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Predator-free enclosures improve post-release survival of stocked common snook

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Abstract

Hatchery-reared fish may not be behaviorally competent in the wild, thus increasing mortality rates of fishes stocked into natural environments. The goal of this study was to determine whether in situ acclimation at release sites can increase survival of juvenile hatchery-reared common snook (*Centropomus undecimalis*), a catadromous fish, stocked into an estuary in Sarasota, Florida. Juvenile snook (76–251 mm fork length) were tagged with coded-wire tags and released in four locations distributed along a salinity gradient of North Creek estuary. Three replicate releases were performed at each location. Overall, 1935 snook were acclimated in enclosures for 3 d, then, released simultaneously with 1925 non-acclimated snook (non caged snook transported direct from the laboratory and stocked into the creek). For recaptures of snook at large for 3 d or more, mean recapture rates of experimental release groups were significantly different (multiway ANOVA testing recapture rates by acclimation treatment, release site, and interactions, $P=0.001$). Specifically, mean recapture rates of acclimated groups were 1.92 higher than those for non-acclimated groups ($P=0.002$); hatchery snook recaptured from two of the four release sites represented 70% of total recaptures ($P=0.001$); interactions between acclimation treatment and release site were not significant ($P=0.71$). Site fidelity was approximately 60% regardless of acclimation condition, and did not significantly influence recapture rates. Thus, in situ acclimation has potential to significantly improve both post-release survival and information gained in stocking programs.

Keywords: Acclimation; *Centropomus undecimalis*; Dispersal; Stock enhancement; Snook; Survival

1. Introduction

Common snook *Centropomus undecimalis* (Bloch) (herein referred to as "snook") are a tropical to subtropical estuarine species of the western Atlantic. In Florida, snook is a highly valued marine sport fish (Muller and Taylor, 2002) and although Florida's snook populations once supported a commercial fishery, it was closed in 1957 to prevent over harvest. Continued high recreational popularity and harvest has maintained concern among resource managers (Muller and Taylor, 2002). Widespread habitat loss (Bruger and Haddad, 1986), cataclysmic events such as winter freezes (Story and Gruder, 1936; Marshall, 1958), and fish kills from red tide blooms also threaten snook populations in Florida. These factors have led fishery managers to investigate the feasibility of snook stock enhancement in Florida.

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Although historical evidence supporting successful marine enhancement is sparse, recent studies indicate that stocked fishes survive and contribute to fisheries landings (Svåsand et al., 1990; Kitada et al., 1992; Leber and Arce, 1996; Leber et al., 1996; Kaeriyama, 1999; Friedlander and Ziemann, 2003; Bartley and Leber, 2005). Development of optimal release strategies is an important focus of stock enhancement research and can significantly increase post-release survival (Munroe and Bell, 1997; Yamashita and Yamada, 1999; Mahnken et al., 2004; Kuwada et al., 2004). Specific stocking strategies include determining optimal size-at-release (Tsukamoto et al., 1989; Yamashita et al., 1994; Leber, 1995), release season, and size–season interactions (Leber et al., 1997, 1998; Sanchez-Lamadrid, 2002; Gwak et al., 2003), and release habitat (Solazzi et al., 1991; Leber and Arce, 1996; Russell et al., 2004; Davis et al., 2005; Andersen et al., 2005). In this study we investigate the influence of in situ conditioning in predator-free enclosures on post-release survival.

Successful foraging and predator avoidance are essential behaviors for juvenile fish survival (Werner et al., 1983; Gilliam and Fraser, 1987; Walters and Juanes, 1993). Fish reared in "psychosensory-deprived" hatchery environments however, have demonstrated significant deficits in their abilities to avoid predation (Olla and Davis, 1989; Brown and Smith, 1998; Olla et al., 1998; Berejikian et al., 1999) and in foraging skills (Hossain et al., 2002) that minimize mortality yet maximize prey intake (as in minimizing μ/g, Werner and Gilliam, 1984). Hatchery selection can also influence behavioral performance, and in laboratory trials Berejikian (1995) found F1 generations of wild steelhead trout fry were more successful at avoiding predation than progeny from hatchery broodstock. Nonetheless, many of these behaviors are learned, and laboratory studies of hatchery juveniles exposed to appropriate stimuli have shown improvements in their performance (Chivers and Smith, 1994; Brown and Smith, 1998; Kellison et al., 2000; Hossain et al., 2002).

Whereas actions in the hatchery can address improvements in behavioral deficiencies (e.g. Schlechte et al., 2005), it is logistically difficult to address these in aquaculture tanks. Conditioning fish in predator-free enclosures in situ may accomplish many of the same goals: physiological acclimation to the surrounding environment, begin learning to feed in the wild, expose fish to predation threat (outside of acclimation cages), yet provide a predator-free environment for these adjustments. Possibly the most important benefit is that in situ acclimation enclosures afford stocked fish an opportunity to recover from transport stress unthreatened by predation. Isolating the relative effects of these potential benefits is problematic, but identifying their collective effects on post-release survival is possible.

Strong evidence documenting actual improvements in post-release survival afforded by acclimation is lacking. Cresswell and Williams (1983) found higher percentages of acclimated brown trout *Salmo trutta* groups compared with non-acclimated groups, but non-acclimated groups also had higher dispersal rates from release sites. In a separate study (Jonssonn et al., 1999), recapture rates of acclimated brown trout were significantly higher than recapture rates of non-acclimated trout two months after release. However, a disproportionate amount of non-acclimated trout migrated away from release sites, and possibly influenced survival estimates. In Japan, whereas survival was not addressed, Kuwada et al. (2004) found higher rates of short-term retention of acclimated striped jacks (*Pseudocaranx dentex*) at release sites than non-acclimated fish, and acclimation is now a routine procedure in striped jack marine ranching activities in Japan. Isolating differences in site fidelity of acclimated and non-acclimated stocked fish is an important step toward understanding post-release survival.

As many species develop strong fidelity responses to their natal origin (e.g. Thorrold et al., 2001), the potential for structuring site fidelity in released organisms has important ramifications on meta-population characteristics. Tag-recapture studies with snook have shown evidence of strong site fidelity in adolescents and adults (Volpe, 1959). Preliminary evidence with juvenile snook releases has also indicated strong site fidelity, (even 1-year after stocking, N. Brennan, unpublished data). In our studies, recapture rates of hatchery-reared individuals (randomly selected from source tanks, tagged, and stocked in specific habitats) at release sites, were significantly higher than recapture rates from neighboring sites (N. Brennan, unpublished data). In the current study, acclimation in enclosures may have strong influences on an individual's short- and long-term fidelity behavior, and understanding relative differences in fidelity of acclimated and non-acclimated groups is important for understanding sub-population characteristics and relative survival rates.

In this paper we evaluate the effects of in situ acclimation on short- and long-term survival of hatchery-reared juvenile snook. We also evaluate acclimation effects on site fidelity. Two null hypotheses were specifically tested: (1) survival of snook conditioned in in situ acclimation enclosures would not differ from snook released directly after transport from the hatchery, and (2) dispersal rates and patterns of acclimated and non-acclimated snook would not differ.

2. Methods

2.1. Experimental design and setup

We used a balanced, two-way factorial design, release-recapture experiment to test effects of acclimation treatment and release site on recapture rates. Time was the blocking variable, and all experimental treatment conditions were blocked over a three-week period with each experimental condition repeated each week (Table 1). Acclimated and non-acclimated juvenile snook were released within four sub-habitats of a creek system (Fig. 1). Acclimated snook were released into an in situ enclosure, held for 3 d, and then released into the wild along with non-acclimated snook (or "naive" fish) just transported from the hatchery. Recapture efforts were subsequently conducted at and around the release sites to evaluate survival and movement patterns of the released fish.

Acclimation enclosures were circular pens made of polyethylene 11 mm square mesh, 1.2 m deep, 4.8 m diameter (approximately 22 m^3; Fig. 2). We attached the ends of the enclosure together by overlapping them approximately 30 cm and securing them with plastic cable ties. Along the entire bottom of the enclosure, approximately 20 cm of the mesh was buried in the substratum to prevent escape of enclosed snook and entrance of predators. This also allowed the enclosed snook access to the substratum. For each enclosure, we used 6–8 steel re-bars (2.4 m long × 23 mm diameter) to support the walls and secure plastic bird mesh over the tops to prevent avian predation. Prior to stocking, predators were removed from the enclosures with a 1.8 m deep × 6 m long seine (3 mm mesh). The seine was swept within the enclosure twice before we closed the mesh ends together.

Our release sites were located in four environmentally distinct habitats of North Creek (NC) estuary (Release sites: North Creek Middle (NCM), Catfish Creek Lower (CCL), North Creek Lower (NCL), and North Creek Outer (NCO); Fig. 1). Each enclosure was situated along shoreline habitat away from strong currents in water at least 0.5 m deep during low tide. Tidal variation at all sites was approximately 0.6 m. NCM was farthest upstream, in brackish water, and *Juncus* sp. (rush) and *Schinus terebinthifolius* (Brazilian pepper) dominated the shoreline. CCL and NCL were located in a lagoon downstream, with *Rhizophora mangel* (red mangrove) as the primary shoreline vegetation. NCO was located outside of North Creek within a series of red mangrove islands near the intercoastal waterway. All enclosures were situated on mud and oyster rubble substrate.

Table 1
Numbers of juvenile snook tagged and released

Release lot	Release date	Creek	Acclimated	Non-acclimated	Total
1	10-Apr-00	CCL	168	169	337
1	10-Apr-00	NCM	167	163	330
1	10-Apr-00	NCO	163	166	329
1	10-Apr-00	NCL	166	169	335
Lot subtotals			664	667	1,331
2	17-Apr-00	CCL	173	161	334
2	17-Apr-00	NCM	160	164	324
2	17-Apr-00	NCO	162	164	326
2	17-Apr-00	NCL	161	164	325
Lot subtotals			656	653	1309
3	24-Apr-00	CCL	144	152	296
3	24-Apr-00	NCM	154	151	305
3	24-Apr-00	NCO	159	157	316
3	24-Apr-00	NCL	158	147	305
Lot subtotals			615	607	1222
Grand totals			1935	1927	3862

Releases occurred at the North Creek estuary system in Sarasota County and specifically at North Creek "middle" (NCM), Catfish Creek "lower" (CCL), North Creek "lower" (NCL), and North Creek "outer" (NCO). Acclimation fish were released into acclimation enclosures, and non-acclimated fish were released outside of the enclosures, nearby. Release dates are weekly and refer to when acclimated and non-acclimated snook were released from the enclosures (after 3 d of acclimation) and transport tanks respectively.

2.2. Tagging and release

All snook used in this study (76–251 mm FL) were reared in brackish water recirculating systems at Mote Marine Laboratory (MML) in Sarasota, Florida. From 3 April–5 April 2000, we tagged the snook with coded-wire tags (CWT, Northwest Marine Technology, Inc., Shaw Island, WA) as described in Brennan et al. (2005). Tags identified experimental treatments: release lot (released on week 1, 2, and 3), release site (NCM, CCL, NCL, NCO), and acclimation condition (acclimated, non-acclimated), (3 × 4 × 2 = 24 batch codes) (Table 1). Numbers of fish released were held nearly constant among release groups (lots, release sites, and acclimation condition), and fish size was randomized among treatments (Table 1). After tagging, snook were held in separate tanks, grouped by release site, week, and acclimation condition. Holding duration varied from 3–17 d after tagging as lot 1 groups were released during the same week as tagging, and lots 2 and 3 were released roughly one week and two weeks after tagging, respectively.

Tag retention estimates were obtained on the day of release as follows. Fish were harvested from tanks, scanned individually for tags, and placed in transport tanks. Lost tags were expressed as a percentage of total

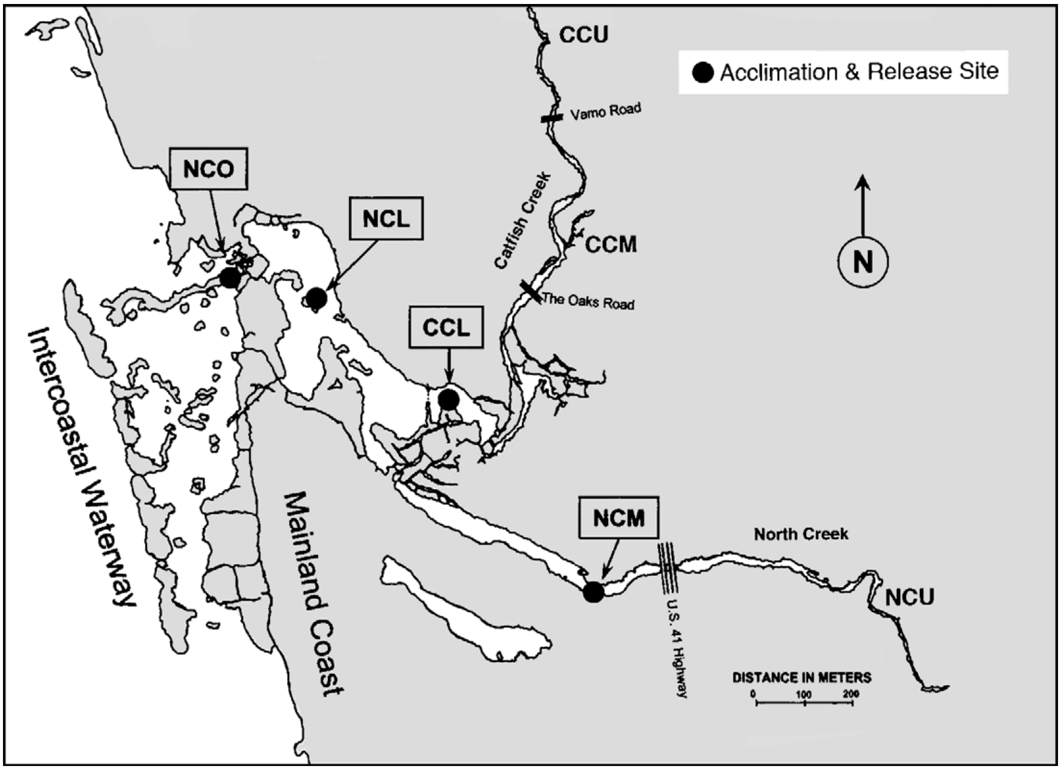

Fig. 1. North Creek estuary system with specific release sites designated in text boxes. Nearby sampling sites (CCU, CCM, NCU) are also mapped. At each release site an acclimation enclosure was set up. Recapture efforts occurred throughout this system.

harvested fish. Snook released at NCM were transported to the release location by truck in 760-liter circular tanks, transferred to 100–150 l coolers, which we carried to the release site (about 150 m away). At the site, we added some brackish water to these containers to allow the snook to acclimate to creek salinities. Snook released at

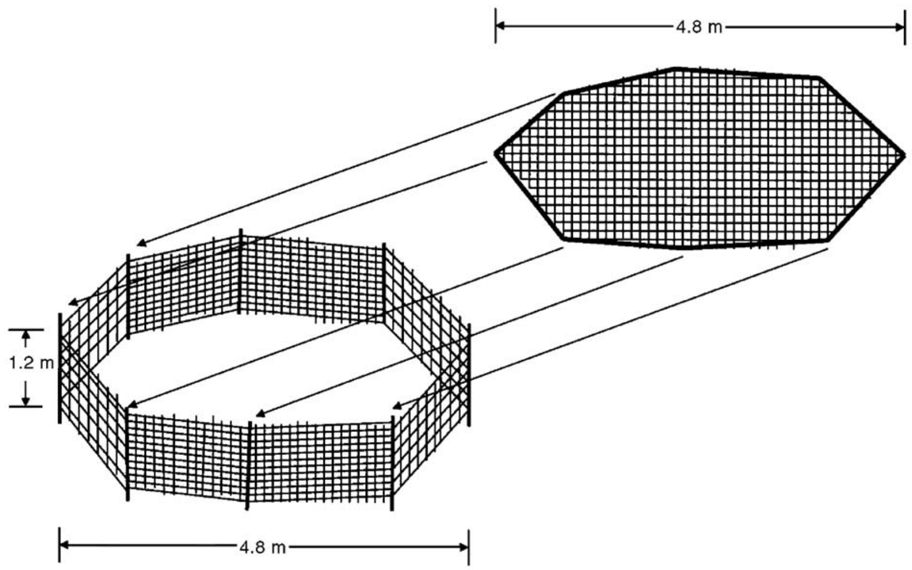

Fig. 2. Schematic drawing of the enclosure design.

NCO, NCL, and CCL, were initially transported by boat from the rearing facility to North Creek estuary in 760-liter circular tanks. Along the way we added salt water to the transport tanks to gradually adjust salinities to match release site salinities (Salinities in the hatchery were about 3–6 ppt versus 15–30 ppt in the wild, Table 2).

At the estuary we transferred the fish to 100-liter tubs, then carried or canoed them the rest of the way to the release sites. We submerged the containers with snook into the water and snook were gently released between 0900–1600, either into acclimation enclosures or directly into the creek just outside of the acclimation enclosures. A total of 3860 hatchery-reared tagged snook were released. Of these, 1935 were acclimated before release into the wild, as discussed below, and 1925 were released without acclimation (Table 1).

Within each of the three release lots (weeks), acclimation fish were stocked in enclosures on Friday and held through the weekend at densities of about 7.4 fish/m^3. On the following Monday, non-acclimated fish were transported from the hatchery and were released simultaneously with the acclimated fish. Acclimated snook were released by cutting cable ties binding the enclosures and pulling the opposing ends of the mesh 1.5 m apart, allowing snook to swim out of the enclosures on their own. Each enclosure was left open for 4 d until it was stocked again the following Friday.

2.3. Data collection and analysis

To quantify survival rates and document dispersal patterns of experimental release groups, we collected snook from the release habitats and surrounding habitats over time (Fig. 1, Table 3). The majority of sampling occurred from 1 April 2000 through 6 February 2001, but we also included collections made through 13 February 2003 in our analysis. Generally, samples were collected (1) during spring, within the same month of the release (e.g. since our release occurred over a three week period, samples were collected in between weekly release events and after release events), (2) during summer, 2–4 months after releases, and (3) during winter, nine to ten months after releases (Table 3). Sampling gear included a 45.7 m long × 3 m deep (1 cm nylon mesh) bag seine, a 21.3 m long × 1.8 deep (1 cm nylon mesh) bag seine, and a 1.7 m diameter 1 cm monofilament mesh cast net. Cast net

Table 2
Transport parameters for snook released into North Creek estuary

Release				Transport duration	Transport conditions			Release site conditions		
Date	Lot	Site	Treatment		Salinity	Temperature b/e	D.O. b/e	Salinity t/b	Temp t/b	D.O t/b.
7-Apr-00	1	NCM	Acclimated	6:40	*	22.0/23.1	8.0/6.7	*	29.1/29	6.4/5.3
7-Apr-00	1	NCL	Acclimated	6:15	*	21.5/23.2	8.0/8.6	31.5/*	25.5/*	9.9/*
7-Apr-00	1	CCL	Acclimated	4:57	*	22.0/23.0	8.0/6.9	28.6/*	27.6/27.4	6.5/4.4
7-Apr-00	1	NCO	Acclimated	6:20	*	21.5/23.2	8.0/8.7	30.6/*	25.5/*	11.9/*
10-Apr-00	1	NCM	Not-acclimated	5:22	1.2	22.8/*	6.5/*	17.9/18	28.8/28.7	10.3/10.9
10-Apr-00	1	NCL	Not-acclimated	3:20	6.0	21.0/23.3	*/9.8	26/*	26.5/*	9.5/*
10-Apr-00	1	CCL	Not-acclimated	4:35	1.2	24.2/*	6.6/*	25.2/*	28.2/28.2	9.0/9.2
10-Apr-00	1	NCO	Not-acclimated	3:45	6.0	21.0/23.3	8.0/6.8	28.7/*	22.9/*	7.1/*
14-Apr-00	2	NCM	Acclimated	4:27	*	23.1/22.9	7.3/6.7	*/*	24.2/26.0	5.8/3.5
14-Apr-00	2	NCL	Acclimated	3:55	6.0	23.0/22.9	6.8/*	26.7/*	26.7/*	5.2/*
14-Apr-00	2	CCL	Acclimated	3:12	*	24.9/24.4	7.5/6.3	21.7/*	26.4/28.1	3.7/2.2
14-Apr-00	2	NCO	Acclimated	4:30	6.0	23.0/22.5	7.0/10.0	25.8/*	24.6/*	3.4/*
17-Apr-00	2	NCM	Not-acclimated	3:11	1.0	25.9/26.1	6.3/7.9	13.2/*	30.7/31.4	7.1/6.8
17-Apr-00	2	NCL	Not-acclimated	2:40	6.0	26.0/26.5	10.0/15.0	25.3/*	29.4/*	6.4/*
17-Apr-00	2	CCL	Not-acclimated	3:45	1.0	25.9/26.8	6.3/8.6	20.3/*	31.0/31.0	8.0/*
17-Apr-00	2	NCO	Not-acclimated	2:45	6.0	26.0/27.6	6.0/15.4	27/*	29.1/*	6.3/*
21-Apr-00	3	NCM	Acclimated	*	1.0	25.4/25.8	16.0/6.3	15.5/*	30.5/30.9	6.5/3.7
21-Apr-00	3	NCL	Acclimated	3:30	3.0	26.0/*	*/*	27.1/*	28/*	5.4/*
21-Apr-00	3	CCL	Acclimated	*	1.0	25.3/25.4	10.0/5.8	22.6/*	28.9/28.9	6.2/5.7
21-Apr-00	3	NCO	Acclimated	3:30	3.0	25.0/*	*/*	27.7/*	27.39/*	6/*
24-Apr-00	3	NCM	Not-acclimated	1:26	*	24.6/25.0	7.4/3.9	29.1/*	27.9/29.1	7.0/2.0
24-Apr-00	3	NCL	Not-acclimated	2:55	3.0	*/*	*/*	28.4/*	25.9/*	5.5/*
24-Apr-00	3	CCL	Not-acclimated	2:33	1.0	24.0/24.8	6.1/8.7	*/*	27.5/27.1	6.9/6.9
24-Apr-00	3	NCO	Not-acclimated	3:12	12.5	*/*	*/*	28/*	25.46/*	5.29/*

Transport conditions include beginning and ending data ("b/e" respectively). Water quality measurements from the release sites were taken at the top and bottom ("t/b" respectively) of the water column. Salinity is measured in parts per thousand, temperature in Celsius, and dissolved oxygen in mg/l. Missing data is denoted with an asterisk.

Table 3
Sampling gear, effort (numbers of replicate gear efforts), and snook catch for sampling activities at release sites and nearby surrounding habitats

Sample months	Gear	Effort								Catch		
		Sampling sites								Total snook	Hatchery snook	
		NCM	NCL	CCL	NCO	NCU	CCM	CCU	Totals		Captured	Harvested
April 2000	Cast net	7	2	12	19	23	0	0	63	80	47	
	21 m seine	20	5	7	13	0	0	0	45	272	83	
	45 m seine	0	6	8	18	0	0	0	32	149	78	
Subtotals										501	208	127
June–August, 2000	Cast net	0	0	0	14	54	0	0	68	14	5	
	21 m seine	10	9	3	9	27	6	0	64	106	17	
	45 m seine	18	18	10	24	0	17	0	87	207	30	
Subtotals										327	52	40
	Cast net	0	0	0	0	18	0	18	36	45	0	
January–February, 2001	21 m seine	3	3	3	3	9	3	9	33	351	10	
	45 m seine	8	6	6	6	0	6		32	824	44	
Subtotals										1220	54	51
Other sampling										2782	26	25
Grand totals										4830	340	243

Recaptures of "Hatchery Snook" were those that were tagged and released as part of this study. Harvested snook were those that were returned to the laboratory, tags decoded, and used in the analysis. Shaded sampling sites are where snook releases occurred. All other sites are within 0.5 km of the nearest release site.

throws were generally targeted toward waters near vegetative cover, and seines were pulled toward the shoreline. Sampling effort was based on catch quota from April–August, 2000, and snook harvests were taken for multiple purposes (e.g. snook diet studies, and tag codes for this study). In January and February, 2001, sampling effort was fixed and we performed six hauls of the 45 m seine, and three hauls of the 21 m seine at NCM, NCL, NCO, CCL, CCM, and CCU (Fig. 1). At NCU effort differed due to logistic restrictions and nine hauls of the 21 m seine and 18 throws of the 1.7 m diameter cast net were performed.

All captured snook were counted, measured, and checked for the presence of CWTs with magnetic tag detectors, and visually examined for external tags. Lengths and weights of the recaptured snook were recorded and CWTs were extracted from the tissue at the laboratory and decoded. We used a multiple linear regression analysis (SAS Institute, 1998, for all statistical analyses) to test for effects of transport parameters (total transport time, and beginning and ending water temperatures, salinity, and dissolved oxygen) on survival (through recapture rates [number recaptured/number released ∗ 100]) for each release group. We pooled recapture data according to time periods based on days after release (DAR) for snook recaptures: 1 through 3 d, and 4 through ≥365 d. Our rationale for the short-term grouping was to determine if treatment effects occurred soon after releases. Recapture rates (proportions) were arc sine transformed to correct for normality and differences in means were considered significant at alpha = 0.05. We used a multiway analysis of variance (ANOVA) to test for differences in recapture rates of snook from acclimated treatments, different release sites, and to test for interactions of the two factors. We performed a multiway ANOVA (1) on all recaptures, (2) on recaptures collected 1–3 d after release, and (3) on recaptures collected anytime after 3 d of the release. Site fidelity (F) was calculated as:

$$F = x_i / y_i * *100 \qquad (1)$$

where x_i is the number of snook from a particular release group (i) recaptured at their original release site, and y_i is the total number of snook recaptured from a particular release group (i) regardless of recapture site.

3. Results

From 11 April 2000 through 13 February 2003, 4830 total snook were captured and of these 340 (7.0%) were tagged individuals from this study (Table 3). Of these 243 were harvested, returned to the laboratory, and tags decoded and used in this analysis. Snook recaptures decreased over time and hatchery snook represented 21.4% (n=195), 6.1% (n=75) and 0.9% (n=24) of the total snook captured 1–59, 60–365, and >365 DAR respectively. Coded-wire tag retention averaged 95.46% +/- 0.51 SE (mean of three lots; 3 d–17 d after tagging).

Transport time to the release sites ranged from 1:26 to 6:40 (hours: minutes) with an average of 3:56. Differences in transport variables (i.e., transport time, changes in temperature, dissolved oxygen, salinity and pH,) (Table 2) did not significantly influence recapture rates (multiple linear regression: $R^2=0.51$, $P=0.233$, $df=11$) for all release groups.

Overall, we recovered 1.78x as many acclimated snook as non-acclimated snook (157 versus 88, respectively), and over time, this pattern of acclimated snook dominating the catch was consistent (Fig. 3). Our multiway ANOVA model using all recaptures was nearly significant ($P=0.06$, $df=23$) and individual treatments (acclimation treatments and release sites) were significant although interactions were not. Initially (for snook captured 1–3 d after release), mean recapture rates of acclimated snook and non-acclimated snook were not significantly different ($P=0.53$, $df=23$, 63 acclimated and 37 non-acclimated). After this (for recaptures of snook at liberty for 4 d or longer), however, our multiway ANOVA was highly significant ($P=0.001$, $df=23$, 94 acclimated and 49 non-acclimated, Fig. 3), mean recapture rates of acclimated snook were 1.92x those for unacclimated snook (highly significant, $P=0.002$), release site significantly affected recaptures ($P=0.001$) and interactions were not significant ($P=0.71$)(Table 4).

The majority of snook recaptured were collected at release sites: of the total recaptured, 219 (89%) were collected at the four release sites, 21(10%) at other sites within the creek system, and 3 (1%) outside of the creek system. Snook released at NCM and NCO represented over 70% of the total number recaptured. Site fidelity of acclimated and non-acclimated snook declined over time: 84% by 1–3 DAR and 43% by one year after release. There were no significant differences between mean site fidelity of acclimated and non-acclimated snook (61% and 71%, respectively, $P=0.46$, $df=7$).

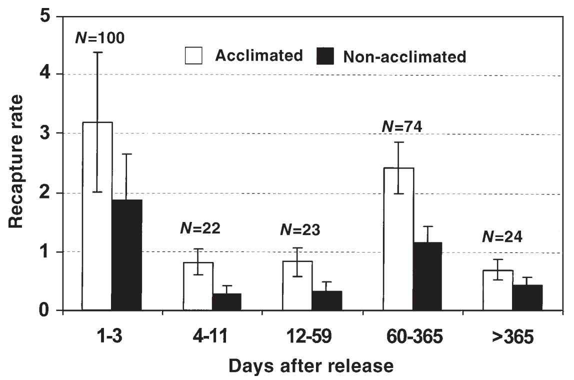

Fig. 3. Mean recapture rates of acclimated and non-acclimated snook over time. Error bars are standard error $n=3$ lots. N-values are the number of snook from this study recaptured in each time period. Recapture rates of acclimated snook, from data lumped from day 4–day 1032 were significantly higher than recapture rates of non-acclimated snook (ANOVA, $P=0.002$).

Table 4
Results of two-way ANOVA testing the influence of acclimation treatment, release site, and interactive effects on recapture rates of release snook

Data grouping (days after release)	Number of recaptures	Treatment	*df*	MSE	*F*	*P*
1–1032	243	Acclimation	1	0.262	4.93	0.041
		Release site	3	0.197	3.69	0.034
		Interaction	3	0.153	0.29	0.834
1–3	100	Acclimation	1	0.11	0.75	0.398
		Release site	3	0.266	1.81	0.185
		Interaction	3	0.005	0.03	0.991
4–1032	143	Acclimation	1	0.264	13.83	0.002
		Release site	3	0.175	9.19	0.001
		Interaction	3	0.009	0.47	0.71

ANOVA's were performed separately on data groupings according to days after release.

4. Discussion

Recapture rates strongly suggest that we significantly increased post-release survival of stocked snook by acclimating them in situ for 3 d before release. This 1.78x gain in survival of stocked snook is a substantial impact from such a simple pre-release treatment. We effectively increased hatchery-release impact in this experiment by 1.78x. Thus, overall hatchery cost per recruit was reduced by about 44% by in situ acclimation.

This acclimation procedure is clearly useful for small-scale releases of hatchery-reared snook. Subsequent studies are now needed to determine if manpower and materials costs for caging can be cost-effective at larger release magnitudes. Given the clear reduction in hatchery costs afforded by in situ acclimation, this is well worth following up with a cost analysis in a large scale stocking experiment.

Acclimation effects were apparent within 3 d after release and were found consistently in subsequent recapture efforts through 1 y after release. Our short-term (1–3 DAR) samples indicated that the acclimation effect probably occurred early on and created a "survival signature" on stocked snook, which was maintained throughout the cohort's existence (Fig. 3 shows how abundance in samples varied, but proportions of the acclimation treatment groups remained fairly constant).

A concern in this study was the confounding effect of dispersal on recapture rate, which could result in a biased estimate of relative survival. We hypothesized that holding snook in an enclosure for 3 d would condition snook to remain at the release site, while snook released outside of enclosures (non-acclimated) would demonstrate higher dispersal rates. We quantified dispersal by thoroughly sampling throughout the study area (at and outside of release sites) to capture both dispersed and non-dispersed snook. Volpe (1959) showed high site fidelity in tagged snook — 79% of his tagged snook were recaptured less than 6 miles (9.66 km) from the release site. In our study, we found that >60% of the recaptured snook were recaptured at their release sites. Mean site fidelities (71% and 61%, for acclimated and non-acclimated groups respectively) were not significantly different, so differential dispersal was not influential.

Investigations on acclimation density and acclimation time are important considerations for future studies. Fish handling and transport activities are known to elevate stress levels (Carmichael et al., 1984a,b; Sulikowski et al., 2005), causing disorientation and unnatural behavior (e.g. lying on bottom while recovering), and increased susceptibility to disease, all of which can significantly increase mortality. While elevated cortisol levels from a stocking event may take 6–8 d to return to pre-stress levels (Strange et al., 1978; Barton et al., 1980; Jonssonn et al., 1999) short-term acclimation can result in significantly improved survival rates (Cresswell and Williams, 1983; this study). Prolonged acclimation in an enclosure could cause cannibalism or parasitism outbreaks, and ultimately override acclimation benefits. At densities of 7.4 fish/m^3, our enclosures significantly increased survival, but further study is needed to determine optimal fish density, acclimation time, and cage design.

In addition to providing an environment for recovery from transport stress, in situ acclimation provides an arena for hatchery-reared organisms to begin learning how to feed in the wild (e.g., snook foraging on the benthic substratum for shrimp and crabs and for drifting amphipods and small fishes in the water column). Within days after cage setup, we observed recruitment of aquatic insects, small crustaceans, amphipods, and fishes (Poeciliidae, *Anchoa* species, Gobiidae, Gerreidae, Sciaenidae) in the cages. Although we did not perform stomach-content analysis of the caged snook, juvenile snook are opportunistic carnivores and consume all of the above species (Fore and Schmidt, 1973; McMicheal et al., 1989; Aliaume et al., 1997). Feeding on prey in the enclosures could provide important nutritional (and behavioral) benefits prior to release. Because transport conditions had no significant effect on recapture rates of released snook and no direct mortality was observed in the enclosures, the probable cause of differential mortality is most likely predation (e.g. by blue crabs, piscivorous birds, larger snook, and other piscivorous fish). If other causes (e.g., abiotic and disease) were significant, mortality should have had an equal effect on both release groups (if not a higher effect on acclimated snook from overcrowded conditions) and we would not expect recapture rates to be so different.

Clearly, significant potential exists to improve survival of naive hatchery fish by acclimating fish to natural conditions prior to release into the wild (e.g. Schreck et al., 1995; Olla et al., 1998; Fairchild and Howell, 2004), and by reducing stress prior to release and during transport (Fairchild and Howell, 2001; Sulikowski et al., 2005). This study provides a reference point for future studies aimed at developing acclimation and stress-reduction procedures, both for use in the hatchery and after harvesting and transporting snook to release sites. A question for future studies is how much of the gain in survival afforded by caging can be more cheaply accomplished in the hatchery and during transport to release sites without using cages. Whereas stock enhancement of common snook in Florida remains in an experimental stage, these results contribute to improve our understanding of post-release mortality, and the need for providing a procedure that allows released individuals to recover from transport and release stress. This study also provides a technique to directly improve survival and potential information return from experimental releases, and aids in the ability of resource managers to implement adaptive management policies.

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