BEHAVIORAL CONDITION OF RED DRUM *SCIAENOPS OCELLATUS*
FINGERLINGS EXPOSED TO HABITAT STRUCTURES AND PREDATORS IN
REARING PONDS

A Thesis

By

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BS, Coastal Carolina University, 2011

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This thesis meets the standards for scope and quality of
Texas A&M-Corpus Christi and is hereby approved.

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ABSTRACT

Stock enhancement programs strive to propagate fish similar to their wild counterparts, but hatchery-reared fish are often deficient in their ability to detect and avoid predation. The objective of this study was to determine if the provision of complexly structured habitat would improve post-stocking survival of hatchery-reared red drum, *Sciaenops ocellatus*, when exposed to free-roaming predators. Experiments were conducted in 0.2 ha rearing ponds between July and December 2016 at the Coastal Conservation Association Marine Development Center in Corpus Christi, Texas. Three habitat treatments (non-vegetated [normal rearing], artificial seagrass, and artificial seagrass with predator exclusion cages) were used to assess if habitat complexity influenced growth and condition. Fish growth (TL) was affected by trial (i.e., seasonality; $P < 0.0001$) but not by treatment ($P = 0.178$). After rearing to the fingerling stage (36 days post-hatch), survival from predation was assessed by exposing red drum to free-roaming predators (pinfish, *Lagodon rhomboides*) in experimental "wild" ponds (0.2 ha) with artificial seagrass for 24 hours. In two trials, fish condition (K) differed significantly among treatments ($P<0.0001$) and was lower in the artificial seagrass treatment with predator exclusion cages compared to the other treatments. Red drum may have been more active and vigilant ("leaner") when exposed to caged predators, while the fish in the unstructured habitat led a more sedentary life ("fat"). Overall, when exposed to free-roaming predators in a "wild simulation" fish reared in ponds with the addition of structured, complex habitat survived better. The results of this study suggest that the provision of complexly structured habitat improved behavioral mechanisms (i.e.,

foraging, predator-avoidance) that may increase post-release survival of hatchery-reared red drum.

ACKNOWLEDGEMENTS

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Introduction

Recreational fishing is both a favorite pastime for millions of Americans, and a high-value business in the United States. A 2011 economic impact assessment indicates that angler expenditures contributed an estimated $56 billion to the economy including $29 billion to gross domestic product and $18 billion in income impacts supporting 364,000 jobs across the United States (DOI 2014a). The 751,000 anglers in the Texas saltwater recreation fishery (DOI 2014b) spent $1.4 billion in angler expenditures during 2011 (Lovell et al. 2013), generating an estimated $3.76 billion in total economic output (Southwick Associates 2013). Saltwater recreational fishing in Texas added 13,000 jobs, generated $1.6 billion in sales, and added $958 million to the state's gross domestic product, and $586 million in personal income (Lovell et al. 2013). The three major targeted species, red drum (*Sciaenops ocellatus*), spotted seatrout (*Cynoscion nebulosus*), and southern flounder (*Paralichthys lethostigma*) are extremely important to the total economic output of the local resource-based economies of Texas coastal communities. In 2011, almost two-thirds of more than 8.1 million saltwater fishing days by residents and non-residents were spent targeting these three species (DOI 2014b).

In the 1970s, the size of red drum populations in Texas bays plummeted due to overfishing and habitat degradation (McEachron et al. 1998). To address the decline in red drum populations, state fisheries managers developed strategies that included initiating a long-term independent fisheries monitoring program, banning commercial gillnetting, recreational fishing regulation changes, and constructing a marine fish hatchery for the purposes of stock enhancement (McEachron et al. 1998). The objective of the stock enhancement program was to release hatchery-reared red drum juveniles to supplement natural stocks (Matlock et al. 1986, Rutledge and Matlock 1986, Matlock

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1990, McEachron et al. 1995, McEachron et al. 1998). The Texas Parks and Wildlife Department has produced more than 680 million red drum fingerlings, releasing 15-20 million red drum fingerlings annually into nine Texas bays and estuaries (Vega et al. 2011). Combined with traditional management tools, stock enhancement has proven to be a powerful combination in managing Texas' red drum fishery.

Wild stocks of red drum have rebounded to near-record highs in Texas bays (Vega et al. 2011). However, even though stock enhancement is a valuable tool for managing depleted populations (Secor and Houde 1998), the culturing of hatchery-reared fishes in open, unstructured ponds may cause the fish to be at a disadvantage upon release into the wild (Grimes 1998). Behavioral mechanisms may be compromised during the hatchery-rearing process or survival rates of hatchery fishes in the wild may be negatively impacted or both (Beck and Rooker 2012). The goal of the present study was to investigate whether the rearing process compromises behavioral mechanisms and if behavioral conditioning can be improved using complex habitats.

Early Life Stage Discrepancies

Enhancement programs strive to propagate hatchery-reared fingerlings that are very similar to their wild counterparts (Leber 2002). However, some differences between hatchery-reared fish and those from the wild have been reported (Stunz and Minello 2001). During the past few decades, stocking programs around the world have made concerted efforts to take a "responsible approach" to the science of stock enhancement (Leber 2002). To maximize utility of stock enhancement as a fisheries management tool, it is very important to be aware of differences between cultured and wild fishes to lessen

any potential negative impacts that stocking hatchery-reared fishes may have to natural stocks.

During early life stages, most marine fishes typically experience a great deal (>99%) of predation-related mortality (Houde 1987, 2002). Predation is a strong and pervasive ecological force, thus various antipredator defenses mechanisms have evolved in the early life stages of marine fishes (Beck and Rooker 2012). When a predator threat arises, many of these defenses are behavioral in nature, including the ability to freeze (Brown and Smith 1998), burrow (Howell and Baynes 1993), school (Pitcher and Parrish 1993) or use habitat refuge (Sogard and Olla 1993). Fish react to predatory threats based upon visual, chemical, and mechanosensory cues with antipredator responses often learned or modified with experience (Magurran, 1990; Magurran and Seghers 1990). The ability for fish to "learn" to respond to predatory threats is of particular interest to hatchery managers because hatchery-reared fishes are often deficient in their ability to detect and avoid predation (Olla et al. 1998). In the case of hatchery-reared red drum, it can be argued that predation awareness deficits may be caused by a lack of habitat complexity and predatory stimuli in the hatchery rearing environment.

The ability for juvenile fish to evade predation is often related to the complexity of available habitat during their early life stages (Heck et al. 1997). In the wild, red drum spawn in coastal waters near passes and inlets where currents carry eggs into structural habitats such as seagrass meadows (Holt et al. 1983), oyster reefs, and marsh. Structural complexity can affect foraging, effectiveness, and selectivity of predators (Heck and Thoman 1981; Eggleston et al. 1998). There is evidence that structural habitat complexity may also support an increase in the growth rate of fishes (Heck and Thoman 1981),

resulting in reduced mortality due to size-selective predation (Sogard 1997). Many

experiments have been conducted in laboratory settings to compare hatchery-reared

fingerlings to their wild counterparts. Olla and Davis (1989) examined predator

avoidance between hatchery-reared coho salmon (*Oncorhynchus kisutch*) and wild coho

salmon. Wild coho salmon consistently survived in greater numbers as compared to

hatchery-reared fish when introduced to predators. Other studies have shown that wild

Atlantic salmon (*Salmo salar*) fingerlings had greater anaerobic capacity and swimming

abilities than their cultured counterparts (McDonald et al. 1998).

Studies have suggested that hatchery-reared red drum may have inferior foraging

and antipredator avoidance behaviors that could result in high mortality rates upon their

release into the wild. Smith and Fuiman (2004) compared behavioral performance

between reared and wild larval red drum and determined that wild red drum had a greater

swimming skills when subjected to startle responses. Beck and Rooker (2008) obtained

18-day post-hatch red drum fingerlings (10–12 mm SL) from a nonvegetated pond and

reared them with and without smooth cordgrass (*Spartina alterniflora*), to quantify prey

capture and antipredator performances. The results indicated that performance varied

substantially among individuals, but ontogeny appeared to have a direct effect on the

development of key survival skills with fish reared with cordgrass. Beck and Rooker

(2012) compared red drum fingerlings that were reared with and without predators. They

found that red drum fingerlings exposed to predatory pinfish (*Lagodon rhomboides*), had

a 300% greater reaction distance and 20–30% greater response distance versus fish reared

without a predator. Stunz and Minello (2001) examined habitat-specific mortality of red

drum using an experimental mesocosm approach by adding habitat structure to 125 L

plastic tanks. Thirty-day post-hatch hatchery-reared red drum (target size 25–30 mm) and similarly sized wild-caught red drum were added to tanks containing various habitat structure. After a two-hour acclimation period, red drum were exposed to predators for six hours. Their study revealed that hatchery-reared red drum suffered higher overall mortality (mean of 4.8 eaten/mesocosm) than wild-caught fish (mean of 4.0 eaten/mesocosm). They suggested that hatchery-reared red drum survival rates may be improved through habitat-related behavior modification.

Objectives

There have been few studies conducted to examine the behavioral performance and habitat-related predation of hatchery-reared red drum. The issue is that hatchery-reared fingerlings spend the early life stages (first 30 days) in an artificial environment. These individuals have no exposure to habitat structure and predators compared to their wild counterparts. Behavioral conditioning, for example, through exposure to habitat structure (habitat effect), at an early larval stage (3–30 days post-hatch [dph]), may reduce predation-related mortality. The objective of the present study was to compare red drum reared using hatchery standard operation procedures in unstructured outdoor ponds (normal rearing environment) to red drum reared in ponds with structured habitats and structured habitats with predator exclusion cages (experimental treatments). The study tested the effects of habitat and predator exposure on survival of hatchery-reared red drum. The two main objectives were:

(1) To compare growth and condition of hatchery-reared red drum fingerlings in a non-structured habitat, a complexly structured habitat, and a complex habitat with caged predators; and

(2) To compare survival of red drum fingerlings reared in the three different habitats after short-term exposure (24-hour exposure period) to free-roaming predators in an experimental "wild" setting.

Materials and Methods

Study Site and Source of Red Drum Larvae

The study was conducted at the Coastal Conservation Association Marine Development Center (MDC) located in Corpus Christi, Texas. Red drum broodfish were held in 13,000 L tanks and subjected to a 150-day photoperiod/temperature regime to induce spawning (McCarty 1990). Once spawning occurred, eggs were collected and transferred to 945 L incubation tanks to hatch. After three days in the incubation tanks, first feeding larvae were transported to three, 0.2 ha ponds and stocked at approximately 292,000 larvae/pond. Outdoor rearing ponds were filled with filtered (500 µm) salt water from the upper Laguna Madre and a combination of chemical inorganic and organic fertilizers were added to promote a rapid zooplankton bloom, a primary food source for larval red drum (Vega et al. 2011). After larvae reached the desired size during the grow-out period (~ day 10) fish were fed a commercial fry feed (Rangen #0 and #1).

Construction of Seagrass Mats

Seagrass mats were constructed to mimic natural shoalgrass (*Halodule wrightii*), the dominant seagrass species found in those Texas bays with seagrass coverage (Short et al. 2010). In local waters (i.e., upper Laguna Madre) stocked by the MDC, shoalgrass averages 3347 ± 555 shoots/m^2 (Gutierrez et al. 2010). However, it was impractical to replicate that density of shoots, therefore, mats were constructed to mimic shoalgrass densities at the lower end of the ranges recorded in both upper Laguna Madre and nearby

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Corpus Christi Bay. Mats were constructed of recycled black plastic pond liner with green polypropylene ribbons (5 mm wide) glued on at an average density of ~1000–1200 shoots/m^2. The blade ribbons averaged ~20 cm in length, the average length found in Texas bays (Short et al., 2010). For ease of construction, recycled pond liner was cut into 1.3 m x 4.8 m sections. Starting at one end, a glue line was put down and precut polypropylene ribbons were laid followed by an additional glue line on top to "lock-in" the blades. One side was bent over to begin a new line. This was repeated until the section was covered. Sixteen sections were produced for a single pond (100 m^2). In each trial (including the 24-hour free-roaming predator exposure), five of six ponds utilized artificial seagrass, totaling 500 m^2 in each trial. After each trial, artificial seagrass was reused in the next trial.

Predator Collection

Pinfish are a primary predator of red drum fingerlings (Fuiman 1994; Rooker et al. 1998) and were used in the study. Due to spatial and temporal variation combined with hydrological influences and habitat availability, pinfish density can vary among habitats throughout the Gulf of Mexico (Chacin 2014). To attempt to accurately simulate densities in the wild during the predator exposure periods, pinfish were stocked at densities found in natural seagrass habitats. Chacin (2014) reported pinfish densities ranging from 8 fish/100 m^2 to 74 fish/100 m^2 in seagrass beds. The average density for this study was 40 pinfish/100 m^2 within seagrass habitats. To utilize 40 pinfish/pond required 120 pinfish/trial (40 pinfish/pond x 3 wild simulated ponds), a number that was attainable and manageable. Most pinfish were collected by cast netting from estuarine areas near the MDC.

Experimental Design – Rearing Process

To test the effect of habitat and predator exposure on hatchery-reared red drum, three 0.2 ha ponds were used during the rearing process. The Control was a pond with an open, unstructured environment (Fig. 1). The Seagrass Only treatment was a pond that contained 100 m^2 of artificial seagrass mats. The Seagrass+Predator treatment was a pond that contained 100 m^2 of artificial seagrass mats as well as four predator exclusion cages (PEC) that were purposely positioned in close proximity to seagrass. Ten pinfish were added to each PEC (10.6 ± 1.4 mm TL, n = 120 [40 pinfish/trial]). Predator exclusion cages were provided by the MDC and were constructed of 1-inch diameter PVC to produce a frame, wrapped in plastic mesh with ¼-inch openings in a cylindrical shape. Each end was wrapped with the same plastic mesh with the top end providing a small hatch opening to allow for feeding and to prevent waterfowl from entering. Predator exclusion cages (0.9 m diameter x 0.9 m height, total volume = 0.57 m^3 [570 L], bottom area = 0.64 m^2) were positioned between the paddlewheel and seagrass mats (Fig. 1C). Predator exclusion cages were placed closer in proximity to the seagrass mats than the paddlewheel. To be consistent, PECs were placed in the same position during each trial.

The study was replicated three times between midsummer (July) through early winter (December) of 2016. Trials were run consecutively, with each trial lasting 37 days. At the start of each trial, three-day post-hatch red drum larvae were stocked into treatment ponds at an average density of 292,000 larvae.

Sample Preparation

After stocking, sampling of fish occurred every three days throughout the rearing process (i.e., 6, 9, 12, 15, 18, 21, 24, 27, 30, 33, and 36 dph). During each sampling day,
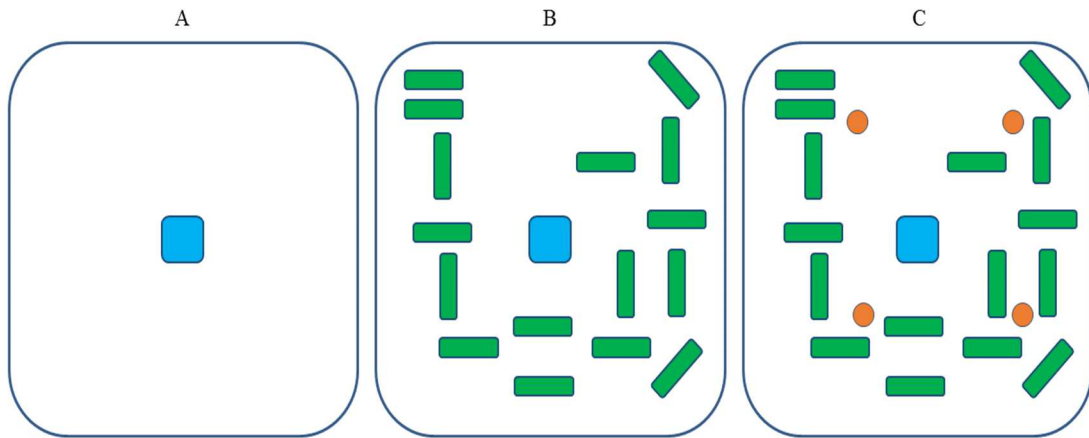
FIGURE 1. *Schematic of the three habitat condition treatments. A) Control – pond with unstructured bottom; B) Seagrass Only treatment – seagrass simulation pond with 16, 1.3 m x 4.8 m sections of artificial seagrass (100 m² total); C) Seagrass+Predator treatment – seagrass simulation pond with predator exclusion cages (PECs) with 16, 1.3 m x 4.8 m sections of artificial seagrass (100 m² total) and four PECs (circles). Center square represents paddlewheel. Diagrams are not to scale.*

30 fish were collected from each pond. For the first two sampling days (i.e., 6 and 9 dph), fish were collected by pulling an ichthyoplankton net (368 μm) diagonally across each pond. For the rest of the trial, fish were collected in and around the Kansas pond kettles (basin in each pond to harvest fish) using a stainless-steel dip net (1.5 mm). Water quality parameters (dissolved oxygen, salinity, temperature, and pH) were measured using a handheld YSI Professional Plus series probe (Yellow Springs Instruments, Yellow Springs, Ohio).

Zooplankton samples were determined by hatchery personnel following their standard operating procedure prior to larvae introduction and throughout the rearing process. Zooplankton samples were collected three times a week (Monday, Wednesday, and Friday) using a Wisconsin-style plankton net (63 μm). Samples were processed to quantify the total zooplankton density (copepods, nauplii, and rotifers) in each pond.

At the beginning of each trial, hatchery personnel determined the total number of red drum larvae stocked into each pond. At the end of each trial, hatchery personnel determined the total number of fingerlings harvested from each pond as well as the percent return.

Growth Indices

Growth indices were calculated using total length (mm) and weight (g) measurements, that were recorded for fish collected during each sampling event. Condition factors was calculated using the formula $K = (W/TL^3)100$, where K = the condition factor, W = weight in grams, and TL = total length in millimeters (Wakeman and Ramsey 1985). Absolute growth of fish over time was calculated using the formula $G = (L_F - L_I)/T$, where G = growth rate, L_f = final length, L_I = initial length, and T = days (Ricker 1979). Specific growth rate (SGR) was calculated using the formula $SGR = 100\% (\ln W_2 - \ln W_1)/(t_2 - t_1)$, where SGR = specific growth rate (rate/d), and W_1 and W_2 represent the initial and final weights at time t_1 and t_2, respectively (Ricker 1979).

Experimental Design – Wild Simulations

To evaluate survivorship of released hatchery-reared fingerlings, another set of three 0.2 ha ponds were used (Fig. 2). These ponds mimicked a "wild" simulation containing 100 m^2 of artificial seagrass in each pond and including free-roaming predators (pinfish). At 36 dph, rearing ponds were drained and all red drum fingerlings were harvested. Five thousand red drum fingerlings from each pond were collected (initial weight before entry into wild simulation) and transferred to their respective wild simulation pond. Remaining red drum from each pond were placed in a hauling unit and released into the wild per normal TPWD procedures. In the wild simulation experiments,
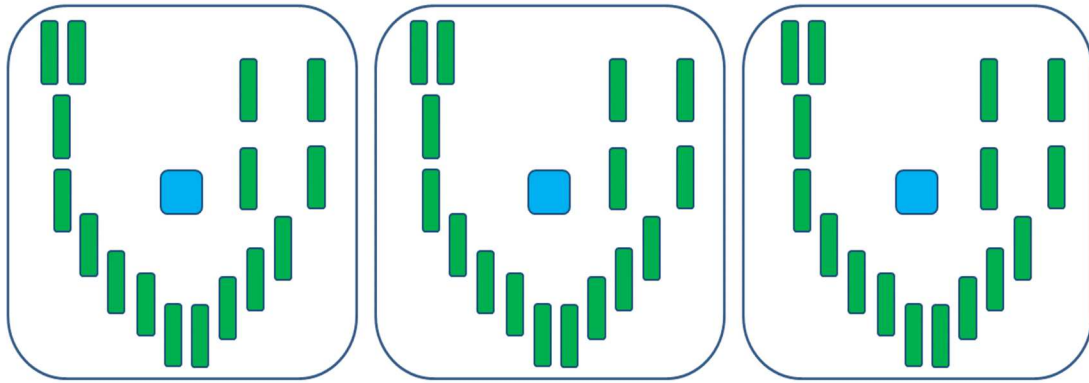
FIGURE 2. *Schematic of wild simulation ponds into which red drum from each habitat conditioning treatment were stocked for 24 hours. Each wild simulation pond contained 16, 1.3 m x 4.8 m sections (100 m² total) of artificial seagrass and 40 free-roaming predators. Diagrams are not to scale.*

free-roaming pinfish (12.4 ± 2.4 cm TL, $n = 360$ [120 pinfish/trial]) were added to each pond (40 pinfish/pond) four to five days prior to red drum introduction. Once red drum were "stocked" into their respective wild simulation, the 24-hour predator exposure period began. After the 24-hour exposure period, ponds were drained simultaneously. Red drum and pinfish were collected from the harvest kettle by dip net. Remaining red drum were placed into a tared bucket and final wet weights were recorded. The ponds were fully drained and remaining fingerlings found in the kettle were added to the survivor count.

Statistical Analyses

A multivariate analysis of variance (MANOVA) was used to test for differences in physicochemical parameters and zooplankton densities among treatments and trials. Because there were significant differences in these parameters among trials, each trail was analyzed separately to determine the effects of treatments on red drum. During the rearing process (3–36 dph), mean and standard error for total length (mm) and weight (g)

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were calculated and recorded for each sampling day. Mean length and weight from each treatment were compared using one-way analysis of variance (ANOVA) to evaluate if there were significant differences among treatments. At the end of each rearing process, ponds were drained and 30 fingerlings were collected from the pond kettle to determine mean length and weight at 36 dph. These lengths and weights were used to calculate condition factor (K) for each treatment at day 36 prior to predator exposure. One-way analysis of variance (ANOVA) was used to evaluate if there were significant differences in K among treatments. After the predator exposure period, remaining fingerlings were collected and survival was calculated (((initial weight – final weight)/initial weight) 100%) for each treatment. In all cases when ANOVA indicated a significant treatment effect ($P < 0.05$), the sources of differences were determined using Tukey's (HSD) test. The statistical software R (Version 3.3.2) was used for all statistical analyses.

Results

Three experimental trials were conducted over six months (July–December). Dissolved oxygen, pH, salinity, and water temperature were measured daily within treatment ponds during each trial (12 July – 12 August; 12 September – 13 October; 5 November – 7 December). Physicochemical parameters varied by trial but showed little variability within a trial (Fig. 3). The results of MANOVA analysis indicated that there were no significant differences in the physicochemical measurements among treatments ($P >$ 0.05) but that there were significant differences among trials ($P < 0.0001$; Appendix 1.1). Similarly, the densities of zooplankters (Fig. 4) were similar among treatments within trials ($P > 0.05$) but MANOVA analysis showed that there were significant differences among trials ($P < 0.0001$; Appendix 1.2). Because there were clearly seasonal
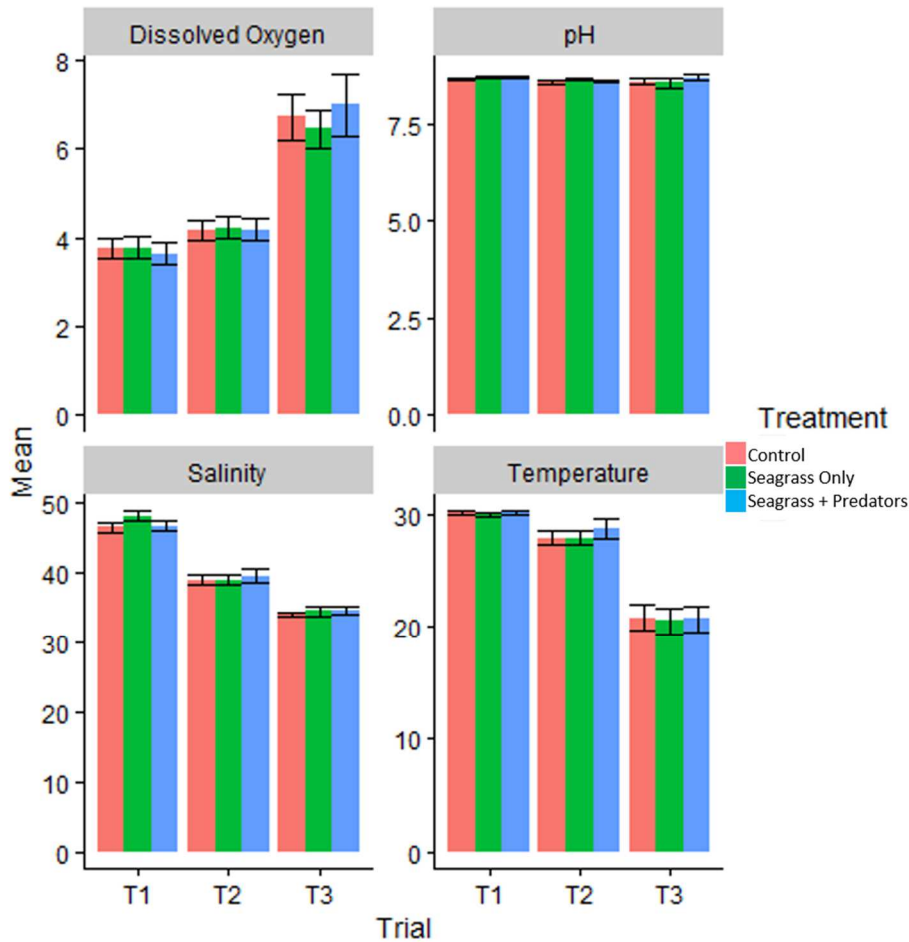
FIGURE 3. *Mean values (mean ± SE) for pond parameters using trial as a blocking factor. There was no significant difference between treatments (P > 0.05) but differences between trials (P < 0.0001).*

differences in the hydrological and biological conditions among trials, each trial was analyzed separately.

Ponds were stocked with about the same number of fish for each trial but the absolute number stocked varied by several tens of thousands to nearly 100,000 between trials (Table 1). Numbers harvested and percent return varied greatly between trials with the worst returns recorded from Trial 2, and the best returns from Trial 3. There was no discernible pattern in the variability in returns with regard to treatment or initial stocking
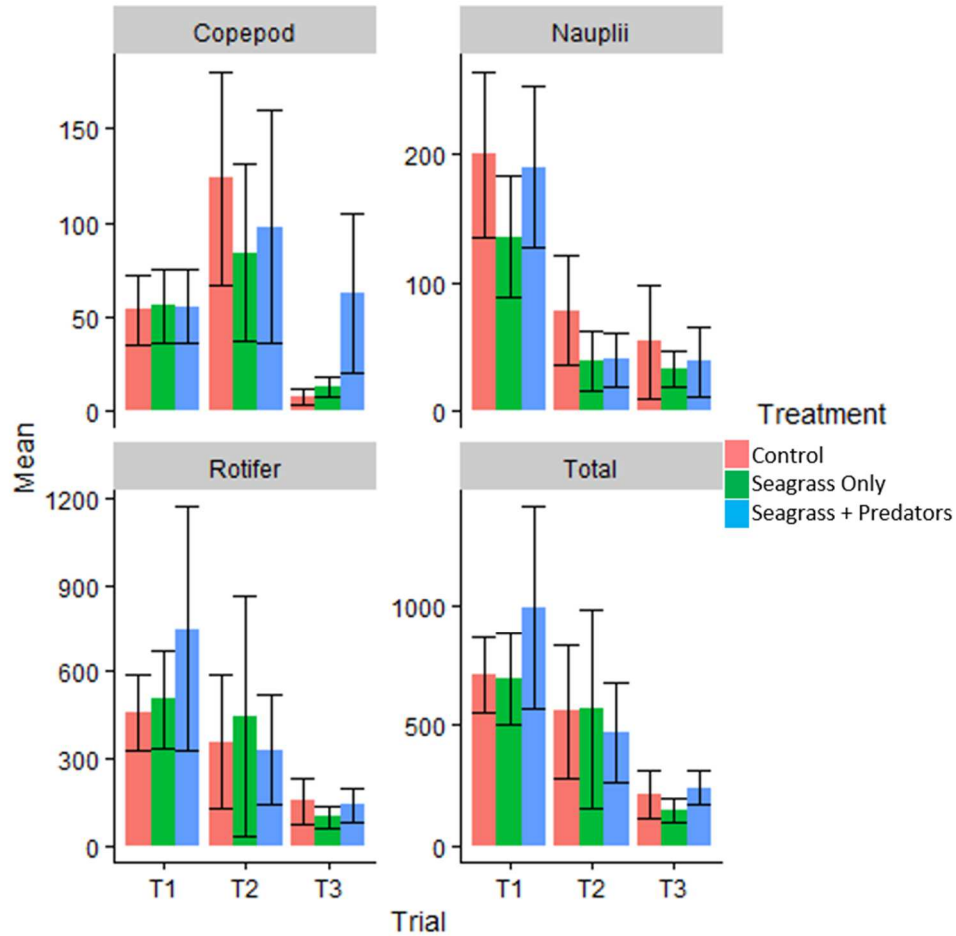
FIGURE 4. *Mean values (mean ± SEM) for zooplankton density using trial as a blocking factor. There was no significant difference between habitat treatments (P > 0.05) but differences between trials (P = 0.003).*

TABLE 1. *Number of fish initially stocked at the beginning of each trial, number of fish harvested at the end of each trial and calculated percent return from each rearing ponds.*

Trial	Treatment	# Stocked	# Harvested	% Return
1	Control	271,594	94,874	34.9
	Seagrass Only	263,808	102,934	39.0
	Seagrass+Predator	266,556	76,095	28.6
2	Control	308,234	57,599	18.7
	Seagrass Only	363,194	30,734	8.5
	Seagrass+Predator	339,836	55,497	16.3
3	Control	263,809	188,298	71.4
	Seagrass Only	279,380	88,389	31.6
	Seagrass+Predator	275,255	233,736	84.9

density. Reduced water temperatures and salinities and increased dissolved oxygen concentrations during Trial 3 may have contributed to its generally better returns.

Trial 1

Trial 1 was conducted between 12 July and 12 August when air temperatures averaged 30 ℃ during the day and dropped into the mid 20's at night. This was reflected in the water temperatures in the experimental ponds which varied little and averaged 30.1 ± 0.06 °C (Fig. 3). The ponds were hypersaline, and average dissolved oxygen was slightly less than 4 mg/L (Fig. 3). Total zooplankton density was variable (Fig. 4), with greatest average density in the Seagrass+Predator treatment pond due to the large number of rotifers. At 36 dph, there were significant differences ($P < 0.0001$) among treatments in the lengths and weights of fingerlings but no significant differences ($P > 0.05$) in condition factor (Fig. 5, Appendix 1.3). The fingerlings harvested from the Seagrass+Predator treatment were significantly longer and heavier than those harvested from either the Control or the Seagrass Only treatments (Fig. 5). Absolute and specific growth rates were highest in the Seagrass+Predator treatment (Table 2). Although specific growth rate in the Seagrass Only treatment was higher than that in the Control, absolute growth rates in the two treatments were identical.

Trial 2

Trial 2 was conducted between 12 September and 13 October when air temperatures averaged 29 ℃ during the day and water temperatures in the experimental ponds averaged 28.2 ± 0.73 °C. Ponds were hypersaline, and average dissolved oxygen was slightly above 4 mg/L (Fig. 3). Total zooplankton was variable (Fig. 4), with the greatest average density in the Seagrass Only treatment pond due to the large number of
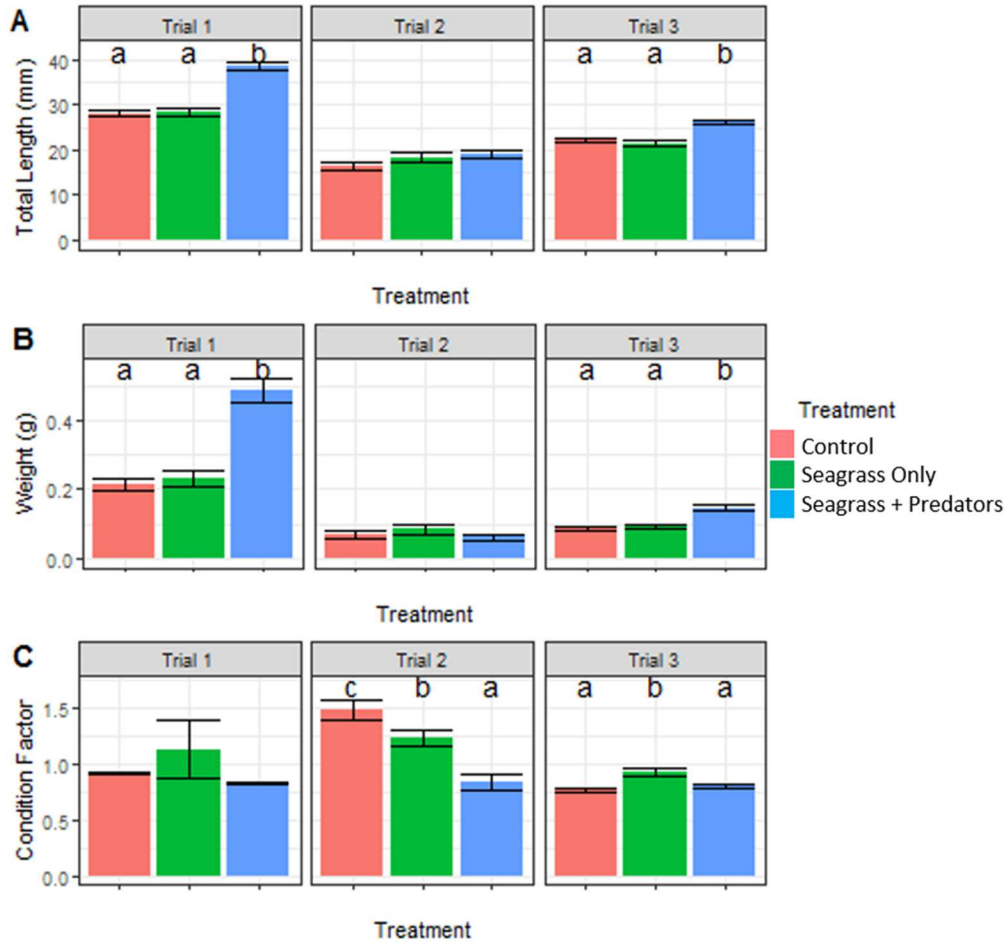
FIGURE 5. *(A) Mean (± SE) total length (mm) of each treatment among the three trials (36 dph). (B) Mean (± SE) weight (g) of each treatment among the three trials (36 dph). (C) Mean (± SE) condition factor of each treatment among the three trials (36 dph). Letters above columns indicate treatments that were significantly different from one another.*

TABLE 2. *Absolute growth vs specific growth of each treatment.*

	Treatment	Absolute Growth (mm/d)	Specific Growth (%/d)
Trial 1	Control	0.84	14.6
	Seagrass Only	0.84	16.1
	Seagrass+Predator	1.17	18.3
Trial 2	Control	0.44	4.02
	Seagrass Only	0.50	16.1
	Seagrass+Predator	0.52	15.3
Trial 3	Control	0.63	18.2
	Seagrass Only	0.61	17.1
	Seagrass+Predator	0.77	18.4

rotifers. At 36 dph, there were no significant differences in the lengths and weights of fingerlings ($P > 0.05$) among treatments but significant differences ($P < 0.0001$) in condition factor (Fig. 5, Appendix 1.4). The highest condition factor was in the Control and the lowest in the Seagrass+Predator treatment (Fig. 5, Table 3). Absolute growth was slightly higher in the Seagrass+Predator treatment compared to the Seagrass Only treatment (Table 2). Although absolute growth was higher in the Seagrass+Predator treatment than the Seagrass Only treatment, absolute growth rates were nearly identical. In contrast, specific growth rate was higher in the Seagrass Only treatment compared to the Seagrass+Predator treatment.

Trial 3

Trial 3 was conducted between 5 November and 7 December. Water temperatures in the experimental ponds varied little and averaged 20.7 ± 1.15 ºC, which was much lower compared to Trial 1 and 2 (Fig. 3). Pond salinity was no longer hypersaline averaging 34.2 ± 0.53 ppt (Fig. 3). Dissolved oxygen concentrations averaged about 6 mg/L (Fig. 3). Total zooplankton density was variable (Fig. 4), with greatest average densities in the Seagrass+Predator treatment pond due to the large number of copepods (Fig. 4). At 36 dph, there were significant differences ($P < 0.0001$) among treatments in lengths, weights, and condition factor (Fig. 5, Appendix 1.5). The fingerlings harvested from the Seagrass+Predator treatment were significantly longer and heavier than those harvested from either the Control or the Seagrass Only treatments. Condition factor was significantly higher in the Seagrass Only treatment compared to the Control and Seagrass+Predator treatments. Absolute and specific growth rates were highest in the Seagrass+Predator treatment (Table 2). Although specific growth rates were higher in the

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TABLE 3. *The initial weight of 5,000 fish at harvest going into the "wild" simulations with condition factor (mean ± SE) at day 36. Final weight of remaining fish after exposure period with calculated percent survival from wild simulations.*

Trial	Treatment	5,000 fish by weight (g) (36 dph)	K (36 dph)	Weight after exposure period (g) (37 dph)	% Survival
1	Control	3810.173	0.91±0.07	2857.63	75
	Seagrass Only	1202.019	1.13±1.39	997.9024	83
	Seagrass+Predator	2018.484	0.83±0.07	1723.65	85
2	Control	399.161	1.49±0.50	181.4368	45
	Seagrass Only	839.1452	1.23±0.43	521.6308	62
	Seagrass+Predator	771.1064	0.84±0.42	639.5647	82
3	Control	476.2716	0.77±0.11	408.2328	86
	Seagrass Only	453.592	0.92±0.17	249.4756	55
	Seagrass+Predator	725.7472	0.80±0.08	657.7084	91

Seagrass+Predator treatment compared to the Control, specific growth rates were nearly identical.

"Wild" Simulation

After their conditioning in the treatment ponds, fish were harvested as normal, and 5000 from each treatment were set aside (Table 3) for the 24-hour exposure to free-ranging predators (i.e., pinfish). Fish from each treatment were released into separate ponds with artificial seagrass cover that was the same in each pond (see Fig. 2) and survival after 24 hours was determined (Table 3). The 36 dph condition of fingerlings was determined prior to their release with significant differences among treatments in Trials 2 and 3 (see Fig. 5C). Condition prior to release into the "wild" simulation ponds did not appear to have an impact on 24-hour survival. Although average condition factor of fish from the Seagrass+Predator treatment was typically lower than fish from the other treatments, survival was consistently greater in fingerlings from the Seagrass+Predator

treatment (Table 3). Fish from the Control treatment generally fared worse than fingerlings in either of the structurally enhanced treatments even when their condition factor was higher than fingerlings from the other treatments (i.e., Trial 2). In fact, in Trial 2, condition factor of Control fingerlings was significantly higher than fish from the other treatments, yet the lowest survival was recorded. Conversely, in Trial 3, condition factor of Control and Seagrass+Predator fingerlings was significantly lower than fingerlings in the Seagrass Only treatment, but survival in the Seagrass Only treatment was lower than either Control fingerlings or Seagrass+Predator fingerlings.

Discussion

The results of study suggest that as habitat complexity increases, survival of hatchery-reared red drum increases. Behavioral mechanisms (e.g., foraging, predator-avoidance, etc.) may have been improved by provision of complexly structured habitat during the rearing process. In a similar study, Rooker et al. (1998) suggested that vegetated habitats reduced the ability for predators to detect and capture prey. Beck and Rooker 2012 found that red drum reared with predators (pinfish) had improved antipredator performances (reaction distance, response distance, and increased velocity) versus red drum reared without predators. Other studies have found that antipredator mechanisms (i.e., predator response, predator avoidance, swimming speed) varies greatly between hatchery-reared red drum and their wild counterparts (Rooker et al. 1998, Stunz and Minello 2001, Smith and Fuiman 2003). In the present study, when red drum reared with structured habitat were added to the wild simulations, they exhibited an evasive behavioral response by immediately swimming to the bottom of seagrass beds, similar to wild red drum (Stunz and Minello 2001). In contrast, fish reared in the unstructured pond

environment were observed schooling at the surface when placed into the wild simulation (personal observation). This schooling behavior may have increased predation from predators. While endogenous factors (i.e., learned behavior) seemed to play a role in improving survival, exogenous factors (e.g., stocking densities, food availability, physiological stress, and environment) need to be considered.

Size-selective predation could have played a role in survival. Throughout all trials there was no significant difference in zooplankton densities or amounts of supplemental feeds supplied among treatments that resulted in no significant difference in lengths of fishes between treatments. However, there were significant differences in fish weights between treatments. This difference could have been due to the presence of structured habitat (Heck and Thoman 1981, Rozas and Odum 1988, Levin 1994), which could have increased food availability in the form of detritus and epiphytic algae (Thayer et al. 1984, Zieman and Zieman 1989, Heck et al 1997). In the present study, Seagrass+Predator treatment had the highest absolute growth rate between trials and the highest specific growth rate (except in Trial 2), reducing mortality due to size-selective predation and producing the highest survival among all trials. Throughout the three trials, the Control group (unstructured) and Seagrass Only treatment produced fish with no significant difference between lengths and weights. Despite the two treatments producing similarly sized fish, the Seagrass Only treatment still produced the second highest survival among treatments (except in Trial 3), evidence that behavioral mechanisms were improved through the presence of seagrass.

In a hatchery setting, red drum condition factor (K) ranges from 0.74-0.99 with an average value of 0.88 (Anderson and Cason 2015), whereas in the present study, K values

ranged from 0.77–1.49 with an average K value of 0.99. A study by Anderson and Cason (2015) found that neither stocking density nor harvest density could explain condition factor. The improved K value in the present study could have resulted in the improved rearing environment from the treatment groups utilizing artificial seagrass. Another aspect that stood out was the low K value across all trials for Seagrass+Predator treatment (36 dph). Although the Seagrass+Predator treatment produced the longest fish throughout the study, it did not produce the heaviest fish. Fish in the Seagrass+Predator treatment were long, but with smaller girth, which reduces their weight, thus reducing K (Froese 2006). The presence of predators during the rearing process may have caused red drum to be more active and vigilante. Increased activity could result in "leaner" fish. In contrast, condition of fish in the Control treatment was at the other end of the spectrum with overall higher K values (36 dph). Fish in the Control were shorter but weighed more. The lack of complexly structured habitat and/or predators in the rearing environment, may have results in the Control living a more lethargic lifestyle and a "fatter" fish. Interestingly, Trial 2 produced the two highest K values of 1.5 (Control and 1.2 (Seagrass Only). Trial 2 occurred during September and October, the time red drum naturally spawn in nearshore waters of the Gulf of Mexico (Wilson and Nieland 1994).

Management Implications

Overall, survival improved in two out of three trials with red drum reared in complex habitats compared to red drum reared in an unstructured environment (normal rearing). This suggests that stock enhancement programs for this species may benefit by providing structured habitats in rearing ponds to improve behavioral conditioning and reduce predation-related mortality. Although there are ethical concerns with using live

predators (Huntington 1984) to provide stimuli to "train" individual fish for subsequent predator-prey encounters, the present study found that using only artificial seagrass in the rearing ponds generally improved survival compared to a normal rearing environment (unstructured). While these results are encouraging, and if stock enhancement programs choose to deploy habitat structure in the rearing ponds, futures studies should investigate suitable material to be used to create artificial structure. Materials should be lightweight, durable, UV resistant, and mimic natural structure found in areas stocked by fish hatcheries. In bays stocked without extensive seagrass beds, such as Galveston Bay, alternative habitat structures (e.g., oysters) can alter behavioral responses of hatchery-reared red drum (Stunz and Minello 2001). For stock enhancement programs culturing other fish species, it is important to understand and utilize artificial habitat that mimics habitat for that species. Future studies should investigate if artificial structure provides additional food sources in the form of epiphytic algae and detritus, reducing the cost of using commercial feeds.

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APPENDIX

APPENDIX 1.1. *Multivariate analysis of variance (MANOVA) table of all pond parameters between trials and treatments.*

	df	Pillai	F	P
Trial	2	1.19	34.46	< 0.0001
Treatment (block)	2	0.05	0.61	0.77
Trial:Treatment	4	0.10	0.62	0.87
Residual err	96			

APPENDIX 1.2. *Multivariate analysis of variance (MANOVA) table of total zooplankton density between trials and treatments.*

	df	Pillai	F	P
Trial	2	0.19	4.48	< 0.0003
Treatment (block)	2	0.02	0.34	0.91
Trial:Treatment	4	0.02	0.22	0.99
Residuals	123			

APPENDIX 1.3. *Analysis of variance table of red drum lengths, weights, and condition factor for day 36 post hatched in Trial 1.*

Source	df	SS	F	P
Length:				
Treatment	2	2088.02	50.13	3.29e-15
Residuals	87	1811.77		
Weight:				
Treatment	2	1.37	34.61	8.74e-12
Residuals	87	1.73		
Condition factor:				
Treatment	2	1.50	0.32	0.32
Residuals	87	56.70		

APPENDIX 1.4. *Analysis of variance of red drum lengths, weights, and condition factor for day 36 post hatched in Trial 2.*

Source	df	SS	F	P
Length:				
Treatment	2	107.82	1.95	0.15
Residuals	87	2408.63		
Weight:				
Treatment	2	0.007	0.81	0.45
Residuals	87	0.358		
Condition factor:				
Treatment	2	6.39	15.84	1.36e-06
Residuals	87	17.55		

APPENDIX 1.5. *Analysis of Variance of red drum lengths, weights, and condition factor for day 36 post hatched in Trial 3.*

Source	df	SS	F	P
Length:				
Treatment	2	399.76	28.03	4.01e-10
Residuals	87	620.30		
Weight:				
Treatment	2	0.065	23.28	7.98e-09
Residuals	87	0.121		
Condition factor:				
Treatment	2	0.391	12.76	1.38e-05
Residuals	87	1.33		