. 1	postlarva	Crustacea	1	1,3
Cumella sp.	adult	Crustacea	1	1
Dynamennella sheareri	adult	Crustacea	0.4	1
*Emerita analoga**	adult	Crustacea	1	1,2
Euphausia mutica	adult	Crustacea	1	2
Euphausia pacifica	adult	Crustacea	1	1,2,3
Exacanthomysis davisi	adult	Crustacea	1	1
Exosphaeroma inornata	adult	Crustacea	2	1
Eyakia sp.*	adult	Crustacea	7	1

Table 2. Continued.

Idotea montereyensis	adult	Crustacea	2	1
Idotea sp.	adult	Crustacea	0.4	1
Majidae sp.	zoea	Crustacea	1	1
Munna stephenseni	adult	Crustacea	4	1
Paguristes turgidus	zoea	Crustacea	0.4	1
Porcenallidae sp.	megalopa	Crustacea	2	1,3
Protohyale frequens	adult	Crustacea	1	1
Synidotea pettiboneae	adult	Crustacea	0.4	1
Upogebia pugettensis	zoea	Crustacea	2	1,2
Nudibranch sp 1	adult	Gastropoda	0.4	1
Unknown	adult	Hemichordate	1	1
Nematoda sp.*	adult	Nematoda	3	1
Amphistichus rhodoterus	juvenile	Osteichthies	1	1
Engraulis mordax	larva	Osteichthies	0.4	1
Gasterosteus aculeatus	juvenile	Osteichthies	1	1
N.I. Egg	egg	Osteichthies	0.4	1
Abarenicola sp.	juvenile	Polychaeta	1	1
Hesionura sp.	adult	Polychaeta	1	1
Nereis vexillosa	juvenile	Polychaeta	3	1
Orbiniidae sp	adult	Polychaeta	3	1
Anoplodactylus oculospinus	adult	Pycnogonida	6	1,3
Phoxichilidium femoratum	adult	Pycnogonida	0.4	1

** Species present in water column and sediment*

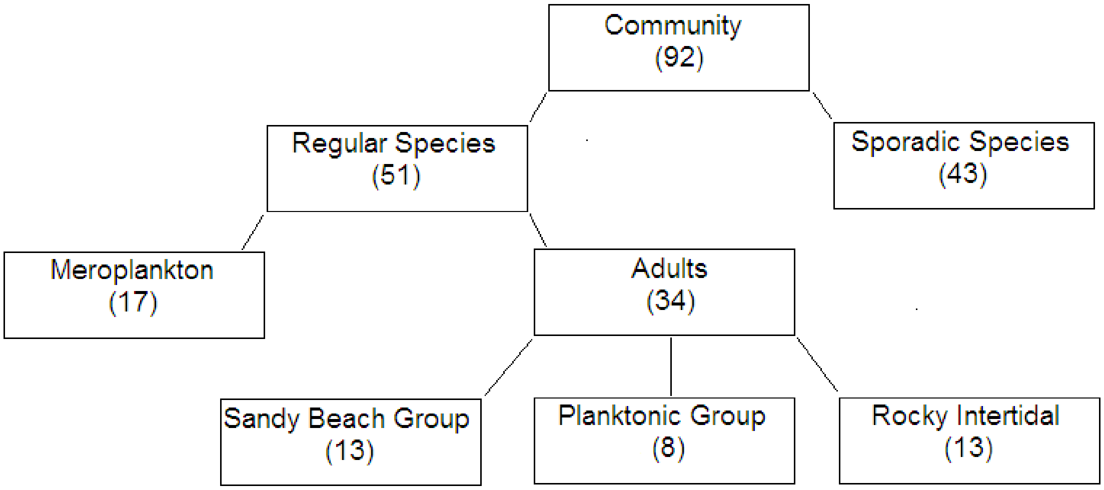

Figure 3. Flow chart explaining how the surf zone fauna was separated based on the number of sampling dates each species was present, the life stage, and the environment they have been cited as inhabiting. Samples taken at three dissipative sandy beaches in southern Oregon during summer 2006. ( ) = number of species.

Community Statistical Analysis

The faunal communities of the three beaches were not significantly different (ANOSIM, n = 28, Global R = 0.06, p = 0.30), and were therefore analyzed collectively in further analysis. At a resemblance level of 45, the samples from the whole community grouped into five significantly different clusters (ANOSIM, n = 28, Global R = 0.978, p = 0.01) based on the date on which they were taken (Fig. 4). Each cluster was formed by a group of dates that were most similar. Within each cluster the samples taken with the top and bottom samples were not significantly different (ANOSIM, n = 28, Global R = 0.02, p = 0.35), and therefore their data were averaged in further analysis. The environmental variable that best explained the community pattern was the Julian date (n = 28, r = 0.84, p = 0.01). Each cluster had one to four species that contributed more than 10% to the similarity of each cluster (Table 4a). *Archaeomysis grebnitzkii* contributed more that 10% to the similarity of four clusters, and *Obelia sp*. and *Littorina plena* (egg case) each contributed to two clusters. The surf-zone water column community was significantly influenced by the Julian date, and *A. grebnitzkii* was the most contributing species. Within the whole community, significantly higher densities (n = 3, F = 99.03, $p < 0.001$) were observed at night than in the day and significant higher diversity and evenness (n = 3, H = 6.23, p = 0.01) were observed during the day (Table 3). Significantly higher diversity values were also observed during spring tides (n = 7, H = 4.81, p = 0.02) when compared to neap tides.

Table 3. Total and mean densities (ind./100 $m^2 \pm$ S.D), species richness, diversity (Shannon Index), and evenness (Pielou's function) values of the surf-zone fauna present in three dissipative sandy beaches in southern Oregon during the summer of 2006. HW, MW, LW = high, mid and low tide respectively. Day and Night = Time of day. Spring and Neap = lunar tides.

		Density	Species Richness	Diversity	Evenness
Beach	Bastendorff	4,077 (6,987)	35 (11)	1.4 (0.8)	0.4 (0.2)
	Horsfall	172	33	2.5	0.7
	Whisky Run	278	32	2	0.6
All Beaches	HW	225 (131)	30 (15)	1.8 (0.6)	0.5 (0.1)
	MW	339 (209)	31 (11)	1.5 (0.4)	0.5 (0.1)
	LW	5959 (8035)	38 (8)	1.3 (0.9)	0.4 (0.3)
	Day	328 (212)	32 (10)	1.8 (0.5)	0.5 (0.1)
	Night	15255 (4297)	43 (4)	0.3 (0.2)	0.1 (0.1)
	Spring	2141 (4482)	39 (8)	1.7 (0.7)	0.5 (0.2)
	Neap	4911 (8318)	30 (10)	1.3 (0.8)	0.4 (0.3)
Sandy Beach	HW	112 (48)	6 (3)	0.7 (0.5)	0.4 (0.2)
	MW	215 (194)	7 (2)	0.7 (0.3)	0.3 (0.1)
	LW	5672 (7940)	9 (2)	0.6 (0.5)	0.3 (0.2)
	Day	182 (156)	7 (2)	0.8 (0.3)	0.4 (0.1)
	Night	14787 (4602)	11 (0)	0.1 (0.1)	0.1 (0.03)
	Spring	1878 (4229)	9 (1)	0.7 (0.4)	0.4 (0.2)
	Neap	4745 (8260)	8 (3)	0.5 (0.5)	0.3 (0.2)
Planktonic	HW	16 (9)	4 (3)	0.8 (0.8)	0.7 (0.2)
	MW	44 (66)	4 (2)	0.9 (0.8)	0.6 (0.5)
	LW	85 (89)	4 (2)	0.7 (0.6)	0.6 (0.2)
	Day	50 (49)	5 (2)	0.9 (0.6)	0.6 (0.3)
	Night	105 (149)	2 (2)	0.3 (0.4)	0.5 (0)
	Spring	51 (100)	5 (1)	1.2 (0.4)	0.7 (0.2)
	Neap	71 (50)	3 (3)	0.4 (0.6)	0.4 (0.3)
Rocky Intertidal	HW	25 (36)	6 (4)	1.2 (0.2)	0.7 (0.2)
	MW	33 (25)	7 (2)	1.3 (0.2)	0.7 (0.2)
	LW	97 (118)	8 (3)	1.3 (0.4)	0.7 (0.4)
	Day	36 (51)	7 (3)	1.2 (0.3)	0.7 (0.3)
	Night	185 (139)	10 (2)	1.4 (0.4)	0.6 (0.4)
	Spring	79 (72)	9 (3)	1.3 (0.3)	0.7 (0.3)
	Neap	57 (119)	6 (3)	1.2 (0.4)	0.7 (0.4)

Table 3. Continued.

Meroplankton	HW	71 (53)	10 (5)	1.1 (0.2)	0.5 (0.1)
	MW	47 (49)	9 (3)	1.3 (0.3)	0.6 (0.3)
	LW	104 (121)	10 (3)	1.3 (0.3)	0.6 (0.3)
	Day	61 (55)	9 (3)	1.2 (0.3)	0.6 (0.3)
	Night	170 (177)	12 (2)	1.5 (0.03)	0.6 (0.04)
	Spring	135 (116)	11 (3)	1.3 (0.2)	0.5 (0.2)
	Neap	34 (25)	8 (2)	1.3 (0.3)	0.6 (0.3)

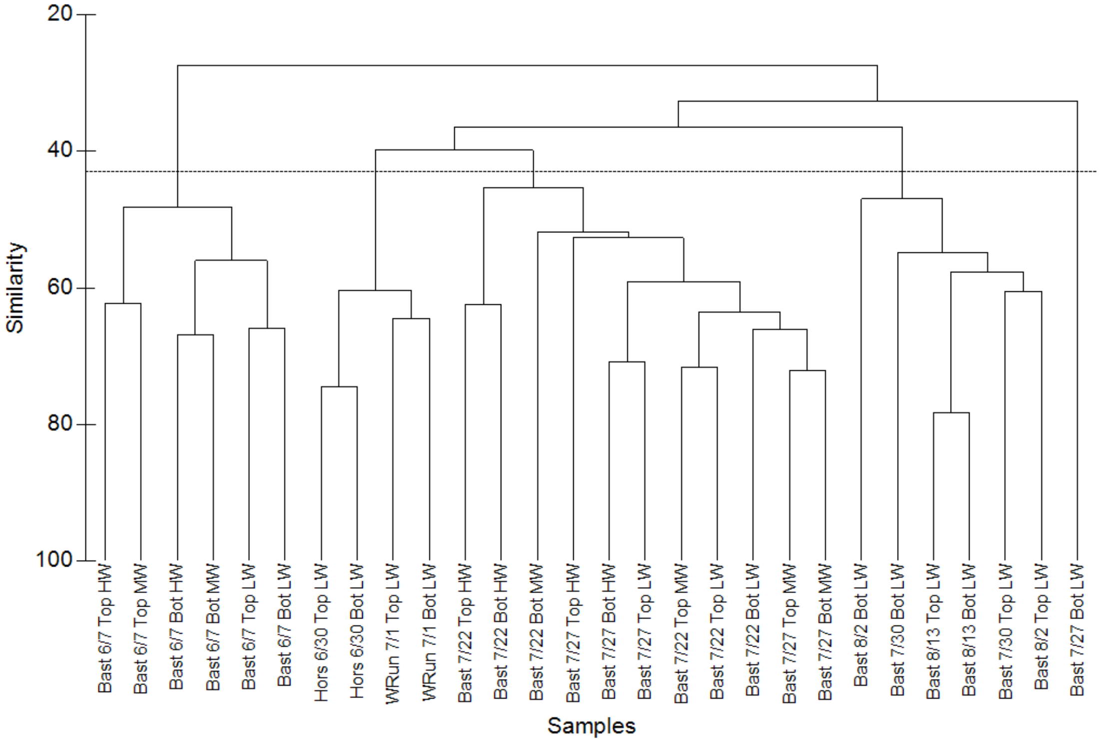

Figure 4. Cluster Analysis of surf-zone fauna. Five significantly different clusters (45%) (n = 14, Global R = 0.98, p = 0.01) were formed. Samples taken at three dissipative sandy beaches in southern Oregon during summer 2006. Data were $\log_{10}$ (x+1) transformed and resemblance values obtained using Bray Curtis Index. HW, MW, LW = high, mid and low tide, respectively. Top and Bot = Top and Bottom net of hyperbenthic sledge. Bast = Bastendorff, Hors = Horsfall, WRun = Whisky Run.

Because *A. grebnitzkii* contributed to the similarity of four clusters and was present in all of the samples in higher number than any other species, its densities were employed to determine dominance. Dominance of *A. grebnitzkii* on the surf-zone water column community was high for all of the samples (0.5±0.3) and was significantly higher during the night that during the day, 0.9±0.04 and 0.3±0.2 respectively (n = 3, F = 37.75, $p < 0.001$).

Sandy Beach Group

The data grouped into four significantly different clusters (63%) (n = 14, R = 0.832, p = 0.01) (Fig. 5). In each cluster, two to four species contributed to similarity with at least 10%. *Archaeomysis grebnitzkii* and *Atylus tridens* contributed with at least 10% to the similarity of four clusters (Table 4b). The environmental variables that best explained the community pattern were Julian date and time of day (n = 14, r = 0.81, p = 0.01). The density, species richness, diversity and evenness differed significantly between day and night (n = 3, F = 69.85, $H \geq 6.4$, $p \leq 0.01$), with higher density and species richness values during the night and higher diversity and evenness during the day (Table 3).

A positive linear correlation was observed between species richness and Julian date (n = 14, r = 0.72, p = 0.01) and a negative linear correlation was observed between diversity and temperature (n = 14, r = 0.58, p = 0.05). Significantly higher total densities were observed during spring tides for *A. tridens* and at night for *A. grebnitzki, Lissocrangon stylirostris, A. tridens, Hartmanodes hartmanae* and *Eohaustorius* *washingtonianus* (n = 3, F ≥ 6.56, p ≤ 0.01). Significant differences were found between the densities of *Excirolana chiltoni* during spring/night low tides (1.5±0 ind./100m^2), neap/night low tides (0.8±1 ind./100m^2), spring/day low tides (0.7±0.3 ind./100m^2) and neap/day low tides (0.4±0.2 ind./100m^2) (2-way ANOVA, Table 5).

Table 4. Similarity Percentage analysis (SIMPER) showing the species contributing to similarity of each cluster formed by the analysis presented in Fig. 2 (a), Fig. 5 (b) and Fig 6 (c).

a)	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Obelia sp.	43.3	16.6	-	-
Archaeomysis grebnitzkii	20.7	11.7	19.4	27.6
Littorina plena (egg capsule)	12.7	12.9	16.4	-
Calanus marshallae	-	14.0	-	-
Atylus tridens	-	-	14.3	11.7
b)	Cluster 1	Cluster 2	Cluster 3	Cluster 5
Archaeomysis grebnitzkii	68.1	41.1	44.8	31.5
Atylus tridens	20.4	19.5	31.3	15.6
Eohaustorius washingtonianus	-	13.2	-	-
Mandilophoxus sp.	-	11.4	-	-
Lissocrangon stylirosris	-	-	-	11.1
c)	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Littorina plena (egg capsule)	38.2	58.9	36.0	26.5
Upogebia pugettensis (megalopa)	23.5	-	-	-
Lophopanopeus bellus (megalopa)	15.9	-	-	24.8
Fabia subquatra (zoea)	14.3	-	-	-
Pachycheles sp. (zoea)	-	11.1	-	-
Crangonidae sp. 1 (megalopa)	-	11.1	-	-
Mytilus sp. (juvenile)	-	-	16.5	-
Cancer magister (megalopa)	-	-	-	20.3
Hemigrapsus orogenensis (zoea)	-	-	-	10.1

Clusters not present because there were fewer than two samples in the group.

Table 5. Results of two-way ANOVA test for differences in *Excirolana chiltoni* densities at low tide. Fixed effects were time of day and lunar tides. Samples taken at Bastendorff, a dissipative sandy beach in southern Oregon.

	df Effect	MS Effect	df Error	MS Error	F	p-level
Lunar tide	1	0.23	4	0.006206	36.52	0.004
Time of day	1	2.16	4	0.006206	347.65	0.00005
Interaction	1	0.20	4	0.006206	32.22	0.005

In the day samples, significantly higher densities were observed in samples taken with the bottom net for *A. grebnitzkii* and *L. stylirostris* ($n = 11$, $F \geq 8.42$, $p \leq 0.008$), and during spring tides for *A. grebnitkii* ($n = 5$, $F = 5.1$, $p = 0.05$). Finally, significantly higher densities were observed in night samples taken with the bottom net for *A. tridens* ($n = 3$, $F = 8.21$, $p = 0.05$). No significant linear correlations were observed between densities of sandy beach species and environmental variables.

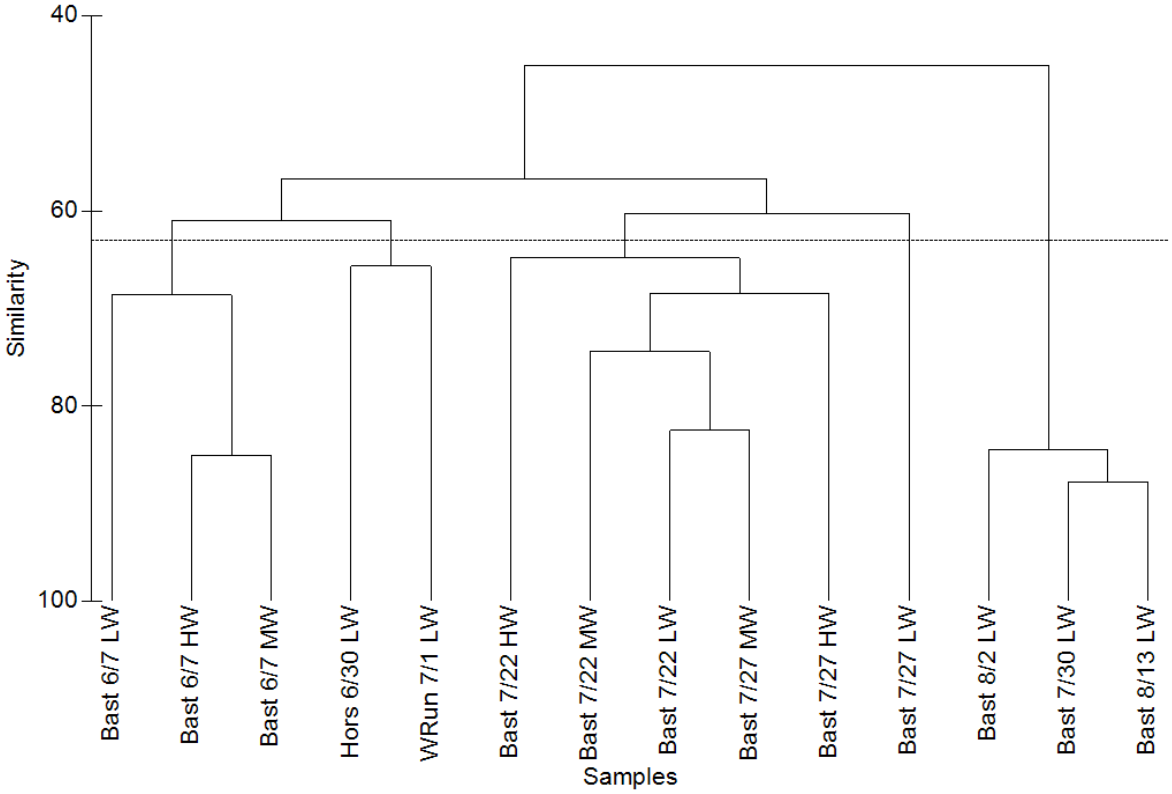

Figure 5. Cluster Analysis of adult sandy beach species inhabitanting surf-zones of three dissipative sandy beaches of southern Oregon, summer 2006. Resemblance cut off at 65% formed four significantly different clusters (n =14, Global R = 0.83, p = 0.02). Data were previously $\log_{10}$ (x+1) transformed and resemblance values obtained using Bray Curtis Index. HW, MW, LW = high, mid and low tide, respectively. Bast = Bastendorff, Hors = Horsfall, WRun = Whisky Run.

Planktonic Group

The Cluster and SIMPER analysis grouped the data into four significantly different clusters (45%) (n = 14, R = 0.545, p = 0.03). In each cluster, one to five species contributed to its similarity with at least 10%. *Calanus marshallae* contributed in more than 10% to the similarity of three clusters, and *Obelia sp*., *Sagitta sp*, and *Lycaeopsis* *themistoides* each contributed to two clusters. The environmental variable that best explained the community pattern was Julian date (n = 14, r = 0.63, p = 0.01). In this group, significantly higher diversity and evenness values were observed during spring tides than neap tides (n = 7, H ≥ 5.66, p ≤ 0.02) (Table 3). Diversity and evenness values were positively correlated with wave height (n = 14, r ≥ 0.60, p = 0.05) (Fig. 6), and negatively correlated with temperature (n = 14, r = 0.62, p = 0.05).

Rocky Intertidal Group

The samples of this group formed four significantly different clusters with low similarity (40%) (n = 14, R = 0.979, p = 0.01). One to five species contributed to the similarity of the clusters with at least 10%. *Jassa shawi* contributed with at least 10% to all clusters, and was the only species that contributed over 10 % to more than one cluster. The environmental variable that best explained the community pattern was Julian date (n = 14, r = 0.70, p = 0.01). Within this group, significantly higher density values were observed during the night than in the day (n = 3, F = 6.46, p = 0.03) (Table 3). Positive linear correlations were observed between (1) species richness and both, the amount of detached macrophytes (n = 11, r = 0.60, p = 0.05) (Fig. 7) and Julian date (n = 14, r = 0.74, p = 0.01), (2) densities and Julian date (n = 14, r = 0.60, p = 0.05), and (3) evenness and temperature (n = 14, r = 0.56, p = 0.05).

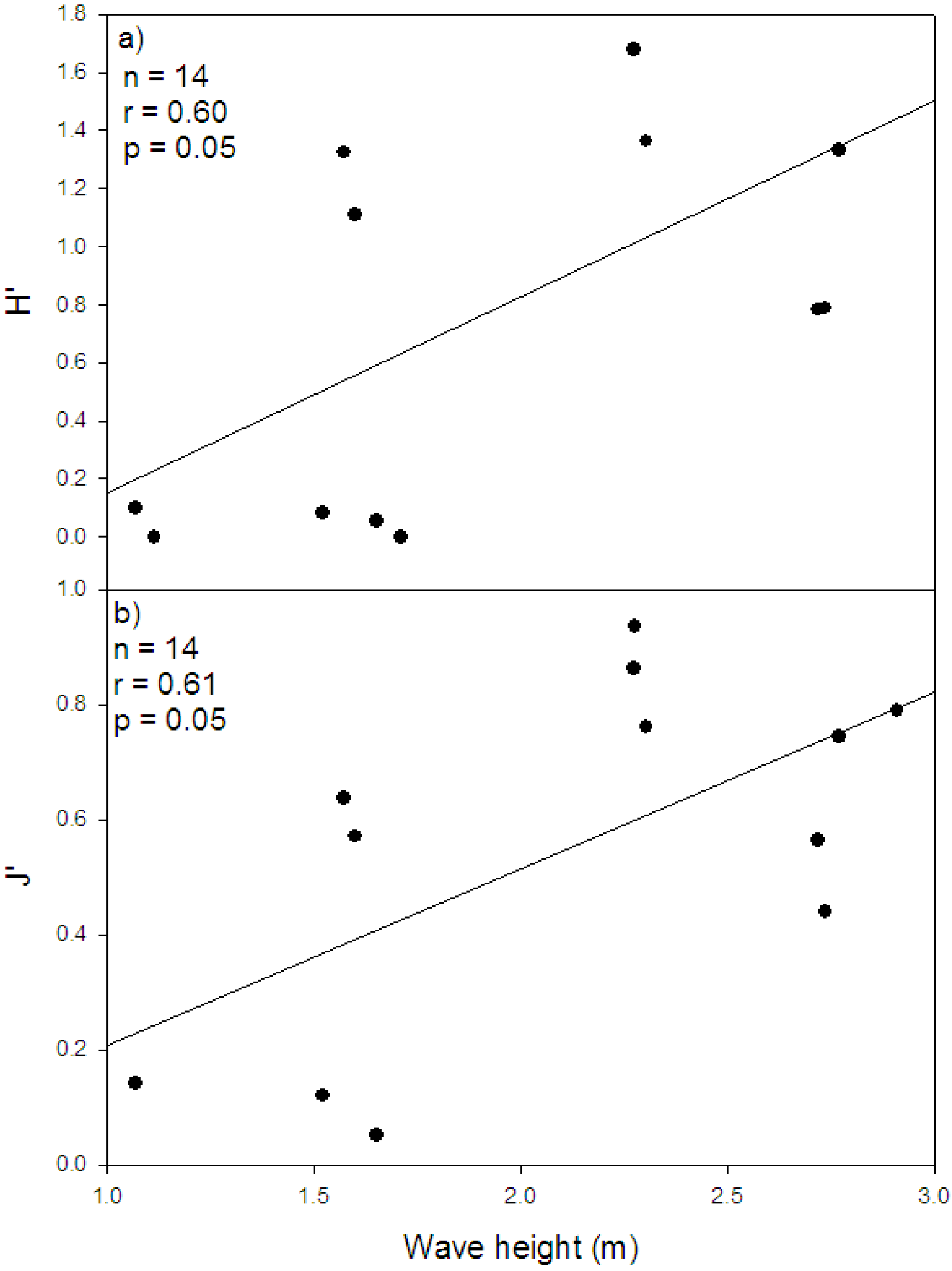

Figure 6. Positive linear correlations between both diversity (H') and evenness values (J') with wave height (Wave, m). Samples taken at three dissipative beaches of southern Oregon in the summer of 2006.

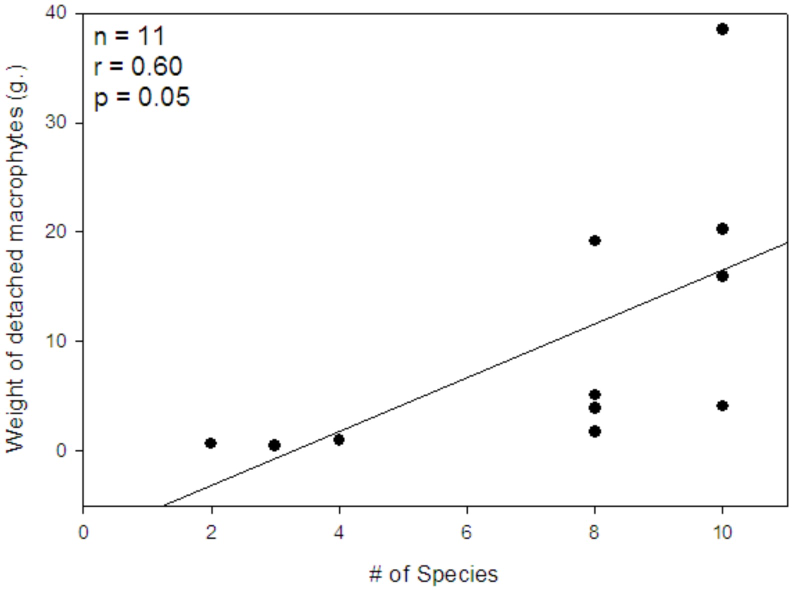

Figure 7. Positive linear correlation between the dry weights of detached macrophytes (g./100 m^2) and the number of species (# of Species) present at three dissipative sandy beaches of southern Oregon during the summer of 2006.

Meroplankton Group

This group was composed of five significantly different clusters (50%) (n =14, R = 0.818, p = 0.01) (Fig. 8). Two to four species contributed to the similarity of each cluster with at least 10%. *Littorina plena* (egg case) contributed with at least 10% to the similarity of four and *Lophopanopeus bellus* (megalopa) to two clusters (Table 4c). The environmental variables that best explained the community pattern were Julian date and temperature (n = 14, r = 0.75, p = 0.01). Density and diversity values were significantly higher during spring tides (n = 7, F = 9.76, H = 3.97, $p \leq 0.05$) than neap tides (Table 3).

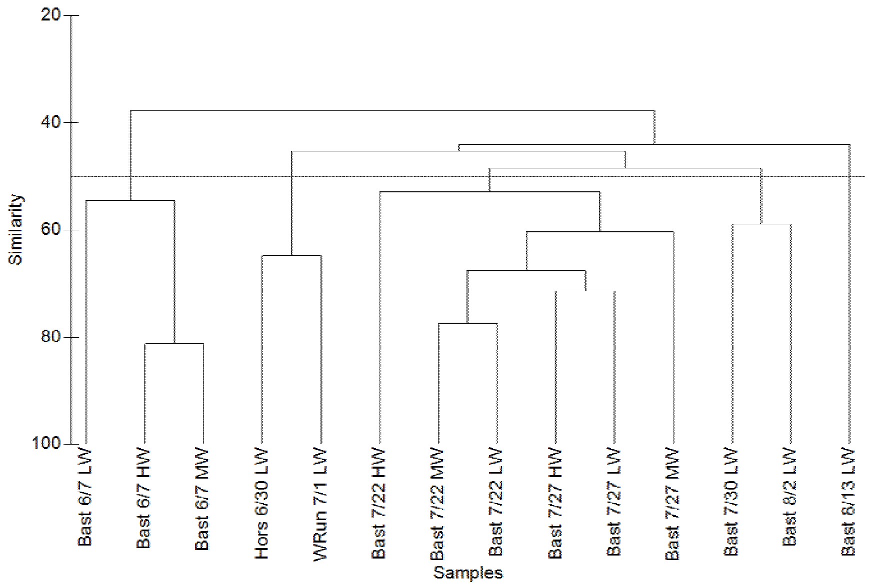

Figure 8. Cluster Analysis of species present as meroplankton in the surf-zone fauna samples. Samples taken at three dissipative sandy beaches of southern Oregon, summer 2006. Resemblance cut off at 50% formed five significantly different clusters ($n = 14$, Global $R = 0.82$, $p = 0.01$). Data were $\log_{10}$ (x+1) transformed and resemblance values obtained using Bray Curtis Index. HW, MW, LW = high, mid and low tide, respectively. Bast = Bastendorff, Hors = Horsfall, WRun = Whisky Run.

A positive linear correlation was observed between both species richness and densities and Julian date ($n = 14$, $r \geq 0.64$, $p = 0.05$). Within each species, densities were significantly higher during (1) spring tides for *Littorina plena* (egg case) and Crangonidae sp. (zoea) ($n = 7$, $F \geq 5.15$, $p \leq 0.04$), and (2) at night for *Lophopanopeus bellus* (megalopa) and Crangonidae sp. (zoea) ($n = 3$, $F \geq 5.93$, $p \leq 0.02$). In day samples, significantly higher densities were observed in samples taken during spring tides for *Neotrypaea californiensis* (zoea) ($n = 5$, $F = 9.40$, $p = 0.01$) and in bottom net samples for Crangonidae sp. (zoea) ($n = 11$, $F = 5.35$, 0.03). Significant linear correlation was observed between *Neotrypaea californiensis* (zoea) and salinity ($n = 10$, $r = 0.63$, $p =$

0.05) (Fig. 9) correlation, which was maintained even when the point with lowest salinity and highest density was eliminated (n = 10, r = 0.64, p = 0.05).

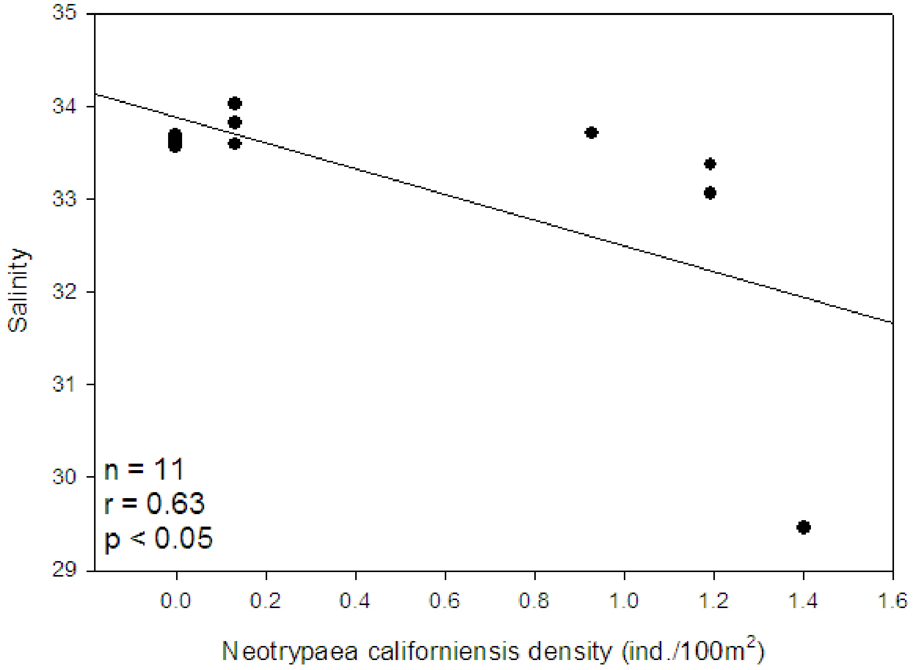

Figure 9. Negative linear correlation between densities of all zoea stages of *Neotrypaea californiensis* (ind./100m^2) and salinity. Samples taken at three dissipative beaches in southern Oregon in the summer of 2006.

A stronger linear correlation was observed between the densities of zoeal stages 1 and 2 and salinity (n = 11, r = 0.73, p = 0.05) (Fig. 10). *Neotrypaea californiensis* was present in the samples in all five zoeal stages. A total of 62 zoea were caught, most of which most were stage 2 (40%). *Upogebia pugettensis* (megalopa) densities were positively correlated with temperature (n = 14, r = 0.75, p = 0.01) and negatively correlated with salinity (n = 14, r = 0.73, p = 0.01). *Mytilus* sp. (juvenile) was positively correlated with the amount of detached macrophytes (n = 11, r = 0.82, p = 0.01).

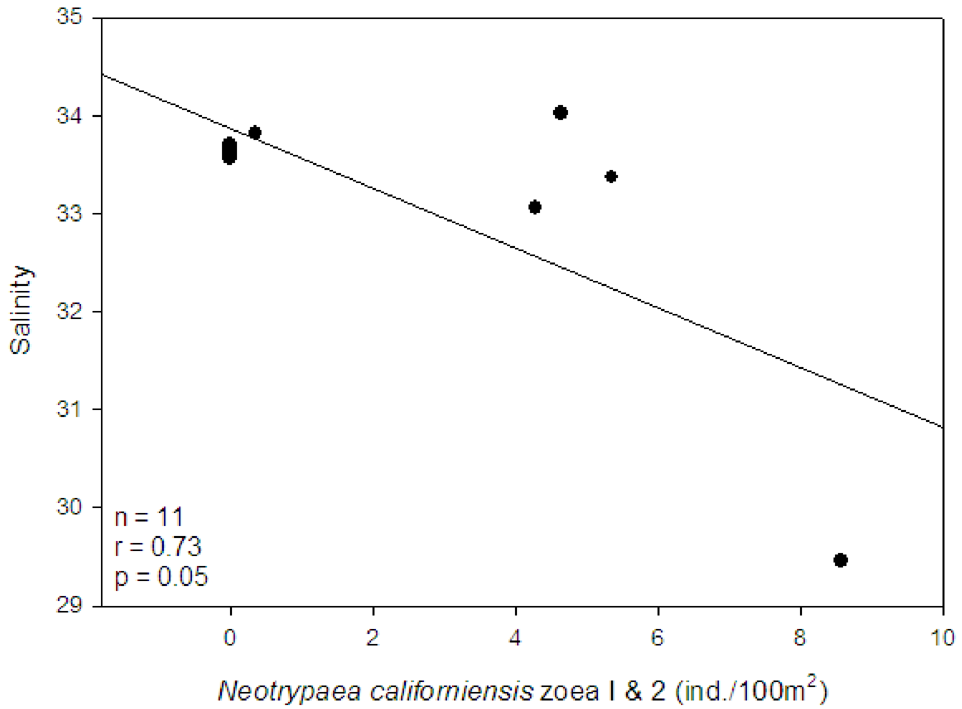

Figure 10. Negative linear correlation between densities of *Neotrypaea californiensis* zoea stages I and II (ind./100m^2) and salinity. Samples taken at three dissipative beaches in southern Oregon in the summer of 2006.

Benthic Fauna

In the sediment cores we found 15 species inhabiting the top 15 cm of sediment at 50 cm in water depth, 13 of which were also present in the water column (Table 2). *Nephtys californiensis* and *Eohaustorius brevicuspis* were present in significantly higher densities in the sediment than in the water column ($n = 28$, $F \geq 79.4$, $p < 0.01$). Densities of *Archaeomysis grebnitzkii* and *Lissocrangon stylirostris* were not significantly different between sediment and water column fauna.

Discussion

General Composition

The results obtained suggest that despite the harsh hydrodynamic conditions, the surf-zones of Oregonian sandy beaches are used extensively throughout the summer by a number of small invertebrate and vertebrate species. The total number of individuals and species caught during the present study were similar than those reported by previous studies of surf-zones in temperate regions (Watkin 1941, Colman & Segrove 1955, Lock et al. 1999, Beyst et al. 2001). However the density and species richness values observed in the present study were lower than those conducted in tropical areas (Dominguez Granda et al. 2004). The higher values could have been because most of the previous studies were conducted during a whole year while this study was conducted only during the summer when environmental conditions for the fauna are optimum. Therefore, we hypothesize that the average densities and species richness we would find in the winter at the three Oregon beaches would be lower than those we found in the summer.

Community Statistical Analysis

The environmental variable that best explained the patterns of the whole community and of the four groups, in which the community was separated, was the date on which the samples were taken. This was probably due to seasonal changes in species composition and densities, and in environmental variables. This has been observed in previous studies (Boysen 1975, Hamerlynck & Mees 1991, Beyst et al. 2001, Richoux et al. 2004). These changes in species composition and densities could have occurred due to an increase in food availability and optimum environmental conditions, which might allow higher reproductive success during the summer.

SIMPER analysis, dominance values and the percentage of occurrence (50 ± 32%) suggest that the most influential, if not dominating, species was a mysid, *Archaeomysis grebnitzkii*, as seen in previous studies (Lock et al. 1999, Beyst et al. 2001, Dominguez Granda et al. 2004, Richoux et al. 2004, McLachlan & Brown 2006). *Archaeomysis grebnitzkii* dominates the surf-zone fauna probably due to several ecological factors, which not all other species exhibit. These factors could be (1) they are direct developers, as all peracarids, and therefore their juveniles recruit directly to the general population, (2) they can burry into the sediment to escape predation, and (3) they are able to maintain their position in the surf-zone by vertically and horizontally migrating. Finally, the dominance by *A. grebnitzkii* in the surf-zone water column fauna increased during the night, which was probably because this is the time when it feeds, most likely on planktonic and benthic harpacticoid copepods, as has been seen in previous studies (Takahashi & Kawaguchi 1998).

Sandy Beach Group

The data suggests that the species of this group are horizontally or vertically migrating during the night from deeper waters or from the sediment into the shallow surf-zone. They may be migrating to feed, mate, find a mate or moult, and they might be doing it at night to avoid visual predators as has been suggested by several previous works (Watkin 1939, 1941, Tully and Céidigh 1987, Mees & Jones 1997, MacLachlan & Brown 2006). Time of day influence was independently observed on *Archaeomysis grebnitzki, Lissocrangon stylirostris, Atylus tridens, Hartmanodes hartmanae* and *Eohaustorius washingtonianus.* The increase in densities of these five species was probably the cause of the reduced diversity and evenness during the night.

Archaeomysis grebnitzkii dominated the fauna at night in both the benthic and surf-zone water column fauna (Mees & Jones 1997, McLachlan & Brown 2006). During the day, *A. grebnitzkii* was found in the water column at higher densities in the bottom net than in the top net and during spring tides than neap tides. During the day, this species could have been maintaining its position in the sediment or right above it while at night it was migrating up into the shallow surf-zone water column. Similar temporal changes in distribution have been observed in two intertidal mysids, *A. kokuboi and A. japonica* (Takahashi & Kawaguchi 1997, 1998). These migrations allow these two species to escape predation during the day by burrowing into the sediment and to feed at night on planktonic and benthic copepods when visual predators are not as effective. Therefore, *A. grebnitzkii* could be migrating for similar reasons.

The significantly higher densities of *Lissocrangon stylirostris* at night and during the day in the bottom net in the water column suggests that this species is maintaining its position on the bottom or very close to it during the day and vertically migrating into the shallow water column during the night, as has been shown in other crangonid shrimp (Lock et al 1999, Dominguez Granda 2001, Mees & Jones 1997, Beyst et al. 2002, McLachlan & Brown 2006). These migrations would allow *L. stylirostris* to escape predation during the day by burrowing into the sediment and to feed at night on *A. grebnitzkii* when visual predators are not as effective. *Archaeomysis grenitzkii* is known to be *L. stylirostris'* preferred food item (Chapter 4).

The significantly higher densities of *Eohaustorius washingtonianus* in the sediment compared to the water column, and during the night compared to the day in the water column, suggests this species is primarily benthic and is only briefly migrating into the water column during the night as has been observed in other species of this genera (Watkin 1939, 1941, Colman & Segrove 1955). These migrations could be taken for non-interactive functions such as feeding, mating, finding a mate or moulting (Tully and Céidigh 1987).

The densities *of Excirolana chiltoni* were significantly influenced by the time of day and the lunar tide at low tide. This was probably because during the night they are migrating into the surf zone water column to mate, find a mate or moult avoiding visual predators (Tully and Céidigh 1987). The higher densites found during spring night time could have been because spring tides are when extreme low tides occur, which could have concentrated individuals in the area. A similar mechanism of concentration has been suggested for other sandy beach isopods (Hough & Naylor 1992, Mees & Jones 1997, Lock et al. 1999, Dominguez Granda 2001, Dominguez Granda et al. 2004).

Atylus tridens was caught at significantly higher densities during the night, and at night it was caught in significantly higher densities with the bottom net. This may have occurred because this species may migrate horizontally from deeper waters into the shallow surf-zone during the night maintaining a position close to the seabed possibly to feed, mate, find a mate or moult as has been suggested for species of this and other amphipod genera (Watkin 1941, Colman & Seagrove 1955, Tully and Céidigh 1987, Mees et al 1997, Lock et al. 1999, McLachlan & Brown 2006). The significantly higher densities caught during day spring tides could have been because individuals were pushed into the surf-zone by the significantly higher waves that occurred during these tides.

Planktonic Group

The diversity and evenness values of the planktonic group were influenced by both the lunar tide and the height of the waves. Wave height was also influenced by the lunar tides, with significantly larger waves present during spring tides. This suggests that more species were being transported to the surf-zone during spring tides when the waves were larger but they were unable to exit, as has been reported in the past (Colman & Segrove 1955, Beyst et al. 2001, McLachlan & Brown 2006). The fact that these species were unable to avoid their entrance and then to exit the surf-zone is probably because these species are not well adapted to living in surf-zones and therefore were unable to use rip currents to leave the zone. Tully and Céidigh (1987) categorized this migration due to wave energy as catastrophic drift.

Rocky/Macrophyte Group

Densities of this group were significantly higher during the night and the species richness was positively correlated with the abundance of detached macrophytes. The higher densities observed at night could have been caused by the migration of several species from the rocky intertidal into the surf-zone for non-interactive or interactive functions (Tully and Céidigh 1987), while being protected from visual predators (Colman & Segrove 1955, Tully and Céidigh 1987, McLachlan & Brown 2006). Possible non-interactive functions are feeding, searching for mates, mating or moulting, while possible interactive functions are crowding, interference, predation and deterioration of habitat quality (Tully and Céidigh 1987). The most abundant species was *Jassa shawi.* The species of this genus are considered tube dwellers of hard substrates (Chapman 2007), however this species was found in every date sampled. This suggests that this species moves into the surf-zone of sandy beaches during the summer to search for non-interactive or interactive functions (Tully and Céidigh 1987), as has been shown for this and other amphipod genera (Watkin 1941, Colman & Segrove 1955, Lock et al. 1999). The positive correlation between detached macrophytes and species richness suggests that certain species were transported on drift algae (Rudy Jr & Rudy 1983, Tully and Céidigh 1987, Chapman 2007). Either because they “clinged to” drift algae after being dragged into the water column or were on macrophytes that became detached. Further support for this suggestion is given by the fact that several of these species (e.g. *Idotea fewkesi, Exosphaeroma amplicauda, Caprella incisa, Caprella verrucosa, Caprella equilibra, Metacaprella anomala, Ampithoe lacertosa, Stenothoides burkanki*) can be found on or feed on macrophytes (Carlton 2007).

Development Stage Group

During spring tides the diversity and evenness of this group increased. These values could have increased because during spring tides we observed significantly larger waves and larger tides. This could have allowed seawater to reach adult, larvae or egg individuals of species present in the rocky intertidal that are usually above the high tide line pulling them off the rocks and/or pushing individuals into the surf-zone. An example of this is *Littorina plena*, whose reproduction is enhanced during the summer months (Rickets et al. 1985, Rudy Jr. & Rudy 1983, Strathmann 1987).

Crangonidae sp. zoea occurred in significantly higher densities during spring tides, at night, and in bottom net samples during the day. This species could have been maintaining its position on or close to the bottom during the day and horizontally and/or vertically migrating into the shallow water column at night. These migrations by crangonid shrimp have been suggested to increase survival, feeding or reproductive success (Lock et al 1999, Dominguez Granda 2001, Mees & Jones 1997, Beyst et al. 2002, McLachlan & Brown 2006).

Crangonidae sp. zoea was influenced by similar factors as *Lissocrangon stylirostris.* On coastal Oregon only *L. stylirostris* is common in surf-zone of sandy beaches (Carlton 2007) and was the only adult crangon species present in our samples, this lead us to hypothesize Crangonidae sp. and *L. stylirostris* are the same species. However, because the larval forms of this species have not been described, no further conclusion could be reached.

Larval densities of the ghost shrimp, *Neotrypaea californiensis,* were significantly higher in the spring day samples and were significantly correlated with salinity. The densities could have been significantly higher only during the day because the day samples were only taken during June and July, the primary reproductive months for this species (McCrow 1971, Johnson & Gonor 1982, Ricketts et al. 1985, Puls 2002). *Neotrypaea californiensis* zoea appeared for the first time in our study on 06/30, which agrees with previous findings that noted highest larval densities during the middle of the summer (McCrow 1971, Johnson & Gonor 1982, Puls 2002). The spring day tides could have increased its densities because higher waves can push larvae closer to shore or because of an increase in flushing rates out of the estuary due to lower low tides. The presence of *N. californiensis* zoea 1 and 2 only at Bastendorff and the negative correlation between their densities and salinity was probably because Bastendorff is located immediately south of the Coos river mouth and during the summer the estuarine plume is usually directed towards the south. *Neotrypaea californiensis* zoea 1 and 2 were therefore probably being exported in the estuarine plume mostly at ebb tide when the plume presents its lowest salinity values (McCrow 1971, Johnson & Gonor 1982, Puls

2002). The distribution of the *N. californiensis* larvae is presently unclear. The fact that the other zoeal stages were present when the salinity was higher along with the absence of these stages in estuaries or offshore (Johnson & Gonor 1982, Puls 2002, Shanks and Dumbauld, personal communication) suggests that these stages maintain themselves close to shore, closer to shore than previously assumed by Johnson & Gonor (1982) and suggested by McCrow (1971). It is likely that *N. californiensis* larvae use the surf-zone as a nursery area before recruiting back to the estuary, as do other thalasinideans (Forbes 1978).

Finally, the positive correlation between *Mytilus* sp. and detached macrophytes may be due to the fact that the juvenile mussels were attached to the macrophytes when the macrophytes were torn off the substrate. The fact that the majority of the juvenile mussels were attached to macrophytes during sample analysis further supports this. Sandy beaches would appear to be a sink for juvenile mussels.

The sandy beach surf-zone fauna present at dissipative beaches of southern Oregon is composed of species with a wide variety of ecologies and whose densities vary temporally and spatially. Most species found have not previously been reported as inhabitants of the sandy beach, some of which could have been transported in drift macrophytes. However, the presence of several of these species throughout the summer suggests that they inhabit the sandy beach during certain periods of time. The sandy beach was the only group that was not influenced by wave height, detached macrophytes or lunar tides, suggesting the species of this group are the only ones not affected by the size of the waves or the flushing rates that may affect the surf-zone. The fauna was dominated by the mysid *Archaeomysis grebnitzkii*, particularly at night. Of the 13 sandy beach species only four, *Archaeomysis grebnitzkii*, *Lissocrangon stylirostris* (as adult and as zoea), *Eohaustorius washingtonianus* and *Atylus tridens* can be considered hyperbenthic species. Finally, several species (i.e. *Neotrypaea californiensis, Lophopanoepus bellus*, Crangonidae sp. zoea) were present during one or more of its developmental stages throughout the summer suggesting that some species use the surf-zone as a nursery or as a transient area

Bridge I

Chapter II revealed that the sandy beach small surf zone fauna present at dissipative beaches of southern Oregon is composed of species with a wide variety of ecologies and whose densities vary temporally and spatially. Most species found have not previously been reported as inhabitants of the sandy beach, some of which could have been transported in drift macrophytes. However, the presence of several of these species throughout the summer suggests that they inhabit the sandy beach during certain periods of time. The sandy beach was the only group that was not influenced by wave height, detached macrophytes or lunar tides, suggesting the species of this group are the only ones not affected by the size of the waves or the flushing rates that may affect the surf zone. The fauna was dominated by the mysid *Archaeomysis grebnitzkii*, particularly at night. Of the 13 sandy beach species only four, *Archaeomysis grebnitzkii, Lissocrangon stylirostris* (as adult and as zoea)*, Eohaustorius washingtonianus* and *Atylus tridens* can be considered hyperbenthic species. Finally, several species (i.e. *Neotrypaea californiensis, Lophopanoepus bellus*, Crangonidae sp. zoea) were present during one or more of its developmental stages throughout the summer suggesting that some species use the surf zone as a nursery or as a transient area. Chapter III attempts to describe the community present in three dissipative exposed flat sandy beaches, analyze the temporal and environmental factors that influence the community, and describe the feeding preferences of the fish species present.

CHAPTER III

THE ECOLOGY OF SURF-ZONE FISH AND MACROCRUSTACEANS OF DISSIPATIVE SANDY BEACHES IN SOUTHERN OREGON, U.S.A.

Introduction

The swimming macrofauna community present in the surf zone of exposed sandy beaches is well studied in several parts of the world, including Belgium, Brazil, The Netherlands, and South Africa (McLachlan & Brown 2006). These studies have found the surf zone to be inhabited by a diverse community comprised mostly of shrimp-like species of macrocrustaceans (e.g. prawns and other shrimp) and fish > 5 mm in length (Beyst et al. 2001a, 2002a, 2002b, McLachlan & Brown 2006). Surf-zone fish are mostly larvae and juveniles, which are using the surf zone as a nursery or as migratory path to other nurseries (Beyst et al. 1999, 2002a, Barreiros et al. 2004, Silva et al. 2004, Crawley et al. 2006, McLachlan & Brown 2006). Adult fish, mostly flatfish, also inhabit the surf zone (McLachlan & Brown 2006). Most of these fish feed on benthic organisms and zooplankton, and are characterized by having highly variable abundance in space and time apparently due to opportunistic feeding (McLachlan & Brown 2006). Some studies have also suggested that surf-zone fishes depend on mysid crustaceans as food (Inoue et al. 2005).

The physical characteristics of the beach (beach slope, exposure), temporal factors (seasons, tides, lunar tides, time of day) and environmental variables (temperature, salinity, turbidity, wave height, wind speed and direction, abundance of detached macrophytes, and density of potential prey) have all been shown to influence the surf-zone environment and the swimming macrofauna community (Clark et al. 1996, Hindell et al. 2000, Beyst et al. 2001a, 2002a, 2002b, Crawley et al. 2006, McLachlan & Brown 2006). Beaches are categorized by the level of exposure (protected to exposed beaches), the way the energy of waves is released or dissipated (reflective to dissipative beaches), and the beach slope (steep to flat beaches) (McLachlan 1980, Short & Wright 1983, McLachlan & Dorvlo 2005).

Despite the fact that more than two-thirds of the Oregon coastline is sandy beach (ODFW 2006), very little work has been done on the surf-zone swimming macrofauna community. Several studies have been conducted on important individual species that inhabit the area, such as English sole, Pacific sardine, Northern anchovy, Surf smelt, and Dungeness crab (Emmett et al. 1991), but no studies have addressed the entire community. This is the first attempt to describe the entire community and analyze factors that may influence it. This study (1) describes the community present in three dissipative exposed flat sandy beaches, (2) analyzes the temporal and environmental factors that influence the community, and (3) describes the feeding preferences of the fish species present.

Materials and Methods

Study Area

The study was conducted on three sandy beaches, Bastendorff Beach (43°35’N, 124°35’W), Whisky Run Beach (43°18’N, 124°40’W) and Horsfall Beach (43°27’N, 124°16’W), all of which are located in Southern Oregon, U.S.A (Fig. 1). Bastendorff is a semi-exposed dissipative beach located immediately south of the mouth of Coos Bay. Whisky Run and Horsfall Beach are exposed dissipative beaches located approximately 15 km south and north of Coos Bay, respectively. Dissipative beaches are flat beaches in which the wave energy is dissipated in the surf zone rather than reflected from the beach face (McLachlan 1980b, Masselink & Short 1993). Additional details of the study sites are given in Chapter 1.

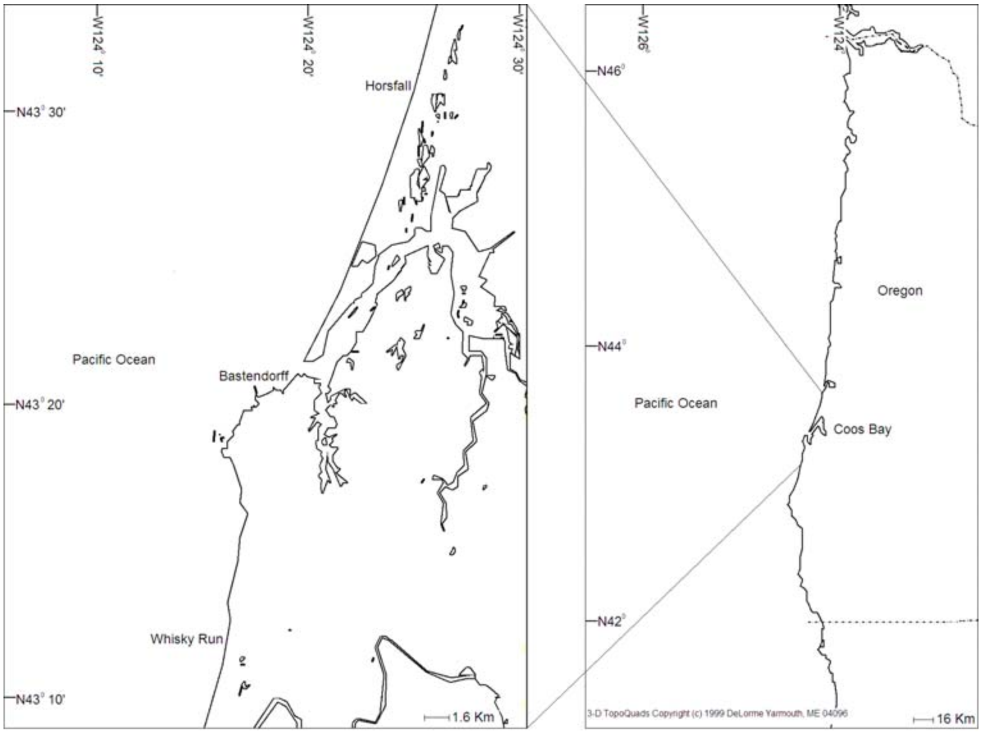

Figure 1. Study area with location of the three dissipative sandy beaches sampled in southern Oregon during the summer of 2006.

Environmental Variables

Temperature, salinity, chlorophyll *a* (Chl-a) and optical back scatter (OBS) data were obtained with a Sea Bird 911-Conductivity-Temperature-Depth recorder (CTD). The CTD was carried into the surf zone and held at approximately one meter depth for two minutes. The dry weight of detached macrophytes was obtained by separating the detached macrophytes in the hyperbenthic sledge tows done for Chapter 1. Wind wave height and wind speed were obtained from NOAA Station 46015, which is located 26 nautical Km West of Port Orford, OR (42°45'24"N, 124°49'45"W). Temperature, salinity, Chl-a, OBS and weight of detached macrophytes were only available for eight of the 17 sampling dates (Table 1).

Biological Sampling

Samples were taken on 17 dates throughout the summer of 2006, 14 at Bastendorff Beach, one at Horsfall Beach and two at Whisky Run Beach. Samples at Bastendorff were taken during the three tides (high, mid and low), the two lunar tides (spring and neap) and during both day and night (Table 1). Samples were collected using a beach seine (1.5 m high and 15 m wide with a 5.0 mm mesh). Three people carried the net at shoulder height into the surf zone to an approximate depth of 1 m where the shallow surf zone borders with the swash zone (McLachlan and Brown, 2006). The net was then opened parallel to shore and towed to the shoreline. This procedure was followed one to three times, with fewer tows being made when the surf was rough. The distance from the shoreline to the point at which the beach seine was first opened and the maximum depth of the water column were measured. The fish caught were anaesthetized with MS-222 (150 mg/liter of seawater) and the entire sample was preserved in 10% buffered formalin.

Table 1. Location and time of sampling during which the swimming macrofauna community of Southern Oregon was sampled during the summer of 2006. Density (individuals/1000 m^2), species richness (S), diversity, (H' – Shannon Index), evenness (J' – Pielou's function), dominance (d - Berger-Parker Index) are also presented. * = dates in which hyperbenthic sledge was used.

Timing of Sampling					Biological Values				
Beach	Date	Tide	Time	Lunar	Density	S	H'	J'	d
Bastendorff	6/7	HW	day	neap	53	5	1.06	0.66	0.50
Bastendorff	6/7	MW	day	neap	302	6	0.59	0.33	0.09
Bastendorff	6/7	LW	day	neap	118	5	1.43	0.89	0.35
Bastendorff	7/22	HW	day	spring	15	4	1.05	0.76	0.00
Bastendorff	7/22	MW	day	spring	5	2	0.41	0.59	0.86
Bastendorff	7/22	LW	day	spring	4	2	0.69	1.00	0.53
Bastendorff	7/27	HW	day	spring	40	6	1.06	0.59	0.59
Bastendorff	7/27	MW	day	spring	123	5	0.30	0.19	0.93
Bastendorff	7/27	LW	day	spring	131	7	0.64	0.33	0.86
Bastendorff	7/30	LW	night	neap	306	8	0.20	0.10	0.97
Bastendorff	8/2	LW	night	neap	198	6	0.17	0.10	0.97
Bastendorff	8/5	LW	day	spring	10	3	0.49	0.44	0.90
Bastendorff	8/9	LW	day	spring	5	3	1.08	0.98	0.29
Bastendorff	8/13	LW	night	spring	939	7	0.09	0.04	0.99
Bastendorff	8/18	LW	day	neap	314	6	0.16	0.09	0.01
Bastendorff	8/25	LW	day	spring	68	5	0.28	0.17	0.94
Bastendorff	9/1	LW	day	neap	42	6	1.07	0.60	0.51
Bastendorff	9/8	LW	day	spring	183	5	0.28	0.17	0.94
Bastendorff	9/15	LW	day	neap	24	4	1.01	0.73	0.56
Bastendorff	9/29	LW	day	neap	30	2	0.67	0.97	0.59
Horsefal	6/30	LW	day	neap	7	1	0.00	****	1.02
Whisky Run	7/1	LW	day	neap	6	2	0.56	0.81	0.71
Whisky Run	8/5	LW	day	neap	12	4	1.22	0.88	0.28

** Value was not possible to obtain.

Table 2. Mean biological values of the swimming macrofauna observed during different times of day, tides and lunar tides. Samples taken at Bastendorff Beach, a dissipative southern Oregon sandy beach in the summer of 2006. Mean densities of all individuals (individuals/1000 m^2), species richness, diversity, (Shannon Index), evenness (Pielou's function) and dominance (Berger-Parker Index) values of a surf-zone swimming macrofauna community (± S.D.).

	Density	Species Richness	Diversity	Evenness	Dominance
High tide	36±19	5±1	1.1±0.0	0.7±0.1	0.4±0.3
Mid tide	143±150	4.3±2.1	0.4±0.1	0.4±0.2	0.60.5
Low tide	169±246	4.9±1.9	0.6±0.4	0.5±0.4	0.7±0.3
Day	86±99	4.5±1.6	0.7±0.4	0.6±0.3	0.6±0.3
Night	481±400	7±1	0.2±0.1	0.1±0.0	1±0.0
Spring tide	151±284	4.6±1.8	0.6±0.4	0.5±0.4	0.7±0.3
Neap tide	140±128	5.1±1.7	0.7±0.4	0.5±0.3	0.5±0.3
Spring Day Low	78±79	4.4±1.9	0.6±0.3	0.5±0.4	0.7±0.3
Spring Night Low	939±0	7±0	0.1±0	0.0±0	1±0
Neap Day Low	90±116	4.3±1.6	0.8±0.3	0.6±0.3	0.5±0.3
Neap Night Low	252±76	7±1.4	0.2±0.0	0.1±0.0	1±0.0

Sample Analysis and Data Treatment

Organisms < five mm in length were considered too small to be swimming macrofaunal species and were eliminated from further analyses. In the laboratory, organisms were identified to species level whenever possible using Rudy Jr. & Rudy (1983), Kathman et al. (1986), Kozloff (1987), Smith & Carlton (1989), Brusca et al. (2001), and Shanks (2001). Densities, percentages, species richness (S), diversity (H'), evenness (J') and species dominance (d) were calculated. Densities (individuals/1000 m^2) were calculated using the total bottom area, which was calculated by multiplying the length of the tow and the length of the beach seine. We calculated the volume of water sampled by determining the slope, or the hypotenuse of a triangle, by using the depth and the length of the tow, then multiplying by the length of the seine. Species richness was measured from the number of species, and the Shannon index was used as a measurement of diversity (Ludwig & Reynolds 1988). Evenness among species was measured with Pielou's evenness function (J') (Pielou 1977). Finally, dominance, or the impact of dominant species, was analyzed with the Berger-Parker index (d) (Berger & Parker 1970). These values are presented with standard deviation (±) wherever ever possible.

Because of the large differences in the community composition and the number of samples among the three beaches, the community analysis was only conducted for Bastendorff. However, data obtained from the three beaches were used to correlate the biological values and environmental variables, and for different English sole analysis. We were not able to use a three-way ANOVA to analyze variances due to tides, lunar tides and time of day because we did not sample during all three tides at night. Instead, densities were compared among samples taken at different tides, day and night, and spring and neap tides using one-way ANOVAs. Pair-wise comparisons were conducted using Tukey's test. We tested for effects of lunar tide and time of day on densities using a partially nested mixed model two-way ANOVA, with lunar tides and time of day as the fixed factors. We were able to use two-way ANOVAs despite the fact that we sampled only once during the spring/night low tide because this was compensated by the fact that we did obtain replicates for spring/day low tide, neap/night low tide and neap/day low tide. However, because of the lack of spring/night low tide replicates we were not able to do any further statistical comparison. All of the assumptions for the analysis of variance were met, except for the homogeneity of variances. To meet this assumption, the data were $\log_{10}$ (x+1) transformed and then tested with an F max test. Because of difficulties meeting the assumptions for an analysis of variance, the four biological variables, S, H', J' and d, were compared among samples taken at different tides, day and night, and spring and neap tides using a non-parametric Kruskal-Wallis test. Five biological variables (Densities, S, H', J', d) were also correlated to temperature, salinity, chlorophyll a, optical back scatter, dry weight of detached macrophytes, wind wave height wind speed, Julian date on which each sample was taken and to the densities of potentially available food. Data on the potentially available food were obtained from Chapter 1, a study that sampled the smaller swimming fauna present in the surf zone of the three beaches at 50 cm of depth. These data were available for eight of the 16 sampling dates (Table 1). The five variables were correlated to the Julian date on which they were taken to analyze the effect of the advancement of the summer season. To analyze possible spatial or temporal patterns in the community data, a non-Parametric Multi-Dimensional Scaling (nMDS) and a Similarity Percentage Analysis (SIMPER) were performed. Prior to the analysis the data were $\log_{10}$ (x+1) transformed and the resemblance was obtained using the Bray Curtis Similarity Index. We used the PRIMER 6 statistical package (Clarke & Gorley 2001). Standard lengths (SL) of all the fish present were measured, and stomach contents identified to the finest taxonomical level possible. For English sole, daily growth rates were calculated, subtracting the mean S.L. of the last date in which the juveniles were caught from the mean S.L. of the first date in which the juveniles were caught and dividing this value by the number of days that separated the first and last date. The wet weight of each English sole food item was also recorded.

English Sole Stomach Content Analysis

The stomach content index (SCI) was calculated as an indicator of stomach fullness using the following equation:

$$SCI = \frac{SW}{BW} x100,$$

where SW is the wet weight (g) of the stomach contents and BW is the wet weight (g) of the fish (Takahashi et al. 1999). The percentage of empty stomachs was recorded but not used in the analysis. The stomach contents were identified to the finest taxonomic level possible using Kathman et al. (1986), Kozloff (1987), Smith & Carlton (1989), Brusca et al. (2001), Shanks (2001). The number of individuals, wet weight of each food item (g.), frequency of occurrence (%F), and numerical percentage (%N) were recorded. The frequency of occurrence (%F) of a diet component was the percentage of fish in a sample, which contained the component (Hynes 1950). These values were arcsin transformed to meet the homogeneity of variance assumption, which was tested using an F max test, and compared using a t-test. Finally, the selectivity in feeding was calculated using the Shorigin index (Berg 1979):

$$Sel. = \frac{\%N_i \ in \ the \ ingested \ food}{\%N_i \ in \ the \ potentially \ available \ food},$$

where Sel. is the feeding selectivity and $\%N_i$ is the numerical percentage of an item. This index was chosen because it is considered an accurate way to compare values obtained from different samples, it compares the ingested food items with the potentially available food at the sampling site and has been used extensively in previous studies (ISI Web of Science, 2007). The data for $\%N_i$ in the potentially available food were obtained from Chapter 1. This related study sampled the smaller swimming fauna present in the whole water column and was available for the first six sampling dates. These samples were taken using a hyperbenthic sledge. We used a hyperbenthic sledge because we consider it to be the best method available to sample the surf zone community due to the amount of seawater it filters per tow (Mees and Jones 1997). The sledge has a 50 x 70 cm mouth opening connected to a 4 m long net with 1 mm mesh. The sledge was hand towed parallel to the shoreline at approximately 50 cm of water depth for 400 m during high, mid and low tides, spring and neap tides and during the day and night. Because of how much time it takes to obtain a sample with the sledge, we considered it was impossible to take replicates, a conclusion also reached in previous works (Watkin 1941). Therefore the tows were made sufficiently long for them to account for possible variances in the fauna due to the different areas present in the surf zone of sandy beaches and to the patchy distribution that species may present (Mees & Jones 1997; Lock et al. 1999). The feeding selectivity values of the fish for the main food items were correlated with the Julian date on which the fish were caught. At the same time, the densities of the same main food item in the water column were correlated to the Julian date on which these prey were caught to observe possible variations in densities with time.

Results

The volume of water sampled with one beach seine tow varied from 451 to 461m^3. The area sampled with one beach seine tow varied from 694 to 708 m^2, of which a mean of 701 m^2 was used to determine density. A total of 2,059 individuals belonging to 19 species were caught (Table 1). These species belonged to Crustacea (5 spp.), Osteichthyes (10 spp.), Cnidaria (3 spp.), Ctenophora (1 sp.) and Cephalopoda (1 sp.). The brachyuran crab *Cancer magister* was present in the megalopal and adult stages, and were considered separate species from each other in the community analysis. The six species with highest frequency of occurrence were the crustaceans *Lissocrangon stylirostris* (71%) and *Emerita analoga* (1.32%), the cnidarian *Obelia sp*. (20.8%), the ctenophore *Pleurobrachia sp*. (1.9%) and the osteichthiens *Pleuronectes vetulus* (English sole) (2%) and *Oncorhynchus tshawytscha* (Chinook salmon) (1.3%). *Lissocrangon stylirostris* was the most abundant species throughout the sampling season with 1,463 individuals caught, or 84±191 ind. per 1000 m^2, and was present on all of the dates and beaches sampled. Because of this, *L. stylirostris* densities were employed to analyze dominance (d). Most of the *L. stylirostris* individuals caught were females (63%), and most individuals were parasitized by the bopariid isopod, *Argeia pugettensis* (62%). A more detailed analysis of *L. stylirostris* ecology can be found in Chapter 4.

Community Analysis

At Bastendorff during the three different tides no significant difference was observed in mean density, species richness, diversity, evenness or dominance values. However, higher density species richness and dominance values were found during low tides. Highest mean diversity and evenness were found during high tide. (Table 2). Density, evenness and dominance values were significantly higher at night than in the day ($n \geq 3$, $F \geq 5.54$, $p \leq 0.03$) (Table 2). At low tide, highest mean species richness and mean densities were observed during spring low tides at night. Highest mean diversity and evenness occurred during neap low tides in the day, and highest mean dominance occurred during neap low tides at night. There was a significant difference among densities in samples taken during spring daytime low tides, spring nighttime low tides, neap daytime low tides and neap nighttime low tides (two-way ANOVA, Table 2 and 3).

Table 3. Results of two-way ANOVA test for differences in surf-zone macrofauna densities at low tide. Fixed effects were time of day and lunar tides. Samples taken at Bastendorff, a dissipative sandy beach in southern Oregon.

	df Effect	MS Effect	df Error	MS Error	F	p-level
Lunar tide	1	122385.1	10	4901.26	24.97	0.001
Time of day	1	272620.7	10	4901.26	55.62	0.00002
Interaction	1	131281.1	10	4901.26	26.79	0.0004

At Horsfall and Whisky Run, because of the number of samples and because the samples were taken during the same tide, lunar tide and time of day, no statistical analysis was possible. However density, species richness and dominance values observed at both beaches were usually lower than the mean values observed at Bastendorff, while evenness and diversity were usually higher at Horsfall and Whisky Run. The higher densities but lower diversity and evenness could have been due to the higher densities presented by *Archaeomysis grebnitzkii* at Bastendorff, especially during the nighttime.

Biological and Environmental Variables

In correlation analyses among the five biological variables (Density, S, H', J', d) (Table 1) at the three beaches and the seven environmental variables, there were two positive correlations. Detached macrophytes had a positive correlation with densities of non-*L. stylirostris* species (n = 11, r = 0.63, p = 0.05) (Fig. 2) and the densities of the mysid, *Archaeomysis grebnitzkii* was positively correlated with *L. stylirostris* densities (n = 14, r = 0.59, p = 0.05) (Fig. 3).

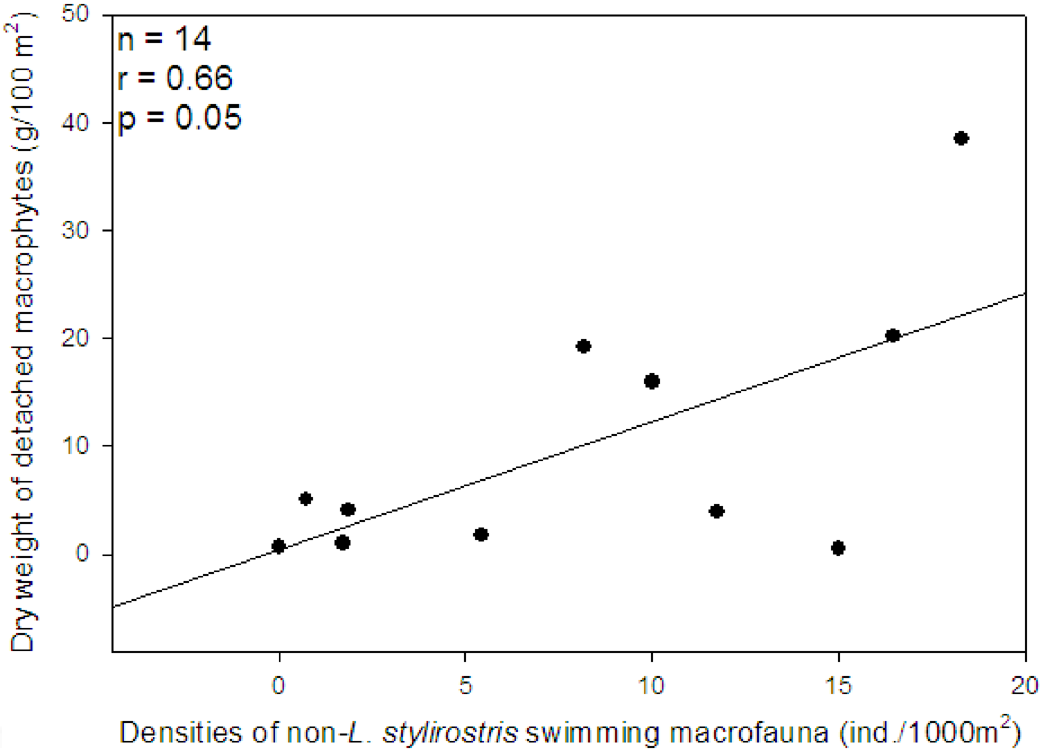

Figure 2. Positive correlation between the diversity (Shannon index, H') and total swimming macrofauna densities (individuals/1000 m^2) minus *Lissocrangon stylirostris* (N – *L. stylirostris*) with the weight of detached macrophytes (Macrophytes) present in three dissipative beaches of southern Oregon in the summer of 2006.

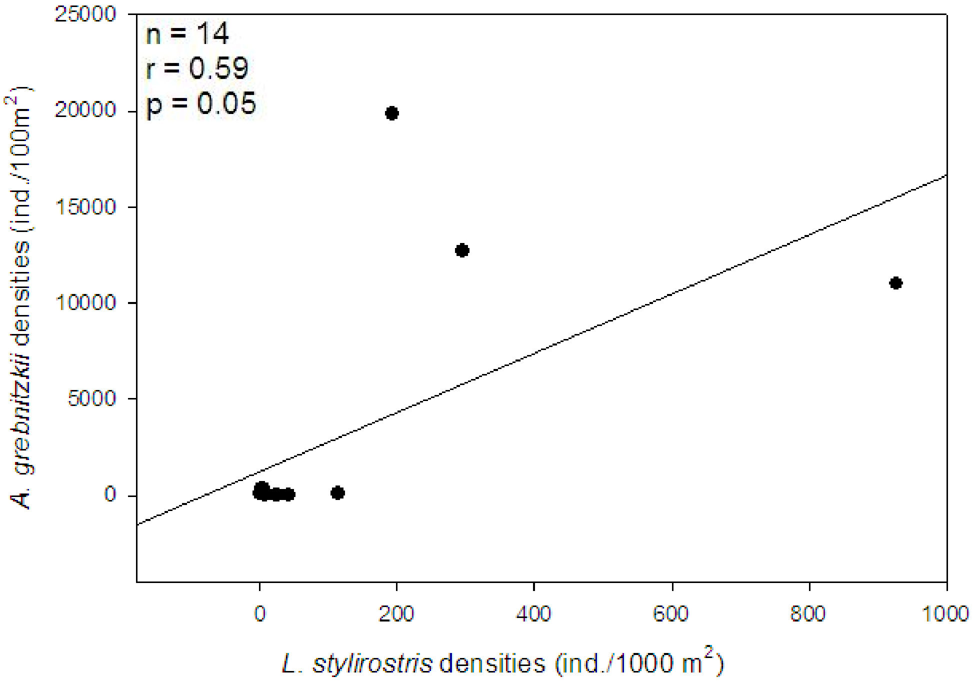

Figure 3. Positive linear correlation between *Lissocrangon stylirostris* densities (individuals/1000 m^3) and the densities of the mysid *Archaeomysis grebnitzkii* (ind. per 100 m^2) present at three dissipative southern Oregon beaches in the summer of 2006.\

Statistical Community Analysis

The nMDS showed no spatial or temporal pattern within the surf zone community at Bastendorff. The samples grouped instead into five clusters at a 45% similarity level, based on the density of *L. stylirostris* present (Fig. 4). The SIMPER analysis suggested each cluster had two to four species that influenced their similarity (Table 4), with *L. stylirostris* influencing four clusters, and *Pleurobrachia sp*. and English sole each influencing two clusters.

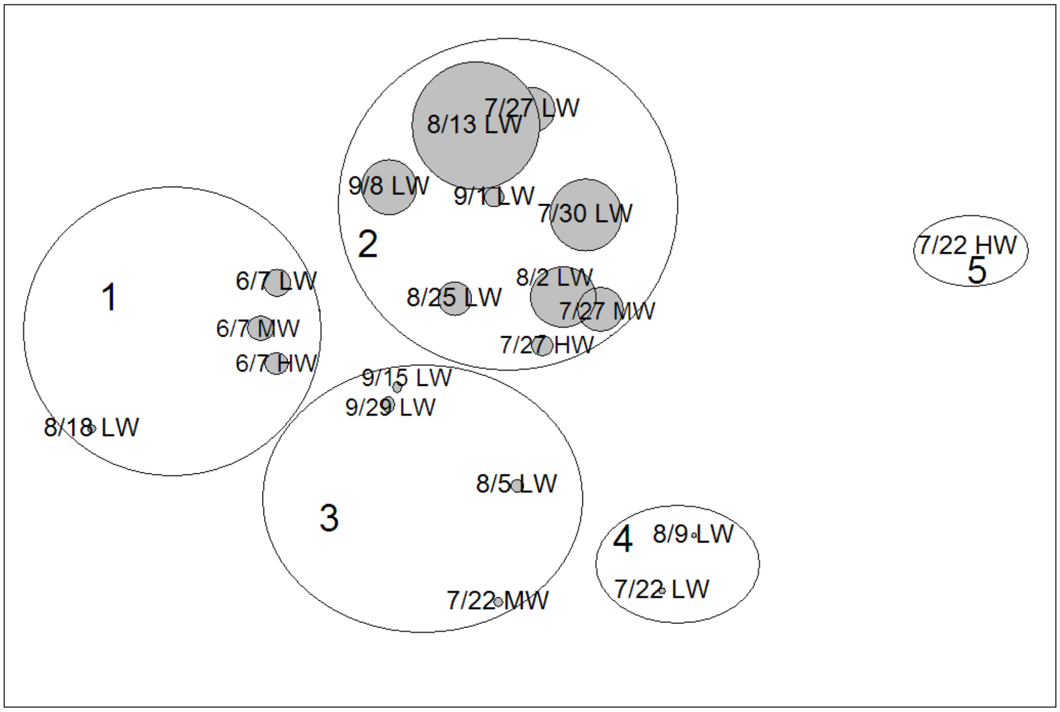

Figure 4. Non-parametric Multi-Dimensional Scaling of the surf-zone swimming macrofauna community present at a dissipative sandy beach in southern Oregon in the summer of 2006. Samples separated into five clusters based on the abundance of the smooth bay shrimp, *Lissocrangon stylirostris*. Bubble sizes are dependent on *L. stylirostris* densities. Resemblance levels for clusters are 45% and stress level is 0.14. Data were $\log_{10}$ (x+1) transformed and the resemblance values obtained with the Bray Curtis similarity index. Name of each sample represents date and tide at which they were taken. HW = high, MW = mid and LW = low tide.

Table 4. Similarity Percentage analysis (SIMPER) showing species contributing to similarity of each cluster formed by nMDS in Fig. 4. Five clusters were formed based on the abundance of the smooth bay shrimp, *Lissocrangon stylirostris*. Resemblance levels for clusters are 45% and stress level is 0.14. Data were previously $\log_{10}$ (x+1) transformed and the resemblance values obtained from the Bray Curtis similarity index.

Species/Cluster	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Lissocrangon stylirostris	45.85	75.39	84.42	43.07
Obelia sp.	29.14	0	10.66	0
Pleurobrachia sp.	11.94	0	0	0
Pleuronectes vetulus	10.79	7.8	0	0
Emerita analoga	0	0	0	56.93
Oncorhynchus tshawytscha	0	7.44	0	0

Cluster 5 is not present because there were fewer than two samples in the group.

English Sole

Forty-eight English sole were caught at Bastendorff on 13 dates and 13 were caught at Whisky Run on two dates. The fish were caught during high (5 ind.), mid (5 ind.) and low (51 ind.) tides, spring (19 ind.) and neap (42 ind.) tides, and day (57 ind.) and night (4 ind.). The individuals had standard lengths (SL) that ranged between 2.6 and 12.5 cm (Fig. 5).

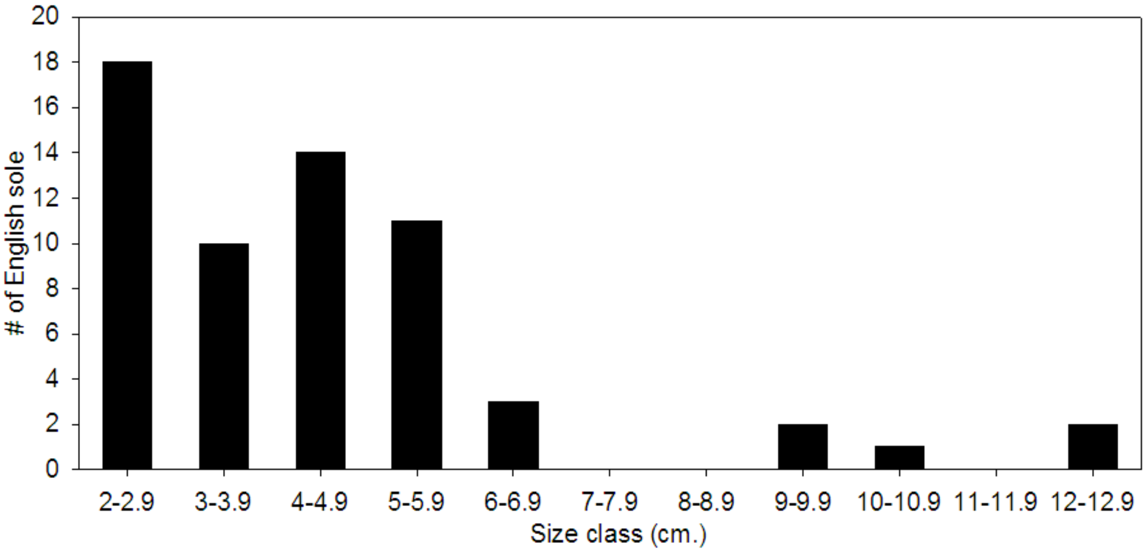

Figure 5. Size-frequency distribution of 61 juvenile English sole caught at two dissipative sandy beaches in southern Oregon in the summer of 2006.

A positive correlation was observed between the mean standard length of the youngest age fish and the Julian date at which they were sampled (Fig. 6) ($n = 7$, $r = 0.93$, $p = 0.05$), with a mean SL of 3±0.2 cm at the beginning of the summer season and 5.4±0.5 cm at the end of the summer, 92 days later (± S.D.). The difference in SL between the first and last Julian date was 2.4 cm, suggesting a growth rate of 0.25 mm per day. Five individuals were excluded from this analysis due to their much larger size (9 – 12.5 cm), which suggested they belonged to an older age group (Fig. 5).

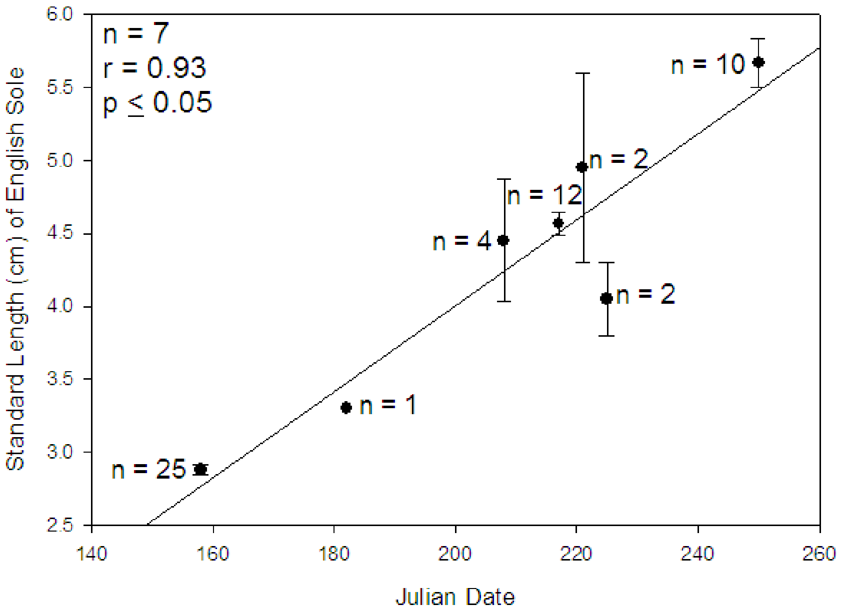

Figure 6. Mean standard lengths of English sole (± S.D) correlated to the Julian date on which they were caught. Samples taken in the surf-zone of two dissipative sandy beaches in southern Oregon during the summer of 2006.

Twenty of the 61 juvenile English sole had empty stomachs and only 28 of the remaining 41 had recognizable food items. These juvenile English sole had preyed on 11 different species of crustaceans. During the three night samples, four juveniles were caught, none of which had empty stomachs. During the 14 day samples, 57 juveniles were caught of which 20 had empty stomachs. The most frequent food item during all sampling dates was the mysid *Archaeomysis grebnitzkii*. The %F (76.95 ± 33.19) and %N (51.92±30.80) of *A. grebnitzkii* was significantly higher than any other food item in all samples (t-test, $p < 0.001$). However, the largest English sole individuals ($n = 2$, SL=12.3 – 12.5 cm) preyed mostly on *L. stylirostris* (%F=100±0, %N=75±53.03). The other species present in % N higher than one were the amphipods *Atylus tridens, Jassa sp* and *Dogielinotus loquax.*

Due to a lack of data on the potentially available food, the Selectivity Index was only possible to calculate for six of the 12 sample dates on which English sole were caught. The Index values varied from 27.9 to 312.4. Feeding selectivity of English sole decreased as the season progressed.

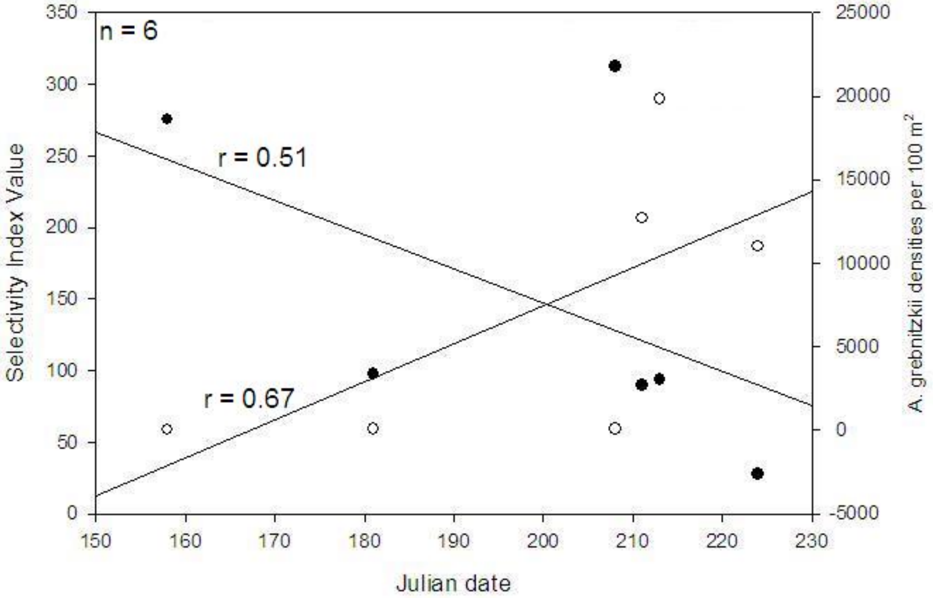

Figure 7. Linear correlations between Julian date towards both the feeding selectivity of English sole (Shorigin index, Berg 1979, closed circles), and the densities of *Archaeomysis grebnitzkii* (ind./100 m^2, open circles). Samples taken in the surf-zone of three dissipative southern Oregon sandy beaches in the summer of 2006.

The densities of the mysid *A. grebnitzkii* increased with season progression (Fig. 7), suggesting the decrease in selectivity is due to an increase in *A. grebnitzkii*. However, the correlations between Julian date with both feeding selectivity values and *A.*

grebnitzkii densities did not meet the critical values for correlations (n = 6, r = 0.51 & 0.67, respectively, p > 0.05).

Other Fish Present

Besides English Sole, juvenile Chinook salmon (see Chapter 3), *Sardinops sagax* (Pacific Sardine), *Hyperprosopon ellipticum* (Silver surfperch) *Amphistichus rhodoterus* (Red tail surfperch), *Leptocottus armatus* (Pacific staghorn sculpin), *Thaleichthys pacificus* (Eulachon smelt), *Hypomesus pretiosus* (Surf smelt), and *Engraulis mordax* (Northern anchovy) were caught at the three beaches (Table 5). These fishes mostly fed on crustaceans, particularly the mysid *A. grebnitzkii* and several species of amphipods and isopods.

Table 5. Fish species present in the swimming macrofauna community, number of dates on which each species was caught, total fish caught (#), mean standard length (SL), main prey items and frequency of occurrence (in parentheses) are shown. Samples were taken at Bastendorff and Whisky Run, sandy beaches in Southern Oregon during the summer of 2006.

Species	Dates	#	SL	Main Prey (%)
Sardinops sagax	2	2	12.5	Chaetognaths (25), Copepods (25), Sand (50)
*Hyperpro*sopon ellipticum	2	3	8	Gammarid Amphipods (57), *Excirolana kincaidii* (14), Cumaceans (7), Insects (7), N.I. Org. (14)
Amphistichus rhodoterus	2	2	12.6	*A. grebnitzkii* (100)
Leptocottus armatus	3	6	12.1	*L. stylirostris* (54), *E. analoga* (31), *A. grebnitzkii* (8), Gammarid Amphipod (7)
Thaleichthys pacificus	1	1	8.8	*A. grebnitzkii* (100)
Hypomesus pretiosus	2	2	10.65	Empty
Engraulis mordax	1	1	4	*

** Individuals in which stomach content analysis was not possible.*

Discussion

Community Analysis

Despite the seemingly harsh hydrodynamic conditions, the shallow surf-zones of these Oregon sandy beaches were used intensively throughout the summer by a number of macrocrustaceans and juvenile fishes. The density and species richness values found at these beaches are lower than those found in other parts of the world (Beyst et al. 2001a, Beyst et al. 2002a, Beyst et al. 2002b, Barreiros et al. 2004, McLachlan & Brown 2006). However, these previous studies were of sandy beaches that were less exposed, located in different latitudes, or the studies were done in deeper waters, used a different sampling methodology or effort; factors, which may significantly alter comparisons between sites (Beyst et al. 2001a). McLachlan & Brown (2006) have suggested species richness of the surf zone macrofauna in temperate regions should be approximately 27 species. This study found a total species richness of 19 in the three dissipative exposed to semi-exposed sandy beaches. The exposure of the three studied beaches, the fact that only the shallow surf-zone was sampled, the size of the beach seine and the number of tows done in this study could account for the lower densities and species richness found. The possibility that the characteristics of the beach and methodology can account for the lower density and species richness values is supported by the fact that only one species of flatfish, English sole, was caught in our samples. Flat fish are common on sandy beaches around the world, and at least seven species are present in shallow soft bottom environments in the Pacific Northwest (Lamb & Edgell 1986, Gibson 2005).

Though not significant, there was a tendency for densities to be higher at low tide then at mid and high tide. Higher densities were most obvious during spring tides when extreme low tides occur. Higher values at low tide could have been due to an aggregation of individuals during low tide because of the reduced size of the surf-zone. Several authors have previously observed low tide aggregation (McLachlan 1980b, Hindell et al. 2000, Beyst et al 2002a, Dominguez Granda 2001, Dominguez Granda et al. 2004).

Lissocrangon stylirostris dominated the swimming macrofauna throughout the summer of 2006, especially during low tides. The dominance by *L. stylirostris* was indicated by the high density and dominance values observed throughout the season, and by the nMDS and SIMPER analysis. *L. stylirostris* was the only recognizable resident species during the summer and has been reported to inhabit the sediment and water column of high-energy sandy beaches, particularly semiprotected beaches (Schmitt 1921, Kuris et al. 1977). The term residency is usually applied to species that inhabit an area during a complete period (Mees & Jones 1997). Dominance of the surf-zone swimming macrofauna by a crangonid shrimp has been reported at other temperate beaches (Beyst et al. 2001, Beyst et al. 2002a, Beyst et al. 2002b). Because of this dominance and the fact that only the shrimp were present in every sample taken, the aggregation and position maintenance of the swimming macrofauna at low tide can only be accounted for *L. stylirostris.*

Using only low tide samples, statistically higher densities of organisms were caught at night than in the day, most of which were *L. stylirostris*. This higher abundance could be due to a vertical migration of the shrimp from the sediment into the shallow water column at night. This migration could be done to feed on the mysid, *Archaoemysis grebnitzkii* their preferred food (Chapter 4) whose densities are highest during low tide at night (Chapter 1). Feeding at night by *L. stylirostris* could also be due to the lower effectiveness of visual predators on shrimp (i.e. sea birds and fish) at night. Vertical migration at night and aggregation at low tide could also explain the significantly higher densities observed during spring low tide night samples, since this is when extreme low tides occur. The influence of lunar tides and light intensity on swimming macrofauna communities has been reported in previous studies (Hindell et al. 2000, Beyst et al. 2001a, Beyst et al. 2002a). The shrimp could therefore be vertically migrating at night to feed on *A. grebnitzkii.*

Biological and Environmental Variables

The positive correlation between the densities of non-shrimp and the weight of detached macrophytes suggests several species, especially fish species, could be attracted to the detached macrophytes in the surf-zone. This attraction could be because these species feed on organisms (i.e. amphipods and isopods) on the detached macrophytes or use the macrophytes as a refuge. This has been observed in previous studies (Hindell et al. 2000, Crawley et al. 2006). *L. stylirostris* densities were independent of macrophyte density perhaps because in the water column the shrimp seek refuge in the sand during the day and feed at night. Non-shrimp species are attracted to the macrophytes in the surf-zone of sandy beaches possibly to feed or to use it as refuge.

English Sole

The presence of English Sole in the surf-zone of sandy beaches did not follow any temporal pattern. At Bastendorff, individuals were caught at high, mid and low tides, spring and neap tides, and during the day and night. Their small size (< 26 cm) suggests that all were one-year juveniles (Harry 1959 in Emmett et al. 1991). English sole were also present in the two samples taken at Whisky Run, a sandy beach 15 km from the nearest estuary; juvenile English sole can be in the surf-zone of sandy beaches that are not immediately next to an estuary. This agrees with previous studies (Gunderson et al. 1990, Emmett et al. 1991). The English sole caught in this study had standard lengths between 26 to 56 mm and 90 to 125 mm. At an approximate length of 55 mm, most juvenile English sole migrate into estuaries and then migrate back to the coast when they are 75-80 mm (Gunderson et al. 1990). The mean standard length of the smaller English sole size classes (26 to 56 mm) increased in size by an average of 0.25 mm per day while residing in the surf-zone. However, this is based on the assumption that the species were present in the surf zone during the whole season. While residing in the surf-zone, the fish were feeding selectively on *A. grebnitzkii*. Juveniles have been previously reported to feed on mysids (Simenstad et al. 1979, Allen 1982, Hogue & Carey 1982, Becker 1984, Bottom et al. 1984). Small juveniles in estuaries (<50 – 65 mm in length) feed primarily on harpacticoid copepods (Toole 1980). Finally, we also observed that the fish had been feeding during the night, which contrasts with previous studies (Allen 1982, Hulberg & Oliver 1979). However the small night sample sizes weakens this suggestion (n = 4).

Most of the fish caught (98%) in this study were juveniles (Emmett et al. 1991, Love 1996, Pruden 2000). Despite the low densities in which we caught several species of juvenile fish, the surf-zone could be acting as a nursery due to the percentage of the Oregon coastline that are sandy beaches (ODFW 2006). This could result in sandy beach surf-zones contributing in higher proportion to the production if individuals that recruit to adult populations than any other environment, a characteristic that is considered primary when defining nursery areas (Beck et al. 2001). The use of the surf-zone of sandy beaches as a nursery has been observed in previous studies (Beyst et al. 2001a, Beyst et al. 2002a, Barreiros et al. 2004, Silva et al. 2004, McLachlan & Brown 2006). Five of the eight fish species, in which stomach content analysis was possible, had fed on the mysid *A. grebnitzkii*. Three fish species had *A. grebnitzkii* as a main prey item, suggesting surf-zone fishes do in fact depend greatly on the presence and abundance of mysid crustaceans as food (Inoue et al. 2005). The surf-zone of sandy beaches is used by several species of fish as a nursery, and most of them feed on the mysid *Archaeomysis grebnitzkii*.

The surf-zone swimming macrofauna present at the sampled dissipative beaches of Southern Oregon was composed of 19 species belonging to six groups. The density of organisms was influenced by the time of day and lunar tides. The shrimp *Lissocrangon stylirostris* numerically dominated the community and was the only species for which residency could be accounted for during the summer season. The density of the non-*L. stylirostris* fauna increased with the increase of detached macrophytes. English sole appear to utilize the surf-zone during several periods of their first year of life where they primarily feed on the mysid *Archaeomysis grebnitzkii*. Most of the other fish in the surf-zone were juveniles, which use the area as a nursery and also feed on the mysid *Archaeomysis grebnitzkii*.

Bridge II

Chapter III revealed that the surf zone swimming macrofauna present at the sampled dissipative beaches of Southern Oregon was composed of 19 species belonging to six groups. The density of organisms was influenced by the time of day and lunar tides. The shrimp, *Lissocrangon stylirostris*, numerically dominated the community and was the only species for which residency could be accounted for during the summer season. The density of the non-*L. stylirostris* fauna increased with the increase of detached macrophytes. English sole appear to utilize the surf zone during several periods of their first year of life where they primarily feed on the mysid *Archaeomysis grebnitzkii*. Most of the other fish in the surf zone were juveniles, which use the area as a nursery and also feed on the mysid *Archaeomysis grebnitzkii*. Chapter IV documented the surf zone macrofauna, during the summer of 2006 in a sandy beach and estimated the time of residency and the feeding habits of sub-yearling Chinook salmon.

CHAPTER III

NEW HABITAT OF SUB-YEARLING CHINOOK SALMON DISCOVERED: THE SURF-ZONE OF A SANDY BEACH

Introduction

There is very little information on the habitat of juvenile Chinook that have recently entered the ocean (Fisher and Pearcy 1995). “Ocean-type Chinook” are those that migrate to sea in their first year of life, and during that first year they are referred to as “sub-yearlings”. Healey (1983) noted ocean-type Chinook salmon had a predominantly coastal distribution throughout their ocean-life. Because of this, he hypothesized that many, if not most, ocean-type Chinook spend their first ocean year in sheltered inside waters, or very close to shore. Later, Dawley et al. (1981), Fisher and Pearcy (1995) and Brodeur et al. (2004) suggested a similar hypothesis. This hypothesis has been partially tested in several studies (Dawley et al. 1981; Miller et al. 1983; Fisher et al. 1983, 1984; Fisher and Pearcy 1995), however these studies were done with scientific vessels with standard techniques (e.g. purse seines and otter trawls) at depths over 4 m (Healey 1991) leaving a large portion of the waters close to shore, including the surf-zone of sandy beaches, unsampled.

Many sub-yearling Chinook leave the estuary during the early summer with standard lengths (S.L.) between 7-8.5 cm (Reimers 1973; Healey 1983; Gray et al. 2002;

Bottom et al. 2005). In the ocean (>1 nautical Km), significant numbers of sub-yearling Chinook are not caught until the fish reach sizes of 12 cm S.L. (Peterson et al. 1982; Fisher and Pearcy 1995, Schabesberger et al. 2003; Brodeur et al. 2004). This leaves a period of time (from approximately 8 to 12 cm) during which the habitat of sub-yearlings is unknown. Dawley et al. (1981) caught large numbers of small fish in shallow marine waters near the surf-zone (4 m depth), 95% of which were sub-yearling Chinook (< 13 cm Fork Length, F.L.). Based on this, Miller et al. (1983) concluded that offshore movement of Chinook salmon is size dependent, beginning when the fish are about 13 cm F.L.

The large general decline of salmon (*Oncorhynchus spp.*) populations, including Chinook salmon, throughout the Pacific Northwest (Nehlsen et al. 199; Ruggerone and Goetz 2004), has led to several Chinook runs being placed on the threatened species list under the U.S. Endangered Species Act (National Marine Fisheries Service 1999). This has caused closures of fisheries in several locations. Despite several tests of the distribution hypothesis for sub-yearling Chinook, very few studies have been conducted close to shore and none in the surf-zone of sandy beaches. This study could provide insight on the habitat of sub-yearling Chinook that have just entered the ocean, which is a missing link in their life cycle. This in turn could allow a better management of the fishery by protecting this species in the surf-zone of sandy beaches from indiscriminate line and seine fishing. Therefore, this study documented the surf-zone macrofauna during the summer of 2006 in a sandy beach. The study also estimated the time of residency and the feeding habits of sub-yearling Chinook salmon.

Materials and Methods

Study Site

The study was conducted at Bastendorff Beach (43°35’N, 124°35’W), immediately south of the mouth of Coos Bay in southern Oregon, U.S.A (Fig. 1). Bastendorff is a 3-Km-long semi-exposed dissipative sandy beach bordered by a rocky shore on the south and a rock jetty at the mouth of the Coos estuary to the north. Dissipative beaches are flat beaches in which the wave energy is dissipated in the surf-zone rather than reflected from the beach face (McLachlan 1980; Masselink and Short 1993; McLachlan and Brown 2006). Additional details of the study site are given in Chapter 1.

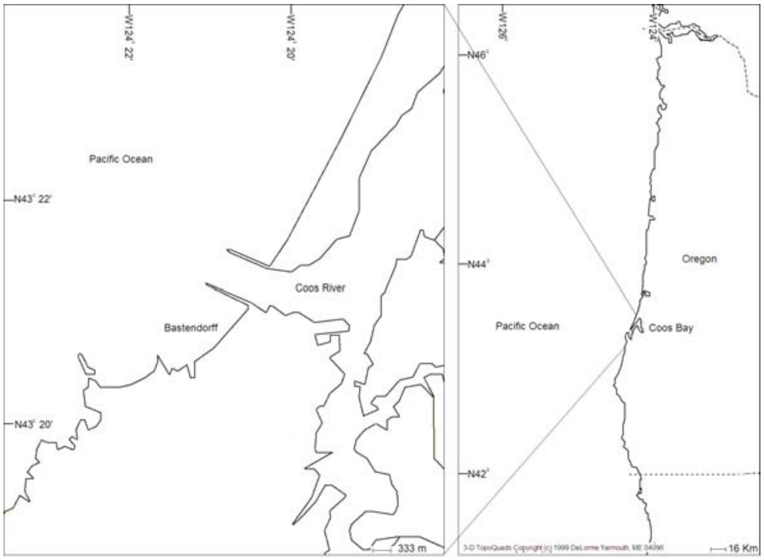

Figure 1. Study area with location of Bastendorff, the dissipative sandy beach sampled in Southern Oregon during the summer of 2006.

Sampling

Samples were taken on 14 dates throughout the summer of 2006 with a 1.5 m high x 15 m wide beach seine with a 5.0 mm mesh. Three people carried the net at shoulder height out into the surf-zone to approximately 1 m depth where the shallow surf-zone borders with the swash zone (McLachlan and Brown, 2006). The net was opened parallel to the shoreline and pulled onto the beach. This procedure was followed one to three times, with fewer tows made when the surf was rough. The distance from the shoreline to where the beach seine was first opened and the maximum depth of the water column were measured. The fish caught were anaesthetized with MS-222 (150 mg/liter of seawater) and the sample was preserved in 10% buffered formalin with the exception of the juvenile Chinook salmon caught on the last 11 sampling dates, which were frozen.

Sample and Data Analysis

In the laboratory, organisms were identified to species whenever possible using Kathman et al. (1986), Kozloff (1987), Smith and Carlton (1989), Brusca et al. (2001), and Shanks (2001). Densities and concentrations are presented as individuals per 1000 m^2 and m^3, respectively. Density (ind./1000 m^2) and concentration (ind./1000 m^3) were calculated using the total area and volume sampled. Area was calculated by multiplying the length of the tow and the length of the beach seine. We calculated the volume of water sampled by determining the slope, or the hypotenuse of a triangle, by using the depth and the length of the tow, then multiplying by the length of the seine. Standard length (SL) of each juvenile Chinook salmon was measured. Differences in monthly mean SL were analyzed with a student's t – test. Data were $\log_{10}$ (x+1) transformed to meet the assumptions of homogeneity of variance, which was the only assumption violated, and which was tested using an F max test. Mean daily growth rates were estimated subtracting the mean S.L. of the last date in which the juveniles were caught with the mean S.L. of the first date in which the juveniles were caught and dividing this value by the number of days that separated the first and last date.

Stomach Content Analysis

The stomach contents of juveniles were identified and weighed for each individual. The stomach content index (SCI) was calculated as an indicator of stomach fullness using the following equation:

$$SCI = \frac{SW}{BW} x100,$$

where SW is the wet weight (g) of the stomach contents and BW is the wet weight (g) of the body of the fish (Takahashi et al. 1999). Since none of the juveniles had an empty stomach, they were all included in the following analysis. The stomach contents were identified to species whenever possible and were analyzed using a Non Parametric Multi-Dimensional Scaling (nMDS) and a Similarity Percentage Analysis (SIMPER) to observe possible changes in the diet composition over time. Prior to the analysis the data were $\log_{10}$ (x+1) transformed and the similarity values necessary to use an nMDS were obtained using the Bray-Curtis Index. We used the PRIMER 6 statistical package (Clarke and Gorley 2001). The stomach content data were also analyzed by comparing the variety and type of prey items with the size of the juvenile fish. The frequency of occurrence, number of individuals, and wet weight of each food item was measured. Finally, the selectivity in natural feeding behavior was calculated using the Shorigin index (Berg 1979), which is as follows:

$$Sel. = \frac{\%N_i \text{ in the ingested food}}{\%N_i \text{ in the potentially available food}},$$

where Sel. is the feeding selectivity and $\%N_i$ is the numerical percentage of an item. This index was chosen because it is considered an accurate way to compare values obtained from different samples, it compares the ingested food items with the potentially available food at the sampling site and has been used extensively in previous studies (ISI Web of Science, 2007). The data for $\%N_i$ in the potentially available food were obtained from Chapter 1. This related study sampled the smaller swimming fauna present in the whole water column and was available for the first six sampling dates. These samples were taken using a hyperbenthic sledge. We used a hyperbenthic sledge because we consider it to be the best method available to sample the surf-zone community due to the amount of seawater it filters per tow (Mees and Jones 1997). The sledge has a 50 x 70 cm mouth opening connected to a 4 m long net with 1 mm mesh. The sledge was hand towed parallel to the shoreline at approximately 50 cm of water depth for 400 m during high, mid and low tides, spring and neap tides and during the day and night. Because of how much time it takes to obtain a sample with the sledge, we considered it was impossible to take replicates, a conclusion also reached in previous works (Watkin 1941). Therefore the tows were made sufficiently long for them to account for possible variances in the fauna due to the different areas present in the surf-zone of sandy beaches and to the patchy distribution that species may present (Mees & Jones 1997; Lock et al. 1999).

Results

A total of 2,017 individuals belonging to 17 species present in 5 different groups were identified from the samples collected with the beach seine (Cnidaria, Ctenophora, Crustacea, Cephalopoda, Osteichthyes). Some species were present in more than one developmental stage. More detail of the accompanying macrofauna can be found in Chapter 2. The area and volume of water sampled with one beach seine tow varied from 694 to 708 m^2 and from 451 to 461 m^3, of which a mean of 701 m^2 and 456 m^3 was used to determine density and concentration.

Forty-eight juvenile Chinook salmon (*Oncorhynchus tshawytscha*) were caught in six of the 14 sampling dates, 07/22, 07/27, 08/02, 08/13, 08/25 and 09/01 (Table 1). Based on the analysis of length and age data from previous studies, the 48 juveniles were categorized as sub-yearling Chinook (Fisher J., Oregon State University, personal communication, based on unpublished data). Individuals were caught in samples taken during the high, mid and low tide, spring and neap tides, and day and night (Table 1). However, we found larger probabilities of capturing juveniles at high (2 of 3 samples or 66.6% of the samples) or mid tide (2 of 3 or 66.6%) than at low tide (5 of 14 or 35.7%); during spring tide (7 of 10 or 70%) than during neap tide (2 of 10 or 20%); and during the night (2 of 3 or 66.6%) than during the day (7 of 17 or 41.2%).

Table 1. Dates on which we sampled for sub-yearling Chinook in the surf-zone of a sandy beach. Table details the sampling date, tide, lunar tide (Lunar), Salmon caught (Salmon) are presented as density (Dens. ind./1000 m^2) and concentration (Conc. ind./1000 m^3, mean standard length of the salmon (S.L.), wet stomach content index (SCI), and mean number of individuals in stomach content (# of prey). All tides = Low (LW), Mid and High tide were sampled. Values presented as means ± S. D.

Time of Sampling				Salmon		SL	SCI	# prey
Date	Tides	Time	Lunar	Dens.	Conc.			
6/7	All	day	neap	0	0	-	-	-
7/22	All	day	spring	3.1	4.8	9.05±0.61	2.1±1.55	18±7.52
7/27	All	day	spring	2.0	3.1	10.69±0.44	2.04±0.84	23.57±10.21
7/30	LW	night	neap	0.0	0.0	-	-	-
8/2	LW	night	neap	0.7	1.1	11.7±0	3.33±0	9±0
8/5	LW	day	spring	0.0	0.0	-	-	-
8/9	LW	day	spring	0.0	0.0	-	-	-
8/13	LW	night	spring	2.9	4.4	12.25±1.06	4.55±0.75	11.5±7.78
8/18	LW	day	neap	0.0	0.0	-	-	-
8/25	LW	day	spring	1.4	2.2	10.2±0.99	4.17±0.95	33±29.7
9/1	LW	day	neap	15.0	23.0	11.55±0.73	5.20±1.89	46.04±34.06
9/8	LW	day	spring	0.0	0.0	-	-	-
9/15	LW	day	neap	0.0	0.0	-	-	-
9/29	LW	day	neap	0.0	0.0	-	-	-

The standard length of the juveniles varied from 8.5 to 12.5 cm. The monthly mean S.L. (± S.D.) increased from 9.6±0.9 cm in July, to 11.3±1.3 in August, and to 11.5±0.7 in September. The mean daily growth rate was of 0.6 mm. A t – test demonstrated significant difference between July and August (n = 25, t = 4.28, p = 0.01) or September (n = 43, t = 1.28, p = 0.001) but not between August and September (n = 28, t = 0.68, p = 0.53).

A total of 29 different prey items and a mean of 4.4±1.9 prey items per fish were identified in the stomach contents of the juveniles (Table 1). The majority of these prey items were amphipods (69%) (Table 2). According to Chapter 1 all the prey items were present in the surf-zone water when the juveniles were sampled. The mean SCI varied from 2.1 on 07/22 to 5.2 on 09/01 (Table 1). The mean SCI for the day (3.4±1.6) and night samples (3.9±0.9) were not significantly different.

Table 2. Frequency of occurrence (%F) and selectivity index (Sel) of the 11 most common prey species present in the stomachs of 48 sub-yearling Chinook salmon sampled in the surf-zone of a sandy beach in Southern Oregon. Selectivity index was not possible to obtain on the last two dates of sampling.

	Date									
	7/22		7/27		8/2		8/13		8/25	9/1
Species	%F	Sel	%F	Sel	%F	Sel	%F	Sel	%F	%F
Jassa shawi	76.9	15.4	100.0	8.6	0.0	0.0	0.0	0.0	100	52.2
Atylus trindens	23.1	0.7	71.4	0.4	0.0	0.0	50	6.0	100	73.9
Archaeomysis grebnitzkii	46.2	0.1	0.0	0.0	0.0	0.0	50	0.3	0.0	60.9
Dogielinotus loquax	84.6	12.3	57.1	1.5	0.0	0.0	0.0	0.0	0.0	17.4
Insects	84.6	80.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.7
Engraulis mordax	0.0	0.0	0.0	0.0	0.0	0.0	50	0.0	0.0	39.1
Excirolana kincaidi	46.2	4.3	0.0	0.0	0.0	0.0	50	31.2	50	8.7
Lophopanopeus bellus	15.4	1.3	14.3	1.8	100	999.0	0.0	0.0	0.0	21.7
Cancer oregenesis/productus	23.1	0.0	14.3	0.0	100	697.7	0.0	0.0	0.0	4.3
Lycaeopsis themistoides	15.4	3.9	14.3	2.7	0.0	0.0	50	0.0	50	4.3
Euphausia pacifica	7.7	0.0	0.0	0.0	0.0	0.0	100	0.0	0.0	0.0

Statistical analysis (nMDS) separated the 48 stomach contents into seven different clusters at a similarity level of 37% and a stress level of 0.15 (Fig. 2). The first five clusters were each a representative of the stomach contents obtained during a particular date. The other two clusters were representative of the contents from 09/01.

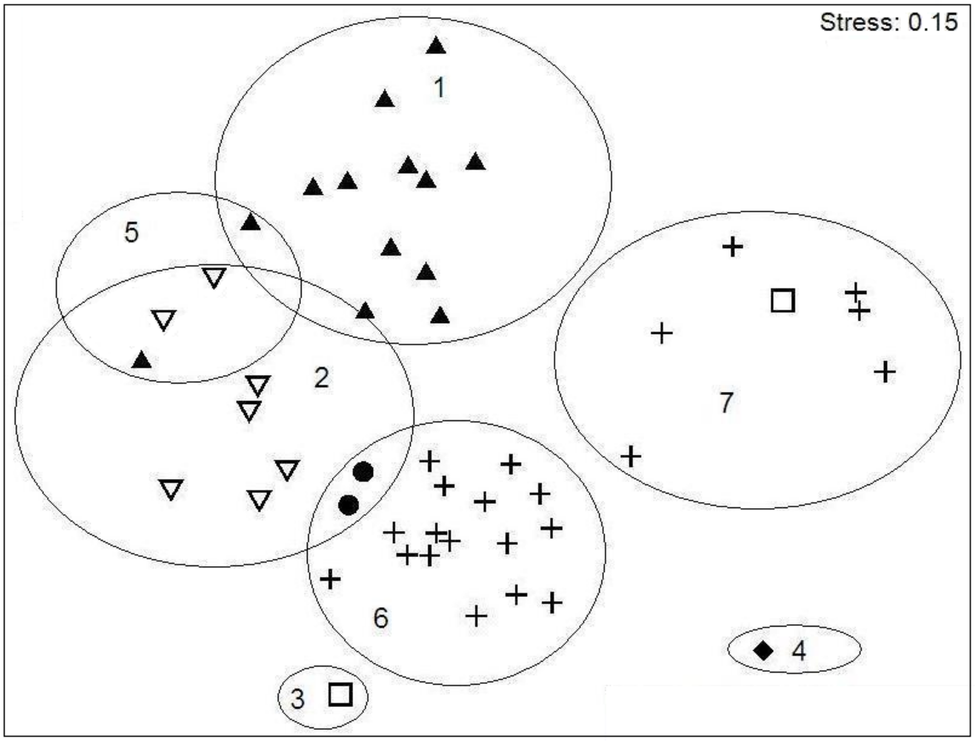

Figure 2. Non Parametric Multi-Dimensional Scaling of 48 Chinook salmon stomach contents sampled in the surf-zone of a sandy beach in Southern Oregon on the summer of 2006. Samples separated into seven clusters by date. Similarity levels for clusters are 37%. Dates: 7/22 (filled triangles), 7/27 (open triangles), 8/2 (open squares), 8/13 (filled diamonds), 8/25 (closed circles), 09/1 (plus signs). Data were previously $\log_{10}(x+1)$ transformed and resemblance values obtained using the Bray Curtis similarity index.

SIMPER analysis indicated that different prey items contributed to the similarity of each cluster, which implies that the main prey items were different for each date

(Table 3). SIMPER analysis also indicated that stomach contents obtained on 09/01 separated into 2 clusters because certain juveniles fed mainly on a gammaridean amphipod (*Atylus tridens)* while others fed mainly on northern anchovy juveniles (*Engraulis mordax*). The standard lengths of the individuals feeding on juvenile anchovy (Cluster 7) were usually larger than those feeding on amphipods (Cluster 6).

A negative correlation was observed between the species richness of the 48 juveniles' stomach contents and their standard length (n = 48, r =0.44, p=0.05), indicating that the variety of prey items decreased as the standard length of the juveniles increased (Fig. 3).

Table 3. Similarity Percentage Analysis (SIMPER) showing the prey items contributing to similarity of each cluster formed by nMDS presented in Fig. 2.

Species	Cluster 1	Cluster 2	Cluster 5	Cluster 6	Cluster 7
Dogielinotus loquax	33.6	7.2	0.0	0.0	0.0
Insect	29.8	0.0	0.0	0.0	0.0
Jassa shawi	12.2	63.9	100.0	10.0	0.0
Gammaridea sp	8.6	0.0	0.0	0.0	0.0
Archeomysis grebnitzkii	5.0	0.0	0.0	14.6	0.0
Megalorchestia pugettensis	4.1	0.0	0.0	0.0	0.0
Atylus tridens	0.0	14.9	0.0	68.9	0.0
Caprella incisa	0.0	10.3	0.0	0.0	0.0
Northern Anchovy Juv.	0.0	0.0	0.0	0.0	98.7

Clusters 3 and 4 not presented because there was less than two samples in group.

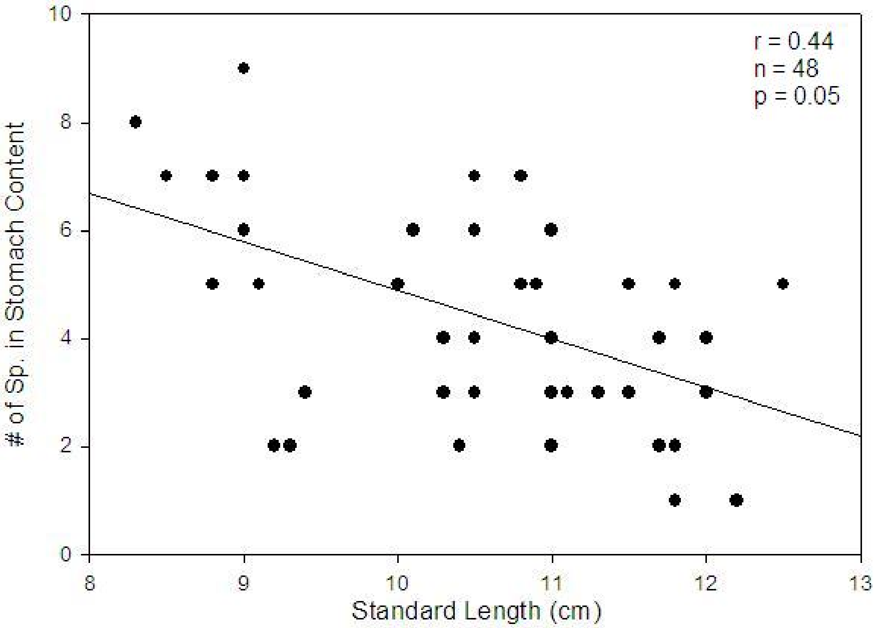

Figure 3. Species Richness of the stomach contents of 48 sub-yearling Chinook salmon correlated to standard length. Juveniles were sampled in the surf-zone of a sandy beach in Southern Oregon.

A comparison of the percentage of invertebrate and fish prey items chosen by juvenile Chinook salmon from different size classes also indicated that the fish shifted their diet from invertebrates towards fish as their standard length increased (Fig. 4). This shift was gradual from 100% invertebrate prey items when the fish had a mean S.L. around 8 cm to 50% invertebrate (mostly amphipods) and 50% juvenile and larval fish prey items when the fish had an approximate mean S.L. of 12 cm. The dietary shift began when the fish measured between 11 and 11.5 cm in mean S.L.

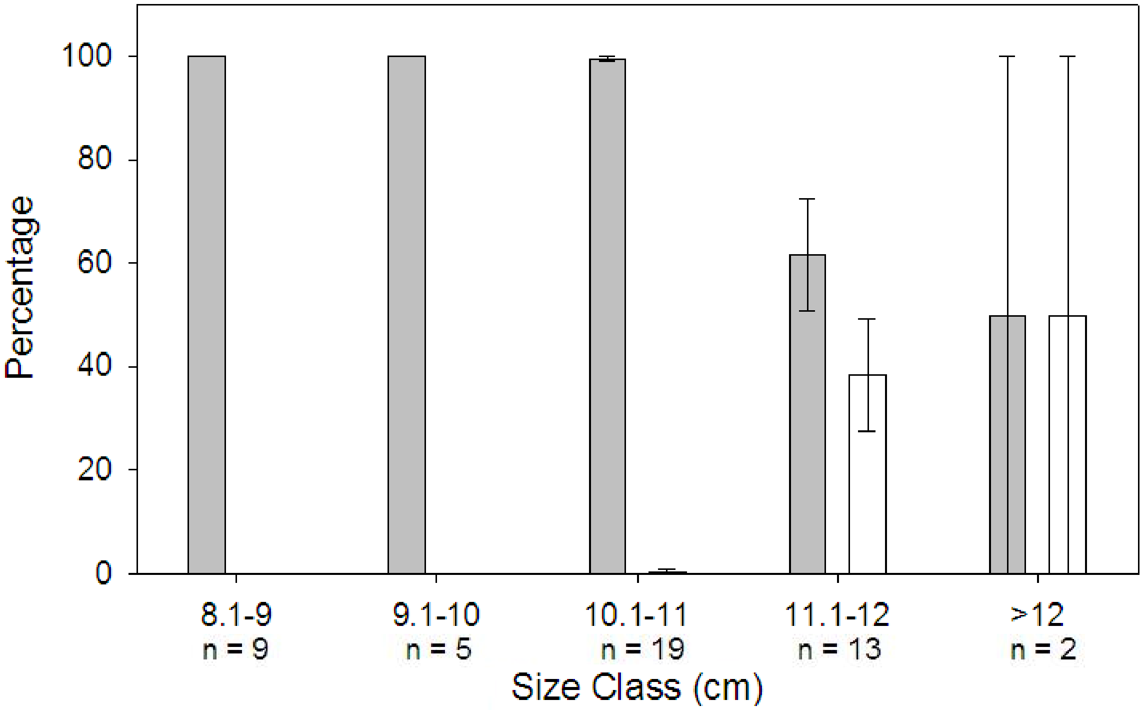

Figure 4. Mean Percentage (± S. E.) of invertebrate (filled bars) and fish prey (open bars) items found in the stomach contents of 48 sub-yearling Chinook salmon caught in the surf-zone of a sandy beach compared to their size class (cm). Samples taken at a dissipative sandy beach of southern Oregon during the summer of 2006.

The frequency of occurrence (%F) and numerical percentage (%N) of the 48 stomach contents indicated that there were seven main food items: three gammarid amphipods (*A. tridens, Jassa shawi* and *Dogielinotus loquax*), a mysid (*Archaeomysis grebnitzkii*), an isopod (*Excirolana kincaidi*), the megalopae of a brachyuran crab (*Lophopanopeus bellus*), and an osteicthyen juvenile (*E. mordax*) (Table 2). However, %N and %F of each date indicated that the importance of these 6 prey items varied with the date and that on 08/02, 08/13 and 08/25 there were other prey items that were as or more important. Due to a lack of data on potentially available food, feeding selectivity analysis was only possible for the first 4 dates in which Chinook was caught. The analysis indicated that selectivity for the main three prey items (*Jassa shawi*, Insects and *D. loquax)* in 07/22 was high. The selectivity value decreased on 07/27 with three different main prey items (*Jassa shawi, A. tridens, D. loquax*). The values obtained in 08/02 showed a large increase in the selectivity of the two new main prey items (megalopae of *Cancer orogenensis/productus and L. bellus*). Finally, 08/13 showed the lowest feeding selectivity of all with three different main prey items (*A. grebnitzkii, Euphausia pacifica and E. mordax*) (Table 2).

Discussion

The presence of sub-yearling Chinook salmon in the surf-zone of a sandy beach supports the distribution hypothesis, which stated that the juveniles spend their first ocean year in sheltered nearshore waters, or very close to shore. . Sub-yearling Chinook leave the estuary in large concentrations measuring 7-8.5 cm S.L. (Reimers 1973; Healey 1983; Gray et al. 2002; Bottom et al. 2005). Such large concentrations are only caught again offshore (>1 nautical Km) when the juveniles reach sizes > 12 cm S.L. (Peterson et al. 1982; Schabesberger et al. 2003; Brodeur et al. 2004). The mean increase of 2.5 cm in the mean standard lengths of Chinook salmon from July to September, the fact that the fish were caught at high, mid and low tide, day and night and during spring and neap tides, and the presence of all the prey items in the surf-zone water column when the juveniles were sampled strongly suggests that juveniles with standard lengths between 8 to 12.5 cm resided in the surf-zone of Bastendorff through out the summer of 2006. This agrees with

Dawley et al. (1981) that found large numbers of fish < 130 cm F.L. in shallow marine waters near the surf-zone (< 4 m).

Based on Healey's (1983) distribution hypothesis and considering the substantial percentage of the total natural mortality during the first months of marine life in juvenile salmon due to environmental conditions, competition and predation (Parker 1968; Mathews and Buckley 1976; Bax 1983; Allen and Hassler 1986; Furnell and Brett 1986; Fisher and Pearcy 1983; Brodeur et al. 1992; Pearcy 1992), their presence in the surf-zones of sandy beaches is reasonable and surprising at the same time, considering the harsh hydrodynamic conditions and the shallowness of the zone. This zone could offer the juveniles shelter from fish or bird predation, an abundant food supply of invertebrates (insects and crustaceans) and other young fish, and low rates of competition, all of which could increase their survival rate. On beaches close to large estuaries the surf zone could also provide low-salinity water masses that have been shown to attract juvenile fish that have just entered the ocean (Fisher and Pearcy 1995). If the juveniles were present, the surf-zone, a zone impossible to sample by standard techniques off scientific vessels, could be a nursery for sub-yearlings that have just entered the ocean. Despite the low densities in which we caught several species of juvenile fish, the surf-zone could be acting as a nursery due to the percentage of the Oregon coastline that are sandy beaches (ODFW 2006). This could result in sandy beach surf-zones contributing in higher proportion to the production if individuals that recruit to adult populations than any other environment, a characteristic that is considered primary when defining nursery areas (Beck et al. 2001). The use of the surf-zone of sandy beaches as a nursery has been observed in previous studies (Beyst et al. 2001a, Beyst et al. 2002a, Barreiros et al. 2004, Silva et al. 2004, McLachlan & Brown 2006). Bastendorff's surf-zone may have been used as a nursery habitat because of the following characteristics. Potential fish predators in the surf-zone of sandy beaches are ospreys, grebes, cormorants and harbor seals (Hodder J., personnal communication). However, during the summer of 2006, only osprey, *Pandion haliaetus,* was observed feeding on fish at Bastendorff. According to Chapter 1 there was a mean of 4,078 possible prey individuals per $100m^2$ (1 to 5 mm in length). The potential prey included mysids, amphipods, isopods, larval and juvenile fish, various crab megalopae and euphausids. These are large and/or highly pigmented animals, prey characteristics that are known to be preferred by juvenile salmon (Peterson et al., 1982, Brodeur, 1989, 1991, Schabetsberger et al., 2003). There were only six species of fish and two species of macrocrustaceans that could have competed with the salmonids for food. Five of these fish were present in lower concentrations than Chinook and in four species, fewer five individuals were caught in total. Finally, fewer than five individuals of macrocrustacean species were caught throughout the summer of 2006 at Bastendorff (Chapter 2). During the summer of 2006, the surf-zone presented salinity values between 29.5 and 33.8, some of which are considered low for oceanic waters ($\geq$ 33), and which could attract juveniles to the surf-zone and aid them in acclimating to full saline oceanic waters, a process that has been known to produce stress and death in juvenile salmonids (Fagerlund et al. 1995).

Like previous studies, our SCI results led us to hypothesize that the fish fed during day (Schabetsberger et al., 2003) and night (Bradford and Higgins, 2001).

However, unlike previous studies, our results also lead us to hypothesize that the juveniles were feeding at similar intensities during the day and night; however, few salmon were caught at night. The results also suggest that fish consumed more as the season progressed and they increased in size.

The statistical analysis suggests that the fish fed opportunistically (2 dates) and selectively (2 dates). The opportunistic behavior was observed on 07/27 and 08/13, when the choice of prey items was proportional to the availability of the prey. This feeding behavior was not observed on 07/22 and 08/02, in which the selectivity values were high. On 07/22 the fish preyed mainly on insects and on the amphipods *Jassa shawi* and *Dogielinotus loquax*. During their residence time in the estuary, juvenile salmonids commonly feed on insects and amphipods (Shreffler et al. 1992; Miller and Simenstad 1997; Gray et al., 2002), suggesting the surf-zone juveniles were feeding on known prey. On 08/02 the fish mainly preyed on *Lophopanopeus bellus* and *Cancer orogenensis/productus*. The high selectivity values observed during this date could have been due to the number of fish caught and to the dominance of the mysid *Archaeomysis grebnitzkii* on the sample (Chapter 1), which greatly reduced the frequency distribution of all the other species present.

Finally, correlation of the size classes of juvenile salmon and number of prey items consumed suggests that as they grew larger they were preying on a smaller variety of prey items. This could have been because the larger fish were selecting larger prey, which was less common in the surf-zone of Bastendorff (Chapter 1). The comparison of the percentage of invertebrate or fish prey items by size classes suggests there was an ontogenetic shift in their diet from invertebrates to larval and juvenile fish. Both changes, a lower variety of prey items and an ontogenetic shift to fish, have been observed in previous offshore studies (Peterson et al., 1982; Brodeur, 1991; Keeley and Grant, 2001; Schabetsberger et al., 2003). Juveniles may leave the surf-zone at the end of the summer when their diet shifts to juvenile fish.

This study presents the first evidence that ocean-type sub-yearling Chinook salmon inhabit the surf-zone of sandy beaches. During the summer, juvenile Chinook increased in size by two centimeters and appeared to feed opportunistically during both the day and night on a large variety of prey items present in the surf-zone. Larger juvenile Chinook in the surf-zone preyed more intensively on a smaller variety of prey items, and shifted their diet towards larval juvenile fish.

Bridge III

Chapter IV presented the first evidence that ocean-type sub-yearling Chinook salmon inhabite the surf zone of sandy beaches. During the summer, juvenile Chinook increased in size by two centimeters and appeared to feed opportunistically during both the day and night on a large variety of prey items present in the surf zone. Larger juvenile Chinook in the surf zone preyed more intensively on a smaller variety of prey items, and shifted their diet towards larval juvenile fish. Chapter V attempted to describe the *L. stylirostris* population present at a dissipative sandy beach in southern Oregon and the environmental variables that influence it, identify the preferred prey items, analyze variation of the sexual composition of the population to gain insight into the sexual system employed by the species, and observe differences between parasitized and non-parasitized individuals.

CHAPTER IV

THE POPULATION ECOLOGY OF THE SMOOTH BAY SHRIMP, *LISSOCRANGON STYLIROSTRIS* (DECAPODA, CRANGONIDAE), AT A DISSIPATIVE SANDY BEACH IN SOUTHERN OREGON, WITH NOTES ON THE OCCURRENCE AND BIOLOGY OF ITS PARASITE, *ARGEIA PUGETTENSIS* (ISOPODA, BOPYRIDAE)

Introduction

The smooth bay shrimp, *Lissocrangon stylirostris*, ranges from Chirikof Island, Alaska, to San Luis Obispo, California (Jensen, 1995). It is common in the surf-zone of high-energy sandy beaches and subtidally on sand or rock down to 80 m. (Jensen, 1995). While the adult shrimp are thought to be limited to cool, high salinity water (Hieb, 1999), studies suggest this and other crangonid species use the estuary as a nursery (Krygier 1974, Hoeman, 1982). The reproductive population is concentrated in the nearshore coastal habitats (Hieb, 1999), and is mostly composed of females that are often larger in size than males (Hoeman, 1982). Population size has been observed to vary with seasons, tides and time of day (Hoeman, 1982; Chapter 2)

Crangonid shrimp exhibit several sexual systems. Many crangonid species are considered gonochoristic, but there are also many species that exhibit protandric hermaphroditism. Several different types of protandry are known to occur among the crangonids. *Notocrangon antarcticus* is considered a simple protandrous hermaphrodite in which all adult individuals reproduce first as males and later as females (Pfeffer, 1887 in Correa and Thiel, 2003). *Crangon franciscorum* (Gavio et al., 2006) and *Crangon crangon* (Linnaeus, 1758 from Gavio et al., 2006) exhibit "protandry with primary females" also referred to as "partial protandric hermaphroditism with primary females" in which individuals are either primary females (they reproduce as females throughout their life) or protandric hermaphrodites (they reproduce first as males and later as secondary females) (Gavio et al., 2006; Linnaeus, 1758 from Gavio et al., 2006). At the age of first reproduction some members of an age group are females and the rest males (Bauer, 2000; Correa and Thiel, 2003; Gavio et al., 2006). *Crangon crangon* is also considered a facultative protandric hermaprodite; they have the capability but not the obligation of changing sex (Schatte and Saborowski, 2006). The sexual system *L. stylirostris* exhibit is unknown. Therefore, one of the purposes of this work was to investigate possible systems employed by the shrimp.

Bopyrid isopods have evolved as branchial parasites mostly of crustaceans and are known to affect aspects of their host's reproduction, growth, metabolism, environmental tolerances and the partitioning of the host's energy budget (Anderson, 1977; Beck, 1980; Nelson, 1986; Jay, 1989; Smith et al., In press). At least 20 species including *L. stylirostris* are hosts to *Argeia pugettensis* (Markham, 1977). This isopod ranges circumboreally in the Pacific, from Korea to San Francisco Bay, California (Markham, 1977). Numerous works have documented the effects of *A. pugettensis* on the growth and reproduction of crangonid shrimp (Gifford, 1934; Nelson, 1986; Jay, 1989). Several studies have reported parasitism by *A. pugettensis* on *L. stylirostris* (Fee, 1926;

Markham, 1977, Hoeman, 1982) but no study has analyzed the effect of the parasite on the shrimp. The bopyrid isopod *Argeia pugettensis*, is a common parasite of *L. stylirostris* but the effect the isopod has on the shrimp is unknown.

The present study attempted to (a) describe the *L. stylirostris* population present at a dissipative sandy beach in southern Oregon and the environmental variables that influence it, (b) identify the preferred prey items, (c) analyze variation of the sexual composition of the population to gain insight into the sexual system employed by the species, and (d) observe differences between parasitized and non-parasitized individuals.

Materials and Methods

Study Area

This study was conducted at Bastendorff Beach (43°35'N, 124°35'W), which is located immediately south of the mouth of Coos Bay in southern Oregon, U.S.A (Fig. 1). Bastendorff is a 3 Km long semi-exposed dissipative sandy beach bordered by a rocky shore on the south and a rock jetty at the mouth of the Coos estuary to the north. Dissipative beaches are flat beaches in which the wave energy is dissipated in the surf-zone rather than reflected from the beach face (McLachlan, 1980; Masselink and Short, 1993). Additional details of the study site are given in Chapter 1.

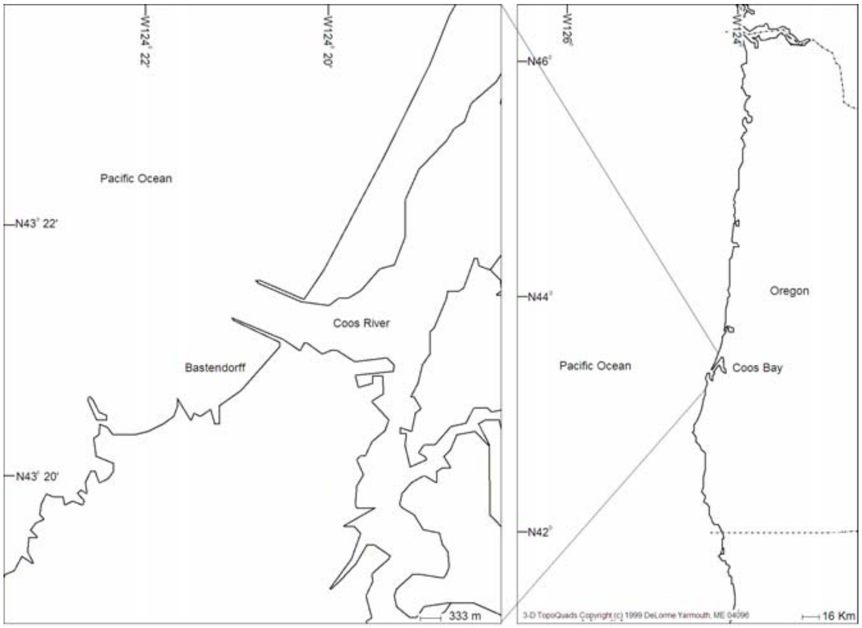

Figure 1. Study area with location of Bastendorff, a dissipative sandy beach sampled in southern Oregon during the summer of 2006.

Sampling

Samples were taken on 14 dates throughout the summer of 2006 (Table 1). Collections were made during high, mid and low tides, during spring and neap tides, and during the day and night. Samples were collected using a beach seine and a hyperbenthic sledge. The beach seine was 1.5 m high and 15 m wide with a 5.0 mm mesh. Three people carried the net at shoulder height into the surf-zone to an approximate depth of 1 m. where the shallow surf-zone borders with the swash zone (McLachlan and Brown, 2006). The net was then opened parallel to shore and towed towards the shoreline. This procedure was followed one to three times, with fewer tows made when the surf was rough. The distance from the shoreline to where the beach seine was first opened and the maximum depth of the water column were measured. The hyperbenthic sledge sampled the swimming fauna present in the whole water column at ~ 50 cm of depth and was only used on the first six sampling dates. We used a hyperbenthic sledge because we consider it to be the best method available to sample the surf-zone community due to the amount of seawater it filters per tow (Mees and Jones 1997). The sledge has a 50 x 70 cm mouth opening connected to a 4 m long net with 1 mm mesh. The sledge was hand towed parallel to the shoreline at approximately ~ 50 cm water depth for 400 m during high, mid and low tides, spring and neap tides and during the day and night. Because of how much time it takes to obtain a sample with the sledge, we considered it was impossible to take replicates, a conclusion also reached in previous works (Watkin 1941).

Table 1. Time of sampling and biological values obtained from an *L. stylirostris* population present at Bastendorff, a dissipative sandy beach in southern Oregon during the summer of 2006. Date, tide, lunar tide (Lunar), time of day (Time) during which the samples were taken. Densities (ind/100 m^2) are presented for the groups: Parasitized males (Par. mal.), Parasitized females (Par. fem.), Non-parasitized males (Non. mal.), Non-parasitized females (Non. fem.), Brooding non-parasitized (Brood. non.) and Brooding parasitized (Brood. par.). Feeding Selectivity values (Select.) of the shrimp towards the mysid *Archaeomysis grebnitzkii* are also presented and were obtained employing the Shorigin index (Berg, 1979). * = dates on which the hyperbenthic sledge was used.

Date	Tide	Lunar	Time	Par. mal.	Par. fem.	Non. mal.	Non. fem.	Brood. non.	Brood. par.	Total	Select.
6/7/06*	HW	Neap	1019	1.4	1.7	0.1	0.9	1.1	0.0	5	
6/7/06*	MW	Neap	1250	0.0	1.7	0.0	0.3	0.7	0.0	3	-
6/7/06*	LW	Neap	1528	0.7	1.0	0.0	1.3	1.1	0.0	4	
7/22/06*	HW	Spring	1207	0.0	0.0	0.0	0.0	0.0	0.0	0	
7/22/06*	MW	Spring	1403	0.0	0.4	0.0	0.1	0.3	0.0	1	1.63
7/22/06*	LW	Spring	1644	0.0	0.4	0.0	0.0	0.0	0.0	0	
7/27/06*	HW	Spring	1504	1.0	2.9	0.3	0.1	0.3	0.1	5	
7/27/06*	MW	Spring	1145	3.3	13.7	0.6	0.4	5.0	0.0	23	2.08
7/27/06*	LW	Spring	824	0.6	6.1	1.1	0.3	3.1	0.0	11	
7/30/06*	LW	Neap	2239	13.6	25.0	3.9	0.1	16.7	0.0	59	1.05
8/2/06*	LW	Neap	0031	12.6	17.1	2.0	0.4	6.1	0.3	39	1.02
8/5/06	LW	Neap	1145	0.3	2.0	0.0	0.0	0.4	0.0	3	-
8/9/06	LW	Spring	1400	0.3	0.0	0.0	0.0	0.0	0.0	0	-
8/13/06*	LW	Spring	2230	23.7	31.1	22.8	0.4	14.4	0.3	93	1.12
8/18/06	LW	Neap	1000	0.3	0.3	0.0	0.0	0.1	0.0	1	-
8/25/06	LW	Spring	1500	1.6	6.7	1.6	0.7	2.3	0.0	13	-
9/1/06	LW	Neap	0800	0.1	2.3	0.1	0.0	1.7	0.0	4	-
9/8/06	LW	Spring	1400	7.1	5.3	11.7	8.6	1.9	0.0	35	-
9/15/06	LW	Neap	0800	0.7	0.9	0.3	0.3	0.6	0.0	3	-
9/29/06	LW	Neap	1800	0.6	1.3	0.7	0.7	0.3	0.0	4	-

Therefore the tows were made sufficiently long for them to account for possible variances in the fauna due to the different areas present in the surf-zone of sandy beaches and to the patchy distribution that species may present (Mees & Jones 1997; Lock et al. 1999). All samples were preserved in 10% buffered formalin.

In the laboratory, organisms were identified to species when possible. *Lissocrangon stylirostris* individuals were separated from the rest of the fauna (see Chapter 1 and 2). All *L. stylirostris* individuals caught in the beach seine were measured, sexed and checked for the bopariid isopod *Argeia pugettensis*. The sex of each shrimp was determined by examining the endopod of the first and second pleopods as described by Butler (1980). A bulge in the shrimp's carapace over either the right or the left branchial chamber indicated parasitized shrimp.

The length measurements were taken from the tip of the rostrum to the tip of the telson. Individuals were grouped into categories of Parasitized male (Par. mal.), Parasitized female (Par. fem.), Non-Parasitized male (Non. mal.), Non-parasitized female (Non. fem.), Brooding non-parasitized (Brood. non.), and Brooding parasitized (Brood. par.). Densities are presented as individuals per 100 m^2. Densities (ind./100 m^2) were calculated using the total area sampled, which was calculated by multiplying the length of the tow and the length of the beach seine. We calculated the volume of water sampled by multiplying the area and the maximum depth of the water column and then dividing this value by two to account for the beach slope.

We were not able to use a three-way ANOVA to analyze variances due to tides, lunar tides and time of day because we did not sample during all three tides at night. Instead, densities were compared among samples taken during the four months (June, July, August, September), three tides (high, mid and low tide), two lunar tides (spring and neap tide) and two times of day (day and night) using one-way ANOVAs. Pair-wise comparisons were conducted using Tukey's test. We tested for effects of lunar tide and time of day on densities using a partially nested mixed model two-way ANOVA. We were able to use two-way ANOVAs despite the fact that we sampled only once during the spring/night low tide because we did obtain replicates for spring/day low tide, neap/night low tide and neap/day low tide. However, because of the lack of spring/night low tide replicates we were not able to do any further statistical comparison. All of the assumptions for the analysis of variance were met, except for the homogeneity of variances. To meet this assumption, the data were $\log_{10}(x+1)$ transformed and then tested with an F max test. The data were plotted as size frequency histograms to observe possible effects of sex and parasitism on size. These size class data were statistically compared using a Kolmogorov-Smirnov goodness-of-fit test (K-S test) (Sokal and Rohlf, 1995).

It is unclear where the shrimp are feeding, in the water column or the sediment. It is also unclear where the shrimp were present when caught with the beach seine, in the sediment or the water column. For this reason, the shrimp caught in the hyperbenthic sledge were counted and observed for possible parasitism. Seventy-one randomly selected shrimp caught in the hyperbenthic sledge from the six dates, 21 non-parasitized and 60 parasitized, were wet weighed, stomach contents analyzed, the Stomach content index (SCI) calculated, and observed for parasitism. The stomach content index (SCI) was calculated as an indicator of stomach fullness in all of the samples using the following equation:

$$SCI = \frac{SW}{BW} x 100,$$

where SW is the wet weight (g) of the stomach contents and BW is the wet weight (g) of the body of the shrimp (Takahashi et al., 1999). The percentage of empty stomachs was recorded, but these were not used in further analysis. The SCI of parasitized and non-parasitized individuals, and individuals caught during the night and day were compared using two one-way ANOVAs (day vs night and parasitized vs non-parasitized). Because of the different time at which the night samples were taken (Table 1) the data from the three night time dates were compared between each other using a one-way ANOVA and a post-hoc comparison of means test (Tukey's test).

The number of individuals, frequency of occurrence (%F), numerical percentage (%N) and wet weight of each food item in grams was recorded. The frequency of occurrence (%F) of a diet component is the percentage of the shrimp in a sample, which contain the component in their digestive tracts (Hynes, 1950). Finally, the selectivity in natural feeding behavior was calculated using the Shorigin index (Berg, 1979), which is as follows:

$$Sel. = \frac{\%N_i \ in\ the\ ingested\ food}{\%N_i \ in\ the\ potentially\ available\ food},$$

where Sel is the feeding selectivity and $\%N_i$ is the numerical percentage of an item. The data for $\%N_i$ in the potentially available food were obtained from the samples taken with the hyperbenthic sledge. The data from these samples are detailed in Chapter 1. This index was chosen because it is considered an accurate way to compare values obtained from different samples, it compares the ingested food items with the potentially available food at the sampling site and has been used extensively in previous studies (ISI Web of Science, 2007).

To observe possible effects of the parasite on the host, 20 parasitized and 20 non-parasitized individuals were taken randomly from four low tide beach seine samples, one sample from each month sampled (6/7/06, 7/30/06, 8/13/06, 9/8/06) to include possible seasonal, lunar or time of day effects. Individuals were grouped by size and divided into parasitized and non-parasitized shrimp. All individuals were dried in a hood for 24 hours. The side in which the parasite was attached on parasitized individuals, and the dry weight and length of the individuals were recorded. The weight of the parasite was subtracted from the weight of the shrimp to obtain the shrimp's real weight.

From the four sampling dates mentioned above, 10 parasitized and 10 non-parasitized new individuals (80 individuals in total) were selected randomly and their stomach contents analyzed. These individuals were wet weighed, measured and their stomach contents analyzed and weighed. Additionally, the parasites were all counted and sexed based on Gifford (1934) and Kozloff (1987).

Finally the fish caught in the beach seine, which according to a stomach content analysis had preyed on *L. stylirostris,* were recorded along with the presence or absence of *A. pugettensis* on these shrimp prey.

Results

The volume of water sampled with one beach seine tow varied from 451 to 461m^3. The area sampled with one beach seine tow varied from 694 to 708 m^2, of which a mean of 701 m^2 was used to determine density. In the beach seine, a total of 2,084 individuals were caught at Bastendorff during the 14 dates sampled, with a mean of 15±24 individuals per 100 m^2 (± S.D.) (Table 1). The majority of these individuals were females (63.1%) and most of the individuals (61.7%) were parasitized by the boparid isopod, *Argeia pugettensis*. Of the females, 39.3% were parasitized, 4.82% were non-parasitized, 18.7% were brooding non-parasitized, and 0.2% were brooding parasitized. Of the males, 22.2% were parasitized and 14.7% were non-parasitized individuals. On the 6 dates sampled with the hyperbenthic sledge a total of 453 individuals were caught, with an average density of 25±68 individuals per 100 m^2.

Temporal Variation

Higher mean densities of both methods were observed during September (Fig. 2), on low tides, spring tides and only significantly at night time ($p \leq 0.008$). A two-way ANOVA found that during low tide significantly higher densities were usually observed during night spring tides followed by night neap tides, day spring tides and day neap tides, however these comparisons were not significant in all of the groups (Table 2, Fig. 3 and 4).

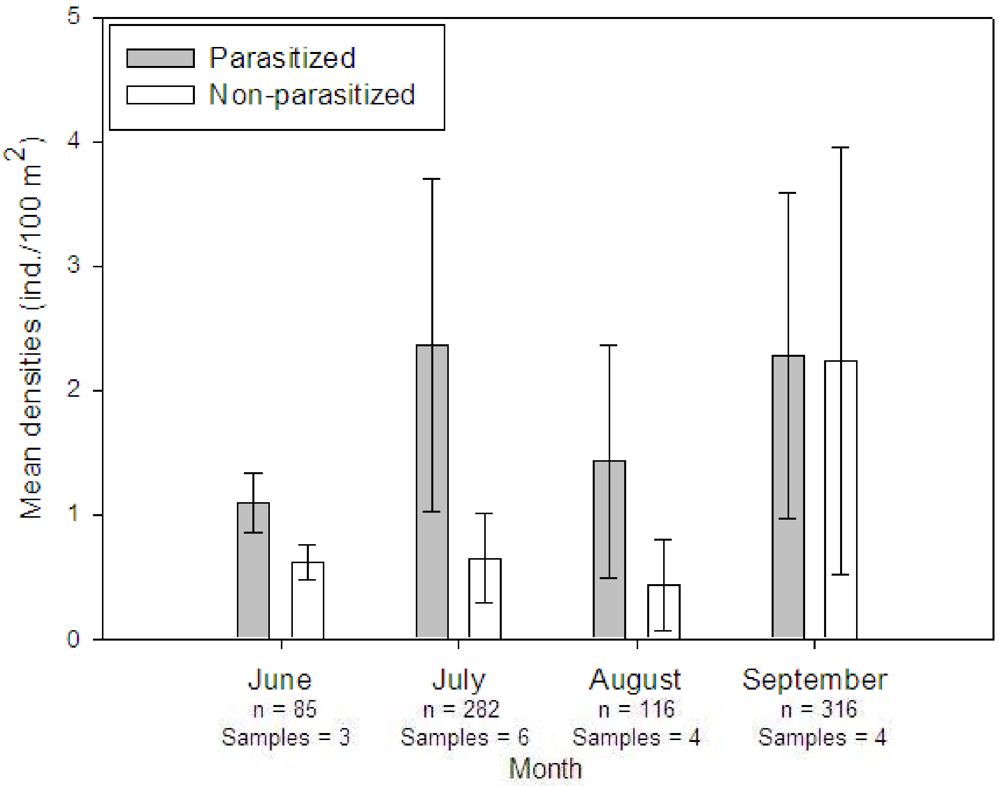

Figure 2. Mean monthly day time densities (ind/100m^2 ± S.E.) of parasitized and non-parasitized *L. stylirostris* observed during the four months sampled in the summer of 2006. There was no significant difference between the monthly densities of parasitized and non-parasitized shrimp.

Size frequency distributions of *L. stylirostris* varied over time. In June, *L. stylirostris* ranged between 3 and 5.4 cm in length (Fig. 5a). In July, a cohort of small individuals with lengths between 1.5 and 3 cm (Fig. 5b) appeared. The abundance of this cohort increased through August and September (Fig. 5c and d). While the percentage of larger individuals (3 to 5.4 cm) began to decrease in July and continued to decrease through August and September.

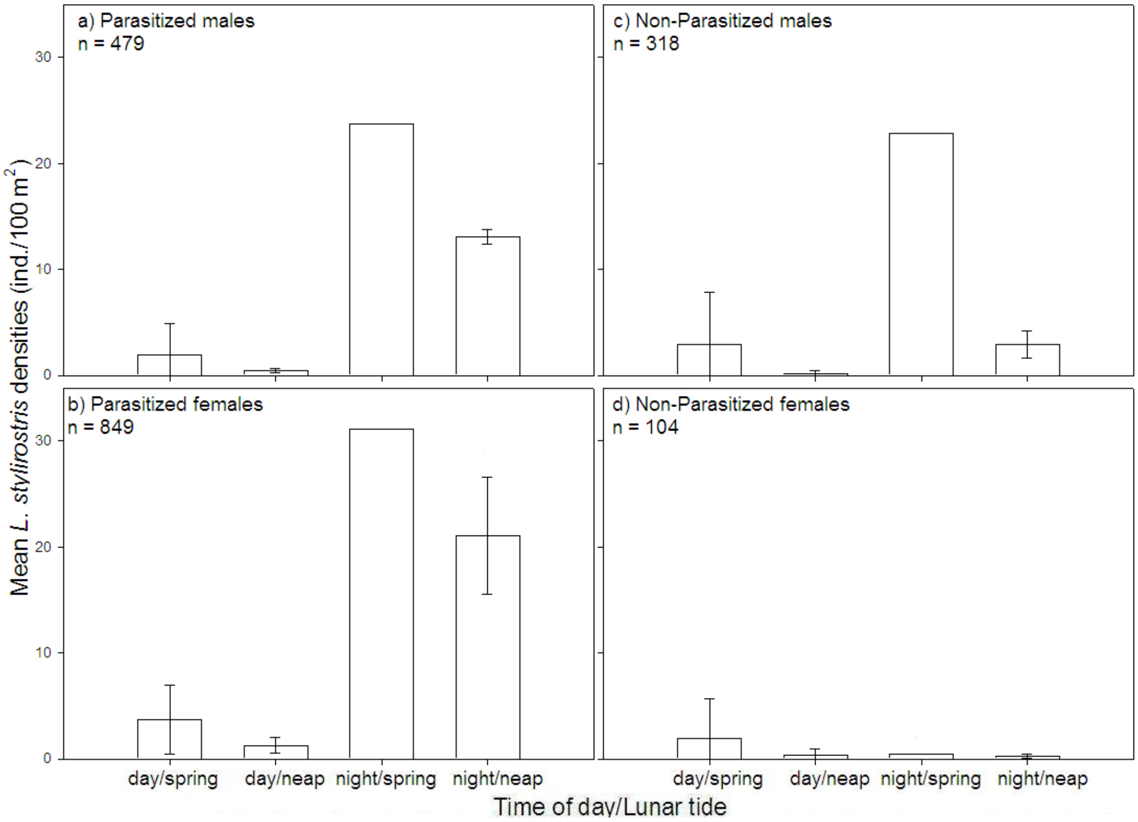

Figure 3. Mean densities (ind./100 m^2± S.D.) of parasitized and non-parasitized male and female *L. stylirostris* observed during day and night and spring and neap tides. Samples were taken at low tide in the surf-zone of a dissipative sandy beach in southern Oregon during summer 2006. The p values are based two-way ANOVAs. Within each group, the density values that did not differ significantly are represented with the same letter. n = number of shrimp in lunar tide/time of day combination.

Table 2. Results of two-way ANOVA test for differences in *Lissocrangon stylirostris* densities at low tide. Fixed effects were time of day and lunar tides. Samples taken at Bastendorff, a dissipative sandy beach in southern Oregon.

a) Parasitized Male Shrimp						
	df Effect	MS Effect	df Error	MS Error	F	p-level
Lunar tide	1	78.27	10	3.63	21.58	0.0009
Time of day	1	632.84	10	3.63	174.46	0.0000001
Interaction	1	45.03	10	3.63	12.41	0.006
b) Parastized Female Shrimp						
	df Effect	MS Effect	df Error	MS Error	F	p-level
Lunar tide	1	83.47	10	7.54	11.07	0.008
Time of day	1	1190.80	10	7.54	157.96	0.0000002
Interaction	1	31.20	10	7.54	4.14	0.07
c) Non Parasitized Male Shrimp						
	df Effect	MS Effect	df Error	MS Error	F	p-level
Lunar tide	1	273.42	10	10.12	27.02	0.0004
Time of day	1	275.49	10	10.12	27.22	0.0004
Interaction	1	158.65	10	10.12	15.68	0.003
d) Non Parasitized Female Shrimp						
	df Effect	MS Effect	df Error	MS Error	F	p-level
Lunar tide	1	1.50	10	5.70	0.26	0.62
Time of day	1	1.34	10	5.70	0.23	0.64
Interaction	1	1.03	10	5.70	0.18	0.68
e) Brooding Non Parasitized Female Shrimp						
	df Effect	MS Effect	df Error	MS Error	F	p-level
Lunar tide	1	7.48	10	6.54	1.14	0.31
Time of day	1	299.69	10	6.54	45.81	0.00005
Interaction	1	2.72	10	6.54	0.42	0.53
f) Brooding Parasitized Female Shrimp						
	df Effect	MS Effect	df Error	MS Error	F	p-level
Lunar tide	1	0.01	10	0.00	2.68	0.13
Time of day	1	0.10	10	0.00	24.11	0.0006
Interaction	1	0.01	10	0.00	2.68	0.13

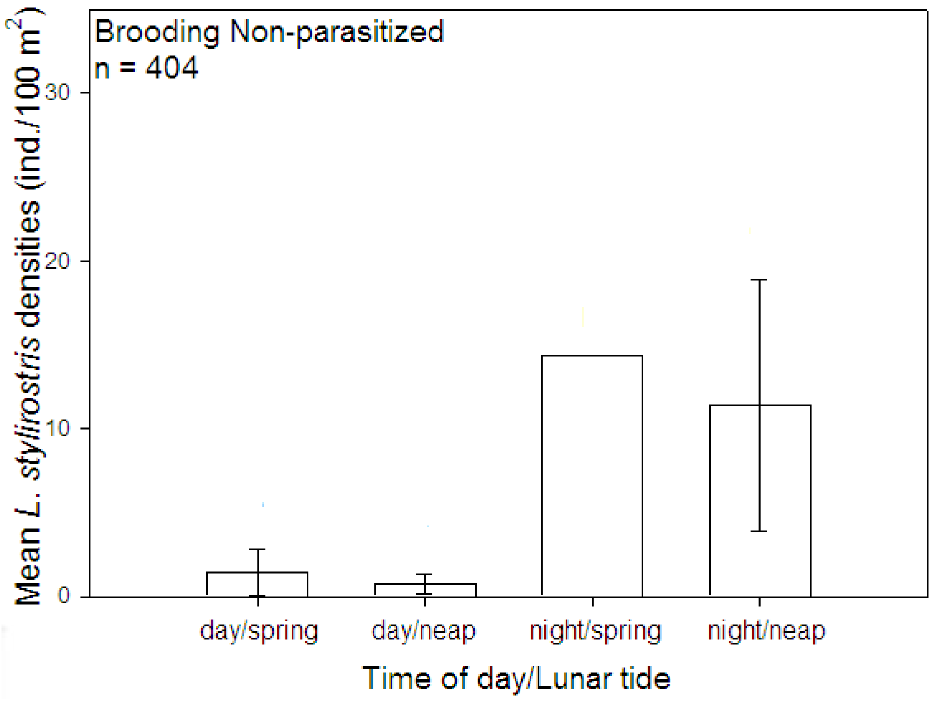

Figure 4. Mean densities (ind./100 m^2± S.D.) of brooding non-parasitized *L. stylirostris* observed during four different times (time of day/lunar tide). Samples were taken at low tide during summer 2006 in the surf-zone of a dissipative sandy beach in southern Oregon. The p values presented are based on two-way ANOVAs. Within each group, the density values that did not differ significantly are represented with the same letter. n = number of shrimp in lunar tide/time of day combination.

In the stomach content analysis, only three prey items were observed. The most frequent food item overall was the mysid *Archaeomysis grebnitzkii*. The frequency of occurrence (90±22) and the numerical percentage (87±30) of *A. grebnitzkii* were significantly higher than any other food item ($n = 7$, $F \geq 21.33$, $p \leq 0.0001$). The other prey items identified were the amphipods *Dogielinotus loquax* and *Lycaeopsis themistoides*. Finally the feeding selectivity of the shrimp towards the mysid *A. grebnitzkii* was low in the five dates analyzed (Table 1).

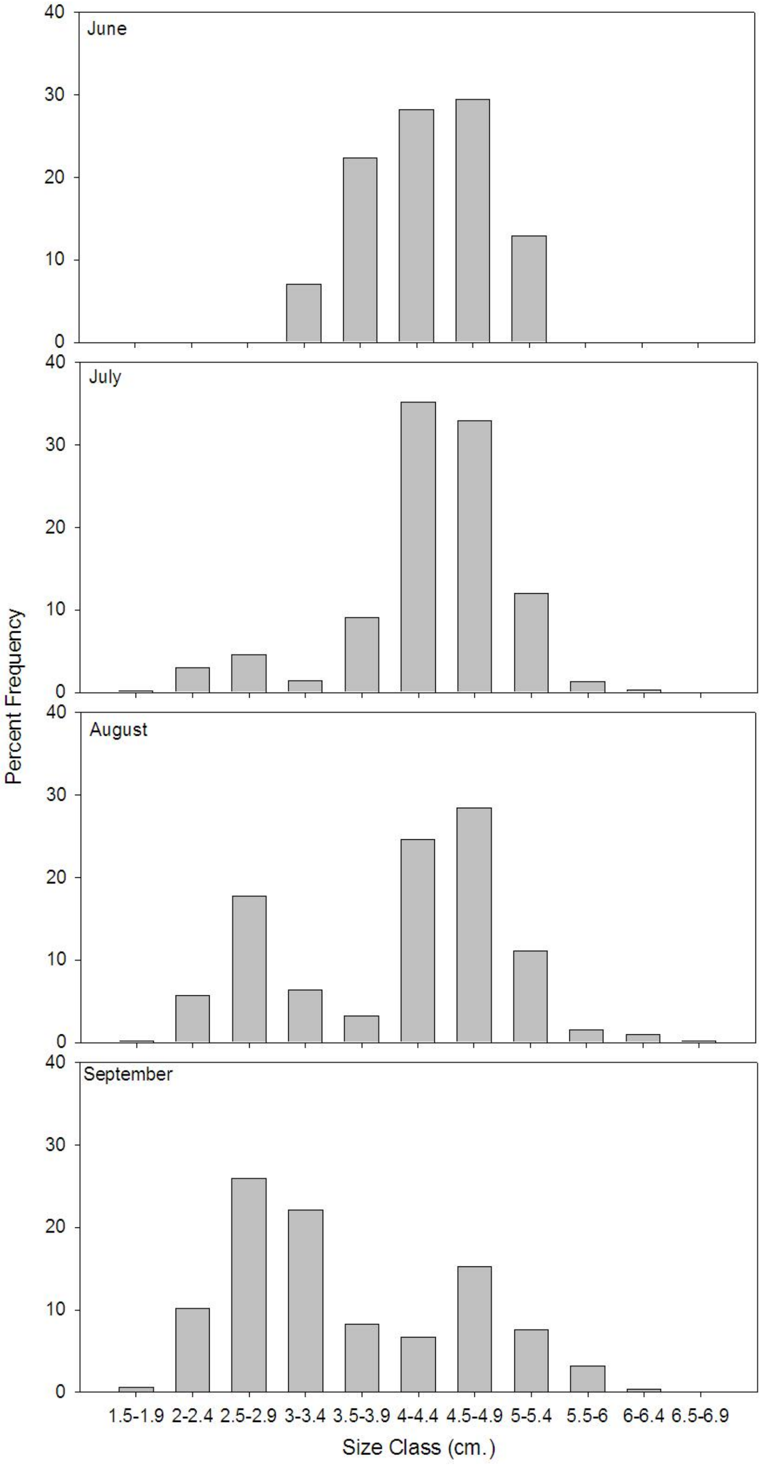

Figure 5. Size percent frequency distribution of *L. stylirostris* collected in the summer 2006 from the surf-zone of a dissipative sandy beach in southern Oregon.

A one-way ANOVA (F=21.27, p=0.02) showed that significantly lower feeding selectivity values were observed in the shrimp caught at night (1.1±0.1) than in the day (1.9±0.3).

Sex and/or Parasitic Variation

Female shrimp varied in size from 2 to 7 cm with the majority between 4-4.9 cm (80%) (Fig. 6a). Males varied from 1.5-4.9 cm with the majority being between 2.5-2.9 (35%) and 4-4.5 cm (20%) (Fig. 6a). There was a significant difference in the size frequency distributions of female and male shrimp (K-S test, n = 797, D = 0.38, p = 0.05). The majority of brooding non-parasitized female shrimp ranged from 4.5-5.4 cm (81%), of which brooding parasitized females ranged from 3.5 and 4.9 cm (80%). The size frequency distributions of these two groups of brooding females differed significantly. However due to the small sample size of the brooding parasitized (n = 5) this result should be considered tentative. The non-brooding parasitized females ranged from 4 to 4.9 cm (88%), where as the non-parasitized non-brooding females ranged between 2.5-4.9 (83%) (Fig. 6b). The size frequency distribution of these two female groups differed significantly (K-S test, n = 104, D = 0.35, p = 0.05). The majority of parasitized males ranged from 2-4.4 cm (69%) whereas non-parasitized males were smaller; 81% were between 2.5-3.4 cm (Fig. 6c). The size frequency distributions of parasitized and non-parasitized male shrimp were significantly different (K-S test, n = 318, D = 0.33, p = 0.05).

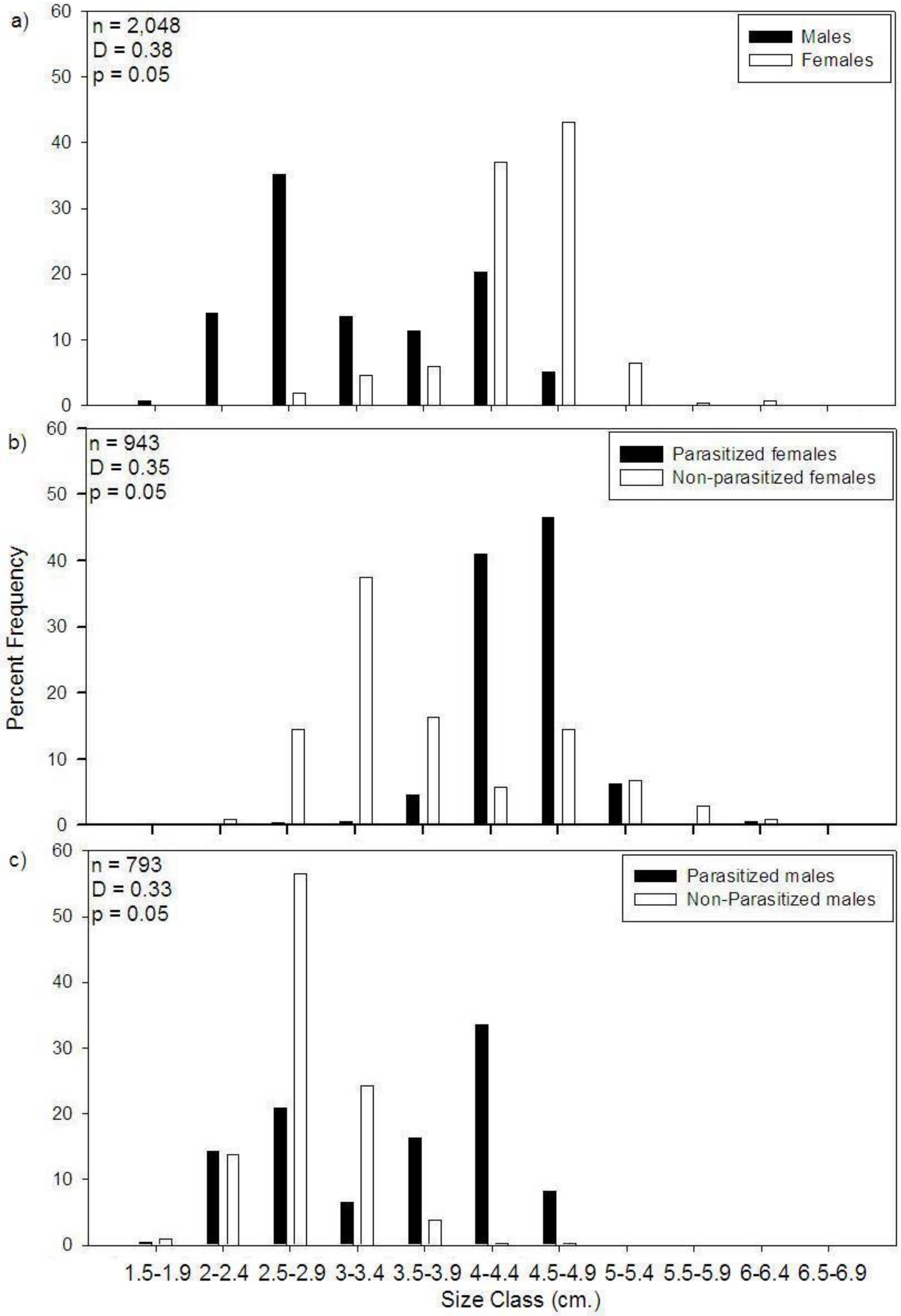

Figure 6. Size frequency distribution of *L. stylirostris* for (a) males and females, (b) Parasitized females, Non-parasitized females, and (c) Parasitized males and Non-parasitized males. Samples were collected in the surf-zone of a dissipative sandy beach in southern Oregon. Distributions compared using Kolmogorov-Smirnov tests, all of which differed significantly ($p < 0.05$).

Adult female isopods were larger than males. A male isopod was always present with a female isopod, whether the female was gravid or not. Males attached to the back of gravid females and in the brood pouch of non-gravid females. Parasites occupied the right side of the host (58%) slightly more than the left side (42%). Few shrimp were parasitized by more than one female isopod (<1%). Non-gravid female isopods were usually present in shrimp smaller than 3.2 cm. Juvenile isopods were present only during the last two dates (8/13/06 and 9/8/06) when gravid and non-gravid female isopods were present.

Differences between Parasitized and Non-parasitized Individuals

Non-parasitized shrimp had significantly higher dry weight than parasitized shrimp, 0.66±0.44 g compared to 0.38±0.16 g, respectively (n = 160, F=28.8, p=0.001). Separating non-parasitized and parasitized shrimp by size class, we observed several differences. In small shrimp (2.1 to 3 cm) the non-parasitized individuals weighed 27% more than the parasitized individuals. This changed for shrimp between 3.1 and 4 cm, where the parasitized individuals weighed significantly more (58%) than the non-parasitized individuals (n = 37, F= 17.02, p=0.002). Interestingly, this pattern again reverses in individuals between 4.1-5 cm, with non-parasitized individuals weighing significantly more (36%) than the parasitized individuals (n = 68, F = 8.18, p = 0.005) (Fig. 7). Based on length measurements of host and parasite, we observed a positive correlation between the length of the isopod parasite and the length of the host shrimp (n = 75, r = 0.84, p = 0.05) (Fig. 8), regardless of the host gender.

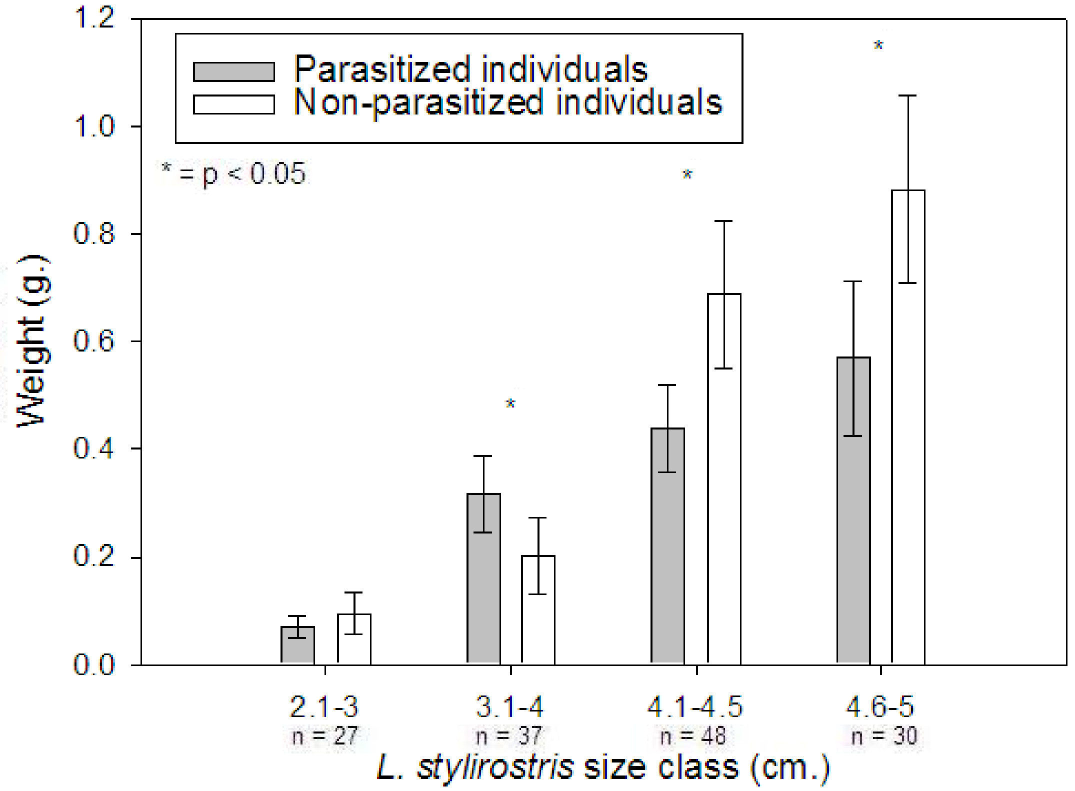

Figure 7. Dry weight comparison by size class between parasitized and non-parasitized *L. stylirostris*. Samples taken throughout the summer of 2006 at a dissipative sandy beach of southern Oregon. Error bars represent standard deviation. *Significant difference ($p \leq 0.005$).

In the beach seine samples, the stomach analysis revealed 18 of the 40 non-parasitized individuals (45%) and 12 of the 40 parasitized individuals (30%) had empty stomachs. No significant differences in SCI values were observed in non-parasitized (0.74±1.32) and parasitized individuals (0.69±0.76). When comparing values for the four combinations of lunar tides and time of day at low tide, highest SCI values where observed during spring night time (0.93±1.41), followed by spring day time (0.88±1.25), neap night time (0.74±0.83) and neap day time (0.31±0.5). However, there were no significant differences due to these factors. Stomachs of these individuals contained primarily detritus and sand with low percentages of gammarid amphipods, and the mysid, *Archaeomysis grebnitzkii.*

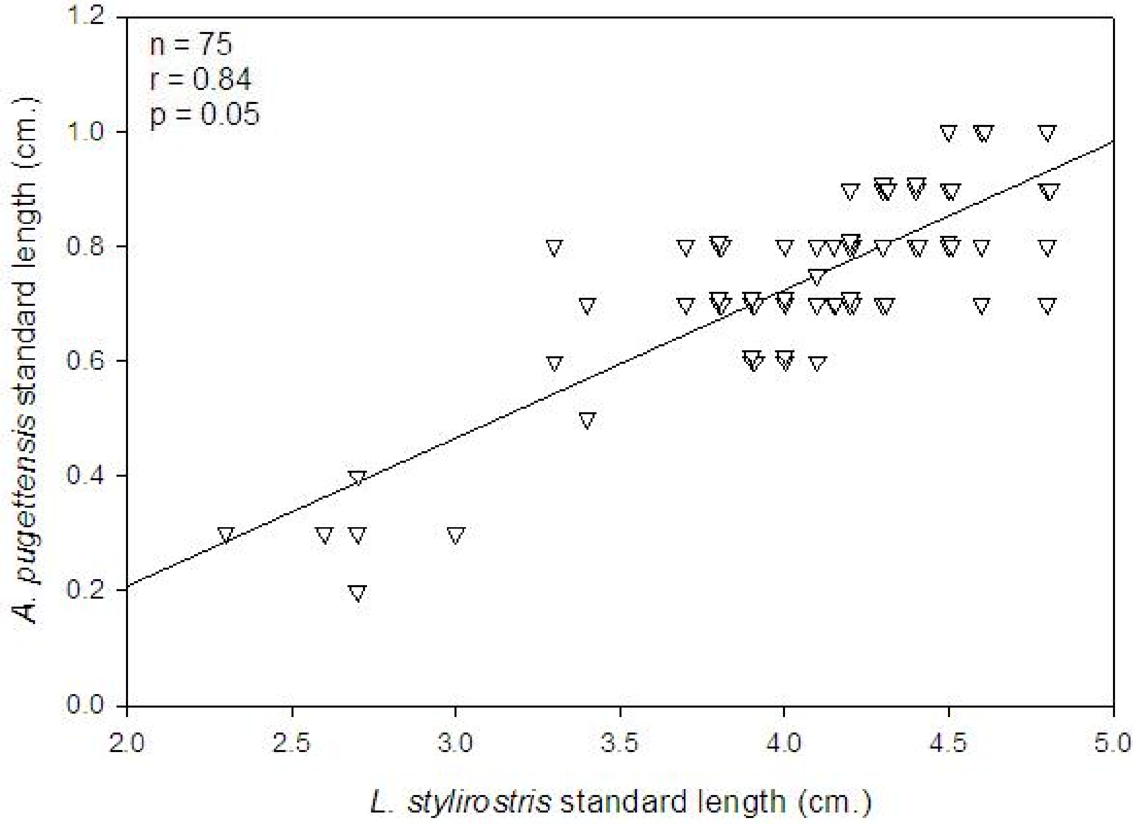

Figure 8. Linear correlation between lengths of *L. stylirostris* and its parasite, *A. pugettensis*. Samples taken in summer 2006 at a dissipative sandy beach of southern Oregon.

In the sledge samples, sixteen of 71 individuals had empty stomachs (23%), including the individual caught on 6/7/06. Parasitized individuals had a higher percentage of empty stomachs (12 of 42, 29%) compared to non-parasitized individuals (4 of 29, 14%). Individuals caught in the day also had a higher percentage of empty stomachs (8 of 23, 35%) than individuals caught during the night (8 of 48, 17%). No significant difference in SCI values was observed when comparing parasitized and non-parasitized individuals, and individuals caught during the day and night. However, significantly higher SCI values were observed in individuals caught at night on 08/02/06 (2.8±1.3) than during the day ($n = 27$, $F= 14.25$, $p = 0.0007$). The SCI of the individuals caught during the three night samples differed significantly from each other ($n = 48$, $F = 7.76$, $p = 0.001$). A post-hoc mean comparison showed that the SCI of 08/02/06 was significantly different than the other two night samples ($p \leq 0.01$) but these other two did not differ significantly from each other. When comparing the individuals caught during 08/02/06, significantly higher values were observed in non-parasitized individuals than in parasitized individuals, with values of 3.6±1.3 and 2.1± 0.7, respectively ($n = 15$, $F = 8.21$, $p = 0.01$).

Only two species of fish in the seine samples had preyed on *L. stylirostris*, English sole/*Pleuronectes vetulus* (2 individuals) and Pacific staghorn sculpin/ *Leptocottus armatus* (4 individuals). In total, the six fish preyed on nine *L. stylirostris* individuals; of which five were parasitized by *A. pugettensis* and three were not. Whether or not the ninth L. stylirostris was parasitized was impossible to determine due to an advanced deterioration of the shrimps body. The shrimp composed 63±53% of English sole prey items and 75±32% of Pacific staghorn sculplin.

Discussion

The presence of *L. stylirostris* in high abundances at Bastendorff Beach during the summer of 2006 was not surprising considering this species has been reported as an inhabitant of high-energy semi-exposed sandy beaches (Schmitt, 1921; Kuris et al., 1977; Rudy Jr. and Rudy, 1983). The similar densities observed during the four summer months seem to be due to a recruitment event that was observed throughout the months of July, August and September, and to the disappearance of the larger shrimp during the same months, probably due to mortality. Hieb (1999) and Jay (1989) reported that in California abundances peaked in July to September, with highest abundances during August and lowest densities from April through June. We found highest densities during September and lowest during June. Hieb (1999) also observed recruitment events during the summer, however, in California these events began in June instead of July. These observations suggest that the life cycle of the shrimp in Oregon follows a similar pattern to that observed in California, where the life span of crangonid shrimp is believed to be 1 to 2 years, depending on the sex (Hieb 1999). The density of the *L. stylirostris* population present at Bastendorff beach is maintained stable throughout the summer probably due to recruitment event and to the disappearance of large shrimp.

The significantly higher density values found at night could be due to a vertical migration of the shrimp from the sediment into the shallow water column during the night. Higher densities at night have been reported in previous studies (Hoeman 1982) (0.2 – 1.0 ind/100m^2 during the day and 6 – 11 ind/100 m^2 during the night). The shrimp's vertical migration may occur in order to feed, primarily on *A. grebnitzkii,* the preferred food item, which has higher densities during low tide at night (Chapter 1). This feeding behavior is also suggested by the higher SCI values and lower % of empty stomachs observed at night in both beach seine and hyperbenthic sledge samples. The significantly higher SCI values found in the 08/02/06 sample were probably due to the time at which this sample was taken (0020). This would suggest the shrimp are in fact feeding at night and that by midnight; the shrimp have eaten significantly more than by 2200, which is when the other two night samples were taken. Feeding during the night would also reduce the risk of predation by visual predators such as sea birds and fish. Finally, the significant density difference found at low, night, spring and/or neap tides suggest the three factors are influencing the population but that the time of day is the strongest influence, a finding supported by previous studies (Hindell et al., 2000; Beyst et al., 2001; Beyst et al., 2002).

Sex variation

The higher percentage of female *L.stylirostris* and the female's significantly larger size than males has been reported previously (Hoeman, 1982; Hieb, 1999). Female shrimp may grow faster and become larger than male shrimp (Meixner, 1969; Oh et al., 1999). However, we also observed a small percentage of males > 4.5 cm (5%) and females < 3.5 cm (4%). There are three possible hypotheses for these observations: (1) The males are not present in the same environment with females during the whole or part of the year due to different patterns of migrations or zonation (Hoeman 1982). (2) Individuals of this species are protandric hermaphrodites like *Notocrangon antarcticus* (Pfeffer, 1887 in Correa and Thiel, 2003), a closely related species, and (3) This species has a system known as “protandry with primary females” or “partial protandric hermaphroditism with primary females” such as *Crangon franciscorum* (Gavio et al., 2006), *Argis dentate* (Rathburn, 1902) or *Crangon crangon* (Linnaeus, 1758 from Gavio et al., 2006) and/or the facultative protandric hermaphroditism exhibited by *Crangon crangon* (Schatte and Saborwski, 2006). While the two first hypotheses would explain the higher percentage of females, they do not explain the presence of large males and/or small females observed in this study. The higher percentages of females and the presence of large males and small females could be explained if the shrimp exhibited facultative and/or partial protandric hermaphrodites, as mentioned in the third hypothesis.

Parasite Prevalence

Previous studies have described parasitazation of *Lissocrangon stylirostris* by the bopyrid isopod *A. pugettensis* (Fee, 1926; Markham, 1977; Hoeman, 1982), however, the percentage of individuals parasitized in this study (63%) was higher than reported in previous works. Hoeman (1982) reported that 8% of the 1,611 *L. stylirostris,* caught over a year carried the parasite. The prevalence increased to 44% of 66 individuals during the summer season. Nelson et al. (1986) and Jay (1989) also reported lower percentages of infestation of *A. pugettensis* in *Crangon franciscorum,* a closely related species. These studies were conducted in Grays Harbor and San Francisco Bay in Washington and California, respectively; which may account for their observed lower infestation rate. The fact that the host inhabited an estuary could have made it more difficult for the parasite to infest the host or for the parasite to survive the host's migrations between estuary and open-ocean due to the change in the physical characteristics of the water body between both habitats. Migration of crangonid shrimp between an estuary and the open coast has been suggested to occur during the reproductive and recruitment periods (Krygier 1974, Hoeman, 1982; Jay, 1989). The difficulty of infesting hosts due to change in water characteristics has been suggested in previous studies (Reisser and Forward 1991, Walker and Lester 2002, Boone et al. 2004). Another explanation for the higher percentages of infestation we found could be the higher densities of the host observed (0.2-16 ind/100m^2 during the day and 18 – 86 ind/100m^2 during the night) compared to those reported by Hoeman (1982) (0.2 – 1.0 ind/100m^2 during the day and 6 – 11 ind/100 m^2 during the night). A host's density can be a limiting factor in the spread of parasites (Sheader, 1977; Nelson et al., 1986; Høeg et al., 2005). In the present study, difficulty for isopods to reach shrimp or the high density of shrimp could explain the higher percentage of infestation, since our study showed higher shrimp density but was conducted on the open coast while previous studies showed lower shrimp abundances but were conducted in estuaries.

Based on the presence of juvenile isopods only in the August and September samples and the cohort of small shrimp observed from July to September, we hypothesize that the isopod and the shrimp's recruitment to the sandy beach are coordinated. However no conclusions could be made since this study only looked at four months of the year, therefore a study of the shrimp and isopod's life cycle inside an estuary and on a sandy beach should be carried out simultaneously.

Differences between Parasitized and Non-parasitized Individuals

Three differences were observed between parasitized and non-parasitized shrimp. (1) Non-parasitized individuals had higher weights but smaller sizes than parasitized individuals, (2) Small percentage of brooding parasitized females, and (3) Higher percentages of empty stomachs and lower SCI values in night samples.

Parasitized individuals presented a lower mass per length ratio than their non-parasitized counterparts. However, the larger size of parasitized shrimp observed in this study could have been due to the appearance of the cohort of small non-parasitized shrimp observed from July to September and the disappearance of larger individuals most of which were probably parasitized. When divided into size classes different results were observed. Non-parasitized shrimp had greater mass when between 2.1 - 3 cm and 4.1 - 5 cm in length. The greater mass of non-parasitized individuals between 2.1 and 3 cm in length could have been due to the initial effect of the parasite on the shrimp since previous studies have suggested that the parasite attaches at an early stage of both host and parasite (Beck, 1980; Nelson et al., 1986; Jay, 1989). The higher weights in non-parasitized shrimp between 4.1-5 cm in length may be due to the fact that 4.1-5 cm is the host size at which female parasites are either reproductive or brooding, and potentially draining more energy from the host (Nelson et al., 1986). In individuals between 3.1-4 cm, parasitized shrimp had higher weights than non-parasitized individuals. This greater weight in parasitized shrimp may occur if the parasite forces the shrimp to increase its weight by increasing the shrimp's feeding (Lester, 2005).

If we compare length and sex of the host shrimp, excluding brooding female hosts, parasitized males and females were significantly larger and more abundant than their non-parasitized counterparts. Studies have reported that bopyrids might cause a slight decrease in host growth rate (Jay, 1989; Somers and Kirkwood, 1991; Lester, 2005), a slight increase in overall male shrimp length (Somers and Kirkwood, 1991; Lester, 2005), and an increase in overall female shrimp length (Nelson et al., 1986). The parasite could therefore be forcing the shrimp to increase its size, which would allow the parasite to increase its size since parasite and host length was positively correlated. This has also been reported in previous studies (Jay, 1989).

Only a small percentage of female shrimp were both brooding and parasitized, 0.2% of female shrimp and 1.2% of brooding females. This could have been because the bopyrid parasite sterilizes the host female or reduces its metabolic activity such that it cannot brood (Beck, 1970; Sheader, 1977; Nelson et al., 1986; Jay, 1989; Lester, 2005). The inability to produce broods in females has been previously observed by several studies (Beck, 1970; Sheader, 1977; Nelson et al., 1986; Jay, 1989; Lester, 2005). The inability of females to brood could reduce the size of the population present at Bastendorff and it could eventually become ecologically extinct, unless there is recruitment of shrimp from another population with lower rates of prevalence.

The higher percentages of empty stomachs and lower SCI values (significantly lower only on 08/02/06) in parasitized individuals were observed in both the beach seine and the hyperbenthic sledge samples. This effect may be due to the parasite reducing the shrimp's feeding capabilities. Several authors have previously suggested that bopyrid isopods might reduce ability to capture food in their hosts by reducing their metabolic activity (Anderson 1975a, b; Bass and Weis, 1999; Bergey et al., 2002; Høeg et al., 2005; Smith et al., 2007). This reduction in host metabolic activity and/or feeding capabilities could explain the higher percentage of empty stomachs and lower SCI values, especially since the host's preferred food are mysids which are considered good swimmers that have a strong predatory attack response (Ritz et al. 1997)

Lissocrangon stylirostris was present throughout the summer in the surf-zone of a dissipative sandy beach in southern Oregon. The population remained stable throughout the summer of 2006, possibly due to a recruitment of small and the disappearance of large individuals. The population presented a higher percentage of females (63%) that were usually larger than males. Their densities varied significantly with the lunar tides (spring and neap) and time of day (day and night), and less intensely by tide level. Individuals fed mostly at night and mostly in the water column on the mysid *Archaeomysis grebnitzkii*. The population had a high prevalence of the bopyrid isopod, *Argeia pugettensis* (62%). Parasitized shrimp were larger than non-parasitized shrimp. We observed the following differences in parasitized individuals: (1) smaller mass per length ratio in parasitized shrimp, (2) very few parasitized female shrimp were brooding, and (3) a higher percentage of empty stomachs and a lower amount of food in their stomachs. These differences lead us to hypothesize that this parasite affects the shrimp by increasing the host’s size and varying the host’s weight at different size classes, sterilizing female hosts, and reducing their capability to feed.

CHAPTER VI

CONCLUDING SUMMARY

Despite the seemingly harsh hydrodynamic conditions, the shallow surf zones of these Oregon sandy beaches were used intensively throughout the summer by a number of invertebrate and vertebrate species. The density and species richness values found at these beaches were similar to those found in other temperate parts of the world (Beyst et al. 2001a, Beyst et al. 2002a, Beyst et al. 2002b, Barreiros et al. 2004, McLachlan and Brown 2006). Because of differences in size; we sampled the fauna using two different methodologies, a hyperbenthic sledge for the smaller fauna, and a beach seine for the macrofauna.

With the hyperbenthic sledge, we caught 49,363 individuals belonging to 92 species, most of which were small crustaceans. Species were separated into five groups; 1) planktonic, 2) rocky intertidal, 3) sandy beach species present as adults, 4) meroplankton, and 5) sporadic/rare species. Community composition was most strongly related to Julian date. Lunar tide, time of day, salinity, wave height and the abundance of detached macrophytes also influenced the community. The species present in the sandy beach group did not seem to be affected by flushing rates or the size of the waves. *Archaeomysis grebnitzkii, Lissocrangon stylirostris* (as adult and possibly zoea), *Eohaustorius washingtonianus* and *Atylus tridens* were able to maintain their position in the bottom of the water column, thus possibly avoiding being flushed out of the surf zone. Some meroplankton may use the surf zone as a nursery or as a transient area towards another environment. The ghost shrimp, *Neotrypaea californiensis*, were present in late summer as five zoeal stages in all sample conditions, suggesting that its larval development occur in the surf zone.

With the beach seine, we caught 2,059 individuals, which were distributed among 19 different species belonging to Crustacea, Osteichthyes, Cnidaria, Ctenophora and Cephalopoda. The smooth bay shrimp, *Lissocrangon stylirostris* dominated the catch (71%) and the community, and was the only species resident in the surf zone through the summer sampling. The community varied over the spring/neap cycle and by time of day, and with the stage of the tide. Detached macrophytes and densities of potential prey items were the only environmental variables that influenced community structure. Eight species of fish were caught in the surf zone, most of which were juveniles that may be using the surf zone as a nursery area. They fed mostly on the mysid *Archaeomysis grebnitzkii*.

Juvenile English sole (Standard Length = 2.6 – 12.3 cm) were caught at two of the beaches throughout the summer (61 individuals), with mean standard lengths increasing as the season progressed. They fed primarily on the mysid, *A. grebnitzkii*, which may influence the densities of the fish.

Forty-eight sub-yearling Chinook salmon were caught over six dates (07/22 to 09/01). Their mean standard length increased from 9.1±0.6 (07/22/06) to 11.6±0.7 cm (09/01/06), with a mean increase of 0.6 mm. per day. Early in the summer, smaller fish fed mostly on amphipods. Later, when the fish were larger, the Chinook fed primarily on larval and juvenile fish. These prey were common in the surf zone. Our results suggest that the juveniles reside in the surf zone of sandy beaches for two months in summer until they reach approximately 12 cm in S.L. when they migrate offshore. During these two summer months they feed on the surf zone plankton.

The smooth bay shrimp, *Lissocrangon stylirostris* had a population that was 63% female, which were generally larger than males. The density of L. *stylirostris* varied with the tides, lunar tides and time of day. A cohort of small shrimp was observed during July to September while large adult shrimp disappeared during the same months. The net effect was that shrimp densities were stable over the summer. The shrimp fed mostly at night on the mysid *Archaeomysis grebnitzkii.* The species seems to exhibit a type of protandric hermaphroditism, however we were unable to determine which. Both male and female shrimp supported an equal, high prevalence of *A. pugettensis* (62%). The parasitized shrimp were (1) larger in size but had lower weight per size, (2) very few brooding shrimp were parasitized (0.2%), and (3) a higher percentage of parasitized shrimp had empty stomachs and significantly lower stomach contents. We hypothesize that the parasite is affecting the shrimp by producing variation in its normal size and weight, sterilizing females and reducing its ability to capture food.

APPENDIX A

RAW DATA OBTAINED FROM SAMPLINGS OF THE SURF ZONE OF THREE DISSIPATIVE SANDY BEACHES AND STOMACH CONTENT ANALYSIS OF TWO SPECES OF FISH

Presented below are the raw data from samplings of the surf zone of Bastendorff, Horsfall and Whisky Run Beach along with the data from the stomach content analysis of juvenile Chinook salmon and English sole. Data obtained from sledge samples are presented in Table 1, from the seine samples in Table 2, data from the stomach content analysis of juvenile Chinook salmon in Table 3 and data from the English sole stomach content analysis in Table 4.

Table 1. Surf zone fauna densities (ind./100 m^2) observed at three dissipative sandy beaches.

	Idotea fewkesi	*Holmesimysis sculpta*	Exacanthomysis davisi	Archaeomysis grebnitzkii	Lissocrangon stylirosris	Eucalanus bungii	*Calanus* sp.	*Allorchestes angusta*	*Ampithoe lacertosa*	*Americhelidium micropleon*	*Atylus tridens*	*Carinonajna barnardi*	*Muggiaea atlantica*	Polyorchis penicillatus	*Pleurobrachia* sp.	*Pleuronectes vetulus*	*Excirolana chiltoni*	*Obelia* sp.	*Emerita analoga*	*Apohyale pugettensis*
Bastendorff 6/7 Top HW	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.1	0.0	0.0
Bastendorff 6/7 Bot HW	0.4	1.8	0.0	66.4	0.0	0.0	0.0	0.0	0.7	0.0	5.0	0.0	0.0	0.4	0.0	0.0	0.0	10.0	0.0	0.0
Bastendorff 6/7 Top MW	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	23.9	0.0	0.0
Bastendorff 6/7 Bot MW	0.0	1.4	0.0	31.4	0.4	0.0	0.0	0.4	1.1	0.0	3.2	0.0	0.4	0.0	0.0	0.0	0.0	96.1	0.0	0.0
Bastendorff 6/7 Top LW	0.4	0.0	0.0	12.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	1.8	0.0	0.4	51.4	0.0	0.0
Bastendorff 6/7 Bot LW	0.0	0.0	0.0	21.1	0.0	0.0	0.0	1.4	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	56.1	0.0	0.0
Horsfall 6/30 Top LW	0.4	0.0	0.0	2.9	0.0	1.4	15.7	0.0	0.0	0.0	1.4	0.0	1.1	0.0	0.0	0.0	0.0	14.6	0.4	0.0
Horsfall 6/30 Bot LW	0.4	0.4	0.0	20.7	0.7	1.4	34.6	0.4	0.0	0.4	2.1	0.0	1.1	0.0	0.0	0.0	0.0	10.0	0.0	0.0
Whisky Run 7/1 Top LW	0.0	0.0	0.0	8.6	0.0	0.0	5.4	0.0	0.0	0.0	2.5	0.0	7.1	0.0	0.0	0.0	0.0	37.9	0.0	0.0
Whisky Run 7/1 Bot LW	0.4	0.0	0.0	86.8	1.1	0.0	16.8	1.8	0.0	0.4	13.6	0.0	6.8	0.0	0.0	0.0	0.0	36.1	0.0	0.0
Bastendorff 7/22 Top HW	0.0	0.0	0.0	15.7	0.0	0.4	1.4	0.0	0.0	0.0	1.1	0.0	0.4	0.0	0.0	0.0	1.4	1.1	0.0	0.0
Bastendorff 7/22 Bot HW	0.0	0.0	0.0	69.3	0.7	0.0	0.4	0.0	0.0	0.0	3.9	0.0	0.0	0.0	0.0	0.0	2.5	0.7	0.0	0.0
Bastendorff 7/22 Top MW	0.0	0.0	0.0	45.0	0.0	0.4	0.4	0.4	0.0	0.0	11.4	0.0	0.0	0.0	0.4	0.0	6.4	0.0	0.0	0.0
Bastendorff 7/22 Bot MW	1.1	0.0	0.0	316.4	0.4	0.4	1.1	0.4	0.0	0.0	31.4	0.0	0.0	0.0	0.4	0.0	2.5	0.0	0.0	0.0
Bastendorff 7/22 Top LW	0.0	0.0	0.0	42.1	0.0	0.0	1.8	0.0	0.0	0.4	12.9	0.4	0.0	0.0	0.4	0.0	0.4	0.0	0.4	0.0
Bastendorff 7/22 Bot LW	0.7	0.0	0.0	287.1	1.8	0.0	1.4	0.4	1.4	0.0	53.2	0.4	0.0	0.0	0.4	0.0	0.0	0.4	0.4	0.0
Bastendorff 7/27 Top HW	0.7	0.0	0.0	5.4	0.0	0.0	10.0	2.1	0.0	0.0	23.6	0.0	0.0	0.0	0.0	0.0	18.6	1.8	0.0	0.0
Bastendorff 7/27 Bot HW	1.1	0.0	0.0	32.9	1.1	0.0	6.8	0.4	2.1	0.0	62.1	0.4	0.0	0.0	0.0	0.0	12.1	0.0	0.0	0.0
Bastendorff 7/27 Top MW	0.0	0.0	0.0	6.8	0.0	0.0	1.4	0.4	0.7	0.0	23.2	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bastendorff 7/27 Bot MW	0.0	0.0	0.0	94.3	0.4	0.0	2.1	1.8	0.4	0.0	46.4	3.6	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0
Bastendorff 7/27 Top LW	1.8	0.4	0.0	48.6	0.7	0.4	17.9	0.7	7.1	1.1	42.9	7.5	0.0	0.0	1.1	0.0	0.0	7.1	0.0	0.7
Bastendorff 7/27 Bot LW	5.7	0.0	0.0	42.9	8.2	0.0	0.0	5.7	28.9	8.6	217.1	20.0	0.0	0.0	0.0	0.4	0.0	2.9	0.0	0.0
Bastendorff 7/30 Top LW	0.0	12.9	0.0	5377.1	5.0	0.0	34.3	0.7	2.9	0.7	24.3	0.0	0.0	0.0	0.0	0.0	2.9	0.0	0.0	0.0
Bastendorff 7/30 Bot LW	3.6	30.0	0.7	7314.3	19.3	0.0	0.7	4.3	0.0	2.1	75.7	10.7	0.0	0.7	0.0	0.0	3.6	0.0	0.0	0.0
Bastendorff 8/2 Top LW	0.7	2.1	0.0	9742.9	3.6	0.0	2.1	0.0	3.6	2.1	37.1	0.7	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0
Bastendorff 8/2 Bot LW	0.0	5.7	0.7	10102.9	26.4	0.0	0.7	0.0	10.7	19.3	72.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bastendorff 8/13 Top LW	0.0	5.0	0.0	4205.7	57.9	1.4	55.0	2.9	16.4	0.0	54.3	2.9	0.7	0.0	0.0	0.0	27.1	165.0	0.0	0.0
Bastendorff 8/13 Bot LW	0.7	12.1	0.0	6817.1	180.0	1.4	37.9	2.1	23.6	5.0	66.4	7.9	0.0	0.0	0.0	0.0	5.7	10.7	0.0	0.0

Table 1. Continued.

Pleuronectes vetulus	Lycaeopsis themistoides	*Nephtys californiensis*	*Eohaustorius washingtonianus*	*Eyakia* sp.	*Mandilophoxus* sp.	*Tiron biocellata*	*Littorina plena*	Lophopanopeus bellus	Fabia subquatra	Upogebia pugettensis	Crangonidae zoea sp. 1	*Gnorimosphaeroma oregonensis*	*Jassa shawi*	*Cancer gracilis* or *antennarius*	*Pachycheles* sp.	*Stenolhoides burkanki*	*Achelia spinoseta*	Crangonidae megalopa sp. 1	Crangonidae zoea sp. 2	Aequorea aequorea	Cancer magister	Idotea montereyensis	Nereis vexillosa	Crangonidae megalopa sp. 2	*Sarsia* sp.
0.0	0.0	0.0	0.0	0.0	0.0	2.1	2.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.4	0.0	0.0	0.0	6.4	0.7	0.7	1.4	0.4	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.4	0.7	0.7	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.7	4.6	0.4	0.0	0.7	0.4	0.0	1.1	0.4	0.4	0.7	0.4	0.7	1.1	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.7	0.0	0.0	0.4	1.1	11.1	0.4	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.4	0.4	0.4	0.4	0.4	0.4
0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	2.5	2.1	0.7	0.4	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.4	0.0	0.4	0.0	0.0	0.0	0.0
0.0	3.2	0.0	0.7	0.0	0.0	0.0	9.6	0.4	0.0	0.0	0.4	0.0	2.1	0.0	2.5	0.7	0.7	1.8	0.0	0.4	0.0	0.0	0.0	0.0	0.0
0.0	0.7	0.4	2.1	0.0	1.4	0.0	6.8	0.4	0.0	0.0	1.1	0.0	1.1	0.0	2.5	0.0	1.1	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.7	0.0	0.0	0.0	0.7	0.0	7.1	0.4	0.0	0.0	0.0	0.0	2.5	0.0	0.4	0.4	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0
0.0	1.8	0.0	1.8	0.0	8.6	0.0	10.7	0.0	0.0	0.0	0.4	0.4	6.1	0.4	0.4	0.0	0.0	0.7	0.0	0.4	0.0	0.0	0.0	0.0	0.0
13.2	0.0	0.0	0.0	0.0	0.0	0.0	41.1	1.1	0.0	0.0	0.0	0.0	0.4	0.0	0.4	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.5	0.4	0.0	0.4	0.0	0.0	0.0	22.1	3.2	0.7	0.0	0.0	0.0	1.1	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0
1.1	0.0	0.4	0.0	0.0	0.0	0.0	31.8	1.4	0.7	0.4	0.0	0.0	8.9	0.0	0.4	0.0	0.4	0.4	0.0	0.0	0.4	0.0	0.7	0.0	0.4
0.4	0.4	0.0	0.0	0.0	0.4	0.0	48.6	2.1	1.8	0.0	0.4	0.0	18.6	0.0	1.4	0.0	0.0	0.4	0.0	0.0	0.4	0.0	2.1	0.0	0.0
0.0	0.4	0.0	0.0	0.0	0.0	0.0	12.1	0.4	0.0	0.0	0.0	0.0	5.0	0.0	1.1	0.0	0.4	0.4	0.0	0.0	0.4	0.0	0.4	0.0	0.0
0.0	0.4	0.0	0.7	0.0	0.0	0.0	24.3	0.7	1.8	0.0	0.0	0.0	14.3	0.0	2.5	0.0	1.8	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0
0.0	0.0	0.0	0.4	0.4	0.0	0.0	22.1	0.4	0.0	0.0	0.0	0.0	22.1	0.0	0.4	0.0	0.4	3.2	0.0	0.0	1.1	0.0	0.4	0.0	0.0
0.4	1.1	0.0	1.1	0.0	0.0	0.4	53.9	1.8	0.4	0.0	0.4	0.0	23.9	0.0	1.1	0.0	1.1	3.6	0.0	0.0	0.7	0.7	1.1	0.4	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.1	0.0	0.0	0.0	0.0	0.0	17.1	0.0	0.0	0.0	0.7	2.5	0.0	0.0	0.4	1.1	0.7	0.0	0.0
0.0	0.7	0.4	0.0	0.0	0.0	0.0	2.5	0.4	0.0	0.0	0.0	0.0	18.2	0.0	0.0	0.0	3.9	1.1	0.0	0.0	0.0	0.0	1.4	0.0	0.0
0.0	2.5	0.0	0.0	0.0	0.4	0.0	21.1	2.9	0.7	0.0	0.4	0.4	36.8	0.0	1.8	0.0	2.9	1.1	0.0	0.0	0.4	0.0	0.7	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.7	0.0	0.0	0.0	2.9	0.0	5.7	0.0	0.0
0.0	0.0	0.0	2.1	0.0	0.0	0.7	34.3	1.4	0.0	0.0	0.7	0.7	222.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.0
0.0	0.0	0.0	2.1	5.7	7.1	0.0	2.9	6.4	0.7	0.0	0.7	0.7	20.7	2.9	0.0	0.7	0.0	5.7	0.0	0.0	7.1	0.0	0.7	0.0	0.0
0.7	0.0	0.0	1.4	0.7	12.1	3.6	9.3	15.7	0.7	0.0	0.7	0.0	12.9	0.0	0.7	0.0	0.0	0.7	0.0	0.0	5.0	0.0	0.0	0.7	0.0
0.0	0.0	0.7	6.4	0.0	0.0	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.1	0.0	0.0	1.4	0.0	2.9	9.3	85.0	2.9	0.0	0.0	0.0	0.0	25.7	0.7	27.9	0.0	0.7	9.3	0.7	0.0	0.7	0.0	0.0	5.7	0.0
0.0	0.0	0.0	4.3	0.0	7.9	9.3	111.4	2.9	0.0	0.0	0.7	0.0	49.3	0.0	55.0	0.7	1.4	19.3	0.0	0.0	0.0	0.0	0.0	10.7	0.0

Table 1. Continued.

Spionidae sp.	Amphistichus rhodoterus	Leptocottus armatus	Caprella incisa	*Cumella* sp.	Cephalopoda egg case	*Thaleichthys pacificus* (larva)	Siliqua patula	Scrippsia pacifica	Placida dendritica	*Sagitta* sp.	Anoplodactylus oculospinus	Porcenallidae megalopa	*Cancer* zoea	Caprella equilibra	Phoxichilidium femoratum	Paguristes turgidus	Caprella verrucosa	Exosphaeroma amplicauda	Laniropsis derjugini	*Diastylis* sp.	Lissocrangon stylirosris	*Hesionura* sp.	*Abarenicola* sp.	Hemigrapsus orogenensis	Euphausia pacifica
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.7	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	3.6	0.0	0.0	0.0	0.0	0.4	0.0	0.0	5.0	0.0	0.0	3.9	0.4	0.4	1.1	0.4	1.1	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.4	0.7	0.4	0.0	0.0	0.0	0.0	0.0	0.0
0.4	0.0	0.0	2.9	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.4	0.4	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0
2.5	0.0	0.0	4.3	0.0	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	1.4	0.0	0.0	0.4	0.0	0.7	0.4	0.0	0.0	0.0	0.4	0.0
0.0	0.0	0.0	2.5	0.0	0.4	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	1.1	0.0	0.0	0.4	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	3.9	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	1.8	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	6.8	0.0	0.0	0.0	1.4	0.0	0.0	6.8	0.0	0.0	0.0	2.1	0.0	0.0	0.7	0.0	1.4	0.4	0.0	0.0	0.0	0.0	0.4
0.0	0.0	0.0	40.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.6	0.0	0.0	0.0	0.0	2.9	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	1.4	0.7	1.4	0.0	0.0	0.0	0.0	0.0
1.4	0.0	0.0	7.9	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.7	2.1	0.0	0.7	0.7	1.4	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.7	0.0	0.0	5.7	0.0	0.0	0.0	31.4	0.0
0.0	0.0	0.0	0.7	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	5.7	0.0
1.4	0.7	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	11.4	0.0	0.0	0.0	4.3	0.0	6.4	0.0	0.0	0.0	5.0	0.0

Table 1. Continued.

Neotrypaea californiensis	Insect sp. 1	N.I. Egg	*Lacuna* sp.	Metacaprella anomala	Munna stephenseni	Upogebia pugettensis	Euphausia mutica	Nematoda sp 1	*Idotea* sp.	Dynamennella sheareri	Unknown/Hemichordate	Synidotea pettiboneae	Leptocottus armatus	Balanus glandula	Dogielinotus loquax	Exosphaeroma nornata	Nereis vexillosa	Majidae sp.	Atylus sp.	*Orbiniidae* sp.	Upogebia pugettensis	Gasterosteus aculeatus	Corophium sp	Mytilus sp.	Cancer orogenensis /productus	*Sipuncula sp.*
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3.2	1.4	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.3	1.1	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.4	0.4	0.0	1.1	0.7	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.7	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.4	0.0	2.9	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.0	0.0
0.0	0.0	0.0	3.9	1.4	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0
7.1	0.0	0.4	1.1	1.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	0.0	0.0
7.5	0.0	0.0	0.7	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0
0.0	0.4	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.4	0.0	0.0
0.0	0.0	0.0	1.8	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0
11.8	0.0	0.0	1.1	3.6	0.0	0.4	0.0	0.0	0.0	0.0	0.4	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.7	0.0	0.0
2.9	0.0	0.0	11.4	0.0	2.9	0.0	0.0	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.7	0.0	0.7	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	1.4	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	1.4	0.0	10.7	2.9	0.0	0.0	0.0	0.0	6.4	6.4
5.7	0.0	0.0	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.7	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.7	0.7	1.4	0.0	1.4	1.4
18.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	2.1

Table 2. Swimming surf zone macrofauna densities (ind./1000m^2) observed at three dissipative sandy beaches of southern Oregon during the summer of 2006.

Beach/Tide/Date	*Idotea fewkesi*	*Lissocrangon stylirosris*	*Polyorchis penicillatus*	*Pleurobrachia* sp.	*Pleuronectes vetulus*	*Obelia* sp.	*Emerita analoga*	*Cancer gracilis* or *antennarius*	*Cancer magister* (megalopa)	*Oncorhynchus tshawytscha*	*Sardinops sagax*	*Hyperprosopon ellipticum*	*Amphistichus rhodoterus*	*Leptocottus armatus*	*Traleichthys pacificus*	Cephalopoda egg case	*Hypomesus pretiosus*	*Engraulis mordax*	*Scrippsia pacifica*	*Cancer magister* (adult)
Bastendorff HW 6/7	0	26	1	3	2	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bastendorff MW 6/7	0	27	1	9	7	257	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Bastendorff LW 6/7	0	41	0	21	24	29	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Bastendorff HW 7/22	0	0	0	0	0	0	4	0	0	9	1	1	0	0	0	0	0	0	0	0
Bastendorff MW 7/22	0	4	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Bastendorff LW 7/22	0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Bastendorff HW 07/27	0	24	0	0	1	0	12	0	1	1	0	0	0	0	0	1	0	0	0	0
Bastendorff MW 07/27	0	115	0	0	0	0	5	0	0	1	0	0	0	0	0	1	1	0	0	0
Bastendorff LW 07/27	1	113	0	0	3	0	0	0	0	6	1	0	0	0	0	3	0	0	0	4
Bastendorff LW 07/30	0	296	0	0	1	0	4	0	0	0	0	1	1	1	1	0	0	0	0	2
Bastendorff LW 8/2	0	193	0	0	1	0	2	0	1	1	0	0	1	0	0	0	0	0	0	0
Bastendorff LW 08/05	0	9	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Bastendorff LW 08/09	0	1	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Bastendorff LW 8/13	1	927	0	1	3	0	0	0	1	3	0	0	0	0	0	0	0	0	0	1
Bastendorff LW 08/18	0	4	0	1	1	305	0	1	0	0	0	0	0	3	0	0	0	0	0	0
Bastendorff LW 08/25	0	64	0	1	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0
Bastendorff LW 09/01	0	21	2	0	1	0	0	0	0	16	0	0	0	0	0	0	0	1	0	1
Bastendorff LW 09/08	1	173	2	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Bastendorff LW 09/15	0	14	2	8	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Bastendorff LW 09/29	0	18	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Horsfall LW 06/30	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Whisky Run LW 07/01	0	4	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Whisky Run LW 08/05	0	3	0	0	6	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0

Table 3. Stomach contents of 48 juvenile Chinook salmon.

Chinook salmon individuals	*Jassa shawi*	Gammaridea sp.	*Allorchestes angusta*	*Ampithoe lacertosa*	*Americhelidium micropleon*	*Atylus tridens*	*Carinonajna barnardi*	*Lycaeopsis themistoides*	*Archaeomysis grebnitzkii*	*Excirolana chiltoni*	Insect	*Dogielinotus loquax*	*oregonensis/productus*	*Euphausia pacifica*	*Tiron biocellata*	*Megalorchestia pugettensis*	*Lophopanopeus bellus*	*Caprella incisa*	*Caprella equilibra*	*Caprella verrucosa*	Caprellidea sp	Crangonidae megalopa sp. 1	Crangonidae megalopa sp. 2	*Crangonidae juv/post*	*Pycnogonida sp.*	*Metacaprella anomala*	*Leptocottus armatus*	*Engraulis mordax*	*Mytilus* sp.
1	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	3	4	0	0	0	3	0	0	0	0	3	2	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	4	1	0	0	0	1	0	0	1	2	3	0	3	0	0	0	8	0	0	0	1	0	0	0	0	0	0	0	0
4	0	2	0	0	0	0	0	0	2	3	3	22	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0
5	2	3	0	0	0	0	0	0	3	1	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	4	0	0	0	0	0	1	0	0	4	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
7	1	2	0	0	0	0	0	0	1	1	5	2	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	1	17	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	1	0	0	0	0	0	0	0	8	4	3	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
10	2	2	0	0	0	0	0	0	0	0	3	4	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
11	2	0	0	0	0	1	0	0	2	0	7	4	3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
12	1	0	1	0	0	0	0	1	1	0	3	12	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
13	3	0	1	0	0	0	0	1	0	0	3	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	24	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	4	2	2	0	0	0	0	0	0	0	0	0
15	35	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	17	0	1	1	0	2	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
17	11	0	0	0	0	2	0	0	0	0	0	3	0	0	0	0	1	3	0	0	0	0	0	0	0	2	0	0	0
18	10	0	0	2	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0
19	7	1	0	1	0	7	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
20	5	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
21	0	0	0	0	0	2	0	2	8	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0
22	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0
23	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0
24	10	2	0	0	0	39	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0

Table 3. Continued.

25	3	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	2	0	0	0	0	64	0	0	9	0	2	0	0	0	0	0	10	0	0	0	0	4	0	1	0	0	0	0	0
27	2	0	0	0	0	73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	1	38	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	4	0	0	0	0	32	0	0	18	0	0	0	0	0	0	0	23	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0
31	3	0	0	0	0	24	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	3	0
32	2	0	0	0	0	61	0	0	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
33	7	0	0	0	0	58	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0
34	2	0	0	0	0	91	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	5	0
36	1	0	0	0	0	43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
37	2	0	0	0	0	16	0	0	16	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	26	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0
39	1	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	6	0
40	2	0	0	0	0	37	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0
41	2	0	0	0	0	3	0	0	83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	0	0	0	0	0	11	0	0	5	0	0	1	0	0	0	0	33	0	0	0	0	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0
45	0	0	0	0	0	11	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0
46	0	0	0	0	0	100	0	0	1	2	0	0	0	0	0	0	2	0	0	0	0	4	0	0	0	0	0	0	1
47	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0
48	0	0	0	0	0	22	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	2	0	0	0	0	0

Table 4. Stomach Content Analysis of 61 juvenile English sole caught at three dissipative sandy beaches.

	Archaeomysis grebnitzkii	*Atylus tridens*	*Lissocrangon stylirostris*	*Jassa shawi*	*Ampithoe lacertosa*	*Dogielinotus loquax*	*Lophopanopeus bellus*	*antenarius/gracilis*	*Euphausia pacifica*	Gammaridea sp.	*Diastylis* sp.
1	5	0	0	0	0	0	0	0	0	0	0
2	0	0	0	1	0	0	0	0	0	0	0
4	1	0	0	0	1	0	0	0	0	0	0
5	12	0	0	0	0	1	0	0	0	0	0
6	7	0	0	0	0	1	0	0	0	0	0
7	12	0	0	0	0	0	1	0	0	0	0
8	2	0	1	0	0	1	0	0	0	0	0
9	0	0	1	0	0	0	0	0	0	0	0
10	1	2	0	0	0	0	0	0	0	0	0
11	6	0	0	0	0	0	0	1	0	0	0
12	1	0	0	1	0	0	0	0	0	0	0
13	0	1	0	0	0	0	0	0	0	0	0
14	1	1	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0
16	1	0	0	0	0	0	0	0	0	0	0
17	0	3	0	0	0	0	0	0	0	0	0
20	1	0	0	1	0	0	0	0	0	0	0
21	3	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0
23	0	1	0	0	0	0	0	0	0	0	0
24	1	0	0	0	0	0	0	0	1	1	0
26	1	0	0	1	0	0	0	0	0	0	0
27	1	0	0	0	0	0	0	0	0	0	0
28	1	1	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0
33	2	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0
36	2	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0	0	0	0
45	3	0	0	0	0	0	0	0	0	0	0
46	1	0	0	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0	0	0	0
49	0	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0
57	0	0	0	0	0	0	0	0	0	0	0
58	0	0	0	0	0	0	0	0	0	0	0
60	0	1	0	0	0	0	0	0	0	0	1
61	1	0	0	0	0	0	0	0	0	0	0

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