

The Effects of Boat Propeller Scarring on Nekton Growth in Subtropical Seagrass Meadows

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Abstract.—An increasing boating population has led to extensive propeller scarring in many shallow seagrass meadows, and research has focused on relating scarring to nekton abundance; however, little information exists on the impacts on habitat functionality. In this study we moved beyond simple measures of faunal density as an indicator of habitat quality by comparing the growth rates of common estuarine nekton in different levels of propeller scarring in Redfish Bay, Texas. Growth rates of selected fauna were examined by using field enclosures and otolith microstructure analysis. Otolith microstructure analysis on pinfish *Lagodon rhomboides* indicated no difference in growth rates at various scarring intensities. We conducted field growth enclosure experiments on a common decapod crustacean, the white shrimp *Litopenaeus setiferus*. White shrimp showed significantly lower growth in highly scarred areas than in reference sites. These results suggest that regions of low-level propeller scarring (less than 15%) may have little effect on small-scale habitat quality. However, higher levels of propeller scarring may affect habitat quality; therefore, more information is needed to characterize the large-scale effects of propellers at higher scarring intensities.

Many species use seagrass meadows as a primary “nursery” habitat (Minello 1999; Beck et al. 2001; Stunz et al. 2002a; Heck et al. 2003). Specifically, seagrass meadows are a structurally complex habitat type providing protection from predation and increased growth rates for associated fauna (Orth et al. 1984; Rozas and Odum 1988; Rooper et al. 1998; Stunz et al. 2002b).

In recent decades, seagrasses have experienced a worldwide decline (Short and Wyllie-Echeverria 1996). Several anthropogenic disturbances have contributed to this decrease in seagrass habitat, including decreased water clarity from dredging, nutrient enrichment, and mechanical damage from boat anchors, mooring chains, and propeller scarring (Tomasko and

Lapointe 1991; Quammen and Onuf 1993; Onuf 1994; Short et al. 1995; Dunton and Schonberg 2002; Uhrin and Holmquist 2003).

Propeller scarring has become a significant problem with the increase in boating activity in shallow seagrass meadows (Dunton and Schonberg 2002). Propeller scars are created when boat propellers cut through the rhizomal mat of a seagrass bed resulting in erosion of the surrounding area (Eleuterius 1987; Zieman 1976; Dawes et al. 1997). This erosion reduces the seagrass bed integrity, which may impact the functionality of the community (Zieman 1976). Previous studies on propeller scarring have focused on seagrass recovery (Dawes et al. 1997), classifying scarring patterns and intensities (Sargent et al. 1995; Dunton and Schonberg 2002), and nekton density patterns (Bell et al. 2002; Uhrin and Holmquist 2003; Burfeind and Stunz 2006). However, we are aware of no studies examining the effect of propeller scarring as it relates to habitat functionality or quality (e.g., growth).

High-value habitats promote fast growth rates and protection from predation. Rapid growth rates reduce the time juvenile fish and invertebrates spend at sizes most vulnerable to predation. We can characterize habitat value by examining growth rates of seagrass-dependent organisms. Juvenile fish and invertebrates use shallow estuarine areas as nursery habitat (Heck and Thoman 1984; Minello 1999), and in these areas they have access to abundant food supplies to promote rapid growth (Boesch and Turner 1984; Kneib 1993).

We can measure growth with a variety of methods; most commonly, it is measured by using field enclosures and analyzing otolith microstructure. Field enclosure experiments are effective for measuring growth over a short period of time in the field (Stunz et al. 2002b). Enclosures restrict organisms to a given scarring intensity but allow access to the bottom substrate for foraging. By enclosing an organism at a given scarring level, one can examine habitat structure as it relates to growth potential. Analysis of otolith microstructure can also be used to examine differences

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in the growth rates of fish. Given the strong correlation between otolith growth and somatic growth (Pannella 1971), the daily patterns recorded in otoliths can be used to estimate recent growth by measuring incremental widths near the otolith margin (Levin et al. 1997; Petrik et al. 1999; Stunz et al. 2002b).

In this study we examined the relative habitat quality of seagrass beds with different levels of propeller scarring using faunal growth as an indicator of habitat quality. To date, there is little information on the effects of propeller scarring on the nursery value of seagrass meadows. Our research is an important conceptual step in linking habitat value to fish production by moving beyond quantifying simple metrics of abundance in relation to habitat, through linking variation in habitat quality (percentage of propeller scarring) to nekton growth rate. Specifically, our objective was to determine whether propeller scarring affected growth rates of fish and decapod crustaceans.

Study Site

Our study site was Redfish Bay, Texas (27°54'27"N, 97°06'45"W), a secondary bay in the 447-km² Aransas Bay complex. Redfish Bay is a barrier-built estuary with freshwater inflows from the Mission and Aransas Rivers (Britton and Morton 1997) and connects to the Gulf of Mexico in Port Aransas via Aransas Pass. The mean daily tidal range is 0.12 m (Rockport, Aransas Bay, National Ocean Service, NOAA), and the tides are mixed and primarily diurnal. Redfish Bay has a maximum water depth of 2.9 m (Montagna et al. 1998) and mean water depth of 0.5 m in the study area. Shoal grass *Halodule wrightii* is the dominant seagrass in this system (Texas Parks and Wildlife 1999); however, turtle grass *Thalassia testudinum*, manatee grass *Syringodium filiforme*, star grass *Halophila engelmannii*, and widgeon grass *Ruppia maritima* also grow in Redfish Bay.

Aerial surveys in 1997 found that 23% of the total area surveyed in Redfish Bay and 97% of Estes Flats, a shallow area within Redfish Bay, had propeller scarring (Dunton and Schonberg 2002). To select study sites in these areas, we used aerial surveys and extensive ground-truthing. Sites were selected with a mean water depth of 0.5 m, because most propeller scars occur in waters shallower than 1 m (Zieman 1976).

The locations of the sites and scarring intensity determination used in this study are described in detail in Burfeind and Stunz (2006). Briefly, we established replicate 10-m × 25-m quadrats (Bell et al. 2002) of three distinct scarring intensities modified from Sargent et al. (1995): low (1.93 ± 0.192% [mean ± SE]), moderate (8.86 ± 0.975%), severe (20.27 ± 1.209%).

Reference sites were located in areas without propeller scarring and within 100 m of scarred sites. Although previous characterizations described scarring of more than 20% as high (Sargent et al. 1995), the number of sites available to us were sufficient to properly replicate our sampling only if we used scarring of more than 15% to represent high levels of scarring. Physical parameters (water depth, salinity, dissolved oxygen, and temperature) were measured at each sampling event. All sites were in monotypic stands of *H. wrightii* with a mean shoot density of 9,083 ± 906 shoots/m (April 2004).

Methods

Otolith microstructure analysis.—We estimated recent growth among various propeller scarring treatment levels by using otolith microstructure analysis. A correlation between otolith and somatic growth has been demonstrated for pinfish (Levin et al. 1997). We measured recent 10-d-increment width near the otolith margin corresponding to recent somatic growth and used that measurement as a proxy for fish growth during this time period. Pinfish were collected from each scarring level and reference sites with an epibenthic sled in spring (17–18 March 2004) and preserved in 70% ethanol. We measured the fish to the nearest 0.1 mm standard length (SL) and did not adjust for shrinking during preservation. We removed the left lapillar otolith from 25 pinfish (SL = 28.5 mm ± 0.236) from each scarring intensity, following the procedures of Secor et al. (1991). Otoliths were placed in immersion oil and read after 48 h. Daily growth ring increments were readily apparent and otoliths did not need further processing. We did not experimentally verify existence of daily growth increments; however, daily growth rings are known to occur in this family (see Francis et al. 1993), and otolith microstructure analysis has been used to measure daily growth in pinfish without age validation (Levin et al. 1997). Because of the significant relationship between otolith diameter and fish length, we could use otolith-based growth as a proxy for fish somatic growth. We determined growth rate by identifying and counting the daily growth rings, using a digital image enhancing system. We measured from the otolith margin in 10 daily growth rings representing the last 10 d of growth. Two observers measured each otolith. If the two measurements were not identical, the otolith was measured for a third time. If there were not two identical length measurements, the otolith was removed from analysis. Mean increment width per scarring intensity was compared by analysis of variance (ANOVA) at $\alpha = 0.05$.

Field growth experiment.—To assess growth rates for decapod crustaceans, we used empirical field-based growth enclosure experiments. Similar growth enclosure experiments have been used successfully to measure short-term growth in estuarine species (see Stunz et al. 2002b). We used 24 field enclosures made from polypropylene barrels (0.283 m²; 60 cm in diameter × 1 m deep) with the ends removed to create a cylindrical enclosure. We used six replicate barrels for each scarring intensity (low, moderate, severe) and six reference sites placed haphazardly in a 10-m × 25-m quadrat of a known scarring intensity. Enclosures were pushed 15 cm into substrate and anchored from the outside with three wooden stakes. We swept enclosures with dip nets (1-mm mesh), removing only predators, and covered enclosure tops with 1-mm-mesh nylon netting. Enclosures were placed where there would be water transport through the sediments and periodic tidal flooding through the top of the enclosure. Previous studies with this experimental system have shown that salinity, dissolved oxygen, and temperature inside the growth enclosures closely tracked conditions outside the enclosures (Stunz et al. 2002b). Water quality conditions were measured three times during the growth trial at 4, 7, and 11 d.

The field growth enclosure experiment began on November 5, 2003, by stocking each enclosure with three white shrimp (mean = 43.6 mm, SE = 1.45). Shrimp were collected in adjacent seagrass meadows, measured to the nearest 1 mm, and marked with an orange visible implant elastomer tag (Northwest Marine Technology; Shaw Island, Washington). The shrimp were held in the enclosures for 11 d and were recovered with dip nets. We determined the growth rate for each shrimp by identifying the individual shrimp, measuring them to the nearest 1 mm, and subtracting the original length measurements. Mean growth was calculated for each replicate enclosure. We used ANOVA to assess the differences in growth at different levels of scarring intensity ($\alpha = 0.05$). Tukey's post hoc test was used for pairwise comparison of mean growth.

Results

Otolith Microstructure Analysis

We found a significant relationship between pinfish length and otolith diameter (diameter = 12.287 · SL + 166.64, $r^2 = 0.46$, $n = 100$, $P < 0.001$); thus, we were able to use otolith increment measurements as a proxy for somatic growth. Increment widths were $55.5 \pm 1.87 \mu\text{m}$ for reference sites, $56.3 \pm 1.14 \mu\text{m}$ for low scarring, $55.34 \pm 1.25 \mu\text{m}$ for moderate scarring, and $59.3 \pm 1.67 \mu\text{m}$ for severe scarring (Figure 1a). The mean increment width for the last 10 d indicated that growth was not significantly different between scarring

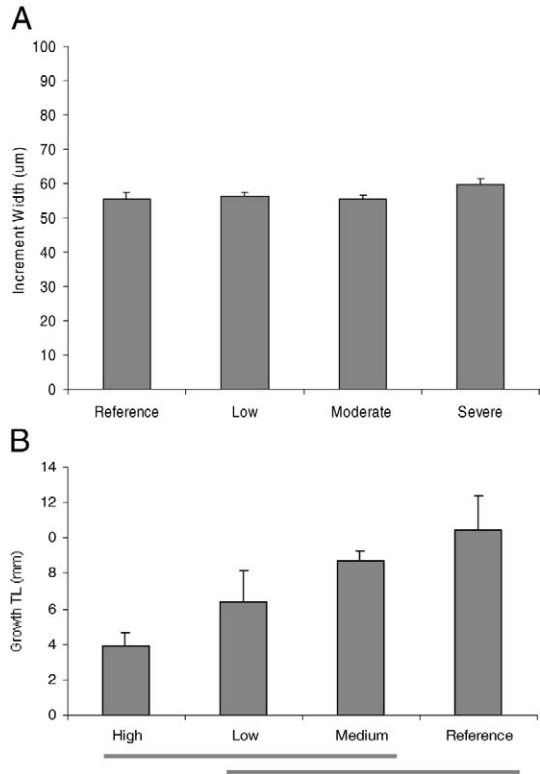


FIGURE 1.—Panel (A) shows mean otolith increment widths for the last 10 d of growth in pinfish collected from four different seagrass beds in Redfish Bay: an undisturbed reference bed and beds with low, moderate, and severe propeller scarring (see text; there were 25 fish from each bed). Panel (B) shows mean \pm SE growth (mm) over the 11-d experiment for white shrimp in field enclosures with distinct scarring intensities. The horizontal bars below the x-axis indicate the results of Tukey's test; scarring intensities above the same bar are not significantly different.

intensities ($n = 25$, $df = 3$, $F = 1.897$, $P = 0.135$, $1 - \beta = 0.99$). These results suggest that pinfish growth is not related to level of scarring intensity.

Growth Enclosure Experiment

Salinity ($23.8 \pm 0.74\text{‰}$), temperature ($23.3 \pm 0.74^\circ\text{C}$), and dissolved oxygen ($7.05 \pm 0.23 \text{ mg/L}$) were measured three times during the enclosure experiment and were similar among scarring intensity treatment levels. We recovered shrimp from six replicate enclosures for moderately scarred sites and from four of six enclosures from reference, low, and highly scarred sites. Overall, there was 76% recovery of all shrimp. Mean white shrimp growth in the enclosure experiment was $10.46 \pm 0.76 \text{ mm}$ in the reference sites, $6.38 \pm 1.76 \text{ mm}$ in the lightly scarred

sites, 8.72 ± 0.57 mm in moderately scarred sites, and 3.92 ± 0.762 mm in severely scarred sites (Figure 1b). The difference in white shrimp growth was significant (ANOVA: $P = 0.016$, $df = 3$, $F = 4.827$, $1 - \beta = 0.93$). Among scarring levels a Tukey post hoc test indicated that white shrimp growth was significantly lower in highly scarred sites than in reference sites, whereas all other sites were similar. Growth rates in reference areas are comparable with those in prior studies (between 0.833 and 1.33 mm/d; Gunter 1950).

Discussion

Enclosure studies are applicable to addressing hypotheses of differential growth among treatments because animals are restricted to a single area. In this case, we tested the hypothesis that propeller scarring would decrease nekton growth rate. We measured white shrimp growth rates in different levels of propeller scarring and found significantly lower growth in severely scarred seagrass beds than in unscarred. White shrimp show no preference in food type (McTigue and Zimmerman 1998) and have been shown to feed on plants (Hunter 1984); it is possible that seagrass, epiphytes, and benthic diatoms are an important part of their diet. Unlike brown shrimp that are known to prefer benthic infauna, white shrimp may be more affected by vegetation removal. However, laboratory studies by McTigue and Zimmerman (1998) showed little to no growth in white shrimp on a plant-based diet, suggesting that a combination of food sources may be necessary (Kneib 1997). This sensitivity to habitat degradation is of particular concern, given that loss of high-quality nursery habitat is thought to be the most serious potential threat to the white shrimp fishery (Webb and Kneib 2002).

Pinfish are abundant and play a significant ecological role in seagrass systems (Potthoff and Allen 2003); therefore, they served as an ideal model species with which to examine otolith-based growth in areas with various levels of propeller scarring. Our examination of otolith microstructure did not show differences in growth among scarring levels and reference areas, though our pinfish growth rates were similar to other studies (Levin et al. 1997). Our results suggest that propeller scars may have limited effect on mobile estuarine fishes; however, these data should be interpreted with some caution. Pinfish were free-ranging before collection, raising the possibility that pinfish were moving between different seagrass beds with different levels of propeller scarring before capture. Because otolith growth tends to be more conservative than somatic growth (Secor and Dean 1989; Sogard and Able 1992; Bestgen and Bundy 1998), analysis of otolith microstructure may be less

able to differentiate small changes in growth rates. Additionally, time differences associated with somatic growth change and subsequent expression in the otolith can have important implications for examining recent growth as related to scarring intensities.

There are two possible explanations for the different effects that propeller scarring has on white shrimp and pinfish. First, propeller scarring may have a greater effect on white shrimp growth than on pinfish growth. However, field-caught pinfish were not restricted to a specific habitat type before capture. Pinfish have relatively high sight fidelity; however, they do move over relatively large areas (Potthoff and Allen 2003). The degree of pinfish movement patterns is unknown, and our sampling areas were often close together or even adjacent to one another. Scarred sites were adjacent to large unscarred areas, and some species use seagrass beds for shelter but forage in adjacent unvegetated habitats (Summerson and Peterson 1984). Therefore, as long as there is sufficient high-quality habitat in adjacent areas, this movement can affect the utility of using growth rates determined by free-ranging fish (Stunz et al. 2002b).

This does not necessarily imply that propeller scarring may not have an effect at some level. Clearly, at some point, increased propeller scarring will degrade habitat and reduce functionality. However, at scarring levels up to 27%, there does not appear to be widespread impact. Examining higher scarring intensities would be beneficial, but in our study areas they are too limited to replicate a treatment level. As well as looking at higher scarring intensities and different spatial scales (see Burfeind and Stunz 2006), modeling may be a useful tool in estimating a threshold point in propeller scarring. More information is needed to characterize the effects of propeller scarring on both the seagrass and nekton. It is important to protect seagrass from propeller scarring until the impacts on nekton and seagrass bed stability are fully understood.

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