

Assessment of Season of Release and Size at Release on Recapture Rates of Hatchery-Reared Red Drum

SCOTT A. WILLIS, WILLIAM W. FALLS, CLYDE W. DENNIS, DANIEL E. ROBERTS,
AND PETER G. WHITCHURCH

Florida Marine Research Institute, Florida Department of Environmental Protection
14495 Harlee Road, Port Manatee, Florida 34221, USA

Abstract.—Stock enhancement is a management tool that may be used to augment depleted wild populations of fish. Red drum *Sciaenops ocellatus* was used as a test species to evaluate the efficacy of marine stock enhancement in Florida. Fingerlings were marked with either coded wire tags or internal anchor tags. Three experiments were conducted to compare tag return rates from fingerlings released during different seasons and at different sizes, to develop guidelines for using internal anchor tags on larger fingerlings, and to assess the entry of hatchery-reared fish into the subadult population.

In the red drum size-at-release experiment, approximately 60,000 fingerlings were graded equally into three size-classes: 60, 90, and 120 mm mean total length (TL). The experiment consisted of two phases: (1) using fingerlings produced during the natural fall spawning period (in season); and (2) using fingerlings produced approximately 6 months later (out of season) by photothermal manipulation of broodstock to induce spawning. Two sampling designs were used at the study site: seine sampling at randomly selected stations and at fixed stations. Red drum recaptures from the released group that had been produced in season totaled 821; there was only one return from the released group that had been produced out of season. In random-station sampling there was no significant difference in recapture rates between size-classes. In fixed-station sampling there was a significant positive correlation between recapture rate and increasing fish size at release. The correlation was already established by day six, and the rates of recapture for the three size-classes remained unchanged during 6 months of poststocking sampling; large fish were 3.7 times more likely to be recaptured than were small fish.

In the second experiment, fingerlings were graded into two size-classes (157.1 and 201.7 mm mean TL), tagged with internal anchor tags, and released. Total returns for the two size-classes after 767 d were 52 (1.4%) and 189 (5.4%), respectively. Fish in the larger size-class were 3.9 times more likely to be returned than were smaller fish, and there was no significant difference between size-classes in either growth rate or net distance traveled postrelease.

In the third experiment, we used trammel nets to sample throughout Volusia County to determine the rate of entry of hatchery-reared fish into the local stocks. A total of 2% of the 395 red drums caught during trammel-net sampling (218–828 mm TL) were hatchery reared. Recapture rates localized in the area where fish were released were higher (4.2%; $N = 168$).

Historically, many people thought that the marine environment contained a limitless supply of marine organisms. In Florida, however, a number of marine fisheries stocks have been recognized as being in numerical decline during the past decade; these declining stocks include common snook *Centropomus undecimalis* (Bruger and Haddad 1986); spotted seatrout *Cynoscion nebulosus* (Laguna 1994); and red drum *Sciaenops ocellatus* (Goodyear 1991). Overfishing has been identified as the most likely factor leading to the red drum stock decline in the mid-1980s (Goodyear 1991). This decline prompted the 1987 closure of the commercial red drum fishery in federally regulated coastal waters and resulted in stricter sport-harvest rules in Florida (Johnson and Funicelli 1991).

Marine stock enhancement is a management tool that may have the potential to augment depleted wild populations of some fish species by supple-

menting or restoring the stocks. Using hatchery-propagated fish in early life stages to remedy declines in fish abundances is particularly attractive because many marine species produce very large numbers of offspring from a single mating. In nature, these fish generally experience high mortality in the early developmental stages. Hatchery culture, however, can mitigate larval mortality factors and increase early life stage survival dramatically. Technological advances now make it possible to produce large numbers of young animals in marine hatcheries and release them into the sea (Matsuoka 1989). Striped mullet *Mugil cephalus* (Leber et al., 1995, this volume; in press); Atlantic cod *Gadus morhua* (Svasand et al. 1990); striped bass *Morone saxatilis* (Dorazio et al. 1991); madai *Pagrus major* (Tsukamoto et al. 1989); and red drum (Rutledge 1989) are marine species that have been shown to have the potential for successful stock enhancement. To

evaluate the efficacy of using marine stock enhancement as a tool to augment natural populations, carefully planned assessment studies must follow hatchery releases. Key components, identified by Blankenship and Leber (1995, this volume), that are needed to develop, evaluate, and manage marine enhancement programs have been incorporated into Florida's marine stock enhancement assessment program.

Marine stock enhancement is not a new concept. As early as the late-1800s, large numbers of Atlantic cod fry were released into Norwegian waters (MacCall 1989). Over a period of 90 years, more than 70 billion Atlantic cod yolk-sac larvae were released into the ocean, but no perceptible evidence of benefit to the population was ever discovered (Shelbourne 1965). Development of new sampling techniques, however, has created renewed interest in Atlantic cod stock enhancement (Svasand et al. 1990). Further interest in marine fish stock enhancement is being spurred by the emergence of new technologies for spawning and rearing fish and by the development of release and monitoring techniques that allow the effects of enhancement to be assessed. Florida, as well as other states (Blankenship and Leber 1995), has adopted a conservative and responsible approach to stock enhancement. To ensure that wild stocks are not adversely affected by the release of cultured animals, Florida Department of Environmental Protection (FDEP) biologists formulated a marine stocking policy that is in draft form (Futch and Willis 1992). All releases have been in accord with the policy requirements for broodstock genetic identification, independent fish health certification, and marking. In addition, FDEP biologists have developed fish health protocols to assess health during culture, before release, and after release. Recently, a 5-year genetics program was initiated to assess the effects that released fish have upon the genetic identities of wild stocks.

Red drum was selected to be a model species for stock enhancement assessment research in Florida for three principal reasons: the technology for culturing red drum had reached a point at which large numbers of fingerlings could be produced routinely in the hatchery (Roberts et al. 1978); there were perceived declines in the wild stock (Goodyear 1991); and the early life history of red drum, knowledge of which can aid in determining the time and place of release, was well documented (Yokel 1966; Peters and McMichael 1987; Daniel 1988). We determined the short-term goals for assessing stock enhancement by conducting a series of pilot studies as well as structured experiments. These pilot stud-

ies and experiments, begun in 1988 and still in progress, were designed to (1) identify and characterize suitable release sites; (2) standardize experimental designs, sampling gear, and sampling procedures; (3) evaluate and refine tagging, transport, and assessment technology; (4) determine the residency time of hatchery-reared juveniles at the release site, their dispersal rates, and their short-term survival; and (5) assess temporal and spatial relationships between hatchery-reared and wild red drum.

Three experiments that were conducted by FDEP biologists are included in this paper. A size-at-release experiment in which the coded wire tag (CWT) was used as the marking technique was designed to yield information on the optimum release size and release season for small fingerlings. A size-at-release experiment in which the internal anchor tag (IAT) was used as the marking technique for larger-sized fingerlings was designed to establish fish growth and dispersal rates and to determine the optimum fish size for use with this tag type. In the third experiment, we used trammel nets to sample subadults and thus assess the entry of hatchery-reared fish into the local wild stocks.

All of the fish released in the three experiments were marked with either CWTs or IATs so that we could evaluate their growth, survival, migration, and subsequent contribution to the wild population.

Tag-return studies can be classified into two main categories: fishery independent and fishery dependent. Each type of study has its own constraints and advantages, uses different methodologies, and gathers different types of information (Wydoski and Emery 1983). In fishery-independent studies, the tagged fish are recovered by biologists, data can be directly correlated to structured assessment experiments, analysis of tag return information can yield very accurate results, and tags do not have to be visible. The tag that was selected for use in the fishery-independent portion of the project was the coded wire tag (Jefferts et al. 1963). The CWT is a stainless steel wire, approximately 1 mm long and 0.254 mm in diameter. The wire contains four rows of notches in a binary code that identifies the batch of fish being marked. The wire is cut from a roll, magnetized, and injected into the fish. The tags are detected during field sampling by passing the captured fish in front of a detector, which identifies the magnetic field associated with the tag.

Coded wire tags, placed into the nasal cartilage of salmonids, have been successfully used for several decades as a mark to differentiate hatchery-reared fish from wild stock (Bergman et al. 1968; Buckley

and Blankenship 1990). Many nonsalmonid fish, including red drum, have shown poor CWT retention when the tag was placed into nasal cartilage (Gibbard and Colura 1980). Selection of the fish's cheek musculature as an alternate tag site has been attempted with generally good results in several other species (Klar and Parker 1986; Dorazio et al. 1991; Leber, in press). Bumgardner et al. (1990) reported low rates of CWT retention in red drums; however, they tagged very small fish, and Bumgardner et al. (1992) speculated that horizontal placement of the tag into the cheek musculature of red drums may have contributed to the low rates of retention. We have conducted short-term retention studies (approximately 4 h post-tagging) on subsamples of all red drums tagged at our facility, and the mean tag retention rate has been 97.3% for the more than 14,600 fish examined between 1990 and 1993. In addition, the results of a 168-d, CWT retention experiment (S. A. Willis et al., FDEP, unpublished data) yielded a tag retention rate of 95.3%.

Fishery-dependent studies depend on the recovery of tags by the fishing public, whose large numbers potentially increase the sampling effort. Tags used in these studies should be highly visible, the return mechanism must be uncomplicated, and a reward system should be used to assure a high return rate (Nielsen 1992). The tag that was selected for use by FDEP staff was an internal anchor tag. The IAT consists of a flat, anchoring base plate and an external streamer. To implant the tag, an incision is made in the lower wall of the fish abdomen. The base plate is inserted into the body cavity, and the streamer extends through the body wall and is externally visible. The combination of an internal base plate and an external streamer prevents the tag from being rejected or migrating to other areas of the body. Fish must be of sufficient size to carry this relatively large tag satisfactorily.

Methods

Experiment 1: CWT Size at Release

The primary release site was Murray Creek, a tidally influenced creek near Ponce Inlet in central Volusia County (Figure 1). This site was selected based upon habitat suitability indices previously established for juvenile red drum (Buckley 1984; Peters and McMichael 1987). This site has consistently yielded young-of-the-year red drums during pilot studies and contains three distinct areas: the creek proper, which is about 2 ha; an upstream area that is separated from the creek itself by a culvert and is

tidally influenced only during storm surges; and a large, shallow borrow pit, about 10 ha in size, that is connected to Murray Creek by a narrow (about 2-m-wide), tidally influenced stream. Murray Creek was the first release site selected in Volusia County, and numerous red drums had already been released there, principally in pilot studies that helped us refine field sampling techniques.

In the size-at-release experiment, we released two separate groups of fish: fingerlings that were produced during the natural fall spawning period (in season) and those that were produced during an artificially induced spawning period approximately 6 months later (out of season). Fish were mechanically graded into three size-classes with mean total length (TL) of approximately 60, 90, and 120 mm. Each size-class consisted of approximately 20,000 fish, and size-classes were differentiated by CWTs injected into the left cheek musculature of each fish (Table 1). All fish were released into the stream that joins the borrow pit with Murray Creek proper.

We sampled at both fixed and randomly selected stations during this experiment. The five fixed stations were selected because they had consistently provided catches of both wild and hatchery-reared red drums during the pilot studies. Two sites (CR1 and CR2) are located in the lower reaches of Murray Creek proper, one site (BP1) is directly adjacent to the borrow pit, and two sites (FW1 and FW2) are in the upper reaches of Murray Creek (Figure 1). Sites FW1 and FW2 are located upstream of a road culvert and are tidally influenced only during flood tides and storm surges. Therefore, this area, which receives freshwater from overland drainage, tends to remain relatively lower in salinity than all other sampling sites.

The randomly selected sampling stations were delineated by dividing Murray Creek, the borrow pit, and the adjacent area to the north of the creek into four sampling zones (Figure 1). The zones are somewhat natural divisions based upon physical parameters, but each area contains a mixture of habitat types. Each zone was then subdivided into 100 ft \times 100 ft grids. Zone 1 (88 grids) contains the borrow pit area. Zone 2 (89 grids) consists of Murray Creek proper and includes the low-salinity area in its upper reaches. Zone 3 (100 grids) includes the area northwest of Murray Creek and extends to the junction of the south fork of Spruce Creek. Zone 4 (108 grids) is the area to the northeast of Murray Creek. In each of the four zones, we sampled three randomly selected grids with a beach seine. The seine was deployed in a circle, and the entire grid was encompassed by the net. Sampling was generally

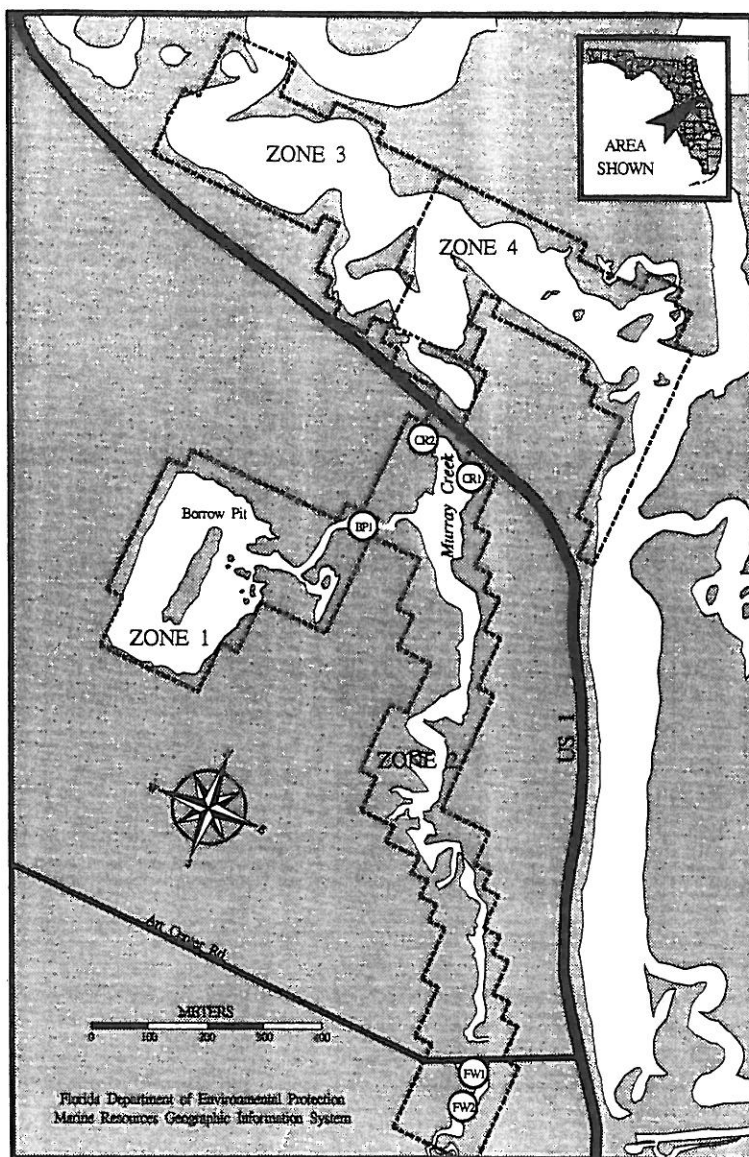


FIGURE 1.—Red drum coded-wire-tag, season-of-release and size-at-release experiments conducted at Murray Creek, Volusia County, Florida. Fixed-station sites are designated by symbols CR1, CR2, BP1, FW1, and FW2. Random-station sites were within zones 1, 2, 3, and 4.

completed in 2 d, took place between 0800 and 1800 hours, and was accomplished biweekly on full and new moon phases each month. To minimize diurnal bias due to sampling time and changing tidal stage, we randomly reordered the sampling sequence of both the random and fixed stations. All captured red drums were enumerated and measured, and all tagged red drums were sacrificed for identification.

We also measured dissolved oxygen, pH, temperature, salinity, and conductivity at each site.

Experiment 2: LAT Size at Release

Fish were hand graded into size-classes smaller and larger than 175 mm TL and tagged with IATs. Subsamples of 225 small and 285 large fish were

TABLE 1.—Size (mean \pm SD), number measured, and total number of red drums released in the coded-wire-tag, size-at-release experiment. Fish were produced during two seasons, and all fish were released at Site BP1 (see Figure 1). Size-classes are described in text.

Fish size-class	Total length (mm)	Number measured	Total released
Fall 1992 ^a			
Small	62.4 (± 7.5)	175	21,857
Medium	83.6 (± 10.1)	200	18,231
Large	118.6 (± 12.6)	251	21,971
Spring 1993 ^b			
Small	65.9 (± 8.4)	300	15,785
Medium	83.3 (± 11.3)	333	21,297
Large	116.0 (± 11.6)	333	14,490

^aIn-season release dates were 8–18 March 1993.

^bOut-of-season release dates were 20 August–2 September 1993.

randomly selected from each size-class to determine the mean fish length for each size-class. The total numbers of fish released in each of the two size-classes were 3,780 fish, with a mean TL of 157.1 ± 12.0 mm (range 131–183 mm), and 3,519 fish, with a mean TL of 201.7 ± 24.6 mm (range 166–375 mm; only 3 measured fish were longer than 283 mm). The fish were transported approximately 250 km to Wilbur Bay in Volusia County, acclimated to ambient conditions, and released after dark. Wilbur Bay is a small embayment adjacent to the Halifax River, is surrounded by numerous small islets, and is located about 6 km north of Murray Creek (Figure 2).

Anglers would be returning the tags from these hatchery-reared fish, making the results fishery dependent. To encourage anglers to return tags, we distributed more than 250 permanent reward signs outlining project goals and the procedure for reporting data on recaptured fish. The reward for reporting tag-related fishery information is a t-shirt that has a replica of the program's reward sign on the back. Requested recapture information includes capture location, fish size and weight, and tag number. Information reported by anglers has provided data on estimates of fish growth and distances traveled as well as on recapture rates for the two sizes of fish released.

Experiment 3: Subadult Survey

Trammel-net sampling of subadult red drums was used to determine if hatchery fish are entering the local fishery. The trammel net that we used has an inner panel of 7.6-cm stretch mesh and an outer panel of 12.7-cm stretch mesh. It is 600 m long by 2.4 m high. Monthly trammel-net sampling (3

d/month) began in November 1992 and continues. We made sets in open-water areas, generally deeper than 1.8 m, from Tomoka Basin in the northern portion of the county to Mosquito Lagoon in the south, a distance of approximately 70 km. All red drums captured were measured (TL) and checked for tags (CWT or IAT). Trammel-net results are reported through 10 February 1994.

Results

Experiment 1: CWT Size at Release

During the first 125 d following the release of the group produced in season (fall 1992), a total of 821 hatchery-reared red drums were recaptured during random- and fixed-station sampling. Of the 821 fish recovered, 426 were recaptured during random-station sampling from 120 seine hauls, and 395 fish were recaptured during fixed-station sampling from 50 seine hauls. Analyses do not include adjustments for estimated tag loss (approximately 3%) or fish loss due to handling.

During the 6 months we sampled after the release of the group produced out of season (spring 1993) only one fish was recaptured. The recovered fish was from the large size-class; however, because it represented less than 0.01% of the fish released, this fish was not included in further analyses.

In random-station sampling of the fish that had been produced in season, significantly fewer fish were recaptured in zones 3 and 4 (7 fish) than were captured in zones 1 and 2 (419 fish); therefore, zones 3 and 4 were not included in the analyses. Zones 3 and 4 are downstream extensions of the original nursery area sampled during pilot studies and were added in an attempt to determine fish distribution beyond the creek proper. Random-station sampling (in zones 1 and 2) data show that there was little difference in the number of fish recovered from each of the three different size-classes of fish released (Table 2). The slope of a regression of the log of the number of fish recaptured on the days postrelease is the average daily mortality rate. This mortality rate, however, includes not only mortality but also emigration of fish from the assessment sampling area and losses due to nonreplacement sampling. An analysis of covariance (ANCOVA; Zar 1984) for random-station sampling in which sampled fish were not replaced in zones 1 and 2 compared regressions by the numbers of fish recaptured in the three size-classes on the number of days the fish had been at large when recaptured. The ANCOVA indicated that there was no significant difference in the mortality rates

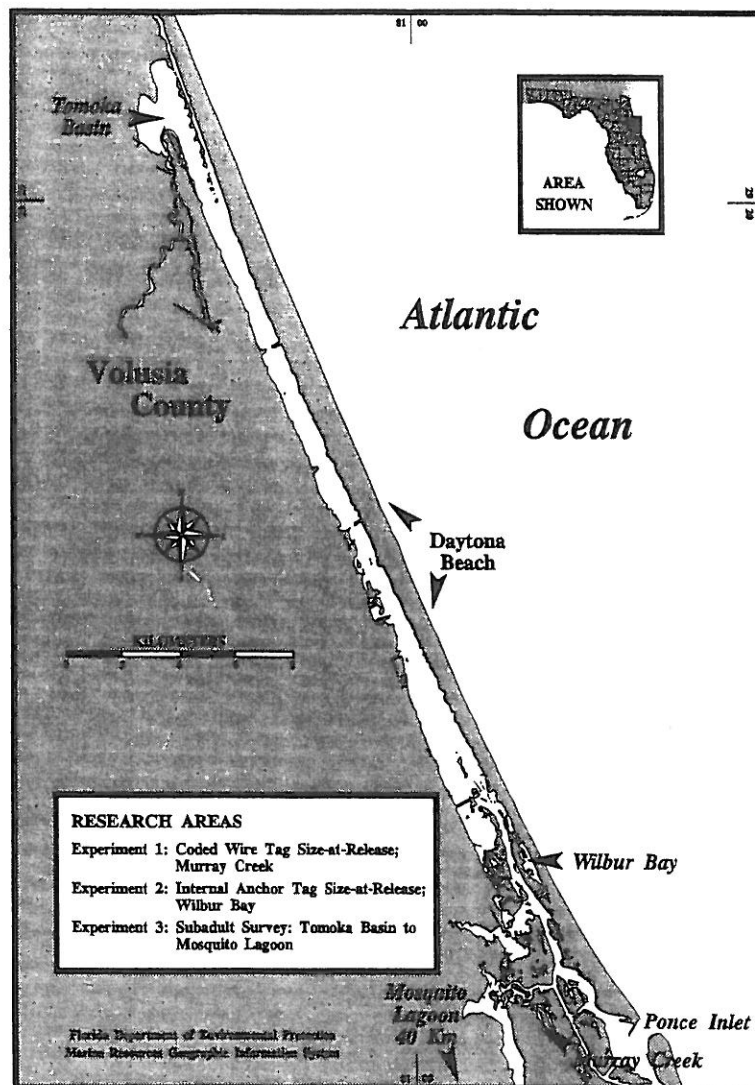


FIGURE 2.—Red drum stock enhancement assessment research areas in Volusia County, Florida.

among size-classes ($F = 0.06$; $df = 2,24$; $P = 0.05$; Figure 3).

The total number of fish recaptured during fixed-station sampling was 63, 117, and 215 for the small, medium, and large size-classes, respectively. Analysis of covariance for fixed stations also showed that there were no significant differences among the mortality rates for the three size-classes of fish ($F = 0.26$; $df = 2,16$; $P = 0.05$). There was, however, a significant difference in the elevation between each of the regression lines ($F = 15.09$; $df = 2,18$; $P < 0.05$), indicating that more larger fish were recaptured than were smaller fish (Figure 4). This differ-

ence between size-classes in the number of fish recaptured in fixed-station sampling was established by the first day of postrelease sampling (day 6) and continued to be evident during most of the biweekly sampling periods for the balance of the experiment (Table 2).

Comparisons of the mean lengths of wild red drums that were captured during both fixed- and random-station sampling also show that more large fish were collected at fixed stations than at random stations during the same sampling periods (Table 3). Several factors may be contributing to higher numbers of fish collected at fixed sites: fixed sites

TABLE 2.—Number of coded-wire-tagged red drums recaptured at fixed (5 samples) and random (12 samples) stations during biweekly sampling in the Murray Creek area. Size-classes are small (S), medium (M), and large (L) as described in text.

Days at large	Fixed stations				Random stations			
	S	M	L	Total	S	M	L	Total
6	23	33	66	122	38	85	84	207
14	25	49	85	159	3	8	12	23
28	7	21	33	61	90	28	11	129
41	4	7	14	25	3	0	1	4
53	3	1	5	9	8	9	8	25
67	1	4	6	11	4	5	4	13
83	0	2	4	6	4	3	5	12
98	0	0	1	1	1	0	10	11
112	0	0	1	1	0	1	0	1
125	0	0	0	0	1	0	0	1
Total	63	117	215	395	152	139	135	426

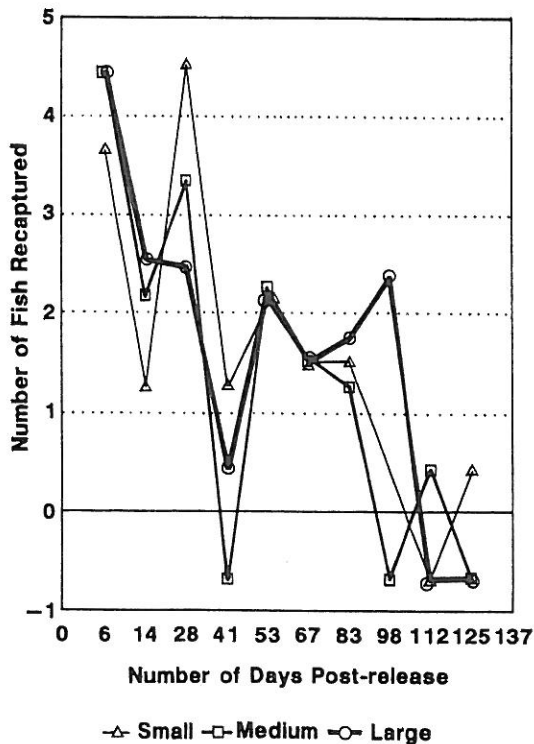


FIGURE 3.—Red drum recapture data for the coded-wire-tag, size-at-release experiment (fall 1992 production season release). The graph shows the number of fish recaptured at random stations on days postrelease (0.5 was added to each fish recapture number to allow zero recaptures to be plotted). Size-classes are small, medium, and large as described in text.

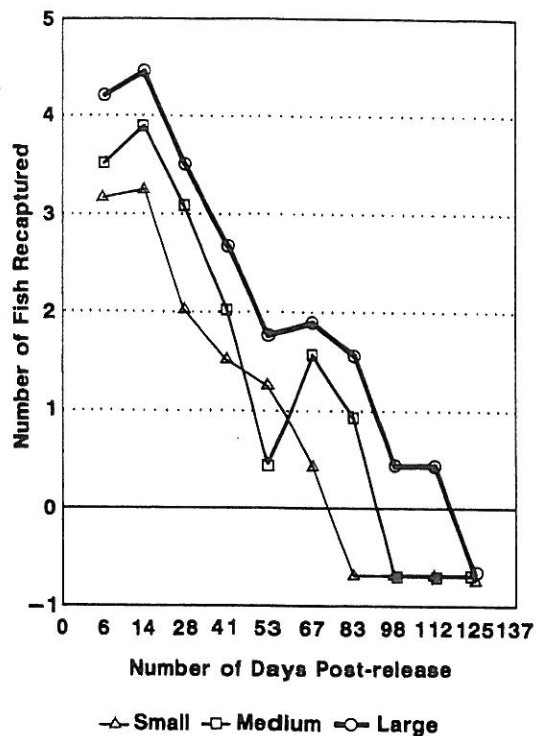


FIGURE 4.—Red drum recapture data for the coded-wire-tag, size-at-release experiment (fall 1992 production season release). The graph shows the number of fish recaptured at fixed stations on days postrelease (0.5 was added to each fish recapture number to allow zero recaptures to be plotted). Size-classes are small, medium, and large as described in text.

are optimal red drum habitat and larger fish preferentially selected these areas; once established in the preferred habitat, the larger fish may exclude the smaller fish from these areas through intraspecific competition; and fish in an optimal habitat grow faster and larger than do cohorts in other areas.

Hatchery-released red drums resided in Murray Creek in relatively high numbers through about days 67–83 postrelease, after which the recovery of hatchery-reared and wild red drums during random- and fixed-station sampling decreased dramatically (Tables 2 and 3). On day 67 after their release, hatchery-reared red drums captured at random and fixed stations had mean TL of 118mm ($N = 13$) and 145mm ($N = 11$), respectively, and the wild red drums captured at both types of stations a mean TL of 138mm ($N = 5$). The total lengths of these fish are consistent with the lengths at which wild red

TABLE 3.—Size and number of wild red drums captured at fixed (5 samples) and random (12 samples) stations during biweekly sampling in the Murray Creek area.

Day at large	Fixed stations		Random stations	
	Mean total length (mm)	N	Mean total length (mm)	N
6	102.8	15	78.5	25
14	126.7	27	123.5	2
28	132.0	9	90.1	11
41	144.0	4	90.0	4
53	155.8	4	136.8	14
67	140.3	3	134.0	2
83	182.0	2	185.5	2
98	206.0	1	0	0
112	0	0	0	0
125	0	0	0	0

drum have been shown likely to move to a different habitat (Peters and McMichael 1987; Daniel 1988).

There were also certain stations, both fixed and random, that offered preferred habitat. At fixed-station CR2, a large number of fish were recaptured during a single sample (75 fish on day 6), and hatchery fish were recaptured there during every biweekly sampling period throughout the experiment. Many fish were also recaptured during single samples at two random stations: 142 fish at station 139 (day 6) and 63 fish at station 142 (day 28). These stations are located nearly adjacent to each other in the middle of Murray Creek proper. The size structure of the fish sampled at these two sites might be expected to be similar because these sets were sampled only 22 d apart, but it was in fact quite different. The ratio of fish in small:medium:large size-at-release classes that were recaptured at station 139 (6 d) was 1:4:3, and at station 142 (28 d) was 25:8:1. Such a change in size-class composition is difficult to explain. These differences in stock size structure as well as differences in results between random- and fixed-station data may be related to the differential use of habitat over time.

Although the fish recaptured during random-station sampling showed no difference between size-

classes, 3.7 times as many fish in the large size-class as in the small size-class were recaptured during the fixed-station sampling. Preliminary data gathered from the trammel-net survey of subadults (Table 4) showed that of the seven CWT fish that were recaptured during sampling, six (86%) were from the larger size-classes which were released during pilot studies. Although this is a very small data set, it supports the fixed-station, size-at-release data indicating that more fish from the larger size-classes may survive than do smaller fish.

Experiment 2: IAT Size at Release

As of 1 December 1993, 241 of the red drums released 15–25 October 1991 (a period of 767 d), had been recaptured (Table 5). Fish from the larger size-class were 3.9 times more likely to be returned as were those from the smaller size-class.

All fish recaptures were classified by time period blocks of 100 d at large, and the two size-classes were compared for mean growth rate (Table 6) and mean distance traveled (Table 7). Analyses of variance indicated that there were no significant differences in either mean growth rate ($F = 0.167$; $df = 1,7$; $P = 0.05$) or mean distance traveled ($F = 0.008$; $df = 1,7$; $P = 0.05$) between the fish in the two size-classes.

The first-year growth of the IAT hatchery-reared fish (0.93 mm/d) was comparable to that reported by Simmons and Breuer (1962) and Peters and McMichael (1987) for wild red drum growth (0.83 mm/d). The first-year growth rate of 0.93 mm/d was calculated from lengths of IAT fish reported by anglers (0–200 d post release; Table 6) and lengths at the hatchery prior to release (165 d).

Experiment 3: Subadult Sampling

A total of 395 red drums ranging in size from 218 mm to 828 mm TL were captured in 110 trammel-net sets throughout Volusia County, from Tomoka Basin in the north to Mosquito Lagoon in the south (Table 4). The eight tagged fish recaptured represented 2% of the total number of red drums captured.

TABLE 4.—Results of subadult red drum trammel-net survey for Volusia County, Florida. Survey conducted from 17 November 1992 through 10 February 1994.

Area of county	Total fish captured			Tagged fish recaptured			Percent tagged fish
	N	Total length		N	Total length		
		Mean (mm)	Range (mm)		Mean (mm)	Range (mm)	
Murray Creek	168	403.0	280–758	7	354.0	280–549	4.2
North and south	227	384.7	218–828	1	586		0.4
Total	395	392.5	218–828	8	383.0	280–586	2.0

TABLE 5.—Release and recapture data for red drums released in the internal-anchor-tag, size-at-release experiment. Release was during 15–25 October 1991, and recaptures were reported for the period 25 October 1991 through 1 December 1993.

Mean total length at release (mm)	Fish released (N)	Fish recaptured		Mean distance traveled (km)	Mean growth (mm/d)	Mean days at large
		(N)	(%)			
157.1	3,780	52	1.4	26.1	0.62	348
201.7	3,519	189	5.4	25.4	0.71	291

Trammel-net sets in the area of Murray Creek, where most of the hatchery fish had been released, yielded a total of 168 red drums, 7 of which (4.2%) were tagged with CWTs. The presence of hatchery-reared fish should continue to increase because none of the approximately 120,000 CWT red drums from the size-at-release experiment should have grown sufficiently since their release to have entered this fishery.

Discussion

Although we saw no difference between the three size-classes in the total number of fish recaptured in the random-station sampling conducted during the CWT size-at-release experiment, we did see significant differences between size-classes in total number of fish recaptured in the fixed-station sampling. These differences occurred after release but prior to day 6 and remained consistent throughout the experiment. Because a difference in apparent success was established so soon after stocking and the degree of difference between size-classes did not change through time, fishery managers could use this information to predict long-term success of hatchery releases of red drum by concentrating assessment sampling efforts soon after release. A size-

at-release effect has also been demonstrated by Leber (in press) who worked with hatchery-reared striped mullet (45–120 mm TL). His analyses suggested that the success of different size-classes is directly related to season and that hatchery contributions can result in as much as a four fold increase in hatchery fish contribution if releases are properly timed.

Less than 0.01% of the red drum fingerlings released in summer (produced out of season in the spring) were recaptured. Several factors could have contributed to the poor recapture rate for these fish. It is possible that some of the fish rapidly emigrated soon after they were released and moved to another habitat out of the sampling area. These fish may yet be recovered in future subadult sampling. Fewer fish of other species were captured during the out-of-season study period than were captured during other portions of the year. The lower numbers of fish may be related to high summer temperatures, which can cause daily temperature fluctuations in shallow backwater areas and therefore make these areas less viable as fish habitat.

In pilot studies, red drums that were produced in the spring (out of season), held in ponds at the

TABLE 6.—Mean growth rate (mm/d) of red drums in two size-classes used in the internal-anchor-tag size-at-release experiment. Numbers in parentheses are numbers of fish recaptured during 100-d time periods. Mean total lengths of fish in the small and large size-classes were 157.1 ± 12 mm ($N = 225$) and 201.7 ± 24.6 mm ($N = 285$), respectively.

Time periods (d) from release to recapture	Growth rate (mm/d)	
	Small	Large
0–100	0.91 (4)	1.18 (30)
101–200	0.70 (5)	0.66 (23)
201–300	0.66 (14)	0.72 (51)
301–400	0.56 (9)	0.57 (42)
401–500	0.56 (8)	0.51 (16)
501–600	0.53 (7)	0.44 (6)
601–700	0.42 (2)	0.46 (12)
701–800	0.55 (2)	0.52 (5)

TABLE 7.—Mean net distance traveled by red drums in the two size-classes used in the internal-anchor-tag size-at-release experiment. Numbers in parentheses are the number of fish recaptured during the 100-d time periods. Mean total lengths of fish in the small and large size-classes were 157.1 ± 12.0 mm ($N = 225$) and 201.7 ± 24.6 mm ($N = 285$), respectively.

Time periods (d) from release to recapture	Net distance traveled (km)	
	Small	Large
0–100	20.2 (4)	18.0 (31)
101–200	9.1 (5)	24.8 (25)
201–300	26.9 (15)	26.7 (52)
301–400	25.4 (9)	24.1 (42)
401–500	21.3 (8)	25.2 (16)
501–600	30.0 (7)	32.8 (6)
601–700	64.5 (2)	25.0 (12)
701–800	46.5 (2)	64.7 (5)

hatchery through the summer, and then harvested, tagged, and released in the fall were recaptured at considerably higher rates than were fish produced similarly but released in the summer (S. A. Willis, FDEP, unpublished data). Although this strategy of holding fish produced out of season and delaying their release until the fall results in higher red drum recapture rates, the fish are being released approximately one-half year out of phase with wild cohorts. Because these delayed-release fish are considerably larger at the time of release than are the wild young-of-the-year red drums that are normally recruited in the fall, intraspecific competition may occur. Releasing hatchery-reared fish out of phase with wild stocks may also result in interspecific competition because red drums released out of season may interact with all other species that are normally using the nursery areas and compete for limited space, food, and territory.

The decline in the number of red drums recaptured within the study site during the CWT size at release experiment was due to a combination of factors, including mortality, emigration, and loss due to nonreplacement sampling. Emigration may be a major contributing factor because the number of red drums recaptured in the study area rapidly decreased just as the fish attained the size at which wild red drums have been shown to move normally from nursery areas. Daniel (1988) found that in coastal South Carolina smaller juveniles apparently remain in marsh areas until they are about 150 mm TL, and then they move into river channels and lower harbors.

Hatchery-reared red drums mixed with similarly sized wild red drums after release. Patchy distribution and schooling behavior were compared between random stations in zones 1 and 2 and fixed stations (all fixed stations lie within the bounds of zones 1 and 2). Patchy red drum distribution was evident: only 27 of the 60 random stations (45%) and 29 of the 50 fixed stations (58%) sampled contained hatchery fish. Wild red drums were captured in only 33 of the 110 random and fixed stations sampled (30%). The association of hatchery fish with wild fish was very high: of the 33 stations where wild red drums were caught, 29 (88%) also contained hatchery fish. Further analysis of the data by identification of microhabitat within zones in relation to red drum recapture rates may yield more complete answers concerning emigration, schooling, and association of hatchery-reared with wild red drums.

The IAT size-at-release experiment illustrates that release of large, hatchery-produced juveniles

(201.7 mm TL) contributes to the public fishery. A total of 5.4% of the large size-class of IAT fish were recaptured by the public (Table 5). Yeager (1988) also demonstrated a size-related benefit in northern Florida: striped bass that were released at 150–250 mm TL were returned 100 times more often than were striped bass that were released at 30–45 mm TL. Analyses also indicated that there was no significant difference in growth rate between the two size-classes of fish released and that the overall growth rate of hatchery-reared fish was similar to that reported for wild red drums.

During the IAT size-at-release experiment, only 18 of the 241 IAT returns were from areas to the south of the release site, and all southerly returns were from areas close to the release site (within 10–12 km). Several interrelated factors may be contributing to the distribution of IAT red drums in the general area to the north of the release site (Figure 2). One factor may be that the direction of water flow in the Halifax River is to the north, although water movement is slow and strongly influenced by tides. Another factor may be that the only input of oceanic water into the Halifax River system in this area is through Ponce Inlet, located about 8 km to the south of the release site. Tomoka Basin, approximately 25 km north of the release site, contributed 96 recaptured fish (40%) and also has a large freshwater input, with salinity generally around 15–20 ppt. Therefore, lower salinity, which has been shown to be important for red drum movement (Yokel 1966), is probably an important factor in the location of recapture. Another factor may simply be that fishing pressure is greater in the more northern portions of the county. The city of Daytona Beach is located on the barrier island near the site where 29 fish were recaptured (Figure 2). These 29 recaptures were made near a bridge that connects the city with the mainland.

Even with several factors influencing movement of fish, hatchery-reared red drums remained within 25 km of the release site during the 767 d postrelease. Osburn et al. (1982) and Murphy and Taylor (1990) also reported low emigration rates from estuarine to nearshore areas for subadult red drums.

Detecting the entry of hatchery-released fish into the public fishery is one of the main goals of this project. Subadult sampling shows that some of the hatchery fish that were released in the early years of the program are now reaching legal size and are near the reproductive size described by Murphy and Taylor (1990). Preliminary analysis of subadult, trammel-net sampling data from November 1992 through February 1994 indicates that hatchery con-

tributions to one local stock of subadult red drums are at least 4.2% and have the potential to be much higher. The criteria for long-term success are (1) entry of hatchery fish into subadult stocks, (2) attainment of reproductive status by these same fish, and (3) contribution of offspring by these hatchery fish to the wild population. The first criterion has been met, the second should soon be met, and the confirmation of the third is the goal of a recently initiated 5-year genetic project that will provide allozyme and DNA analyses to show if hatchery fish are contributing offspring.

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