Survival and movement of hatchery-reared red snapper on artificial habitats in the northern Gulf of Mexico

A . M. Chapin, S. T. Szedlmayer and R. P. Phelps

SEDAR31-RD17

13 August 2012

Fisheries Management and Ecology

Fisheries Management and Ecology, 2009, **16**, 28–36

Survival and movement of hatchery-reared red snapper on artificial habitats in the northern Gulf of Mexico

A. M. CHAPIN, S. T. SZEDLMAYER & R. P. PHELPS

Department of Fisheries and Allied Aquacultures, Auburn University, Auburn, AL, USA

Abstract Hatchery-reared age-0 red snapper, *Lutjanus campechanus* (Poey), were released onto artificial habitats in the Gulf of Mexico. Fish showed 12.7% survival after 7 months on small habitats (0.86 m^3) and 3.1% survival after 8 months on large habitats (3.9 m^3). Emigration was estimated by the movement of fish to unstocked habitats and accounted for 76.8% of the total decline in abundance at release sites after 26 days. Fish showed higher survival and growth rates on small habitats (27.6% at 26 days; 0.33 mm day^{-1}) compared with large habitats (13.2% at 34 days; 0.26 mm day^{-1}), which may have been due to increased predation and competition on large habitats. Fish became evenly distributed among adjacent habitats 26 days after release, indicating that stocking densities at release habitats were above carrying capacities. These observations suggested that providing additional habitat around red snapper release sites would increase survival.

KEYWORDS: hatchery fish, movement, red snapper, site fidelity.

Introduction

Few studies have evaluated survival and movement of age-0 red snapper, *Lutjanus campechanus* (Poey), on artificial habitats yet such information is important for the management of this species. For example, decline in age-0 red snapper abundance from particular locations is usually considered total mortality, but this decline may also have a significant emigration component, as red snapper shift habitat with growth (Bradley & Bryan 1975; Szedlmayer & Conti 1999; Szedlmayer & Lee 2004). These previous studies were based on length–frequency analysis and lacked direct measures of age-0 red snapper movement through mark-recapture studies.

Mark-recapture studies of age-1 red snapper have reported site fidelity up to 4 months and homing abilities from distances up to 2 km (Workman & Foster 2002; Workman, Shah, Foster & Hataway 2002). These studies also suggested that age-0 red snapper quickly colonised experimental habitats (1.5×1.5 'webbing reefs') after age-1 red snapper had moved off these habitats. No mark-recapture studies of age-0 red snapper have been reported.

The lack of mark-recapture studies of age-0 red snapper is probably because of low expected survival from most tagging methods. The use of hatchery-reared fish can overcome these high mortalities compared with tagging wild fish and allow for direct measures of movement by recapturing marked individuals. Recent advances have improved the culture success for marine fishes to provide adequate numbers for field studies (Blankenship & Leber 1995), and new tagging techniques have made the use of hatchery fish in movement studies more practical (Collins, Smith & Heyward 1994; Bruyndoncx, Knaepkens, Meeus, Bervoets & Eens 2002). For example, oxytetracycline and alizarin have been used to mark fish with high mark retention and low mortality rates (Szedlmayer & Howe 1995; Beckman & Schulz 1996; Lagardere, Thibaudeau & Begout Anras 2000). Visible implant elastomers (VIE) is a recent method also suitable for movement studies of young fishes and allows identification of individual fish by SCUBA divers up to 6 m away (Frederick 1997; Willis & Babcock 1998; Close 2000; Olsen & Vollestad 2001).

In this study, hatchery-reared age-0 red snapper were used to examine survival and movement on artificial habitats. Fish were marked with both VIE and chemical marks to take advantage of *in situ* VIE detection by SCUBA divers and longer-term detection

Correspondence: Stephen T. Szedlmayer, Marine Fish Laboratory, Department of Fisheries and Allied Aquacultures, Auburn University, 8300 State Highway 104, Fairhope, AL 36532, USA (e-mail: szedlst@auburn.edu)

doi: 10.1111/j.1365-2400.2008.00620.x

of chemical marks through fish recapture. To reduce excessively high initial mortality as a result of disorientation and predation, hatchery red snapper were provided with newly constructed artificial habitats, i.e. no other wild fish were present at the time of release (Munro & Bell 1997; Olla, Davis & Ryer 1998). The objectives were to estimate survival and movement of hatchery age-0 red snapper released onto two different sizes of artificial habitats in the Gulf of Mexico. Mark retention and mark effects on growth and survival were also evaluated with laboratory studies.

Materials and methods

Marking effects and mark retention

Red snapper were raised at the Claude Peteet Mariculture Center, Gulf Shores, Alabama from May to August 2003. Laboratory fish were marked with VIEs, alizarine red S (ARS) and oxytetracycline dihydrate (OTC) to evaluate their usefulness with red snapper. If successful, the four colors of VIEs and two chemical marks would allow eight different double marking combinations. All fish were anaesthetised in 150 mg L^{-1} of tricaine methanesulphonate prior to marking and when checking for mark retention (Palmer & Mensinger 2004). Age-0 fish were weighed, measured (mean ± SE = 12.4 ± 0.29 g; 68.4 ± 0.54 mm SL), and marked with VIEs (n = 20), marked with VIEs and 200 mg ARS L^{-1} seawater for 20 h (n = 38), marked with VIEs and 200 mg OTC L^{-1} seawater for 20 h (n = 42), or not marked (control, n = 20). The VIE mark was injected under the external edge of both eye membranes with a 25 gauge hypodermic needle. These marked red snapper were held in nine circular tanks to examine mark retention and growth. Tanks were 1.5 m diameter by 0.7 m height, but were all part of the same 11 000-L closed seawater system. Percent survival was examined over 5 months; fish size (SL mm and weight g) was measured at 30 and 60 days and mark retention was measured at 7 and 48 days after marking.

Field study

Study sites were located in the northern Gulf of Mexico, 26 km south of Dauphin Island, Alabama, USA, within the Hugh Swingle General Permit area. Sixteen small artificial habitats were constructed from plastic coated wire (1.2 × 1.2 × 0.6 m, 12.9 cm^2 mesh, steel cages). Each habitat contained two concrete blocks (20 × 20 × 41 cm) and 10 sections of PVC pipe (31.0 cm long, 10.0 cm diameter) for added structure.

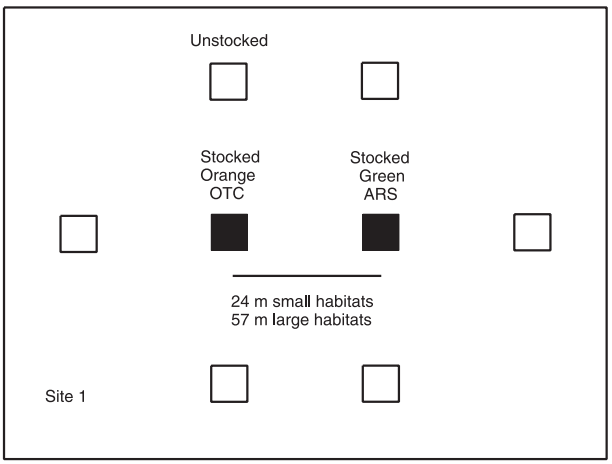

Figure 1. Habitat design and array for site 1. Other sites not shown but all had the same design with eight habitats. Solid squares are the stocked center habitats and open squares are the unstocked habitats. Distances among each habitat are shown for small and large habitat arrays.

Small habitats were placed on the bottom at a depth of 23 m on 10 September 2003. The habitats were arranged in two arrays (sites 1 and 2) of eight habitats each. Within each small site, habitats were placed 24 m apart with two centre and six surrounding habitats (Fig. 1). Sites 1 and 2 were 206 m apart. The above design was repeated with 16 large artificial habitats (2.5 × 1.3 × 1.2 m, steel cages). Each large habitat had one side open, three sides covered with 2.5 × 10.2 cm mesh and the top and bottom were solid metal sheets. These large habitats also contained four internal horizontal fiberglass shelves and two internal vertical steel mesh walls (2.5 × 10.2 cm mesh). The large habitats were also arranged in two arrays (sites 3 and 4) of eight habitats each and placed at a depth of 20 m on 7 October 2003. Within each large site, habitats were placed 57 m apart with two centre and six surrounding habitats (Fig. 1). Sites 3 and 4 were 900 m apart and 6.2 km from the small habitat sites 1 and 2.

Hatchery red snapper were marked from 14 to 29 August 2003, with one of four VIE colours: red, orange, green or yellow. Samples (n = 30) of fish from each colour were individually weighed and measured at the time of marking [mean ± SE = 109.9 ± 0.7 mm total length (TL) and weight = 25.4 ± 0.5 g]. After marking, fish were held in their original holding tanks (1060 L) for up to 2 weeks, then on 9 September 2003 placed into separate 150-L, oxygen-enriched transportation tanks (Carmichael & Tomasso 1988). While in the transportation tanks, fish were also marked in a 200 mg L^{-1} solution of ARS or OTC for 20 h prior to

release onto small habitats. As above, another group of hatchery red snapper was marked with VIEs and chemical marks from 29 September to 7 October 2003 and released onto large habitats. These hatchery fish had a (mean ± SE) TL of 130.8 ± 1.3 mm and weight of 42.3 ± 1.4 g at the time of release onto large habitats. Fish were released onto each habitat by SCUBA divers that transported fish from the surface to the bottom in a live bag (0.9 m diameter, 0.95 m high, 5 mm mesh, with five metal rings to hold shape).

The two centre habitats within each small site were stocked on 10 September 2003 with red snapper that were marked with one of the following VIE-chemical combinations: site 1 (orange-OTC $n = 95$, green-ARS $n = 95$) and site 2 (yellow-OTC $n = 98$, red-ARS $n = 100$). The six surrounding small habitats at each site were not stocked. The two centre habitats at the large sites were stocked on 8 October 2003 with red snapper that were marked with one of the following VIE-chemical marks: site 3 (red-OTC $n = 248$, green-ARS $n = 299$) and site 4 (yellow-OTC $n = 122$, orange-ARS $n = 68$).

Small habitats were visually surveyed by SCUBA divers 1 week, 1 month and 7 months after stocking. Large habitats were surveyed at 1 and 8 months after stocking. On all surveys, SCUBA divers counted all fish and assigned them to 25 mm size class intervals based on estimated length. All fish inside and within 2 m of each habitat were counted. A remote recording YSI-6920 meter measured temperature (°C), dissolved oxygen (DO, mg L^{-1}) and salinity (ppt) at 1 m above the bottom at each site during surveys.

The last survey for both small and large habitats also included a fish trap sample. Small fish traps (0.22 m^3, mesh size 2.5 cm^2) were baited with squid and fished for 15 min at each habitat. To estimate hatchery red snapper survival and carrying capacity, after trapping divers visually surveyed all habitats for any red snapper still present (marked or unmarked) that may have been missed by the trap. All fish species captured in the traps were placed on ice and weighed and measured in the laboratory. About six scales were removed from each red snapper, mounted onto slides with Permount, and viewed under blue-violet light (wavelength 440 nm) on an Olympus BH-2 compound microscope to detect OTC and ARS marks. If scales failed to show marks, otoliths were examined.

Data analysis

The laboratory-held fish were analysed with analysis of covariance (ANCOVA) to compare survival (percent alive/time) among tagging methods of control, VIE marked and VIE-chemical marked (Zar 1999). Analysis of variance (ANOVA) was used to test for differences among number of marked fish on stocked, unstocked and alternate habitats for each survey period on both small and large habitats. Fish counted on alternate habitats are defined as the presence of stocked fish that had moved from their original stocked habitat to the adjacent stocked habitat within a particular site. At the end of the study, the mean carrying capacity (fish m^{-3}) of red snapper on a habitat was estimated by adding the trap sample captures to those visually counted on habitats after trapping. An ANOVA was used to compare total number of red snapper (marked and unmarked) on stocked compared with unstocked habitats for each time period. An ANOVA was also used to compare the five most abundant species present on small habitats 27 days after stocking to large habitats 34 after stocking and small habitats 210 days after stocking to large habitats 243 days after stocking. Differences were considered significant at $\alpha = 0.05$. After significance was detected, tests were followed by Duncan's multiple range comparison test to show specific differences (Zar 1999).

Results

Marking effects and mark retention

No significant differences were detected in survival of fish with VIE marks, VIE-chemical marks and control fish ($F = 0.89$, d.f. = 2, 8, $P = 0.42$; Fig. 2). Chemical marks showed higher mark retention compared with VIE marks. The OTC mark showed a fluorescent

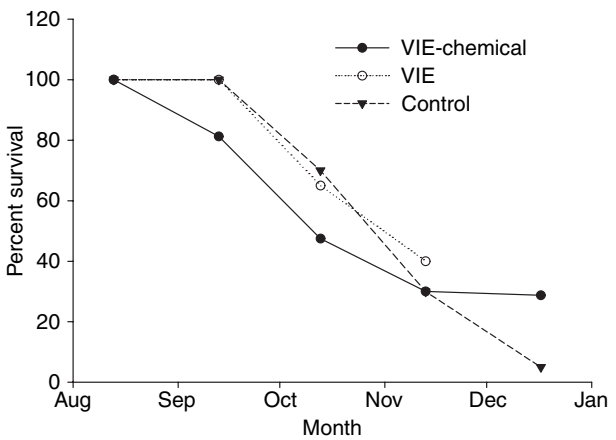

Figure 2. Percent survival of marked red snapper in the laboratory over time. Control, no mark; VIE, visible implant elastomer mark; VIE-chemical, visible implant elastomer and either alizarine or oxytetracycline mark.

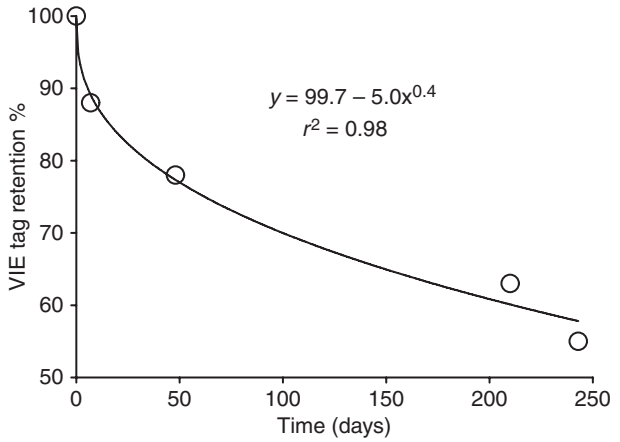

Figure 3. Percent visible implant elastomer (VIE) mark retention over time.

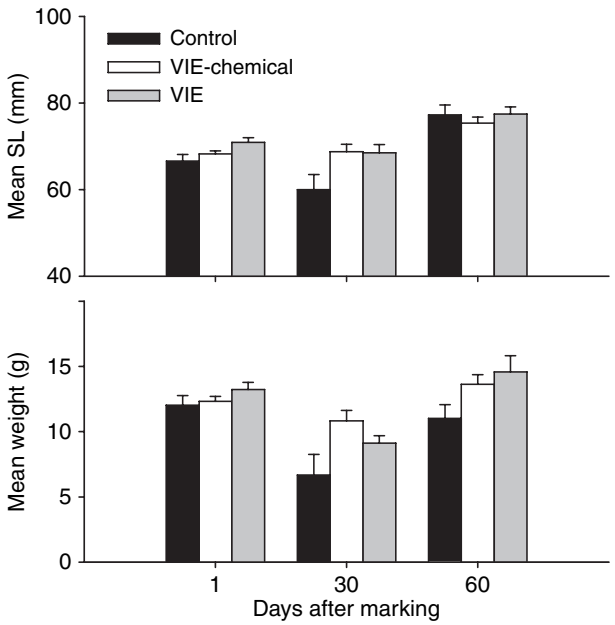

Figure 4. Comparisons of mean ± SE standard length (mm) and weight (g) over days for marked red snapper in the laboratory. Control, no mark; VIE, visible implant elastomer mark; VIE-chemical, visible implant elastomer and either alizarine or oxytetracycline mark. No significant differences were detected within time periods ($P < 0.05$).

yellow ring while the ARS mark showed fluorescent purple-red marks on scales and otoliths. Samples taken from laboratory-held fish at 48 ($n = 99$) and 90 days ($n = 28$) after marking showed 100% mark retention for chemical marks. VIE mark retention showed an exponential decline over time ($y = 99.7-5.0x^{0.4}$, $r^2 = 0.98$), where y is the mark retention and x is days after marking. Percent mark retention at 0, 7 and 48 days was based on laboratory held fish. VIE mark retention at 210 and 243 days was based on field recapture of marked fish, i.e. fish that had lost their VIE mark were identified from chemical marks (Fig. 3).

Mean SL and weight of laboratory marked fish showed no significant difference compared with control fish at 1, 30 and 60 days after marking (Fig. 4). Near the time of release, temperature, salinity and DO were similar between hatchery conditions (25.0–25.8 °C; 26.9–29.9 ppt; 6.0 ppm) and field conditions at the release site (26.3–28.4 °C; 33.7–33.9 ppt; 8.2 ppm).

Movements

All estimates of hatchery fish still present on artificial habitats were adjusted for tag loss using the estimated rate of exponential decline from hatchery and double-marked field recaptures. Stocked age-0 red snapper showed survival up to at least 243 days (last survey). After 7 days, stocked red snapper showed at least 65.0% survival on the small sites, with 22.9% observed at their release habitat, 38.7% on surrounding unstocked habitats and 3.4% on the alternate stocked habitat within each site. After 26 days, stocked red snapper showed 27.6% survival on the small habitats, with 6.4% on stocked habitats, 18.7% on unstocked habitats and 2.5% on the alternate stocked habitat. After 212 days, stocked red snapper showed 12.7% survival on small habitats, with 4.7% on stocked habitats, 5.4% on unstocked habitats and 2.6% on the alternate stocked habitat.

After 34 days, stocked red snapper showed 13.2% survival on large habitats, with 2.8% on stocked habitats, 9.7% on unstocked habitats and 0.8% on the alternate stocked habitat. After 243 days, stocked red snapper showed 3.1% survival on large habitats, with 0.5% on stocked habitats, 2.5% on unstocked habitats and 0.1% on the alternate stocked habitat.

Stocked red snapper evenly distributed themselves among small habitats within 26 days after stocking with few significant differences detected among habitats. After 7 days, the mean number of marked fish on their original release habitat (stocked) was significantly higher than the mean on the alternate stocked habitat, but no significant differences were detected compared with the surrounding unstocked habitats within each small habitat site ($F = 5.3$, d.f. = 2, 17, $P = 0.02$; Fig. 5). After 26 and 212 days, no significant differences were detected in mean number of marked fish among habitats within each small site ($F = 2.3$, d.f. = 2, 17, $P = 0.13$; $F = 0.09$, d.f. = 2, 17, $P = 0.91$; Fig. 5). Fish did show some limited

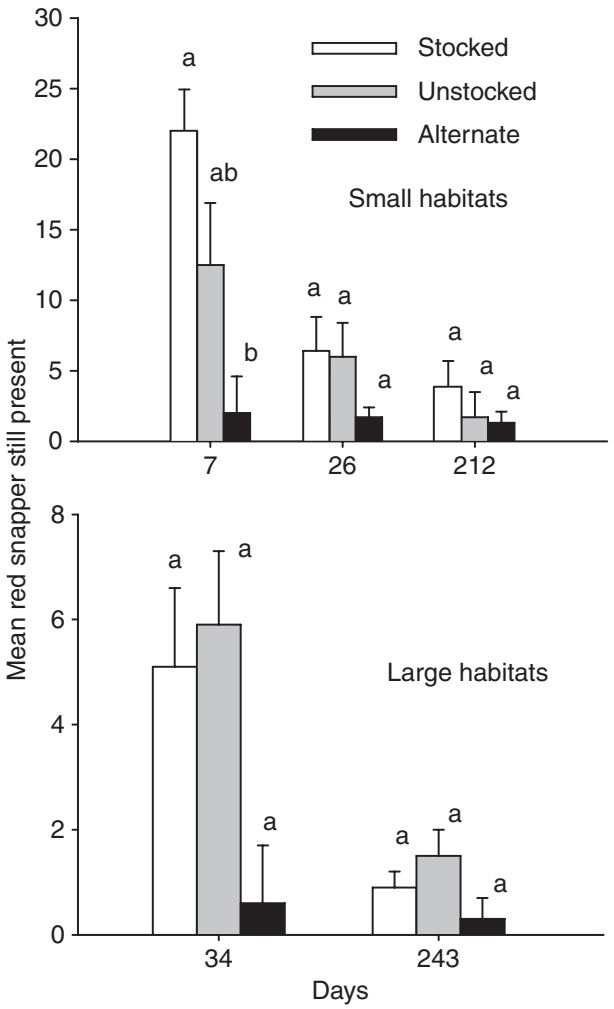

Figure 5. Mean ± SE number of VIE tagged red snapper present over days on small and large habitats. Stocked, marked fish on original site of release; unstocked, marked fish that had moved to an unstocked habitat; alternate, marked fish that had moved to an adjacent stocked habitat within a particular array. Bars with the same letter were not significantly different ($P < 0.05$).

movement between the small habitat sites, where four fish were found on the other small habitat site 206 m from where they were stocked.

Similar patterns of even distributions were observed for large habitats. After 34 and 243 days, no significant differences were detected in mean number of marked fish among habitats within each large site ($F = 2.68$, d.f. = 2, 17, $P = 0.10$; $F = 1.59$, d.f. = 2, 17, $P = 0.23$; Fig. 5).

Carrying capacity

The mean number of all red snapper (hatchery and wild) on small habitats after 26 days was 30.1 m^{-3} and increased to a mean of 55.6 m^{-3} after 210 days. No significant differences were detected between the mean number of all red snapper on stocked compared with unstocked small habitats after 26 days ($F = 0.75$, d.f. = 1, 14, $P = 0.40$) and after 212 days ($F = 0.34$, d.f. = 1, 14, $P = 0.57$). For the large habitats, mean number of all red snapper per habitat was 6.7 m^{-3} after 34 days and increased to 15.9 m^{-3} after 243 days. No significant differences were detected in the mean number of all red snapper between stocked and unstocked large habitats after 34 days ($F = 4.1$, d.f. = 1, 14, $P = 0.06$) and 243 days ($F = 0.25$, d.f. = 1, 14, $P = 0.63$).

Growth

At the time of stocking small habitats, mean TL of age-0 red snapper was 110 mm, ranging from 89 to 123 mm and mean weight was 25 g, ranging from 13 to 36 g. Marked fish caught in trap samples ($n = 35$) from small habitats after 212 days had a mean TL of 179 mm, ranging from 134 to 211 mm and a mean weight of 99 g, ranging from 36 to 147 g. These hatchery fish released on small habitats grew at a rate of 0.33 mm day^{-1} over a period of 212 days.

At the time of stocking large habitats, mean TL of age-0 red snapper was 131 mm, ranging from 102 to 165 mm and mean weight was 42 g, ranging from 19 to 85 g. After 243 days, mean TL of marked fish caught in trap samples ($n = 11$) was 193 mm, ranging from 154 to 226 mm and mean weight was 117 g, ranging from 59 to 188 g. These hatchery fish released on large habitats grew at a rate of 0.26 mm day^{-1} over 243 days.

Comparison of small and large habitats

More red snapper were stocked on the larger habitats, but no significant differences were detected between the number of hatchery red snapper still present on small and large habitats after 1 month ($F = 0.25$, d.f. = 1, 30, $P = 0.62$) and small and large habitats after 8 months ($F = 2.04$, d.f. = 1, 30, $P = 0.16$).

After 1 month, there were significantly more lane snapper, *Lutjanus synagris* (L.), ($F = 7.0$, d.f. = 1, 28, $P = 0.01$) on large habitats, but more tomtate, *Haemulon aurolineatum* Cuvier, ($F = 8.7$, d.f. = 1, 18, $P < 0.01$) on small habitats. After 8 months, there were significantly more tomtate ($F = 4.2$, d.f. = 1, 30, $P = 0.05$) and vermilion snapper, *Rhomboplites aurorubens* (Cuvier), ($F = 14.3$, d.f. = 1, 17, $P < 0.01$) on large habitats but significantly more bank sea bass, *Centropristis ocyurus* (Jordan & Evermann), ($F = 8.3$, d.f. = 1, 24, $P < 0.01$) on small habitats (Table 1).

Table 1. Percent abundance (%) and mean ± SE number per habitat of the six most dominant species present on habitats over two survey periods

	Small habitats 26 days after stocking			Large habitats 34 days after stocking		
Species	%	Count	TL mm	%	Count	TL mm
Lutjanus campechanus	47	26 ± 5.0	111 ± 2.1	39	26 ± 2.3	134 ± 1.2*
Haemulon aurolineatum	18	31 ± 9.7*	79 ± 1.5	10	9 ± 2.3	120 ± 1.6*
Orthopristis chrysoptera	< 1	3 ± 0.5	113 ± 0	21	14 ± 6.0	149 ± 1.0*
Rhomboplites aurorubens	4	4 ± 0.7	110 ± 1.5	8	8 ± 2.0	113 ± 1.5
Balistes capriscus	2	2 ± 0.3	118 ± 4.1	6	4 ± 0.9	157 ± 7.1*
Lutjanus synagris	2	2 ± 0.3	77 ± 7.2	7	6 ± 1.4*	112 ± 1.7*
Centropristis ocyurus	4	2 ± 0.5	98 ± 5.6	< 1	1 ± 0	88 ± 0
		212 days after stocking			243 days after stocking	
Lutjanus campechanus	44	48 ± 8.1	143 ± 1.0	23	62 ± 18.5	173 ± 1.5*
Haemulon aurolineatum	34	41 ± 6.8	126 ± 0.5	24	73 ± 14.5*	152 ± 0.9*
Orthopristis chrysoptera	5	5 ± 0.8	159 ± 2.8	25	99 ± 48.1	156 ± 0.6
Rhomboplites aurorubens	< 1	2 ± 0.5	118 ± 3.3	21	74 ± 11.1*	150 ± 1.1*
Balistes capriscus	< 1	1 ± 0	113 ± 0	1	3 ± 0.8	227 ± 5.8*
Lutjanus synagris	< 1	2 ± 0.3	98 ± 3.7	< 1	2 ± 0.4	146 ± 9.9*
Centropristis ocyurus	4	5 ± 0.8*	131 ± 2.3	< 1	2 ± 0.4	158 ± 12.7

*significant differences ($P \leq 0.05$).

After 1 month, red snapper ($F = 86.8$, d.f. = 1, 824, $P < 0.001$), tomtate ($F = 300.3$, d.f. = 1, 339, $P < 0.001$), pigfish, *Orthopristis chrysoptera* (L.), ($F = 31.7$, d.f. = 1, 203, $P < 0.001$), gray triggerfish, *Balistes capriscus* Gmelin, ($F = 10.4$, d.f. = 1, 70, $P < 0.01$) and lane snapper ($F = 49.1$, d.f. = 1, 121, $P < 0.001$), showed significantly larger size classes on large habitats compared with small habitats. After 8 months, red snapper ($F = 237.9$, d.f. = 1, 1750, $P < 0.001$), tomtate ($F = 427.3$, d.f. = 1, 1826, $P < 0.001$), vermilion snapper ($F = 8.2$, d.f. = 1, 1039, $P < 0.01$), grey triggerfish ($F = 8.0$, d.f. = 1, 46, $P < 0.01$) and lane snapper ($F = 19.6$, d.f. = 1, 48, $P < 0.001$) all showed significantly larger size classes on large habitats compared with small habitats (Table 1).

Discussion

Mark retention, laboratory survival and growth

Similar to studies with other fish species, OTC and ARS both showed high (100%) mark retention in otoliths and scales of red snapper with little effect on survival and growth (Szedlmayer, Able, Musick & Weinstein 1991; Szedlmayer & Howe 1995; Eckmann, Czerkies, Helms & Kleibs 1998; Lagardere *et al.* 2000). The VIE marks were advantageous in that they were highly conspicuous fluorescent marks and observable without recapture but had lower mark retention compared with chemical marks. Field growth rates of marked hatchery fish (0.26 and 0.33 mm day^{-1}) were similar to estimates for wild age-0 red snapper (0.29–0.39 mm day^{-1}; Holt & Arnold 1982; Szedlmayer & Conti 1999). Thus, VIE marks are suitable for shorter period experiments where recapture is a disadvantage, while chemical marks are more suitable over longer time periods where recaptures can be applied.

Field study

Hatchery red snapper showed similar survival (3.1–12.7% after 7–8 months) compared with other mark recapture studies of hatchery fish. For example, Mathews & Ishida (1989) released 27 512 age-0 coho salmon, *Oncorhynchus kisutch* (Walbaum), (175 mm FL) tagged with coded-wire-tags (CWT) and reported 8% were still present after 1 year. Return rates for hatchery turbot tagged with T-anchor tags were 9.5% within the first year after release (Iglesias & Rodriguez-Ojea 1994). Leber, Brennan & Arce (1995) recaptured 2% of released striped mullet (60–130 mm TL) tagged with CWT after 7 months, similar to the 3.1% survival of red snapper on large habitats in this study.

The greatest reduction in the number of marked fish usually occurs shortly after release. This may be caused by suppression of anti-predatory skills in the rearing environment (Munro & Bell 1997; Olla *et al.* 1998; Brown & Laland 2001), as predation was the most significant factor influencing stocking success in two studies (Tsukamoto, Kuwada, Hirokawa, Oya, Sekiya, Fujimoto & Imaizumi 1989; Smedstad, Salvanes,

Fossa & Nordeide 1994). To offset such initial predation, the small habitats used in this study were built with a mesh size (12.9 cm^2) small enough to provide stocked red snapper protection from predators. Time to recovery from the stresses associated with stocking may also play an important part in survival of hatchery fish. The artificial habitats in this study were built the same day fish were stocked. Releasing fish onto habitats with no initial predators or competitors probably increased survival by allowing fish time to adapt and recover from stocking. Olla & Davis (1989) reported that a recovery period of 90–240 min allowed 'stressed' coho salmon time to adapt to their new environment. Also, no initial predators or competitors may have provided hatchery fish time to learn to forage before recruitment of wild fish (Olla *et al*. 1998).

Hatchery red snapper showed higher residency and faster growth rates on small habitats compared with large habitats. Also, the density of red snapper (hatchery and wild fish) on the small habitats was three times greater compared with the large habitats. This may result from a combination of increased risk of predation on the larger habitats as a result of larger mesh size and one open side and increased abundance of potential predators and competing species from wild populations.

It can be difficult to determine the cause of reduction in the frequency of marked fish released into the marine environment with many different abiotic and biotic factors (Leber, Arce, Sterritt & Brennan 1996). For example, environmental conditions may differ in the hatchery compared with the field. However, in this study temperature, salinity and DO were similar between laboratory and field conditions at the time of release and suggested that changes in these abiotic factors did not cause substantial mortality of hatchery red snapper.

In most studies, decline in numbers of marked fish cannot be separated into mortality or emigration, and this usually results in overestimates of mortality. In this study, the release site was surrounded by other unoccupied habitats, which allowed estimation of age-0 red snapper emigration to nearby artificial habitats. When red snapper were initially released onto the habitats, they remained together in a school near or on the habitat. Sometime after stocking (0–34 days), many red snapper moved 24 m to nearby small habitats and 57 m to nearby large habitats that were not stocked. For example, after 26 days 6.4% of the hatchery red snapper were observed on their release habitat, while 21.2% had moved to adjacent habitats 24 m away within a site. If similar movement proportions were also functioning on decline in marked fish, 76.8% of their total decline may be due to movement rather than mortality. Also, on the small habitats four fish moved 206 m to the second site of small habitats, which suggested that movement may account for an even greater percentage of hatchery fish decline in abundance.

Over all survey periods, the number of hatchery red snapper that had moved to the second stocked habitat (alternate) appeared lower than the unstocked habitats. Although no significant difference was found, probably because of low sample size, these trends were consistent. Perhaps based on the peak total (wild and hatchery) red snapper estimates after 7 months (55.6 m^{-3}), stocking densities were well above the carrying capacity of these artificial habitats and these high densities deterred other stocked fish from moving onto that habitat.

In conclusion, through the placement of habitats surrounding stocked habitats emigration and decline in abundance of age-0 red snapper from a stocked habitat was found to be not total mortality but also contained a substantial component of movement. Habitat size was important when stocking fish, as survival and growth were higher on smaller habitats. Also important, artificial habitats appear to have a carrying capacity, as age-0 red snapper became evenly distributed among the habitats. These observations of habitat limits suggested that increasing the number of hatchery-released fish may not increase survival, but that providing some type of unoccupied habitat along with releases of hatchery red snapper would be beneficial.

Acknowledgments

Thanks to R. Schroepfer, R. Sutterer, C. MacKichan, L. Grove, B. Wildberger, M. Lingo, and A. Piko for their help with tagging and data collection. Also, thanks to D. Moss, A. Ferry and the Claude Peteet Mariculture Center for raising the fish for this project. This project was funded by Marine Resources Division, Alabama Department of Conservation and Natural Resources 2003–2004, USDA 2002–2003 award number 2002-3442111942. This is a contribution of the Department of Fisheries and Allied Aquacultures, Auburn University and the Alabama Agricultural Experiment Station.

References

Beckman D.W. & Schulz R.G. (1996) A simple method for marking fish otoliths with alizarin compounds. *Transactions of the American Fisheries Society* **125,** 146–149.

Blankenship H.L. & Leber K.M. (1995) A responsible approach to marine stock enhancement. *American Fisheries Society Symposium* **15,** 167–175.

Bradley E. & Bryan C.E. (1975) Life history and fishery of the red snapper (Lutjanus campechanus) in the northwestern Gulf of Mexico: 1970–1974. *Proceedings of the 27th Annual Gulf and Caribbean Fisheries Institute and the 17th Annual International Game Fish and Research Conference*. Miami Beach, FL, **27,** 77–106.

Brown C. & Laland K. (2001) Social learning and life skills training for hatchery reared fish. *Journal of Fish Biology* **59,** 471–493.

Bruyndoncx L., Knaepkens G., Meeus W., Bervoets L. & Eens M. (2002) The evaluation of passive integrated transponder (PIT) tags and visible implant elastomer (VIE) marks as new marking techniques for the bullhead. *Journal of Fish Biology* **60,** 260–262.

Carmichael G.J. & Tomasso J.R. (1988) Survey of fish transportation equipment and techniques. *The Progressive Fish-Culturist* **50,** 155–159.

Close T.L. (2000) Detection and retention of postocular visible implant elastomer in fingerling rainbow trout. *North American Journal of Fisheries Management* **20,** 542–545.

Collins M.R., Smith T.I.J. & Heyward L.D. (1994) Effectiveness of six methods for marking juvenile shortnose sturgeons. *The Progressive Fish-Culturist* **56,** 250–254.

Eckmann R., Czerkies P., Helms C. & Kleibs K. (1998) Evaluating the effectiveness of stocking vendace (Coregonus albula (L.)) eleutheroembryos by alizarin marking of otoliths, *Archiv für Hydrobiologic Special issues Advances in Limnology* **50,** 457–463.

Frederick J.L. (1997) Evaluation of fluorescent elastomer injection as a method for marking small fish. *Bulletin of Marine Science* **61,** 399–408.

Holt S.A. & Arnold C.R. (1982) Growth of juvenile red snapper *Lutjanus campechanus,* in the northwestern Gulf of Mexico. *Fishery Bulletin* **80,** 644–648.

Iglesias J. & Rodriguez-Ojea G. (1994) Fitness of hatchery-reared turbot, *Scophthalmus maximus* L., for survival in the sea: first year results on feeding, growth, and distribution. *Aquaculture and Fisheries Management* **25,** 179–188.

Lagardere F., Thibaudeau K. & Begout Anras M.L. (2000) Feasibility of otolith markings in large juvenile turbot, *Scophthalmus maximus*, using immersion in alizarin-red S solutions. *ICES Journal of Marine Science* **57,** 1175–1181.

Leber K.M., Brennan N.P. & Arce S.M. (1995) Marine enhancement with striped mullet: are hatchery releases replenishing or displacing wild stocks? *American Fisheries Society Symposium* **15,** 376–387.

Leber K.M., Arce S.M., Sterritt D.A. & Brennan N.P. (1996) Marine stock-enhancement potential in nursery habitats of striped mullet, *Mugil cephalus*, in Hawaii. *Fishery Bulletin* **94,** 452–471.

Mathews S.B. & Ishida Y. (1989) Survival, ocean growth, and ocean distribution of differentially timed releases of hatchery coho salmon (*Oncorhynchus kisutch*). *Canadian Journal of Fisheries and Aquatic Sciences* **46,** 1216–1226.

Munro J.L. & Bell J.D. (1997) Enhancement of marine fisheries resources. *Reviews in Fisheries Science* **5,** 185–222.

Olla B.L. & Davis M.W. (1989) The role of learning and stress in predator avoidance of hatchery-reared coho salmon *(Oncorhynchus kisutch*) juveniles. *Aquaculture* **76,** 209–214.

Olla B.L., Davis M.W. & Ryer C.H. (1998) Understanding how the hatchery environment represses or promotes the development of behavioral survival skills. *Bulletin of Marine Science* **62,** 531–550.

Olsen E.M. & Vollestad L.A. (2001) An evaluation of visible implant elastomer for marking age-0 brown trout. *North American Journal of Fisheries Management* **21,** 967–970.

Palmer L.M. & Mensinger A.F. (2004) Effects of the anesthetic tricaine (MS-222) on nerve activity in the anterior lateral line of the oyster toadfish, *Opsanus tau*. *Journal of Neurophysiology* **92,** 1034–1041.

Smedstad O.M., Salvanes A.G.V., Fossa J.H. & Nordeide J.T. (1994) Enhancement of cod, *Gadus morhua*, L., in Masfjorden: an overview. *Aquaculture and Fisheries Management* **25,** 117–128.

Szedlmayer S.T. & Conti J. (1999) Nursery habitats, growth rates, and seasonality of age-0 red snapper, *Lutjanus campechanus,* in the northeast Gulf of Mexico. *Fishery Bulletin* **97,** 626–635.

Szedlmayer S.T. & Howe J.C. (1995) An evaluation of six marking methods for age-0 red drum, *Sciaenops ocellatus*. *Fishery Bulletin* **93,** 191–195.

Szedlmayer S.T. & Lee J.D. (2004) Diet shifts of juvenile red snapper (*Lutjanus campechanus)* with changes in habitat and fish size. *Fishery Bulletin* **102,** 366–375.

Szedlmayer S.T., Able K.W., Musick J.A. & Weinstein M.P. (1991) Are scale circuli deposited daily in juvenile weakfish, *Cynoscion regalis*? *Environmental Biology of Fishes* **31,** 87–94.

Tsukamoto K., Kuwada H., Hirokawa J., Oya M., Sekiya S., Fujimoto H. & Imaizumi K. (1989) Size-dependent mortality of red sea bream, *Pagrus major*, juveniles released with fluorescent otolith-tags in News Bay, Japan. *Journal of Fish Biology* **35,** 59–69.

Willis T.J. & Babcock R.C. (1998) Retention and *in situ* detectability of visible implant flourescent elastomer (VIFE) tags in *Pagrus auratus* (Sparidae). *New Zealand Journal of Marine and Freshwater Research* **32,** 247–254.

Workman I.K. & Foster D.G. (2002) The webbing reef: a tool used in the study of juvenile red snapper (*Lutjanus*

campechanus). *Oceans '02 MTS/IEEE Conference Proceedings, The Marine Technology Society* **1,** 146–150.

Workman I.K., Shah A., Foster D.G. & Hataway B. (2002) Habitat preferences and site fidelity of juvenile red snapper (*Lutjanus campechanus*). *ICES Journal of Marine Science* **59,** S43–S50.

Zar J.H. (1999). *Biostatistical Analysis*, 4th edn. Upper Saddle River, NJ: Prentice-Hall Inc, 663 pp.