PROGRESS REPORT

Hovel and Regan: Eelgrass in San Diego Bay: Assessing Eelgrass Habitat Function for Recreationally Important Species

Funding dates: February 1, 2008 – December 31, 2010

Progress report date: August 2010

Summary of project:

The goal of this project is to enhance our knowledge of the function of seagrass as a habitat for recreationally important species in San Diego Bay (SDB). In SDB, eelgrass serves as a habitat for a variety of species such as juvenile giant kelp fish, barred and spotted sand bass, calico bass, and spiny lobster. Eelgrass may serve as an important refuge for these species, particularly in their juvenile stages, and eelgrass houses many small invertebrates that provide food. Despite the widely cited function of eelgrass as a nursery habitat for species such as these, critical information regarding the function of this habitat is missing. In this project we conduct experiments in SDB and in the new Coastal and Marine Institute Laboratory (site of the new Center for Bay and Coastal Dynamics) that are focused on the effects of eelgrass habitat structure on ecological relationships. These are intended to provide a more complete understanding of how eelgrass functions as a foraging and refuge habitat for organisms in SDB. We have integrated these experiments with a mathematical model that allows us to greatly increase the scope of the results. We also have to use our experiments and model to educate San Diego's youth about marine ecology and the importance of habitat in SDB. In addition to educational benefits for K-12 students, undergraduate, and graduate students, our results can benefit SDB by informing predictions of the consequences of eelgrass loss for SDB organisms, and will provide improved ability to restore seagrass in the event of habitat loss.

Expected results and progress:

The expected results listed in our proposal were:

1. Complete a field experiment in San Diego Bay that examines how seagrass habitat characteristics interact with predation to dictate the abundance and distribution of several seagrass-dependent species.
2. Complete laboratory experiments focused on the effects of organismal behavior on prey survival.
3. Complete a revised version of our predator-prey model using information gleaned from field experiments that predict the consequences of eelgrass loss for SDB, meet with Port personnel to describe the scope of our findings, and submit recommendations for conservation and restoration of eelgrass in SDB based on our findings.

4. Complete a program in which SDSU graduate students and faculty teach K-12 students in two local afterschool programs about the value of SDB habitats for marine species and the value of using mathematical tools to study marine animals.

Our progress to date on these expected results is:

1. *Complete a field experiment in San Diego Bay that examines how seagrass habitat characteristics interact with predation to dictate the abundance and distribution of several seagrass-dependent species*

The field experiment in SDB has been completed; see attached figures 1 – 4. This study was the major portion of a master's thesis for a San Diego State University graduate student, Eliza Moore. In this study, sampling and experimentation were used to determine the preferred habitat of fishes (predators) and invertebrates (prey). We sampled within the edge and interior of eelgrass beds in three locations in SDB for fish abundance and diversity, abundance and diversity of invertebrates, and eelgrass habitat structure. Briefly, we found that eelgrass habitat structure increases from the edge to the interior of beds, that fish preference for edges or interiors varies by species, and that many epifaunal invertebrates prefer dense eelgrass, regardless of location within the bed. In an accompanying field experiment in which we controlled fish (predator) access to discrete areas of eelgrass beds, we found that eelgrass complexity (e.g. the density of eelgrass shoots, or relative biomass of shoots) was the overriding factor in dictating where most small invertebrates (that serve as food for fishes) would be found. However, variation in this trend was prominent, with different species having different preferences.

This portion of the project was published in *Oikos*, a widely-read and high-impact peer-reviewed ecology journal, in early 2010.

2. *Complete laboratory experiments focused on the effects of organismal behavior on prey survival* (**UPDATED**)

Three sets of laboratory experiments have been completed. Two ancillary field projects accompanied these lab experiments (described below).

Set 1: These experiments (see figures 5 – 6) were performed by an undergraduate honors thesis student at San Diego State (Rachel Lannin). They took place in laboratory aquaria and sought to determine how the structural complexity of seagrass influences the behavior of fish predators and their invertebrate prey during predator-prey interactions. In this experiment, we exposed grass shrimp (prey) to fish predators (juvenile giant kelp fish) in laboratory aquaria, and monitored the foraging behavior of fishes and the escape behaviors of shrimp as the amount of habitat structure in aquaria changed. By transplanting eelgrass into aquaria, shrimp and fish were provided with 6 different levels of eelgrass structure, ranging from very low (20 shoots per m^2) to high (320 shoots per m^2). We determined whether the survival rate of shrimp varied with the amount of eelgrass structure (this is known as the "habitat-survival function") but also how fish altered their foraging strategies, and shrimp their escape strategies, with increasing habitat structure. Additionally, we added a treatment in which the abundance of shrimp prey increased with seagrass structural complexity, as this more closely resembles reality.

We found that survival of shrimp epifauna increased with seagrass structure only when the density of shrimp increased with structure. Fish detection rates of their shrimp prey decreased with seagrass structure but shrimp density modified this relationship. This means that prey density is as important, or more important to consider when assessing how seagrass habitat influences the foraging of juvenile fishes. This is the first experiment in seagrass habitat to quantify the relative effects of prey density and structure on fish foraging, an important function of seagrass nursery habitat. We have written a manuscript and are in the final stages of revision before submitting to a peer-reviewed journal.

Set 2: An additional set of experiments were follow-ups to those of set 1 (see figures 7-8). Three undergraduate students, including one representing Grossmont Community College via the SDSU BRIDGES program, conducted experiments in the summer of 2010 to provide more information on the effects of seagrass structure and prey density on juvenile fish foraging. These students used a wider range of seagrass structure and prey density than used in set 1, and quantified the same aspects of predator and prey behavior as in our previous experiments. Their results corroborated those of the student who conducted our set 1 experiments. This was notable because it was important to determine if the same effects of habitat structure and prey density would be observed over wider ranges. These results were presented by the students at the annual Western Society of Naturalists conference in San Diego, CA in November 2010, which is an international conference on marine biology that is attended by approximately 600 marine biologists.

This lab experiment was accompanied by a field experiment conducted in the summer of 2010. The field experiment sought to determine whether the distribution of juvenile fishes is correlated primarily with seagrass structure or with the density of their prey. We used throw traps to sample discrete areas of seagrass habitat near Shelter Island in SDB, and we accompanied these samples with samples of epifaunal abundance and seagrass habitat structure. We presently are completing the laboratory analysis of the epifaunal samples (these take many hours to go through, and are being processed by SDSU student volunteers) and we have completed the data entry for the fish and seagrass samples. When the data set is complete we will be able to gauge whether fishes select habitat primarily based on the density of their prey or the structure of their habitat.

Set 3: These experiments are in their final stages and are being conducted by Kelly Tait, an MS student in the Hovel lab, in outdoor mesocosms provided with flow-through seawater from San Diego Bay (see figures 9-10). These experiments are designed to determine how seagrass structure influences habitat selection behaviors by epifaunal organisms (grass shrimp) and juvenile fishes. Organisms are provided with choices of simulated eelgrass habitat within mesocosms (dense eelgrass or sparse eelgrass). After an initial set of selection experiments in which only habitat is the only factor, we add a predatory threat to determine if this results in a change in habitat selection. In a third experiment we add food to determine whether this motivates organisms to change their preferred habitat. Our results suggest that shrimp and fishes prefer dense to sparse eelgrass (which coincides with results from the field experiments in objective 1), but that an increased threat of predation reverses this preference for shrimp, but not for fish. Instead, fish remain within dense seagrass even if large predatory fishes are there, but they move much less and take on a vertical orientation to better hide behind seagrass blades.

This lab experiment is being accompanied by field experiments within seagrass habitat at Shelter Island that are designed to determine if habitat selection by prey organisms under natural conditions mirrors that seen in the laboratory under more controlled conditions (see figure 11).

We are finding that grass shrimp movement from seagrass is higher when predatory threats are present, but only when seagrass density is sparse. Under high seagrass density, grass shrimp prefer to remain hiding in eelgrass rather than moving and exposing themselves to predators. We also are seeing more movement at night, suggesting that grass shrimp may move among seagrass patches at night when visually-oriented predators cannot hunt for them.

Set 3 experiments were presented by Kelly Tait at the annual Western Society of Naturalists conference in San Diego, CA in November 2010.

3. *Complete a revised version of our predator-prey mathematical model using information gleaned from field experiments that predict the consequences of eelgrass loss for SDB*

In June 2008 and 2009, PIs Hovel and Regan revised the existing initial mathematical model of how predator and prey organisms interact in eelgrass habitat and how this is influenced by habitat structure. The overall goal is to determine what factors lead to the highest success of juvenile fishes, which constitute mesopredators in seagrass beds (i.e., those animals that hunt for prey, but also are hunted as prey). In 2008, the primary upgrade to the model was the inclusion of habitat complexity (e.g. shoot density and relative biomass) into the digital "landscapes" within which our digital "organisms" interact. Previously, we used the model to evaluate how seagrass habitat fragmentation influenced predator-prey interactions among fishes (predators) and prey (invertebrates like grass shrimp). Now, we have incorporated variability in eelgrass habitat complexity into the landscapes, and based the patterns of habitat complexity on real maps of SDB eelgrass beds obtained from scans made by a scientific echosounder (data obtained by Hovel and Dr. Kwang-Young Kim of Chonham University in Korea; see figure 12). The scans, made in different seasons, have allowed us to structure the modeled landscapes to simulate those in SDB. We are now awaiting the final data analysis of the lab experiment and field experiment so that we can include those results in the model, specifically, aspects of predator and prey behavior and habitat preferences for each trophic level.

In 2009 the PIs incorporated a much more extensive behavioral repertoire for predator and prey organisms into the model. Prey have preferences for particular habitat types (e.g. dense seagrass, or patch edges) based on results from the field experiments from objective 1. Predator and prey behaviors change with eelgrass structure, based on the laboratory experiments conducted already, and those presently being completed. Preliminary data are shown in figure 13. As the final data come in from lab and field experiments, we will be able to refine the behavioral repertoires of the organisms in our model, and provide a more accurate prediction of how seagrass structure influences nursery habitat function for juvenile fishes.

4. *Complete a program in which SDSU graduate students and faculty teach K-12 students in two local afterschool programs about the value of SDB habitats for marine species and the value of using mathematical tools to study marine animals.*

We have conducted a variety of exercises with the Ocean Discovery Institute (formerly Aquatic Adventures) to educate underrepresented youth about marine ecology, the value of marine habitats, and mathematical modeling. The group has visited the Coastal and Marine Institute Laboratory to conduct an experiment examining how habitat influences predator-prey interactions. This simple experiment quantified how the efficiency of hunting for small fishes changes with the addition of habitat structure into experimental arenas. Second, we have conducted two instructional sessions in the SDSU Biology Department's computer laboratory, in which students used our mathematical model to perform an experiment on predator-prey interactions in simulated seagrass habitat. The students were given a short lecture to introduce the concept of modeling, and they then followed instructions to build their own mathematical model in NetLogo. This simple model allowed the students to create a world in which predator and prey organisms interact, and in which habitat can be added or removed to act as a protective area for prey. Finally, the students used our full model for seagrass habitat to test how changing the behaviors of the organisms influenced the effectiveness of seagrass nursery habitat.

Figure 1. Sites for surveys and experiments for Objective 1. SI = Shelter Island, NCB = north Coronado Bridge, SCB = South Coronado Bridge.

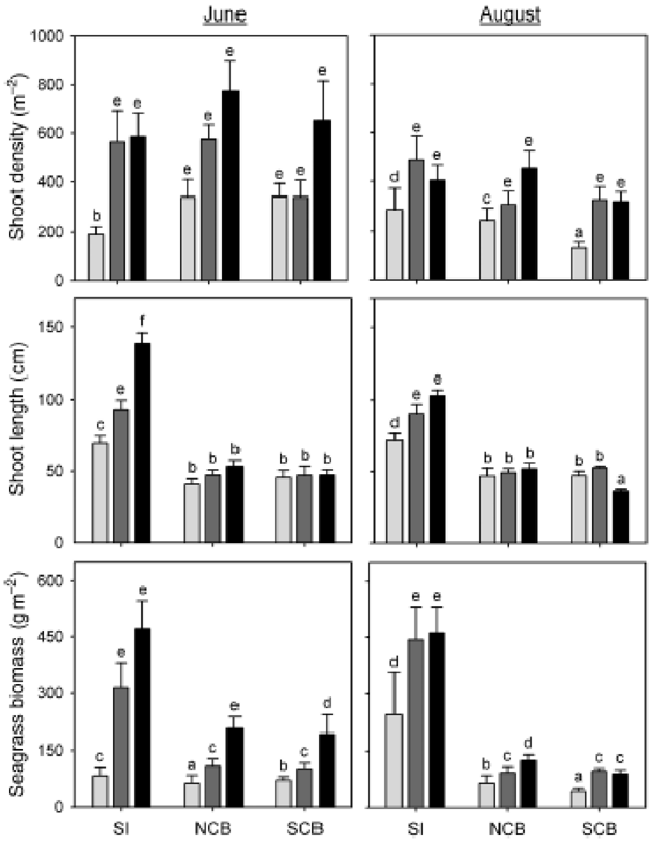

Figure 2. Results of eelgrass sampling surveys in 2008 showing that eelgrass habitat structure (measured as biomass, shoot length, or shoot density) generally increases from eelgrass patch edges (light gray bars) to inner edges (dark gray bars) and interiors (black bars), but that trends are site-specific. Sites are Shelter Island, North Coronado Bridge, South Coronado Bridge.

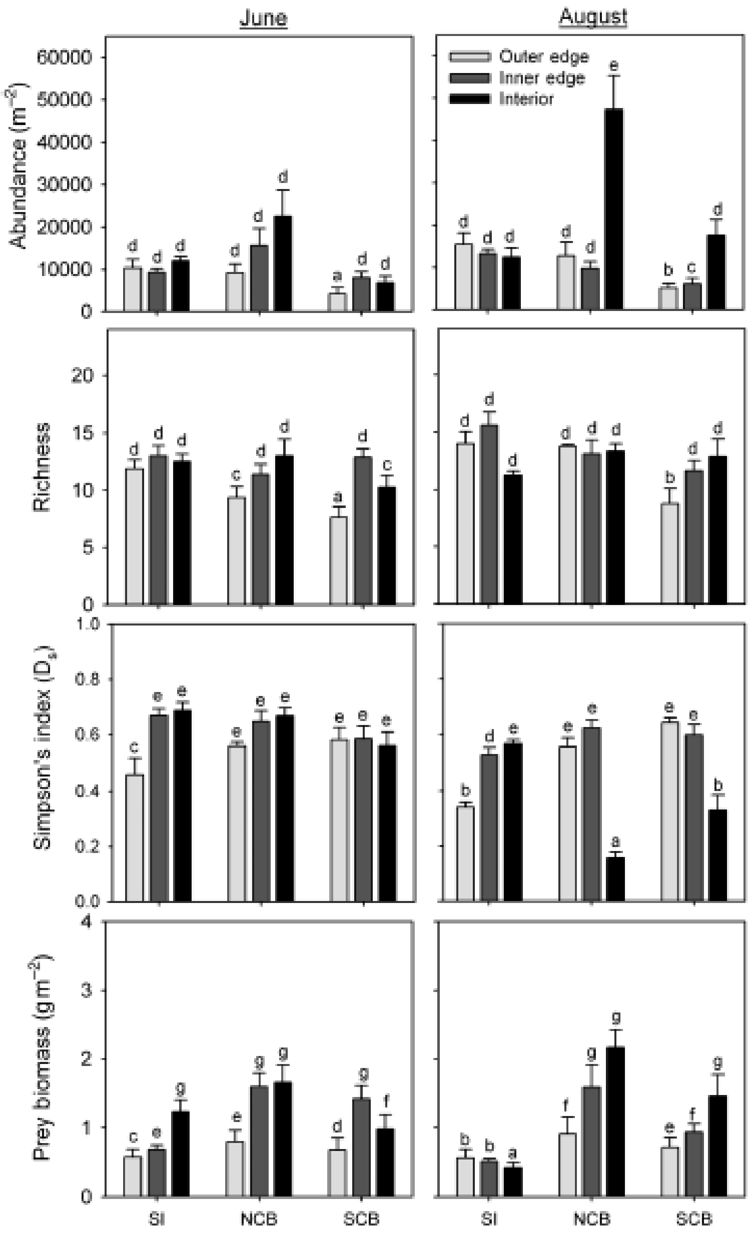

Figure 3. Abundance, species richness, diversity, and biomass of epifauna (generally, small crustaceans and mollusks that serve as prey for fishes) at three sites (Shelter Island, North Coronado Bridge, South Coronado Bridge) in SDB in 2008. Bars, from left to right for each group, represent samples at edges, inner edges, and interiors of eelgrass patches.

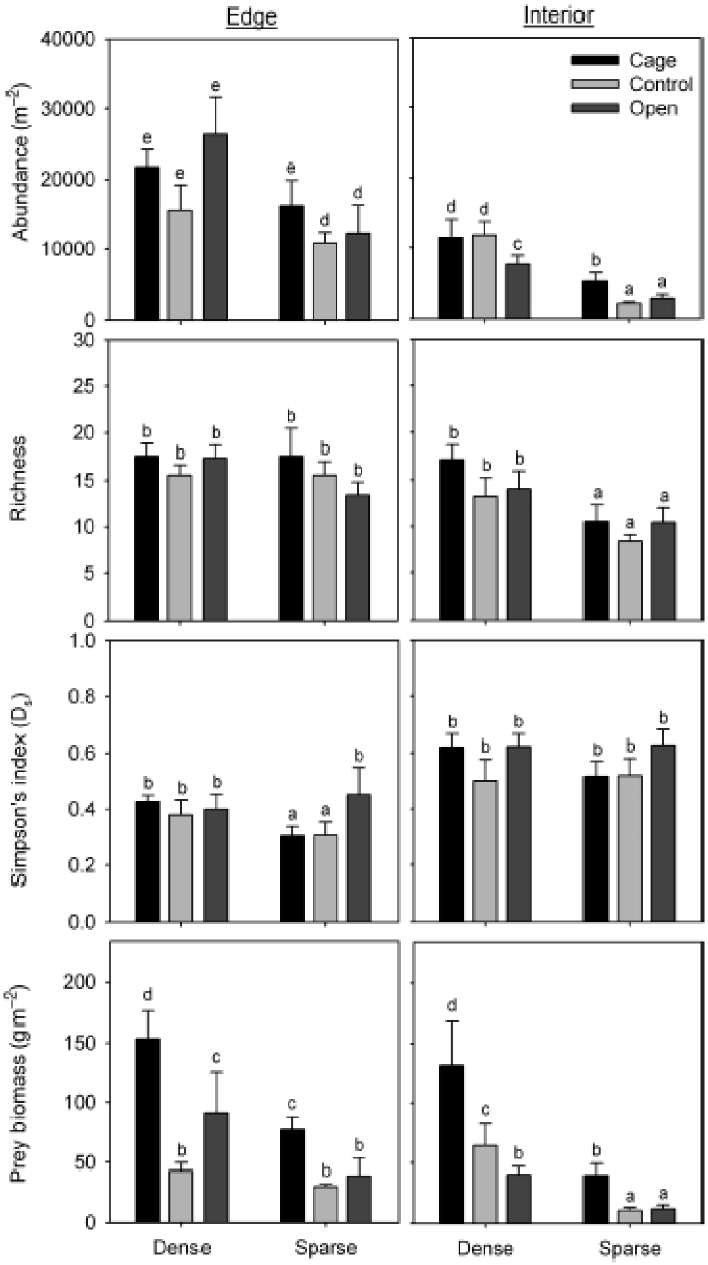

Figure 4. Results from the field experiment in 2008. Artificial seagrass (dense or sparse) was used to control seagrass habitat structure in small plots within the edges or interiors of eelgrass patches. Caged plots were protected from fish predation, and open and control plots allowed fish predators access to the artificial seagrass. The experiment tested whether the epifaunal community differed between patch edges and interiors, between dense and sparse seagrass, and between treatments with and without fish predators. Generally, epifauna (prey for fishes) preferred dense eelgrass, though some common prey items (e.g. amphipods) preferred patch edges. Fish predation overall was not as important as location and structure in dictating epifaunal abundance.

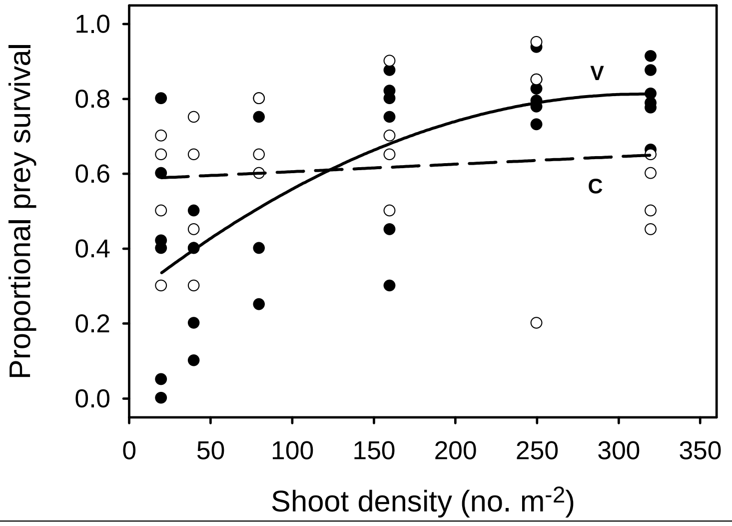

Figure 5. Results from the laboratory experiments for aobjective 2 (set 1). As seagrass structural complexity increased, grass shrimp prey had higher survival when grass shrimp density increased with seagrass structure (DARK CIRCLES & LINE MARKED "V"), but not when shrimp density was held constant (WHITE CIRCLES AND LINE MARKED "C"). Increases in shrimp density with structure are common for small crustacean prey in seagrass habitat, but the protective value of seagrass often is experimentally assessed with constant levels of prey.

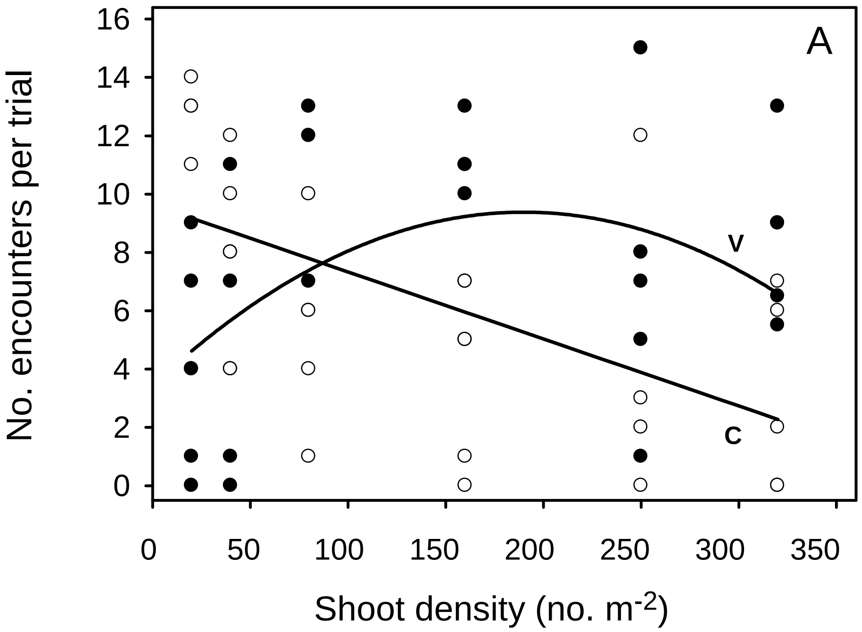

Figure 6. Results from the laboratory experiments for objective 2, set 1. As seagrass structural complexity increased, juvenile giant kelpfish predators were able to detect more prey when shrimp density increased with seagrass structure to a point, after which seagrass structure became dense enough to limit their detection rates (see line marked "V"). When prey density was held constant, the number of shrimp prey detected by kelpfish decreased linearly (see line marked "C").

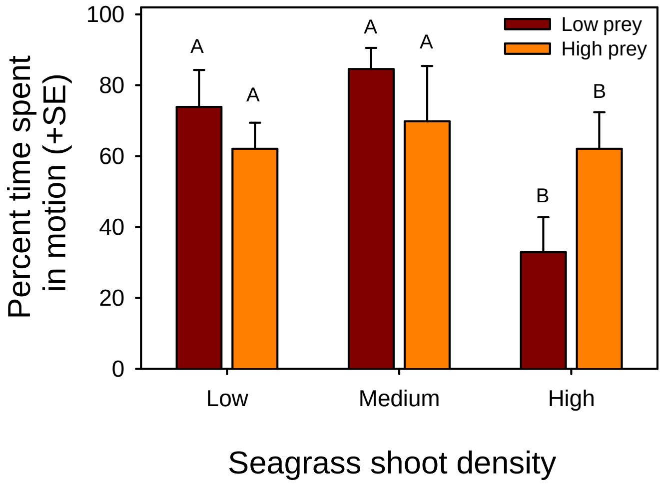

Figure 7. Results from the lab experiments (set 2) in which juvenile giant kelpfish foraged on grass shrimp in laboratory mesocosms. Shown is the percentage of time fish spent in motion relative to seagrass shoot density and prey density (low vs. high). The graph suggests that at high shoot densities, when hunting conditions are hard for fish, they move less and switch to a sit-and-wait mode of predation.

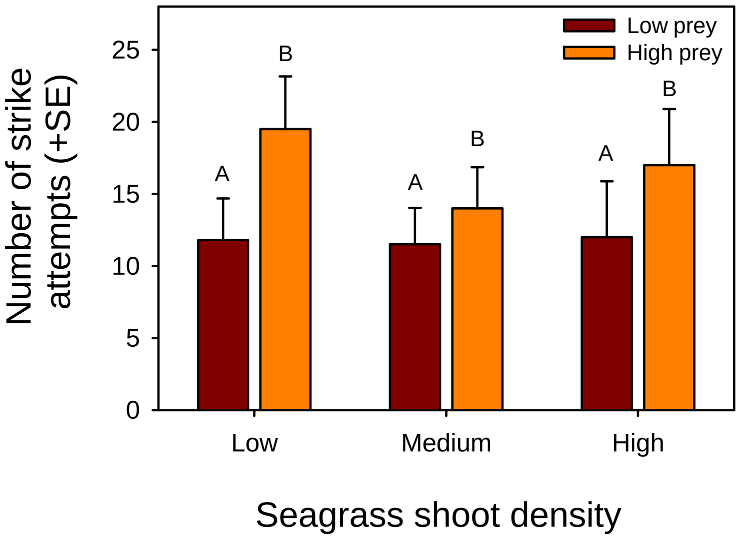

Figure 8. Results from the lab experiments (set 2) in which juvenile giant kelpfish foraged on grass shrimp in laboratory mesocosms. Shown is the number of predation attempts made by kelpfish on grass shrimp prey relative to seagrass shoot density and prey density (low vs. high). Kelpfish decisions to strike at prey were not influenced by structural complexity, but were influenced by prey density.

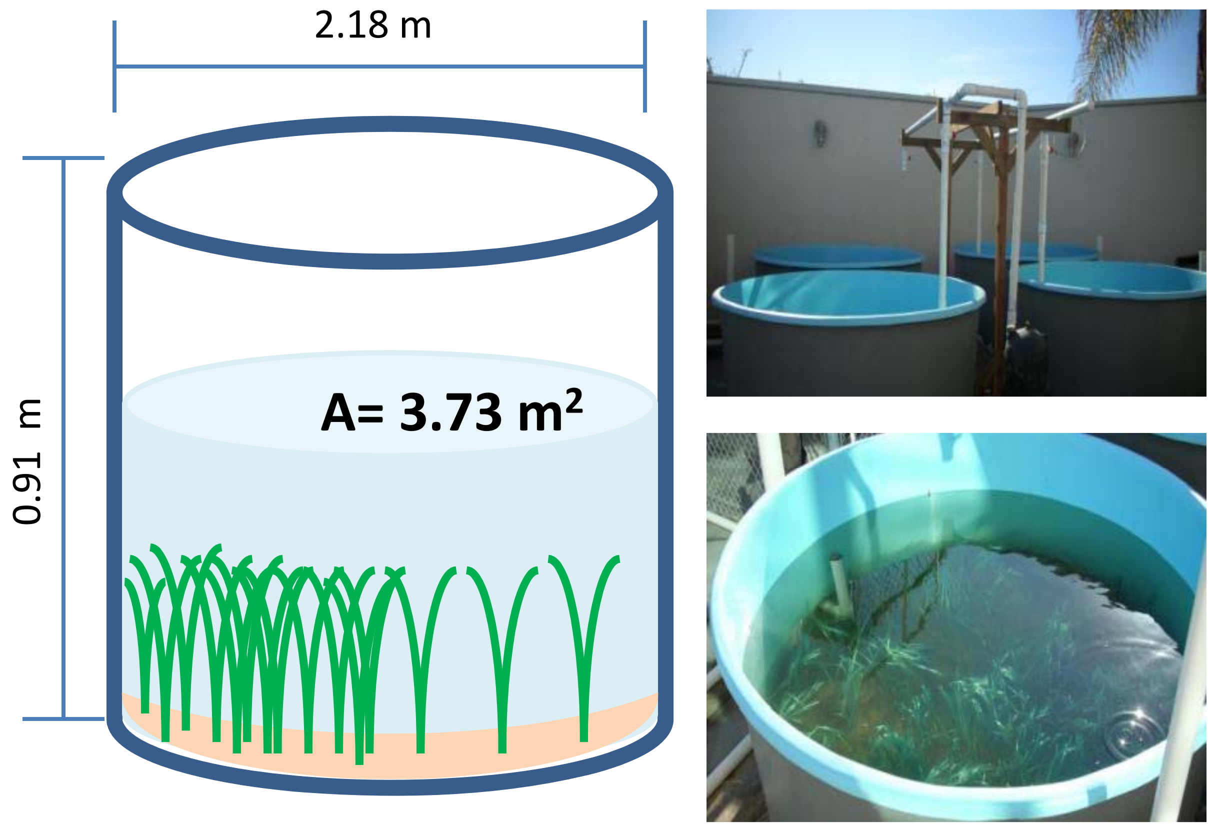

Figure 9. Schematic and photos of the mesocosms used for part 2 laboratory experiments on fish and epifaunal behavior at the SDSU Coastal and Marine Institute Laboratory.

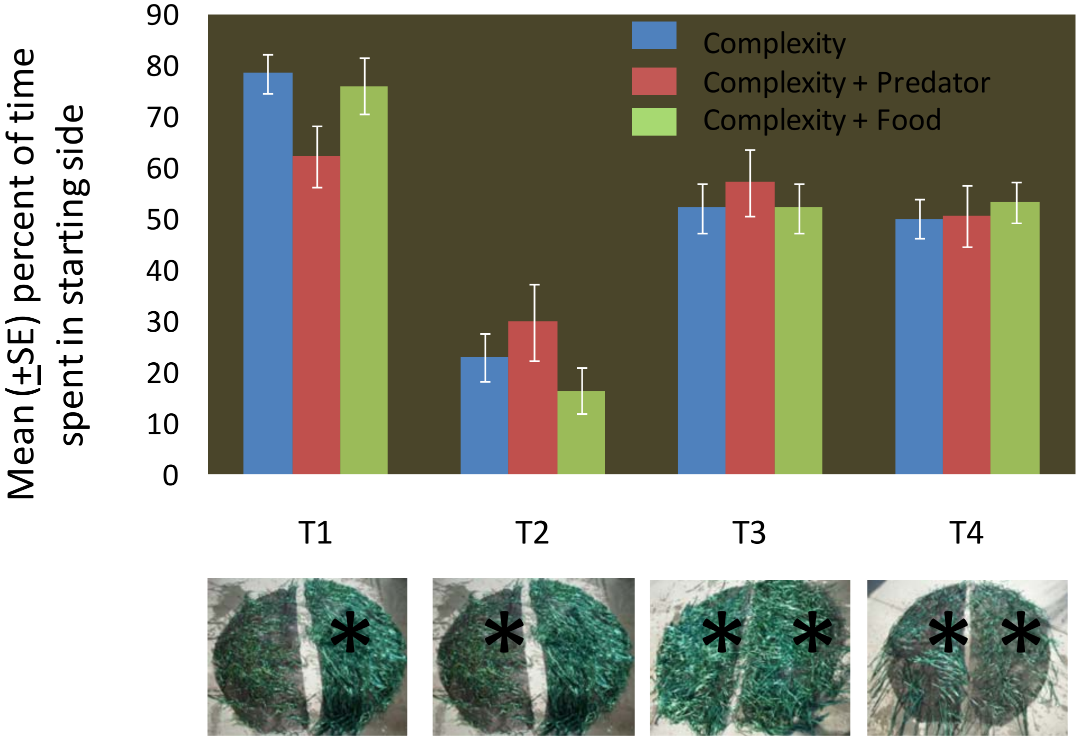

Figure 10. Results from the mesocosm experiments for kelpfish. Shown is the percentage of time fish spent on the starting side of the mesocosm over the course of 1 h. Mesocosms had either one side of high density seagrass and one side of low density seagrass (T1 and T2), or only high (T3) or only low (T4) seagrass. Asterisks in the pictures denote the starting side of the fish as the trials began. The results indicate that kelpfish remained on the high density side of mesocosms when they began there, and generally moved from the low density side to the high density side when they began elsewhere (blue bars). The red bars show that when a predatory threat was introduced to the high density side, this preference decreased somewhat. The results were more dramatic for grass shrimp, which switched preference from high density seagrass to low density seagrass when a predator was added to the high density side (data not shown). The two treatments with the same levels of seagrass density (T3 and T4) were used to account for any potential bias in the experiment due to extraneous factors.

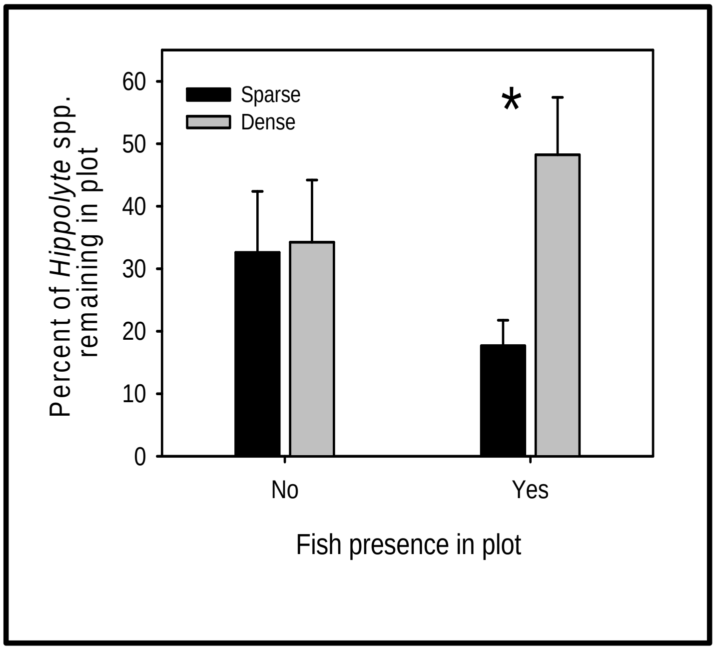

Figure 11. Results of a manipulative field experiment conducted at Shelter Island in San Diego Bay in summer 2008 to examine retention rates of grass shrimp in sparse and dense seagrass patches. Grass shrimp (200 m^{-2}) were stained with neutral red and released within cages that excluded mesopredators or included mesopredators (= 2 juvenile giant kelpfish). Data represent the percent of stained shrimp that remained within the starting location after 2 h. Error bars denote 1 SE.

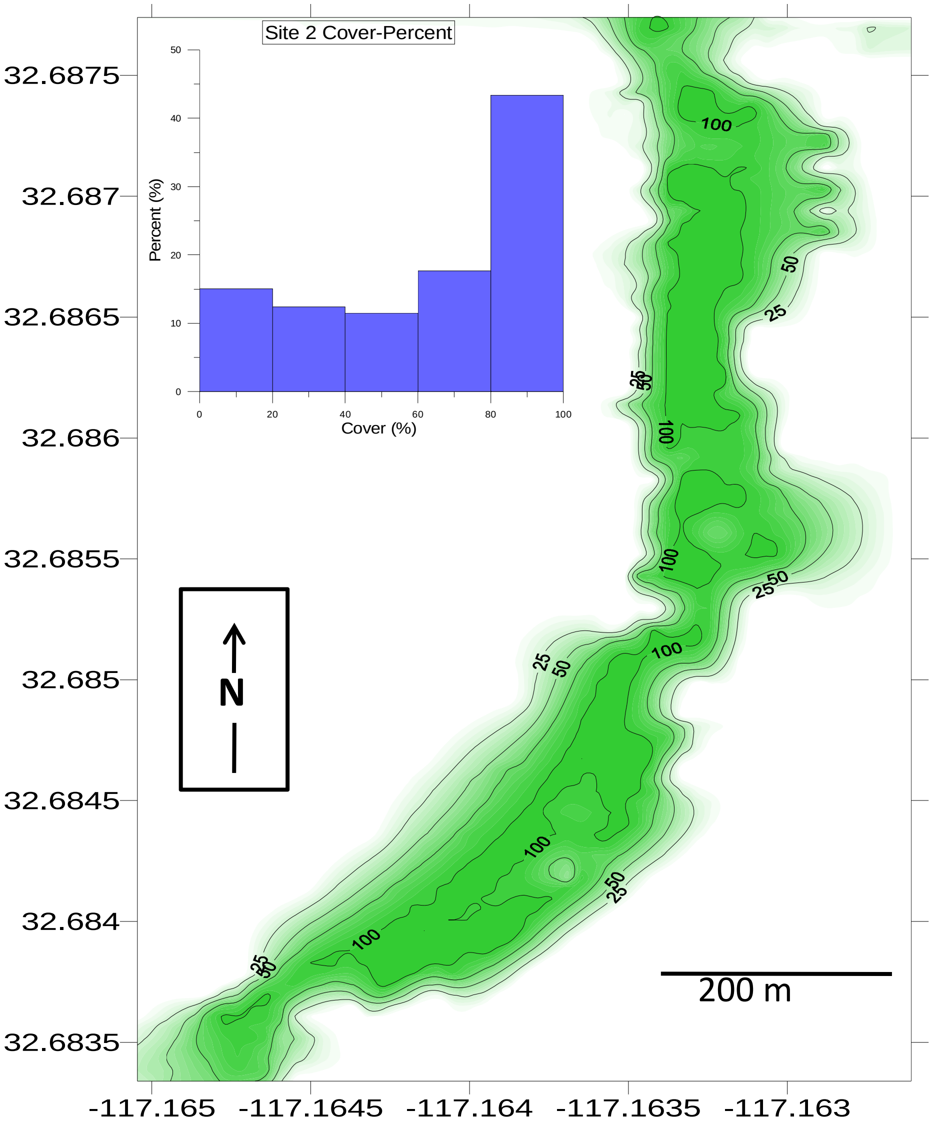

Figure 12. Map of seagrass biomass at Shelter Island in summer 2008. Contour lines denote relative levels of seagass biomass, with 100% representing full seagrass cover. Note how biomass generally increases from the patch edge to interior. Inset shows the proportion of total seagrass habitat comprised of each biomass category; this site is dominated by high eelgrass biomasss.

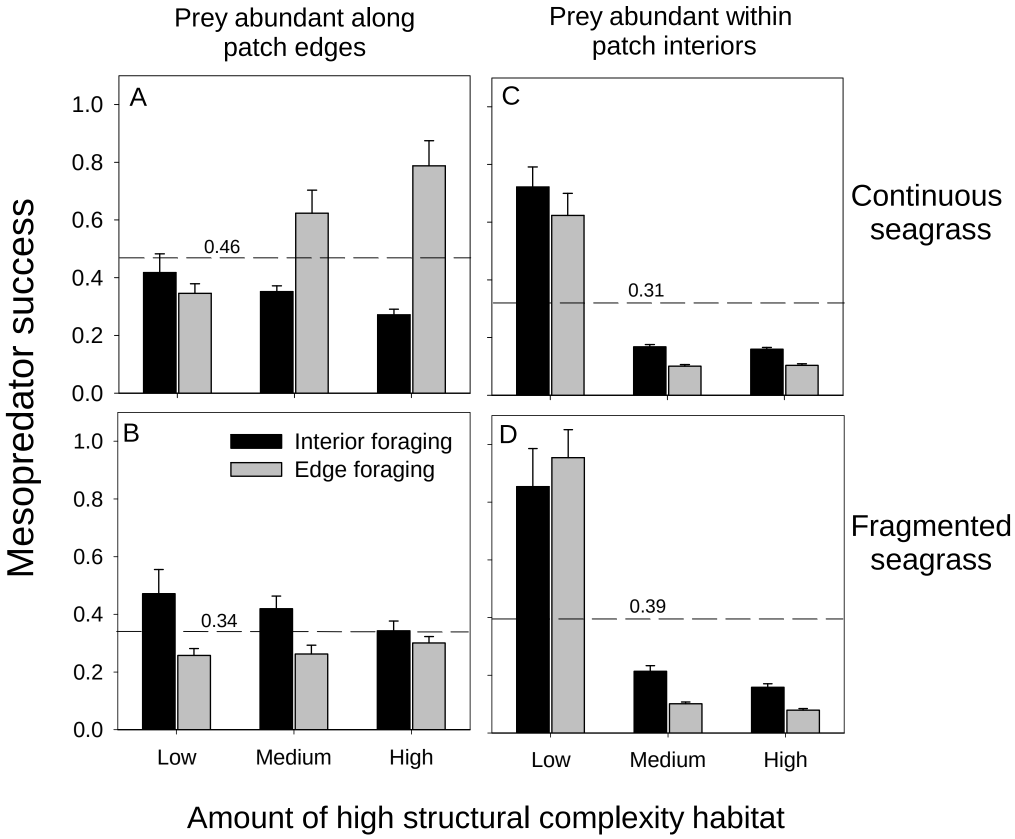

Figure 13. Preliminary results from the mathematical model in which prey and predators are placed into continuous or fragmented seagrass habitat. Within each landscape type, the amount of seagrass that constitutes protective, high complexity seagrass varies from low, to medium, to high. In keeping with results from the field, epifaunal prey are either abundant along patch edges, or within patch interiors. Finally, the predators are provided with preferences for foraging at patch edges, or within patch interiors. The preliminary results indicate that the success of juvenile fish mesopredators (Y axis; this is a ratio of prey consumed to mortality, with higher success representing more prey consumed and higher survival) increases with structural complexity in continuous seagrass when prey are abundant along patch edges and fish mesopredators forage along edges. In all other situations, however, mesopredator success decreases with structural complexity, either due to lower prey biomass consumed (e.g. if prey are abundant in regions not commonly occupied by fish mesopredators) or if fish mesopredators have lower foraging success due to an increase in structural complexity.