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Seagrass fragmentation impacts recruitment dynamics of estuarine-dependent fish

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ABSTRACT

Seagrass beds are a key component of the estuarine landscape supporting high productivity, abundant marine life, and serve as nursery areas for many estuarine-dependent species. With increasing anthropogenic activity, there is concern about overall habitat loss *via* fragmentation and what effects this may have on local biotas relying on seagrasses for persistence. To examine these effects, fragmented seagrass beds (*Halodule wrightii*, Ascherson 1868) in two different bay systems, Corpus Christi and Aransas Bay, Texas, were delineated, quantified, and mapped, and red drum (*Sciaenops ocellatus*, Linnaeus 1766) was used as a model species to test for impacts of fragmentation on this common estuarine-dependent species. Red drum density, growth, and movement were measured in response to varying levels of fragmentation (*i.e.*, High, Medium, and Low). No difference in initial recruitment of red drum density was observed among fragmentation levels for newly settled arrivals. However, there was a significant size effect; larger fish were found in non-fragmented areas. Growth rates were also compared among fragmented habitats using both RNA:DNA ratios and otolith microstructure, and no significant effect of growth among fragmentation levels was found. Migration potential was measured at the landscape-level within and among fragmented seagrass meadows by tagging and releasing 200 juvenile red drum into three separate replicated fragmented networks. Within 24 h, only one fish was recaptured within the original fragmented network. The vast majority of recaptured fish were found in the nearest continuous non-fragmented seagrass bed over 50 m from their release point. These results suggest a temporal transition of small newly recruited red drum, where individuals settle ubiquitously among varying levels of fragmentation but over time migrate toward more continuous beds. This study provides evidence that there may be a fragmentation "threshold" for red drum, whereby once a habitat becomes too fragmented; individuals either suffer higher mortality or more likely move to more continuous landscapes. Overall, this study suggests that habitat fragmentation and loss of more continuous seagrass meadows may have negative impacts on estuarine-dependent species using these areas as their primary recruitment habitat.

1. Introduction

On a global scale, both terrestrial and marine environments are experiencing stressors such as overexploitation, physical modification, nutrient and sediment pollution, introduction of nonnative species, and climate change (Waycott et al., 2009). Often, a result of much of these impacts is habitat loss (Pandolfi et al., 2003; Rapport et al., 1998; Skole and Tucker, 1993; Vitousek et al., 1997; Waycott et al., 2009). When environments experience degradation or loss, they typically go through phases of fragmentation (Jaeger, 2000). Often, widely-separated patches appear and will continue to shrink in size and eventually disappear (Forman, 1995). In the past, attention has centered on more obvious and well-known environments such as tropical rain forests, coral reefs, and mangrove forests. However, recent attention has focused on seagrass ecosystems that are characterized by overall loss rates comparable to those of more charismatic ecosystems (Waycott et al., 2009). Seagrass habitats support abundant and diverse communities and provide nursery habitat for many estuarine species (Beck et al., 2001; Chambers, 1991) and availability of nursery and juvenile habitat is essential when determining the dynamics and structure of marine fish populations (Connell and Jones, 1991). Therefore, understanding fragmentation's effect on these systems is timely and important for the maintenance of many marine ecosystems.

Examining the relationship between fish recruitment and nursery availability at the landscape-scale provides a better understanding of spatial and temporal requirements for population persistence, and the impacts of fragmentation on these processes. An important link exists between fish recruitment and the quality of available nursery habitat (Minello, 1999). Ultimately, survival rates of new recruits may be

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lowered if they settle into compromised environments (Levin and Stunz, 2005). Thus, selection for viable nursery habitat is paramount, as they must provide for some level of growth and protection from predation (Stunz and Minello, 2001; Stunz et al., 2002a). Rapid growth to adult stages often confers lower prey vulnerability and ultimate contribution to adult populations. Thus, growth rate is a useful proxy for assessing the health of nursery habitats and survival into adulthood (Houde, 1987). The use of RNA:DNA ratios and otolith microstructure has become a well-accepted method for determining both age and growth rates in juvenile fish (Caldarone et al., 2006; Hovenkamp and Witte, 1991; Rooker and Holt, 1996) among various habitat types. However, each has its own advantage and utility. For example, DNA is species-specific and relatively constant throughout an organism's life while RNA levels increase with somatic growth. Hence, higher RNA:DNA ratios represent faster growth while lower RNA:DNA ratios reflect slower growth (Buckley et al., 1999). Similarly, patterns recorded in otolith microstructure are useful for measuring fish growth rates at various life history stages (Campana and Neilson, 1985; Secor et al., 1991) and can also be used as a proxy for recent fish growth and habitat quality (Stunz et al., 2002b).

Understanding animal movement patterns within the environment is fundamental to the study of animal ecology and to resource management strategies (Pittman and McAlpine, 2003). When areas become more fragmented, distances between individual patches increase, possibly causing density dependent processes to influence survival through local interactions. As a patch shrinks in size, these effects may become magnified unless migration to a more suitable habitat occurs. The well-known “Settle-and-Stay Hypothesis” (Bell and Westoby, 1986) predicts that fish remain in the seagrass beds they first arrive in, as predation risks are too great and outweigh benefits of moving to new areas. Red drum movement within large seagrass beds has been suggested (Rooker et al., 1998a, 1998b), and directly observed by Bushon et al. (2007). Fragmented seagrass meadows present an opportunity to empirically test the “Settle-and-Stay Hypothesis” under varying levels of patchiness. Mark-and-recapture experiments are effective ways to monitor animal movements (Etnier, 1972; Turchin and Thoeny, 1993; White and Burnham, 1999), and a study by Bushon et al. (2007) tagged red drum (<50 mm TL) using visible implant elastomer (VIE; Northwest Marine Technology, Inc.) to track movement patterns within large continuous seagrass meadows. Bushon et al. (2007) recaptured a marked red drum three days after release, 200 m from its original release point, suggesting that red drum are capable of covering relatively large distances in short periods of time. Here, this work is expanded upon by incorporating inter-patch movement of juvenile red drum within a fragmented network of seagrass beds in a replicated experimental design.

Red drum are an economically important, estuarine-dependent species whose habitat requirements and recruitment are well-understood (Holt, 1993; Pattillo et al., 1997; Rooker and Holt, 1997; Stunz and Minello, 2001) making them an ideal study species. Their transition from juvenile into adulthood is critical and relative changes in daily growth can have important consequences for recruitment (Houde, 1987) and regulating their year-class strength (Scharf, 2000). Juvenile red drum can enhance survival by selecting environments that maximize energy intake and minimize predator interactions (Sogard, 1997). Additionally, well-established models for both otolith microstructure and RNA:DNA ratios in red drum have been developed (Rooker and Holt, 1996; Stunz et al., 2002b) for this species making them an excellent model to assess distribution, habitat selection, and growth rates within different levels of seagrass fragmentation.

The overall goal of the study was to experimentally test the response of an estuarine-dependent species to variability in fragmentation of seagrass meadows in terms of distribution, growth, and movement. Specifically, the objectives of this study were to: (1) map patchy networks of seagrass beds within Corpus Christi Bay and Aransas Bay that represent varying levels of fragmentation; (2) describe the effect of seagrass bed fragmentation on red drum density and size distribution; (3) examine whether growth rates of red drum are influenced by levels of fragmentation; (4) and observe fine-scale movement of juvenile red drum within a fragmented seagrass system.

2. Materials and methods

2.1. Study site

Two bay systems along the northwestern Gulf of Mexico, Aransas Bay and Corpus Christi Bay, Texas were chosen to test impacts of fragmentation level on an estuarine fish. The system is separated from the Gulf of Mexico by Mustang Island and Padre Island, and major exchange with Gulf water occurs through Aransas Pass and Packery Channel (Fig. 1). The Environmental Protection Agency (1999) has recognized Aransas and Corpus Christi bay systems as containing habitats of significant importance, as more than 490 species of birds and 234 species of fish are found in these bays. Much of this diversity is driven by several species of seagrass that cover over 138 km^2. These species include: *Thalassia testudinum* Banks ex König 1805, *Halophila engelmannii* Ascherson 1868, *Syringodium filiforme* Kutzing 1860, and *Ruppia maritima* Linnaeus 1753, but the dominant species is *Halodule wrightii*. According to Wilson and Dunton (2012), the estimated seagrass coverage mentioned above is most likely in decline.

2.2. Mapping

In each bay system, nine adjacent study plots (50 m × 100 m) were selected representing varying levels of patchiness from continuous *H. wrightii* seagrass meadows to highly fragmented beds. Plots were initially chosen haphazardly from each bay system based upon a visual approximation of cover, taking into account the size, number, and proximity of patches within each plot. Thus, a highly fragmented site was characterized by having small seagrass patches far apart (>2 m), while a medium fragmented site consisted of larger patches closer together (<2 m; Fernandez et al., 2005). Low or no fragmentation was represented by large continuous seagrass meadows (≥1000 m^2). Study sites had both fragmented plots and continuous meadows within close proximity to minimize differences in hydrodynamic conditions (Fig. 2).

Fragmentation was further mapped and characterized for each individual seagrass patch within every study plot using a sub-meter GPS (Trimble® GeoXT™ GeoExplorer® 2008 series). High-resolution shapefiles were created in the field and later quantified in ArcMap software, version 9.3 (Arc View, ESRI, Redmond, CA, USA). All maps and measurements made within ArcMap were done so using a WGS 1984 UTM Zone 14 N projection. Plots were mapped within a maximum of three weeks prior to sampling events to minimize change in cover and spatial arrangement of patches through growth or degradation. Percent seagrass cover was used as an approximation for fragmentation *per se* (Fernandez et al., 2005; Robinson et al., 1995) and verified using ArcMap. Substrate was classified as either seagrass or bare substrate. Mean and standard error (SE) for percent cover within a standardized sampling grid (50 m × 50 m) was calculated for each fragmented plot. Within each bay, three low cover plots (≤20% seagrass), three medium cover plots (25–55% seagrass), and three continuous plots (≥75% cover) were selected (Fig. 3). In an associated study, these same sites are described in much greater detail including 23 landscape pattern indices (Hensgen et al., 2014).

2.3. Sampling (densities and size distribution)

Samples for density estimates were collected during two sampling events for each plot during red drum peak recruitment in fall 2009 (Oct. 21–Nov. 2), (Rooker and Holt, 1997). Suitable patches within mapped plots were randomly selected and sampled using an epibenthic