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RECRUITMENT AND COLONIZATION OF MACROALGAE TO A NEWLY CONSTRUCTED ROCKY INTERTIDAL HABITAT IN THE NORTHWEST GULF OF MEXICO

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ABSTRACT: Marine macroalgal assemblages on artificial structures play an important ecological role in coastal and estuarine ecosystems and may supplement natural communities in nearby waters. The rocky jetties of Packery Channel, located near Corpus Christi, Texas represent a recent addition of hard structure for colonization in the northwest Gulf of Mexico. The purpose of this research was to monitor the initial immigration of macroalgal species during the first year of colonization and determine the effects of wave energy on recruitment. Ten sampling sites were established along the offshore portion of the new Packery Channel jetties. Samples were taken bimonthly from along a 10 m transect between September 2006 and July 2007, with quadrats (20 x 30 cm) sampled every meter by destructive harvesting techniques. Biomass data obtained from this study assess composition and establish a timeline for algal recruitment. Within the first year macroalgal richness was found to be 40 species. Multivariate analyses show strong linkages between rate of recruitment and site location. Sites with the highest level of wave energy exhibited significantly increased biomass and simultaneous decreased richness values, indicating recruitment is affected by wave energy at a microhabitat scale.

INTRODUCTION

Granite jetties, found along the mouth of inlets, serve to stabilize channels. By extending beyond the sandbars and breaking waves, jetties allow for calmer waters within the channels and help to stabilize the channel itself. The granite rocks also serve an additional function of providing habitat for an array of organisms. Along the Texas coast, jetties offer a significant source of hard substratum for attached macroalgae. Over 80 species of macroalgae have been reported from a single jetty community in Texas (Baca et al. 1979, Edwards 1976, Edwards and Kapraun 1973, Kaldy et al. 1995).

Dispersal of seaweed propagules, including those of macroalgae, is influenced by a variety of physical and biological factors (Gaylord et al. 2002). Coastlines exhibit complex hydrodynamic conditions such as upwelling and long-shore drift. These processes make it difficult to understand dynamics such as colonization, persistence, and post-disturbance recovery. Most seaweed propagules are able to settle immediately upon release, and the majority are thought to settle within a few days (Santelices 1990). Most long-distance transport of species is actually thought to occur via drifting plants or fertile fragments carried by currents (Chapman 1986, van den Hoek 1987).

The algal flora of Texas is largely of tropical affinity. However, there is a distinct cool temperature flora that develops during the winter and early spring (Edwards and Kapraun 1973). The result is a Texas coast with a variation of macroalgae characteristic of both the northern Gulf of Mexico (GOM) and the tropics. A recent study of the macroalgae of the Port Mansfield jetties, located about 129 km to the south of Packery Channel, reported 14 species that had not been previously recorded for the area, increasing the rich-

ness of that pass to 50 species (Klootwyk 2006). Several of these species had been previously recorded for the Port Aransas area (e.g., *Gelidium pusillum* and *Gracilaria tikvahiae*), while others had only been found to the south near Port Isabel (e.g., *Codium taylorii*). Studies are therefore needed to document the presence or absence of algal species for Packery Channel. Data from this study will aid in understanding dispersal patterns of macroalgae along the Texas coast.

The assessment of flora recruiting to jetties during the initial stages of habitat development is very important. Hard substratum provides a large vertical relief and support for dense covers of attached microalgae (periphyton), macroalgae, and epifauna (Fikes and Lehman 2008a). These communities influence food webs and affect benthic productivity by increasing the deposition of organic matter around hard structures (Atilla et al. 2003) as well as providing a food source and refuge.

Describing algal composition and colonization is an important step in understanding marine ecosystem function. There are general patterns of early colonizers, such as ephemeral algae (e.g., *Porphyra*, *Ulva*), being gradually replaced by larger perennial algae (e.g., coralline algae) (Chapman and Underwood 1998). In New South Wales, Australia, results demonstrate that there is no simple seasonal or biogeographical pattern in the development of algal assemblages, which indicate the importance of small-scale influences.

Models have been developed showing that the productivity potential of an algal-dominated system increases with decreased disturbance (Steneck and Dethier 1994). In intertidal communities this may explain cosmopolitan trends of low diversity in high energy habitats. The jetty system of Packery Channel contains varying levels of wave

energy dependant upon site location. The present study further looks at the affect of these energy levels on the colonization patterns of a developing macroalgal community.

MATERIALS AND METHODS

Study site

Packery Channel is located on Padre Island, near Corpus Christi, Texas and connects the GOM to the Laguna Madre (Figure 1). Construction of the jetties and the dredging of Packery Channel were completed in late September 2006. The pass and its entrance are stabilized by jetties composed of stacked granite blocks, which extend about 427 m out from the shoreline. The channel that runs the length of the pass is about 43 m wide and 3.5 m deep (U.S. Army Corps of Engineers 2003). The base of

nel completion resulted in a lack of submerged substrate suitable for algal growth. For this reason, data from sampling sites 5 and 6 are not presented. GPS waypoints were recorded for use in site identification and spray paint was applied to the granite substrate above the high tide level to mark sampled sections of jetty. This was done in order to reduce the risk of duplicate sampling at one location.

Replicates sites were identified for each of 4 energy levels: high, moderate, low, and protected. Sites 1 and 2 were considered high energy, sites 3 and 8 were considered moderate energy, sites 9 and 10 were considered low energy, and sites 4 and 7 were considered protected. A flow meter was originally used to measure differences in energy levels between sites, but was proven to be unsuccessful at those sites with large amounts of wave energy. Sites were therefore distinguished by making visual observations of wave amplitude, turbidity, and current. Due to the southeasterly nature of the winds in this region, sites to the south of the jetty system received more energy than those to the north.

Bimonthly sampling took place between 15 September 2006 and 22 July 2007. At each site, vertical transects consisting of polypropylene braided rope marked every meter were used. Transects began with the high tide line and continued over the granite substrate for 10 m (or until the granite blocks met the sandy substratum). At each marking, a 20 x 30 cm area was scraped clear of any material within the margins of a copper tubing quadrat. Spray paint was used to mark each transect location, and successive sampling events were conducted about 1 m away from the previous sampling location. The first sampling event utilized an airlift to assure that no macroalgal materials were overlooked. Material obtained from the destructive sampling was collected in pre-numbered mesh "bio-bags" (500 μ m) as it was scraped from the granite substrate. Once transferred to pre-labeled field jars, samples were preserved with 2% glutaraldehyde and seawater solution. Spatial and temporal patterns in biomass for all species were determined by analyzing dry weights.

Data analysis

Algal biomass density (g/m^2), expressed as the mean density from all quadrats sampled at each site for each month, was analyzed with analysis of variance (ANOVA, $\alpha = 0.05$) using the general linear model procedure in SAS 9.1. We used a factorial design with 2 main fixed treatment effects, month (sampling period, 6 events), and site (position on jetty, 8 locations). The distribution of the residuals was analyzed using the UNIVARIATE procedure, and data were transformed ($\log_{10}(x+1)$) to minimize heteroscedasticity. We expected to see a site-month interaction term, and therefore explored the relationship further by conducting 2 separate one-way ANOVA models if a significant interaction was observed. Mean differences among months and sites were tested using Tukey's HSD ($\alpha = 0.05$).

Community data were analyzed with PRIMER v6 (Plym-

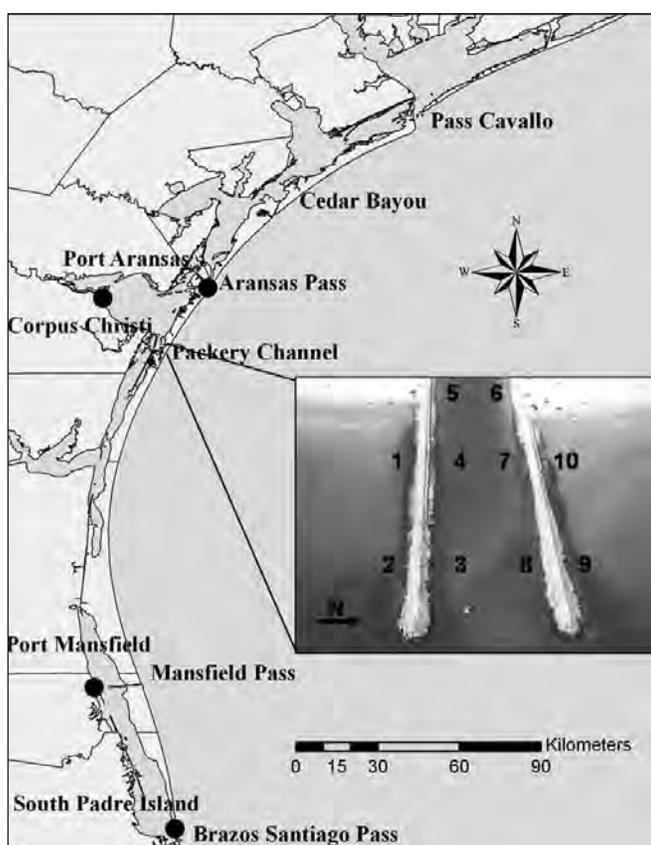


Figure 1. Packery Channel in relation to the Gulf of Mexico and the Texas coast. Inset: image of Packery Channel jetties with the sampling sites indicated.

the north jetty is located at 27°36.836'N, 97°12.044'W.

Sampling techniques

Both the channel and the gulf sides of the north and south jetties were examined. Five sites were selected on each of the jetties (Figure 1); however, only 4 sites were sampled on each, 2 on the Gulf side and 2 on the channel side. This was a result of immediate sediment accumulation at 2 of the channel sites, those recessed beyond the shoreline. Accretion above the low tide mark upon chan-

TABLE 1. Taxonomic list of confirmed species collected for Packery Channel study. Systematics follow Wynne (2005).**Rhodophyta**

CERAMIALES

Ceramiaceae

- Aglaothamnion halliae* (Collins) N. Aponte, D.L. Ballant. & J.N. Norris
Centroceras clavulatum (C. Agardh. in Kunth) Mont. in Durieu de

Maisonneuve

- Ceramium flaccidum* (Kütz.) Ardis
Ceramium cimbricum H.E. Petersen in Rosenv.
Spyridia hypnoides (Bory in Belanger) Papenf.

Rhodomelaceae

- Bryocladia cuspidata* (J. Agardh) De Toni
Bryocladia thyrigera (J. Agardh) F. Schmitz in Falkenb.
Chondria dasyphylla (Woodw.) C. Agardh
Chondrophyucus poiteaui (J.V. Lamour.) K.W. Nam
Digenea simplex (Wulfen) C. Agardh
Polysiphonia denudata (Dillwyn) Grev. ex Harv. in Hook.

CORALLINALES

Corallinaceae

- Jania adhaerens* J.V. Lamour.
Haliptilon cubense (Mont. Ex Kütz.) Garbary & H.W. Johans

GELIDIALES

Gelidiaceae

- Gelidium pusillum* (Stackh.) Le Jolis
Pterocladia bartlettii (W.R. Taylor) Santel.

GIGARTINALES

Hypneaceae

- Hypnea musciformis* (Wulfen in Jacquin) J.V. Lamour.
Hypnea spinella (C. Arardh) Kütz
Hypnea valentiae (Turner) Mont.

Solieriaceae

- Agardhiella ramosissima* (cf.) (Harv.) Kylin
Agardhiella subulata (C. Agardh) J. Agardh

GRACILARIALES

Gracilariaceae

- Gracilaria tikvahiae* McLachlan
Hydropuntia caudata (J. Agardh) Gurgel & Fredericq

HALYMENIALES

Halymeniaceae

- Grateloupia filicina* (J.V. Lamour.) C. Agardh
Grateloupia pterocladina (M.J. Wynne) S. Kawaguchi &
 H.W. Wang in Wang *et al.*

RHODYMENIALES

Rhodymeniaceae

- Champia* (cf.) *parvula* (C. Agardh) Harv.

Ochrophyta

DICTYOTALES

Dictyotaceae

- Dictyota menstrualis* (Hoyt) Schnetter, Hörnig, & Weber-Peukert

ECTOCARPALES

Acinetosporaceae

- Feldmania indica* (Sond.) Womersley & A. Bailey

Ectocarpaceae

- Ectocarpus siliculosus* (Dillwyn) Lyngb.

Scytosiphonaceae

- Petalonia fascia* (O.F. Müll.) Kuntze

Chlorophyta

BRYOPSISDALES

Bryopsidaceae

- Bryopsis pennata* J.V. Lamour
Bryopsis plumosa (Huds.) C. Agardh

CLADOPHORALES

Cladophoraceae

- Chaetomorpha aerea* (Dillwyn) Kütz.
Chaetomorpha linum (O.F. Müll.) Kütz.
Cladophora albida (Nees) Kütz.
Cladophora dalmatica Kütz.
Cladophora ruchingeri (C. Agardh) Kütz.
Cladophora vagabunda (L.) C. Hoek

ULVALES

Ulvaceae

- Ulva fasciata* Delile
Ulva flexuosa Wulfen
Ulva lactuca L.

outh Routines in Multivariate Ecological Research, Plymouth Marine Lab). Algal species were ordinated by site and date combinations, and multidimensional scaling (MDS) and hierarchical clustering with the group-average procedure were used to compare biomass values between sites and sampling months using the Bray–Curtis similarity coefficient.

A one-way analysis of similarities (ANOSIM), using individual plot biomass density (g/m^2) data, was used to test between groups of samples by site and month. Resemblance similarity data were analyzed using Global R and p-values in a pairwise manner to compare species biomass among sites and months. SIMPER analysis was used to test for community dissimilarity between variables for sampling site and month. These data were used to break down the similarity matrix and determine which species of algae were responsible for dissimilarity between sites and months.

RESULTS**Species richness**

This study resulted in the initial identification and confirmation of 40 species of macroalgae growing along the rocky jetties of Packery Channel, Corpus Christi, Texas (Table 1). This represents 25 species of Rhodophyta (9 families), 4 species of Ochrophyta (4 families), and 11 species of Chlorophyta (3 families). Cheney's Floristic Ratio was found to be 9, indicating a highly tropical flora.

Species richness by sites over time showed an immediate abundance of macroalgal species occurring early in the study, indicating that a number of species were quick to recruit to the newly available granite substrate. Overall, January was the time of highest richness in this study, and species richness began to decrease after March as the warmest months of the year approached. Site 9 was the only site which did not follow these typical trends, exhibiting the highest richness in May. The sampling events with the greatest richness were site 7 in March and site 4 in January with 23 species each (Figure 2). Site 7 exhibited the overall highest richness of 33 species.

Biomass

A significant site–month interaction was detected in the two–way ANOVA model (ANOVA: $F = 2.98$, $df = 35$, $p < 0.001$). This was expected, as sites colonized differently between sampling months and locations. Subsequent one-way ANOVA identified significant differences between months (ANOVA: $F = 6.92$, $df = 5$, $p < 0.001$), with higher biomass during the cooler months (Figure 3A) and sampling sites (ANOVA: $F = 17.14$, $df = 7$, $p < 0.001$), with higher biomass at the higher wave energy sites (Figure 3B).

The mean total algal biomass collected for this study was about $197.4 \text{ g}/\text{month}$. The highest overall collected grand mean algal biomass density was in March 2007 ($112.83 \text{ g}/\text{m}^2$). Site 1, the highest energy site, had the highest overall collected grand mean algal biomass density of $114 \text{ g}/\text{m}^2$, and site 9, a low energy site, had the lowest overall collected grand mean

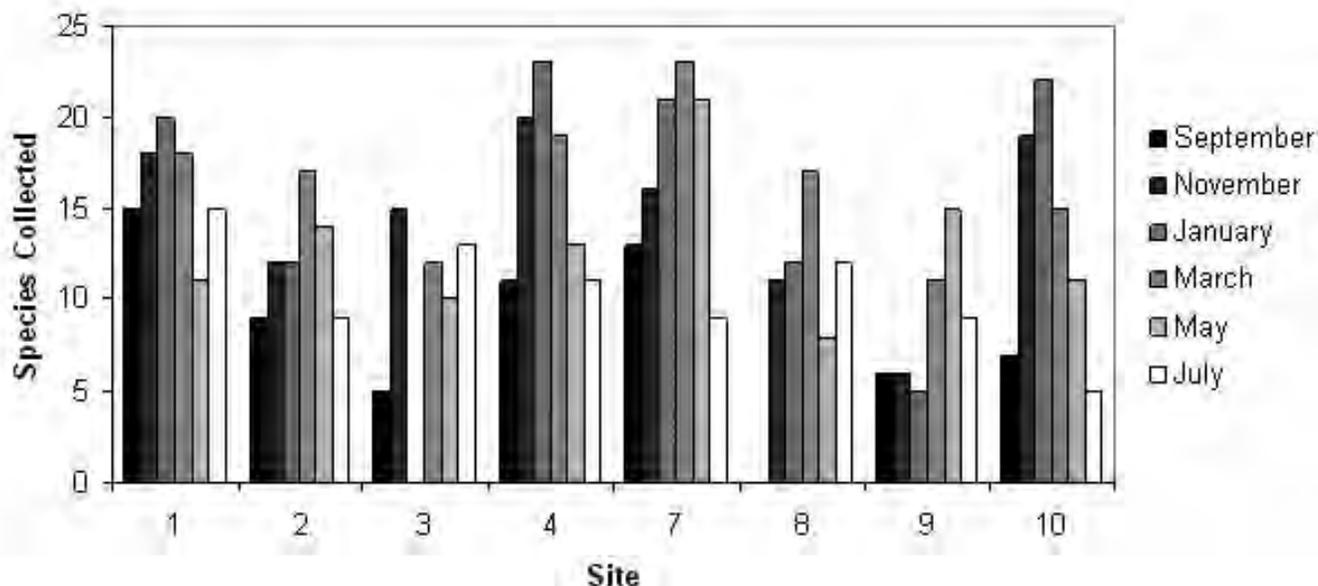


Figure 2. Species richness totals by site for each sampling month for the study.

algal biomass density of 15.5 g/m² (Figure 3). Rhodophyta made up the highest percentage of initial biomass (93.1%), followed by Chlorophyta (6.7%) and Ochrophyta (0.2%).

Monthly biomass values indicate that there was much variation in algal abundance throughout the year and between sites. Individual sites were dominated by Rhodophyta, with the exception of site 9 in March and May, where Chlorophyta was dominant. On 3 separate occurrences, all quadrats along a transect were fully devoid of algal growth, which account for a biomass of zero for that sampling event.

Community analysis

Cluster analysis (Bray-Curtis) for sites showed about a 48% similarity between all sites for species data, including data for the duration of the study (Figure 4). All sites, with the exception of site 9, were found to be about 57% similar. Sites 10 and 4 had the highest overall similarity (~80%), followed by sites 3 and 8 (~74%) and sites 1 and 2 (~73%).

Cluster analysis (Bray-Curtis) for sampling months revealed about a 67% similarity between all months for species data, including data for the duration of the study (Figure 5). All sampling months, with the exception of September, were found to be about 70% similar. November 2006 and January 2007 had the highest overall similarity (~83%), followed by May and July 2007 (~72%).

Pairwise comparisons revealed a highly significant site-effect on species biomass (Global R = 0.183, p = 0.1%). SIMPER showed that sites 1 and 9 were the most dissimilar (98.13%) and shared only 17 similar species (Table 2). Mean within-site similarity was about 26%.

ANOSIM revealed a significant month effect on species biomass (Global R = 0.057, p = 0.1%). SIMPER analysis shows that September 2006 and July 2007 were

the most dissimilar (85.92%) and shared only 16 similar species. Mean within-month similarity was about 30%.

Community analysis by site over time shows a trend in increasing community stabilization (Figure 6). Initially, sites in close proximity spatially to one another were found to exhibit up to an 80% similarity. When comparing all sites, however, they were only about 40% similar. By the end of the study, sites within close proximity were found to be no more than 60% similar, but overall similarity between sites had increased to 60% similarity. Site 9 was a clear outlier for assemblage data and was excluded in this analysis.

Second-stage MDS analysis conducted on only protected and high energy treatments showed a pronounced separation (Figure 7). Wave energy is clearly shown to affect community development.

Species contributions

The most abundant alga of this study was *Bryocladia thyrsgera*, contributing the highest overall biomass with 340.6 grams dry biological weight (28.8% of overall collected biomass). *Grateloupia filicina* followed with 309.2 grams dry weight (26.1% total biomass), and *Bryocladia cuspidata* with 183.9 grams dry weight (15.5% total biomass). These three species combined made up 70.4% of the total collected biomass for this study.

Using MDS analysis and cluster overlays (percentages), many species were found to vary significantly between sites. Generally, species tended to decrease in abundance when moving from south to north, with sites 1 and 2 having the highest biomass. This was true for most top contributors, such as *B. thyrsgera*, *B. cuspidata*, and *G. filicina*. Sites 8 and 9 exhibited some exceptions in higher biomass of some calm-water (low energy) species such as *Ulva flexuosa* and *Ectocar-*

pus siliculosus. Species which contributed most to overall site differentiation (SIMPER) tended to be those species that exhibited the most variation in site percent composition.

Further analysis using MDS plots and resemblance overlays showed that some species also varied significantly between sampling months. Eurythermal species such as *G. filicina* and *B. thysigera* remained present year round, whereas species such as *Petalonia fascia* and *U. flexuosa* varied considerably over the course of the year. Twenty of the 39 species examined were found to recruit during the first month after jetty completion. Only one species, *Chaetomorpha linum*, was found to recruit during the latter part of the study (July 2007).

DISCUSSION

This study shows that bare substrate along the Texas coast colonizes rapidly and that wave energy (exposure) directly af-

fects community structure and development in macroalgal assemblages. Species richness for this study was expected to increase over time, as would be seen in any habitat during the early stages of development. After only one year, species richness for Packery Channel (40) was found to be similar to that of Port Mansfield Pass (37) which has a well-developed macroalgal community (Klootwyk 2006). All species identified for Packery Channel have been reported from either Port Aransas, Port Mansfield, or both, with the exception of *Agardhiella ramosissima*. It is interesting to note that these data promote the idea that species recruiting to Packery Channel may come from both locales. There is also the potential for algae to recruit from additional hard substrate such as oil platforms and natural rock banks (i.e., 7 ½ Fathom Reef, about 86 km from the Packery Channel jetties).

Seasonality of macroalgae in warm-water regions is often related to temperature and desiccation (Mathieson et al. 1981, Mathieson and Penniman 1986). Species like *P. fascia* are only found during the cooler months, whereas species such as *U. fasciata* occur only during the warmer months. These shifts in species presence data directly add to the changing richness over time. Additionally, prevailing wind-driven near-shore currents along the Texas coast shift between summer and winter. These directional changes in wind-driven currents may further explain species recruitment patterns.

Results show an overall increase in biomass with an increase in wave energy. This indicates that energy, and not depth, determined the biomass potential for the algal community of Packery Channel. Edwards and Kapraun (1973) found that exposure to wave energy did not strongly influence species composition between sites along the Port Aransas jetties. The Port Aransas area has been described to have a richness of 88 species (Edwards 1976), much greater than Port Mansfield (37) and Packery Channel (40). Klootwyk (2006) found that sites exhibiting algal growth at greater depths also showed an overall increase in average biomass, although data taken from quadrats occupying the upper meter of the water column showed no significant difference between sites.

Cheney's Floristic Ratio was found to be 9.0 for this study which is exceptionally high when compared to other macroalgal communities from the Gulf Coast (Table 3). Temperature is the major factor controlling geographical distribution of marine algae (Edwards and Kapraun 1973) and, therefore, high ratios (meaning a more tropical flora) should be found progressing from north to south. This finding for Packery Channel may be inaccurate due to an incomplete development of the community structure since water temperature for this study ranged from 11–29.5°C (Fikes 2008), which is uncharacteristic of a tropical environment. Cheney's Floristic Ratio was designed to characterize established communities, an attribute that Packery Channel has not yet achieved.

Low biomass during late summer months is likely a result of increased stress in the form of heat and desiccation on

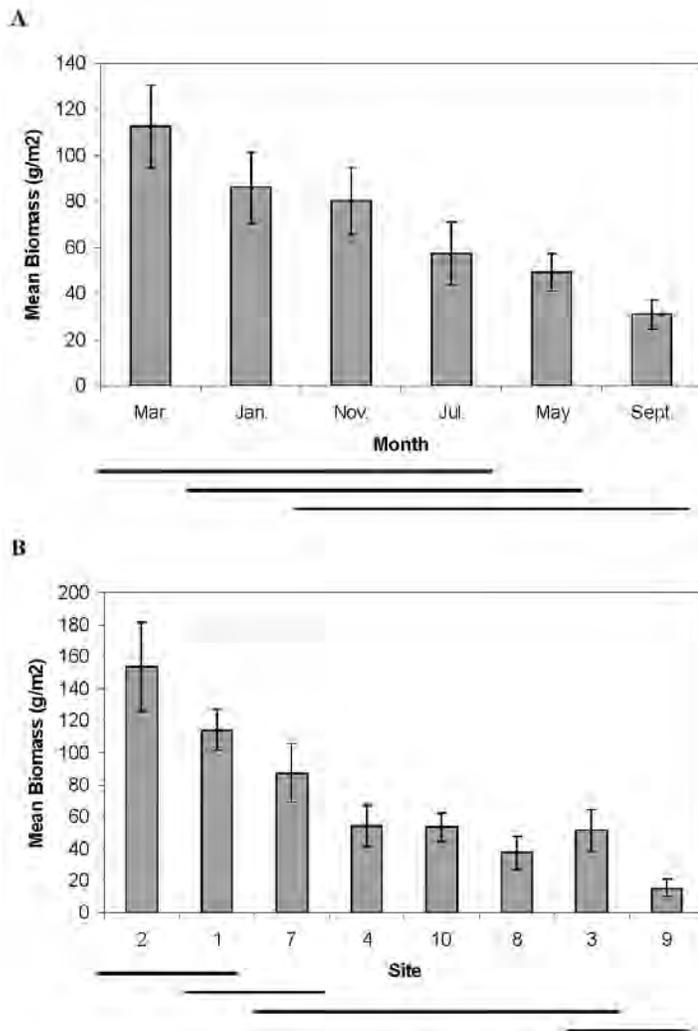
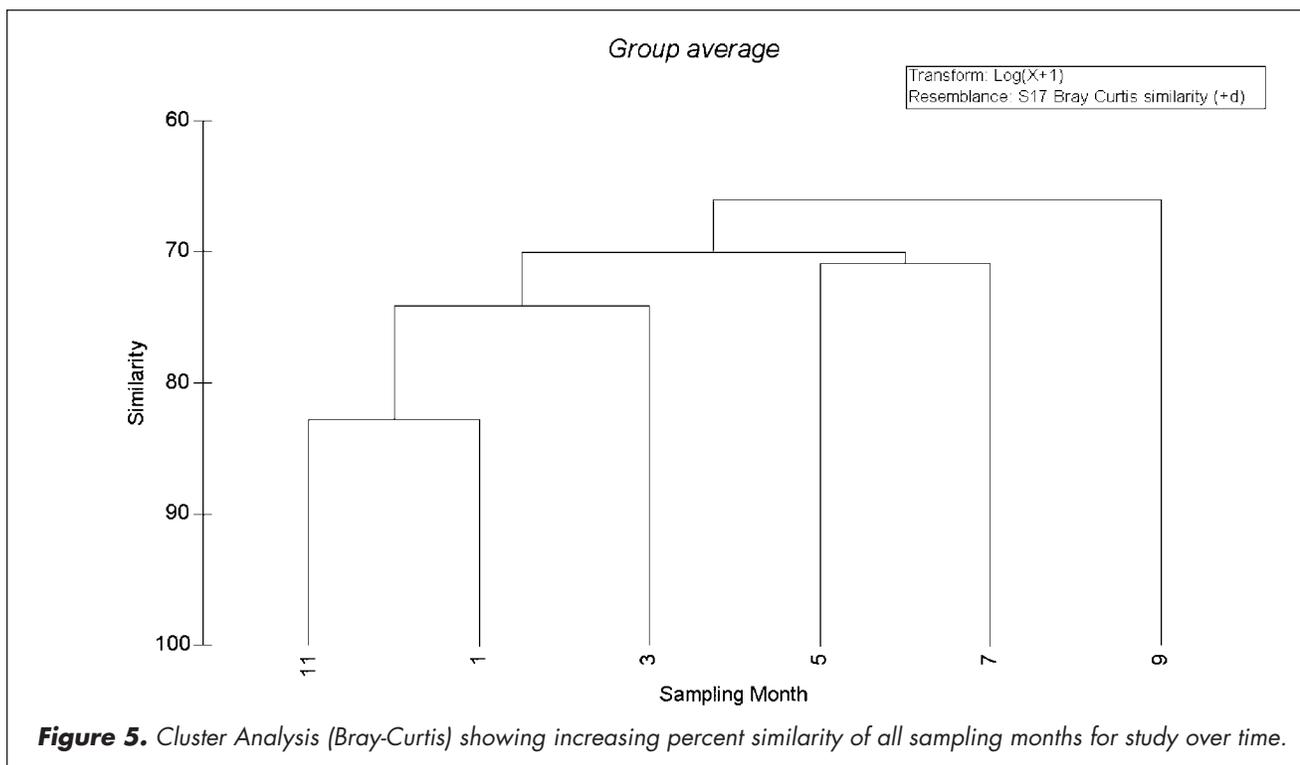
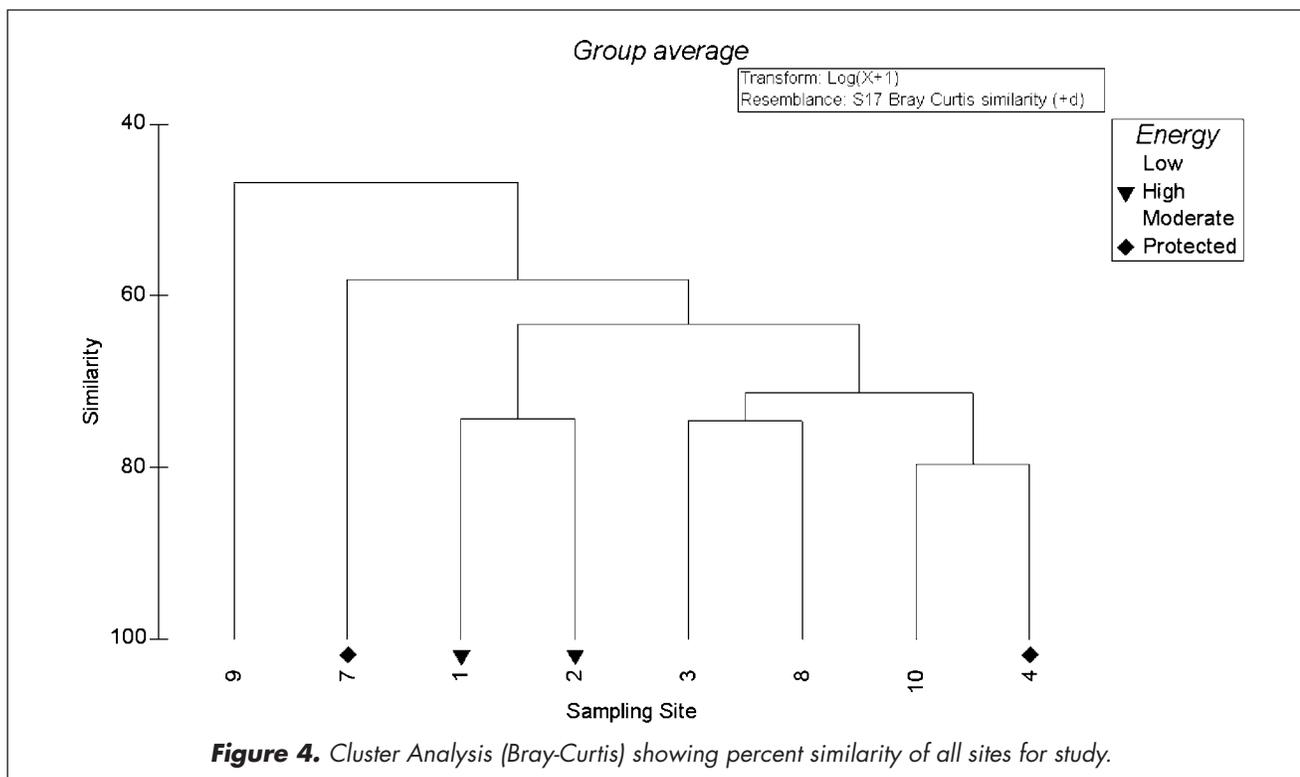


Figure 3. Algal biomass (grand mean \pm se) in relation to (A) sampling month for all sites and (B) sampling site for all sampling months. Sites are arranged from high energy (left) to low energy (right). Horizontal lines below graph show significant differences between months and sites (ANOVA, $p < 0.001$); bars sharing lines are not significantly different (Tukey's post-hoc test $\alpha = 0.05$).



macroalgal productivity (Dawes 1981, Edwards and Kapraun 1973, Round 1981, Kaldy et al. 1995). In this study biomass reached its peak during the spring, with a significant decrease in May. The overall decrease in summer biomass coincided with a decrease in species richness. Benz et al. (1979) found that there is little correlation with a single environmental factor, suggesting a synergistic effect on biomass.

Site differences in this study may be representative of varying levels of wave energy. Agan and Lehman (2001) found that Rhodophyta dominated algal coverage along the Port Aransas jetties. These authors also found that Rhodophyta abundance was greater along the channel side of the jetty (low energy) and Chlorophyta abundance was greater along the surf side (high energy). Sites with high levels of

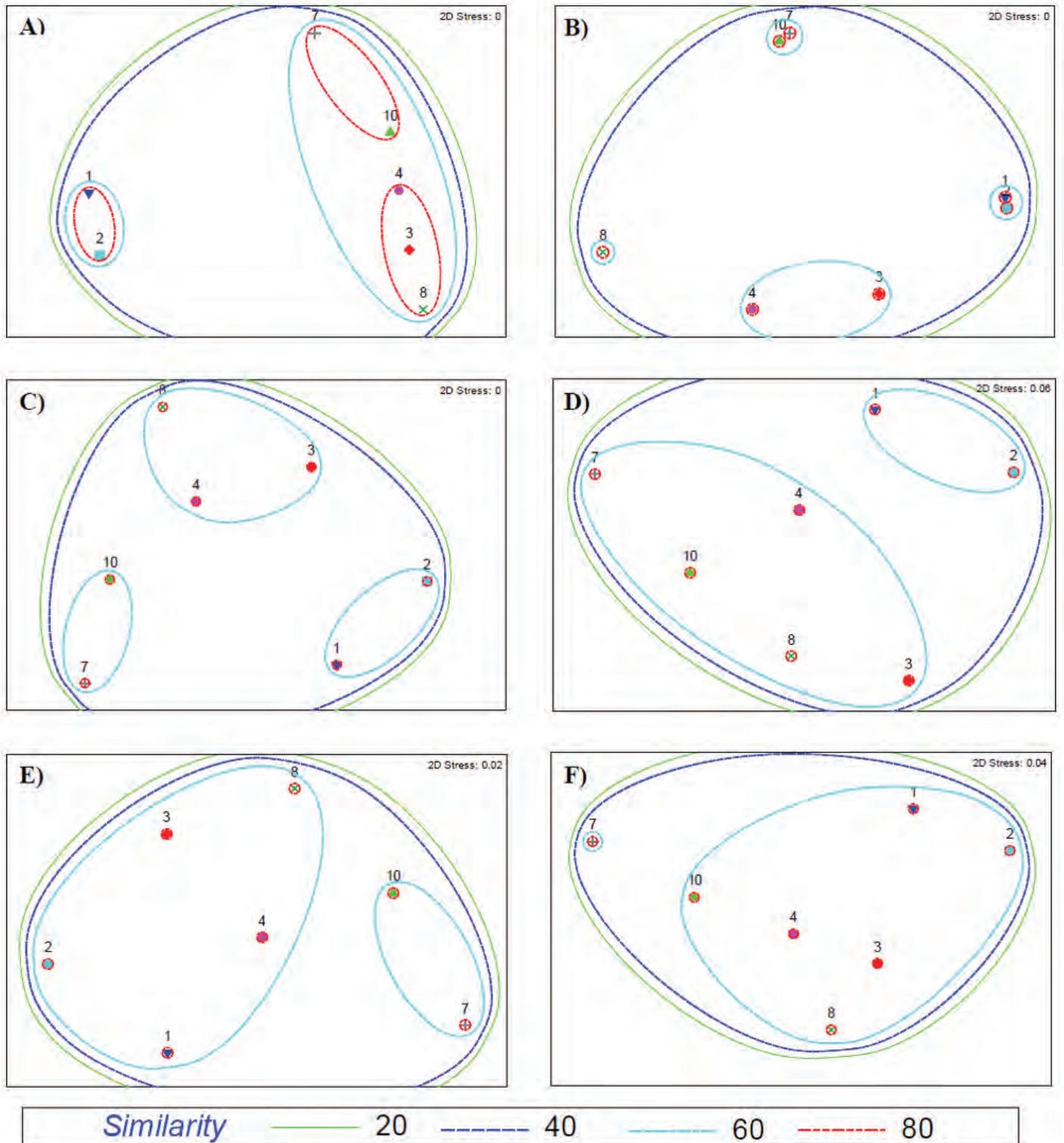


Figure 6. Multidimensional scaling (MDS) plots showing site similarity (two-dimensional distance) over time for the duration of the study. Each MDS plot (A-F) is based on 2 months of data and are cumulative (A = 2 mo, B = 4 mo, C = 6 mo, etc). Numbers represent sites as in Figure 1. A. September 2006. B. November 2006. C. January 2007. D. March 2007. E. May 2007. F. July 2007.

wave energy have also been found to have increased overall biomass (Agan and Lehman 2001, Klootwyk 2006). Similar trends in biomass were observed for this study.

Quadrats sampled within a particular site showed little similarity (19.96–43.34%). Species of algae typically vary in abundance spatially and temporally, governing algal assem-

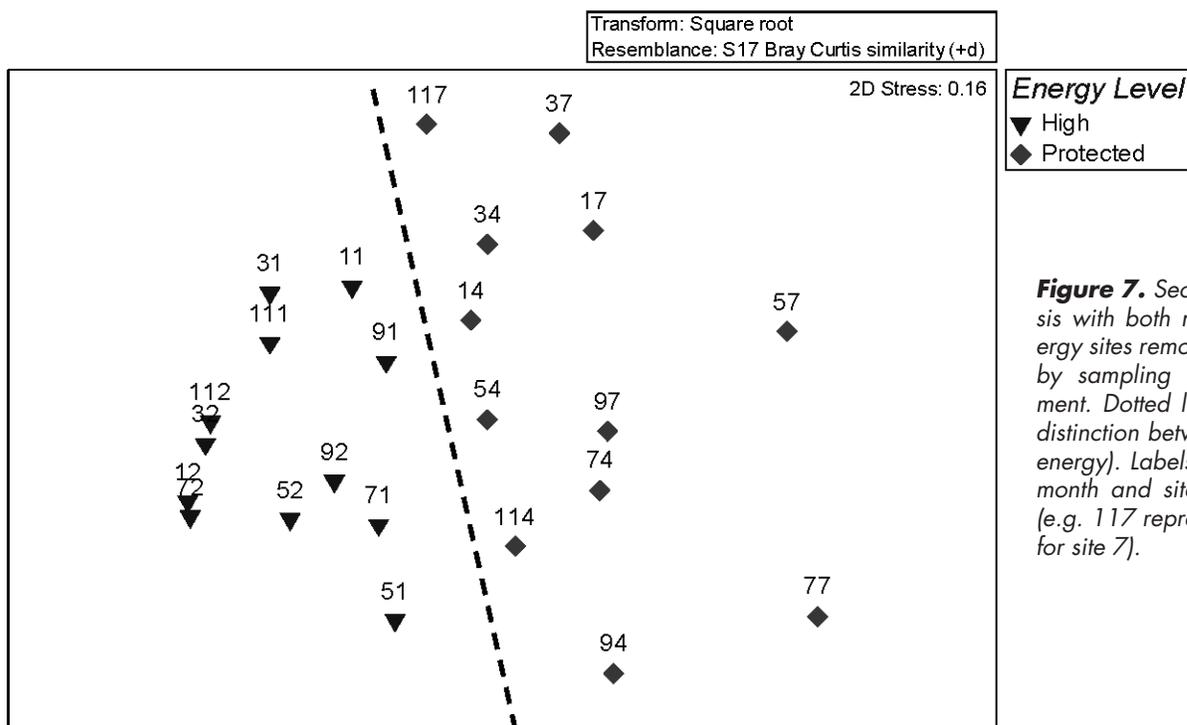


Figure 7. Second-stage MDS analysis with both moderate and low energy sites removed. Scaling is plotted by sampling event for each treatment. Dotted line represents a clear distinction between treatments (wave energy). Labels on plot represent the month and site for that set of data [e.g. 117 represents November data for site 7].

blages that are patchy in structure and composition (Dayton 1971, Lubchenco 1980, Jernakoff 1985, Foster 1990, Chapman and Underwood 1998). Variation in wave-exposed rocky shores has been documented when examined at a scale of replicate quadrats, sites, or shores, (Underwood and Chapman 1997) which has led to difficulty in examining most benthic communities, including macroalgal assemblages.

Site 9 was found to be significantly different from all other sites in all aspects of this study. The stunted development of this site is likely a direct result of pass bathymetry. Data from the Texas Coastal Ocean Observation Network (TCOON) reveals that a rather large bottom depression has formed at the end of the north jetty. This pit creates an upwelling of sediments making the area more turbid than others and could account for the decreased richness and biomass. For these reasons, site 9 was excluded when looking at community dynamics of the system over time.

Increased turbidity from sediment transport in and around the channel may result in a reduction in the water depth at which algal growth occurs. Algal growth along Texas coastal jetties is known to occur at depths of up to 3 m (Britton and Morton 1989). During this study, growth was not found to occur at depths of more than about 1 m. Due to the gradual slope of the jetties at Packery Channel this “zone of algal growth” was analyzed without compromising sampling intensity.

Community analysis showed that both sampling months and sites were significantly different from one another. When compared to biomass data from Port Mansfield’s macroalgal commu-

nity, it is evident that seasonal variation should not be interpreted from this study. Sampling months were all found to be about 60% similar, unlike that of Mansfield Pass, with consecutive sampling events (months) exhibiting about 80% similarity (seasonality). This inconsistency may be interpreted as macroalgal community development of Packery Channel and is not representative of true seasonal variation of an established macroalgal community.

Seven species were found restricted to either the chan-

TABLE 2. Average community dissimilarity (SIMPER) between all sites for Packery Channel study (given as %). Value in parentheses represents the total number of species the sites share. An * indicates that the two sites were significantly different (ANOSIM).

Site	1	2	3	4	7	8	9	10
1	(28)							
2	59.59	(22)						
		(20)						
3	*81.97	*77.24	(20)					
	(19)	(19)						
4	*78.88	*82.74	83.33	(31)				
	(25)	(21)	(19)					
7	*81.71	*87.90	*90.65	*81.76	(33)			
	(26)	(20)	(18)	(27)				
8	*86.32	*85.15	91.26	83.34	87.12	(22)		
	(19)	(16)	(15)	(20)	(21)			
9	*98.13	*97.31	*96.85	*95.13	*94.43	*96.43	(20)	
	(17)	(17)	(15)	(20)	(20)	(17)		
10	*79.80	*83.36	*89.46	79.22	74.93	*84.94	*94.12	(26)
	(23)	(18)	(16)	(24)	(23)	(19)	(19)	

TABLE 3. Floristic affinities along the Gulf Coast (north to south) using Cheney's Floristic Ratio (R =Rhodophytes, C =Chlorophytes, and P =Phaeophytes [O =Ochrophytes]) (Cheney 1977).

Location	R	C	P (O)	Cheney	Reference
Galveston, TX	14	8	5	4.4	Lowe and Cox 1978
Port Aransas, TX	53	21	12	6.2	Edwards and Kapraun 1973
Port Aransas, TX	52	21	14	5.2	Edwards 1976
Packery Channel, TX	25	11	4	9.0	This study
Port Mansfield, TX	22	11	6	5.1	Klootwyk 2006
South Padre Island, TX	35	17	12	4.3	Sorenson 1979
South Padre Island, TX	76	36	18	6.2	Boca et al. 1979
Veracruz, Mexico	46	34	11	7.3	Lehman and Tunnell 1992

nel or surf sides of the jetties at Packery Channel. All of these species exhibited markedly low biomass values and occurred in relatively few samples. The generalization still applies that species vary in their tolerance to surf exposure (Widdowson 1964, Kapraun 1980). Energy tolerance may not be the only reason for their habitat restriction. All species with growth limited to one side or the other were also absent by the end of the study, so they may have also been limited in their range due to factors of competition.

All sites for this study (with the exception of site 9) were found to be about 55% similar in community structure. Those sites exhibiting the most similarity (e.g., sites 3 and 8, sites 1 and 2) were those with similar location along the jetties and similar levels of wave energy. These data indicate that wave energy (represented by site location and exposure) has a direct affect on colonization of algae.

Space and seawater inorganic nutrients are considered to be the limiting resources for macroalgae in most temperate systems (Chapman and Craigie 1977, Sousa 1985). Successional studies have shown that disturbance facilitates invasion of species by reducing competitors or increasing resources (D'Antonio 1993). This is especially true for intertidal habitats where disturbance affects community structure and organization (Dayton 1971). Disturbance for this study may be a result of the continued turbidity caused by resuspended sediments in and around the channel.

Although poorly studied, competition is important in most algal communities (Paine 1990) as these processes determine patterns of abundance. Important interactions occur between physical factors, grazing, and levels of interspecific competition (Graham and Wilcox 2000). Factors and variables are constantly changing within a community, and only those species that are capable of withstanding such pressures continue to thrive. In some cases, opportunistic species rapidly colonize a habitat, and they are thus given the competitive edge for space. Several genera identified in this study have been shown to be opportunistic colonizers, such as *Hypnea* and *Ulva* (Biebl 1962, Russell and Balazs 1994).

Colonization studies should not be treated in the same manner as successional studies due to differences in factors affecting immigration to substratum. In new habitats, competition is drastically reduced and space is not initially limited. This may be the reason why early colonizers have a markedly higher biomass in proportion to other species. This study is more representative of algal colonization than secondary successional studies due to the fact that there was no established algal population in the general area of sampling. This study relies on community development from initial stages of colonization, meaning that only species with propagules in nearshore currents and adjacent habitats had the potential to recruit.

This study represented the first report of *A. ramosissima* from along the Texas coast (Fikes and Lehman 2008b). The occurrence of this species may promote the idea that though our flora shows a tropical affinity, some species may not have the means to compete with native flora. Their reproductive propagules may be present in the water column but never have the chance to stabilize within a community.

Both *B. cuspidata* and *B. thysigera* were found among the top three most abundant species for this study. *Bryocladia* has been found to dominate the Port Aransas, Port Mansfield, and Galveston jetties as well, indicating that it is a species of major importance along the Texas Gulf Coast (Wardle 1992). These species are typically associated with a "turf" formation, providing habitat for large numbers of benthic infauna (Valerio-Berardo and Flynn 2002). This makes them very important contributors to overall ecosystem function via bottom-up control. Bottom-up control and top-down control likely act as joint determinants of community structure in rocky intertidal communities (Menge 2000).

Grateloupia filicina, a species that is important commercially (Wong and Chang 2000) and ecologically, was found to be the second most abundant species collected during the study. It was also found to be the dominant species occurring at Mansfield Pass (Klootwyk 2006). This species is categorized as a thick leathery species, similar to *Gracilaria* spp., allowing

for survival in high energy environments (Littler et al. 1983). This supports the occurrence of *G. filicina* in large quantities in sites 1 and 2, those with the highest levels of wave energy.

Hypnea musciformis was found to be one of the top contributing species for this study, and it is known to be an early colonizer and fast-spreading species in macroalgal communities around the world. In the Hawaiian Islands, *H. musciformis* has been introduced into many communities (Russell and Balazs 1994) and has become incorporated into the diet of the green sea turtle (*Chelonia mydas* L.) which is found in great numbers throughout the Coastal Bend region, including Packery Channel.

Coralline algae are a conspicuous component of intertidal and shallow subtidal algal turfs, are among the first to recruit into these assemblages, and show a negative correlation between abundance and ephemeral coverage (Coleman 2003). *Haliptilon cubense* and *Jania adhaerens* were both found occurring in the macroalgal turf relatively early in the study (January 2007), but their abundance was very limited. At this time many species of ephemeral algae were found occurring within the turf, possibly accounting for the low biomass of corallines. The low abundance could have also been due to the slow growth that these macroalgae typically exhibit.

The green algae *C. linum* was found to develop late in this study, and was most often found occurring in the supratidal splash zone along the jetties. Species of *Chaetomorpha*, along with *Ulva* and *Bryopsis*, are known for their ability to with-

stand partial desiccation (Biebl 1962). This element adds to the complexity and diversity of the macroalgal community of Packery Channel, as well as most rocky intertidal communities.

Few studies examine the roles of artificial habitats and their ecological role as surrogates to natural communities (Bulleri 2005). Until jetties were constructed along the Texas coast, the outer shores were limited in algal growth because they lacked the necessary hard substratum.

Previous Texas algal collections described species of *Ulva*, *Gracilaria*, *Gelidium* and *Hypnea* as the most dominant macroalgae of the Corpus Christi Bay area (Agan and Lehman 2000). These species are all found dominating the Port Aransas jetties. Representatives from each of these genera were also collected from Packery Channel, perhaps providing additional contributions to the bay community. Possible sources for these macroalgae include Corpus Christi Bay and the Upper Laguna Madre via water exchange during low tides and nearby coastal jetty communities via longshore currents.

Macroalgae immediately began to attach to the rocky substratum and these communities quickly become rich in species diversity. Though biomass values may be comparable to that of nearby systems, newly forming assemblages show pronounced patchiness in community structure. Over time these communities exhibit a more even distribution, with similar site locations showing increased similarity. An increase in energy results in both a decrease in richness and increase in biomass during habitat colonization and development.

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