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Triploid Grass Carp in Lake Marion, South Carolina

by James P. Kirk, K. Jack Killgore, James V. Morrow, Jr., WES
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Prepared for Headquarters, U.S. Army Corps of Engineers

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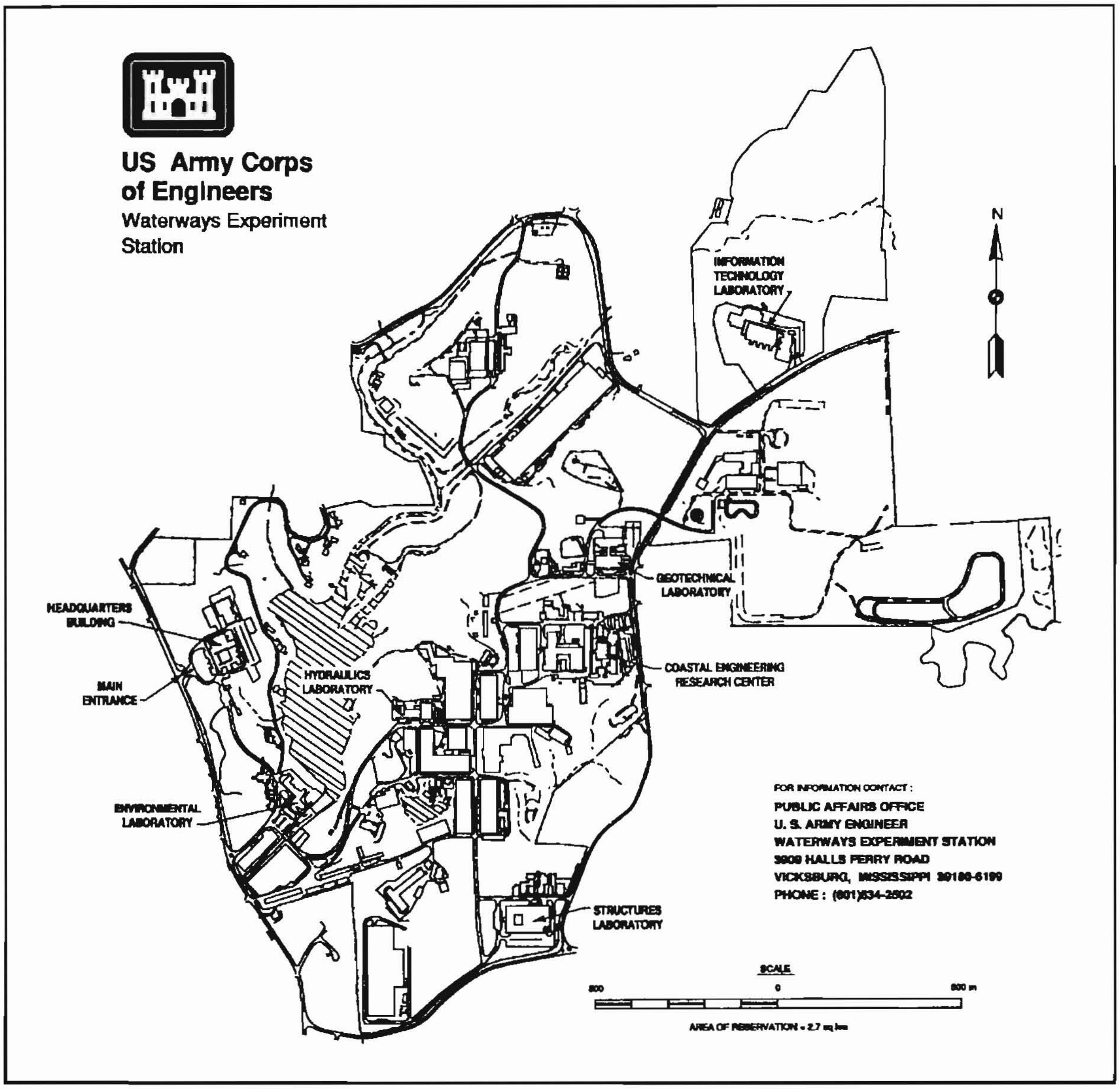

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Preface

The work reported herein was conducted as part of the Aquatic Plant Control Research Program (APCRP), Work Unit 32738. The APCRP is sponsored by the Headquarters, U.S. Army Corps of Engineers (HQUSACE), and is assigned to the U.S. Army Engineer Waterways Experiment Station (WES) under the purview of the Environmental Laboratory (EL). Funding was provided under Department of the Army Appropriation No. 96X3122, Construction General. The APCRP is managed under the Center for Aquatic Plant Research and Technology, Dr. John W. Barko, Director. Mr. Robert C. Gunkel was Assistant Manager for the APCRP. Program Monitor during this study was Ms. Denise White, HQUSACE.

This report was prepared by Dr. James P. Kirk, Dr. K. Jack Killgore, and Mr. James V. Morrow, Jr., Aquatic Ecology Branch (AEB), Ecological Research Division (ERD), EL, WES, and Dr. Jeffrey W. Foltz, Department of Aquaculture, Fisheries, and Wildlife, Clemson University, Clemson, SC. This study was supervised by Dr. Alfred F. Cofrancesco, Chief, AEB, and Dr. Conrad J. Kirby, Chief, ERD. Dr. John W. Keeley was Director, EL.

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1 Introduction

The grass carp (*Ctenopharyngodon idella*), first introduced to the United States in 1963 as a biocontrol agent for aquatic vegetation, has rapidly expanded its range (Guillory and Gasaway 1978; Clugston and Shireman 1987). More recently, the triploid grass carp has gained popularity because the fish is sterile, has feeding habits similar to diploids, and can be a relatively inexpensive, long-term source of control for nuisance aquatic vegetation (Wattendorf and Anderson 1984; Sutton 1985; Allen and Wattendorf 1987). The use of grass carp to control nuisance aquatic vegetation is not without controversy (Ware and Gasaway 1976; Gasaway 1978; Fedorenko and Frazer 1978). Often, this fish has been stocked at densities producing no effect on target aquatic vegetation or completely eliminating all aquatic vegetation (Sutton 1977; Leslie et al. 1987; Santha et al. 1991; Kirk 1992). Other concerns include elimination of nontarget aquatic vegetation, migration out of the system, adverse effects on fish communities, and potential movement into or through estuarine nursery areas (Bain 1993).

Triploid grass carp populations were monitored in the Santee Cooper reservoirs from 1989-1994. The Santee Cooper reservoirs (Lakes Marion and Moultrie and the connecting canal) cover approximately 70,000 ha and were impounded in 1941 for flood control and hydropower. These reservoirs have supported important recreational fisheries (Sample 1990) and a self-sustaining striped bass population (*Morone saxitalis*). The system, especially upper Lake Marion, has a long history of nuisance aquatic vegetation problems (Inabinette 1985). During the 1980s, hydrilla (*Hydrilla verticillata*) initially became established in the upper reaches of Lake Marion, occupying about 5,000 ha and causing severe access and low dissolved oxygen problems. Over time, hydrilla has spread throughout both reservoirs and currently covers approximately 20,000 ha (de Koslowski 1994). Triploid grass carp were legalized for use in 1985 and were first stocked in 1989 as part of a control program that included both herbicides and triploid grass carp. From 1989 through 1992, 100,000 triploid grass carp were stocked yearly; in 1993 and 1994, 52,500 and 152,000 fish were stocked.

Studies were conducted on movement, age, and growth of triploid grass carp. Radiotelemetry was used to monitor movements and quantify habitat use. Population attributes were derived using age and growth techniques.

This report summarizes these studies and provides recommendations and conclusions on using triploid grass carp as a biocontrol agent in large water bodies.

2 Movements and Habitat Use of Triploid Grass Carp

Introduction

Migrational movement in grass carp occurs when water temperature reaches 15 to 17 °C (Aliev 1976). A rise in water level or increased flow rates also cause grass carp to exhibit migrational movement (Stanley, Miley, and Sutton 1978). Therefore, there was concern that triploid grass carp may migrate up the rivers and away from the target control area. A study was conducted to (a) determine the magnitude and direction of grass carp movements; (b) determine if grass carp remain in the targeted vegetation areas; and (c) examine characteristics of habitats utilized by triploid grass carp.

Methods

Eighty-two triploid grass carp were surgically implanted with radio transmitters identified by a distinct frequency (45 fish in the 1989/1990 study and 37 fish in the 1990/1991 study). Life spans of transmitters were 9 months, and transmitter frequencies ranged from 48.036 to 49.527 kHz. Grass carp were anesthetized using a bath containing 100-mg/ℓ MS-222 and 25-mg/ℓ Furacin. Each fish was weighed to the nearest 0.01 kg and measured to the nearest millimeter. Anesthetized fish were placed in a v-shaped operating trough so that the fish, excluding its abdomen, was submersed in water containing MS-222 and Furacin. A small aquarium aerator was used to maintain adequate oxygen levels in the operating trough. A radio transmitter was then surgically implanted using the procedure described by Schramm and Black (1984). Surgical gloves were worn, and instruments and transmitters were disinfected prior to use.

Scales were removed from the incision area, and a 5-cm longitudinal incision was made in the ventral wall 6 cm anterior to the pelvic girdle. A transmitter was then inserted into the body cavity and the incision closed with nonabsorbable silk sutures. Oxytetracycline (50-mg/kg body weight) was injected into the body cavity before the last suture was stitched. Fish were then immediately released into the lake at Pack's or Elliot's flats (1989/90 study) or approximately 1 km north of Santee State Park during the 1990/91 study (Figure 1).

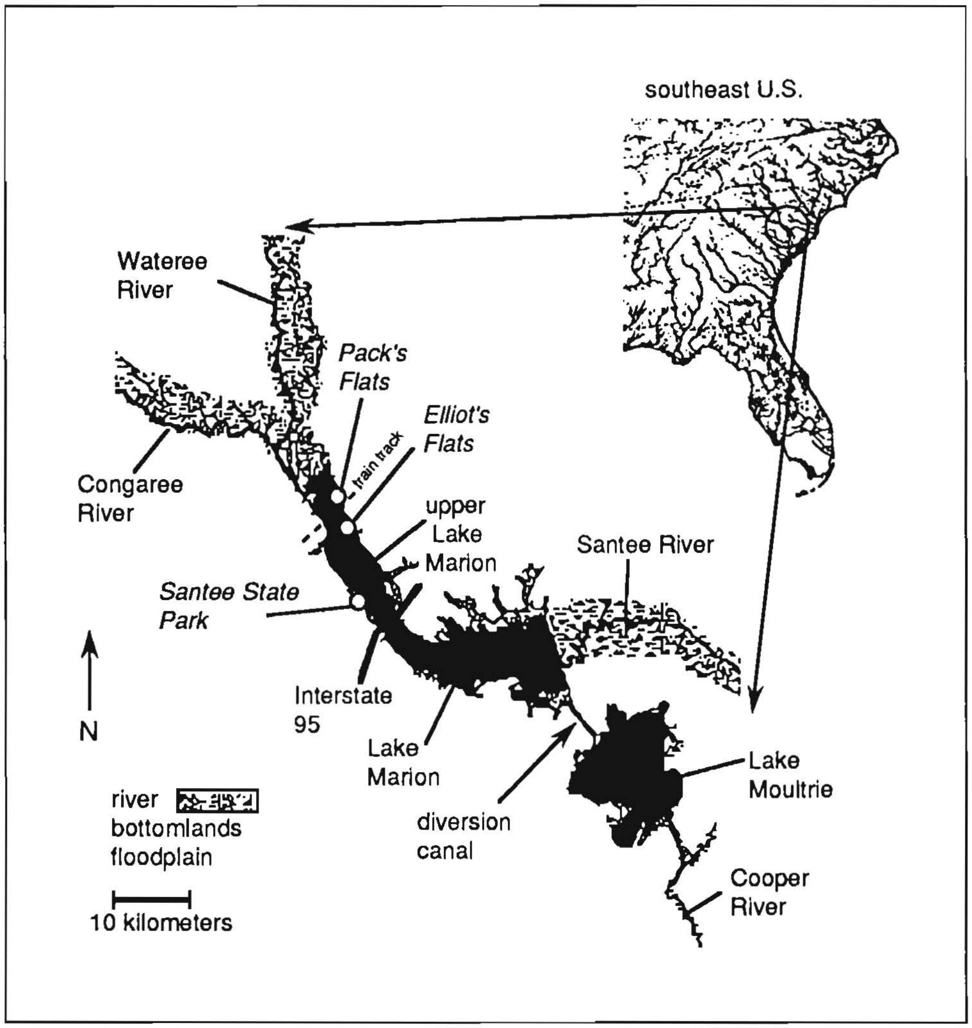

Figure 1. Upper Lake Marion study area in relation to Santee-Cooper (Lakes Marion and Moultrie) system

An Advanced Telemetry Systems (Model 2000) radio receiver was used. Boat searches for implanted grass carp were conducted 3 days per week for 18 months. Signals were received while boating with a Telex Communications (Model 64 B-S) four element yagi antenna. Once a signal was picked up by the receiver, the antenna was rotated to ascertain direction, and the boat was maneuvered in that direction. Signal strength increased as the fish was approached. The coax cable was then disconnected from the antenna and dropped in the water beside the boat. Intensity of the signal indicated when the boat was within 25 m of the fish. Air searches of the Santee-Cooper system were conducted monthly during the initial study in order to locate any fish that had not been located in 14 days. Air searches were not conducted during the second study because all fish were regularly located.

Once a fish was located, date, water depth, and Loran latitude and longitude coordinates were taken. Water temperature and dissolved oxygen were measured at the surface and on the bottom with a YSI dissolved oxygen meter (Model 51B) to the nearest 0.1 °C and 0.1 mg/ℓ, respectively. Mean dissolved oxygen was calculated from the surface and bottom values. An aquatic vegetation sample was taken from the surface and bottom with a rake.

Aquatic vegetation was identified (Pennwalt Corporation 1984) in the field. The species that comprised the largest proportion of a sample was categorized as primary vegetation, and the species that comprised the next largest proportion was categorized as secondary. Vegetation density in the general vicinity of the fish location was categorized into one of four categories: (a) vegetation covers ≥50 percent of the surface; (b) vegetation covers <50 percent of the surface; (c) vegetation present but submersed; or (d) vegetation sparse. Habitat type was categorized as one of five types: (a) river channel (Santee, Congaree, or Wateree); (b) open water with creek channels (OWCC); (c) open-water shallow flats (OWSF); (d) thick cypress swamp (TCS); and (e) open water with scattered cypress trees (OWCS).

Fish locations were plotted on a digitized map that indicated the Santee River channel. Days elapsed and distance moved (to nearest 0.01 km) between readings were computed for each fish. Minimum net daily movement was then computed as net kilometers/elapsed days. Distance from the river channel to the fish was computed along a line perpendicular to the fish and the river channel. Distances were recorded to the nearest 0.01 km. Distance of grass carp from the river channel was tested with a t-test (null hypothesis that the distance = zero).

Core use area and home range estimates were calculated for individual fish using the bivariate scatterpoints (Longitude = Y_1 and Latitude = Y_2) of grass carp locations. Core use areas were computed as the 95-percent confidence region (i.e., ellipse) to each fish's mean location, whereas home ranges were based on a 95-percent confidence region to each fish's observations (Sokal and Rohlf 1969). Average core use and home range areas were computed from log10 transformed values. Similarly, the statistical center of distribution for both studies was computed as the 95-percent confidence region (i.e., ellipse) to the sample mean.

Results

Triploid grass carp used in this study averaged 704 mm total length (SE = 15) and 4.4 kg live weight (SE = 0.2) at the time of release. Fish were located on 225 occasions in the first study and 180 occasions during the later study. Average elapsed time between locations of an individual fish was 10 and 17 days for the first and second study, respectively. The longest distance moved by a fish was 10.6 km over 4 days, while the averages were 0.29 km/day (SE = 0.01) and 0.10 km/day (SE = 0.01) for the 1989/90 and 1990/91 studies, respectively.

Grass carp in this study did not demonstrate a preference for the river channel in Lake Marion (Figure 2). Mean distance of grass carp from the river channel was 1.75 km (SE = 0.08) and 1.01 km (SE = 0.07) for the first and second studies, respectively. These mean distances were significantly different from zero ($t = 22.84$, $p = 0.0001$; $t = 14.21$, $p = 0.0001$).

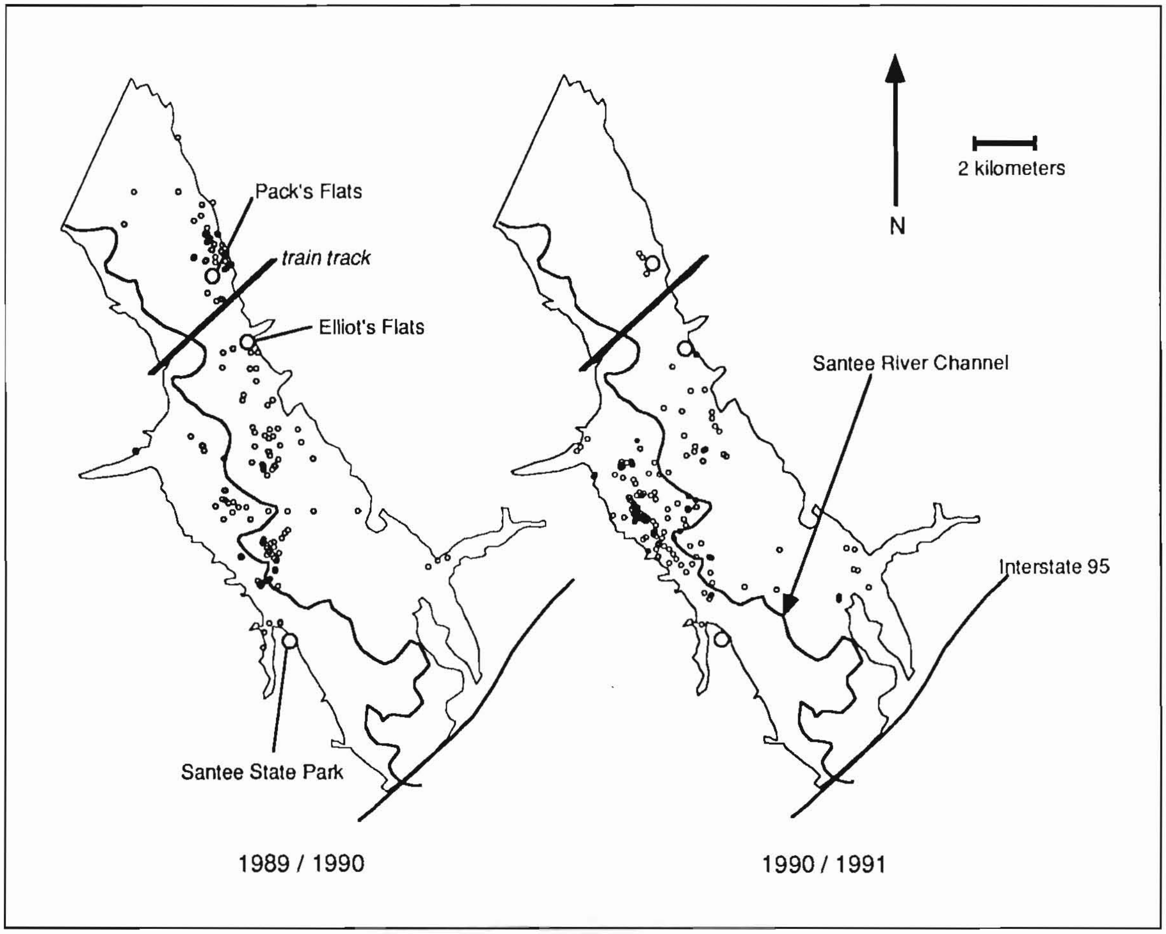

Figure 2. Locations of radio-tagged adult triploid grass carp in upper Lake Marion, SC (Each dot represents one or more individual fish locations)

Grass carp in the 1989/90 study showed an average individual core use area of 49 km^2 and an individual home range of 165 km^2. As a group, they were distributed from Pack's Flats to Santee State Park (Figure 2). Grass carp in the second study had an average individual core use area of 9 km^2 and only 49 km^2 for average individual home range (Figure 2). As a group, fish in the second study were located principally in an area known as Stumphole Flats about 3 km north of Santee State Park (Figure 2).

Surface dissolved oxygen concentrations at fish locations remained above 8 mg/ℓ most of the year, but bottom concentrations averaged less than 1 mg/ℓ in May. Water temperatures at fish locations were similar to the pattern that occurs in the upper lake: winter temperatures of 10 °C and summer high temperatures of 29 °C. There was a 2 to 5 °C difference between surface and bottom temperatures at fish locations, which ranged in depth from 2 to 3 m.

No studies to date have quantified the different proportions of habitat and aquatic vegetation types in upper Lake Marion. Fish were located in open-water shallow flats or adjacent open-water cypress stands 66 and 70 percent of the time during the 1989/90 and 1990/91 studies, respectively (Figure 3). Depths averaged 2 to 3 m. Grass carp locations in thick cypress swamps accounted for only 19 and 25 percent of the locations.

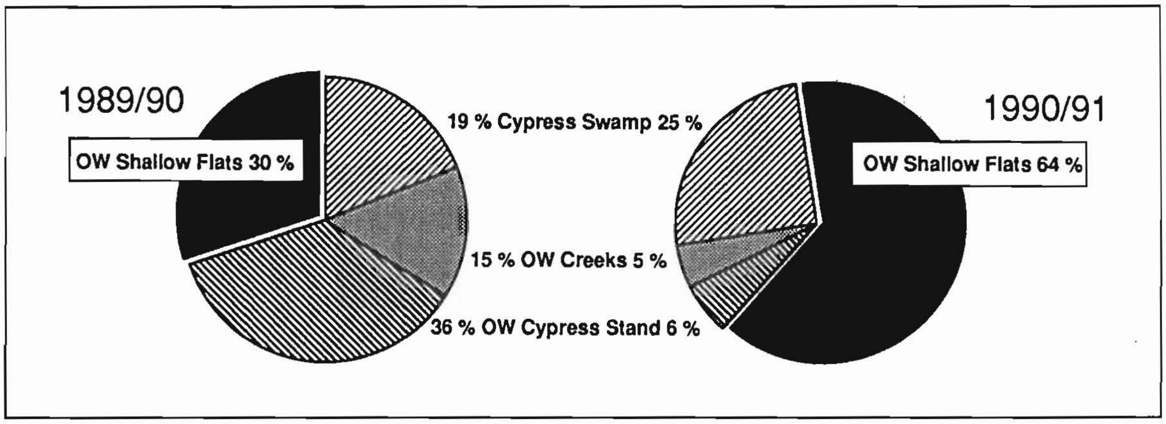

Figure 3. Habitats utilized by radio-tagged adult triploid grass carp in upper Lake Marion, SC

Seventy-two and fifty-three percent of recorded grass carp locations were in areas with aquatic vegetation at the water's surface during the two study periods (Figure 4). Also, 66 and 70 percent of fish locations were in areas dominated by hydrilla (Figure 5). Elodea *(Egeria densa)* was the predominate vegetation type in only 11 and 6 percent of fish locations. Other vegetation types, which included duckweed (*Lemna* spp.), musk-grass *(Nitella)*, and

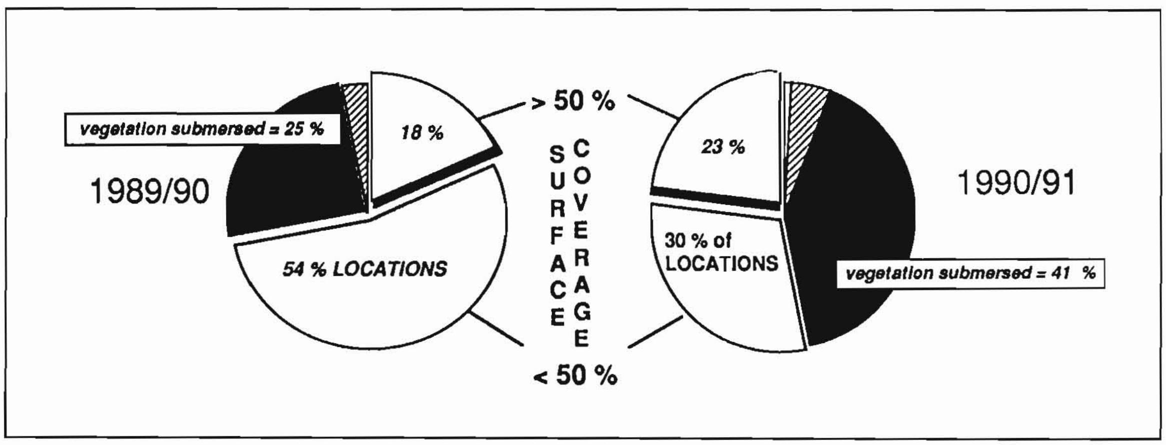

Figure 4. Relative abundance of surface vegetation at locations of radio-tagged adult triploid grass carp in upper Lake Marion, SC

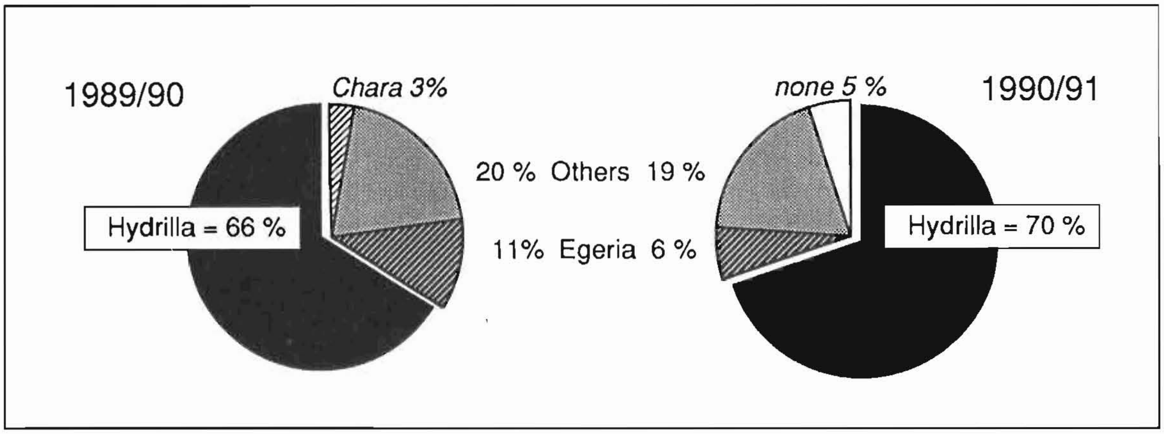

Figure 5. Predominate aquatic vegetation at locations utilized by radio-tagged triploid grass carp in upper Lake Marion, SC

coontail (*Ceratophyllum demersum*), accounted for 20 an 19 percent of the locations.

Discussion

Magnitude of movements were less than those reported for adult fish by Bain et al. (1990). Bain et al. (1990) reported that adult fish movement averaged 33 km over a 4-month period (i.e., about 0.27 km/day) and that one fish traveled 6 km/day. In the study herein, fish moved an average of 0.10 to 0.29 km/day. However, it is difficult to make direct comparisons between studies without knowledge of the frequency of observation. For example, a fish could travel 1 km each day for 10 successive days, but if it finished at its origin and had not been observed for 10 days, net daily movement would compute as zero. Higher movement rates reported for the first study (1989/90) were for grass carp released at two widely separated points in upper Lake Marion, South Carolina. Also, fish probably moved to avoid widespread low dissolved oxygen events that occurred during 1989 and 1990 in the uppermost cypress swamps and adjacent flats. In the 1990/91 study, grass carp generally remained in the shallow flats located within 2 km of their release site. In both years, however, fish remained in upper Lake Marion, the target area. Core use areas traveled by grass carp were close to values reported by Chilton and Poarch (1994) for triploid grass carp in a Texas reservoir.

Shallow flats and adjacent areas were most frequented by grass carp, probably due to higher dissolved oxygen and abundant submersed vegetation. Thick cypress swamps in contrast are characterized by low summer dissolved oxygen concentrations (Bates and Marcus 1989). Thus, utilization of more open areas probably provides grass carp with a suitable combination of food density and dissolved oxygen concentrations.

3 Population Attributes of Triploid Grass Carp

Introduction

Biologists at the U.S. Army Engineer Waterways Experiment Station are using a stocking model to recommend appropriate grass carp stocking rates (Miller and Decell 1984). This model requires input such as age structure, biomass, and growth. To adequately monitor triploid grass carp populations in large water bodies and acquire information for model support, collection and aging techniques were necessary. In this chapter, development of efficient methods of collection and aging are discussed, as well as population attributes of density, growth, and biomass of triploid grass carp stocked in the Santee Cooper reservoirs, South Carolina.

Methods

Initial efforts to collect triploid grass carp using conventional collection methods failed. However, grass carp were collected successfully using skilled bowfishermen at night (Kirk et al. 1992).

Length-weight information from triploid grass carp (for fish of both sexes) was used in backcalculation. Collected fish were measured for total length to the nearest millimeter and weighed to the nearest 10 g. The length-weight relationship was computed using a power function (Ricker 1975): weight = intercept × length ^{slope}.

Scale annuli were used for aging and backcalculation in 1992. Victor and Brothers (1982) found that utricular otoliths (lapilli) were suitable for age determination in cyprinids. Eventually, all three pairs of grass carp otoliths were located; utricular otoliths, lapilli, appeared to lay down annual rings that agreed well with annuli laid down on scales (Kirk, Morrow, and Killgore 1994). Figure 6 shows otolith locations and where lapilli should be sectioned.

Marginal increment techniques were used to determine the month of otolith annulus formation. The percent occurrence of opaque margins on sectioned

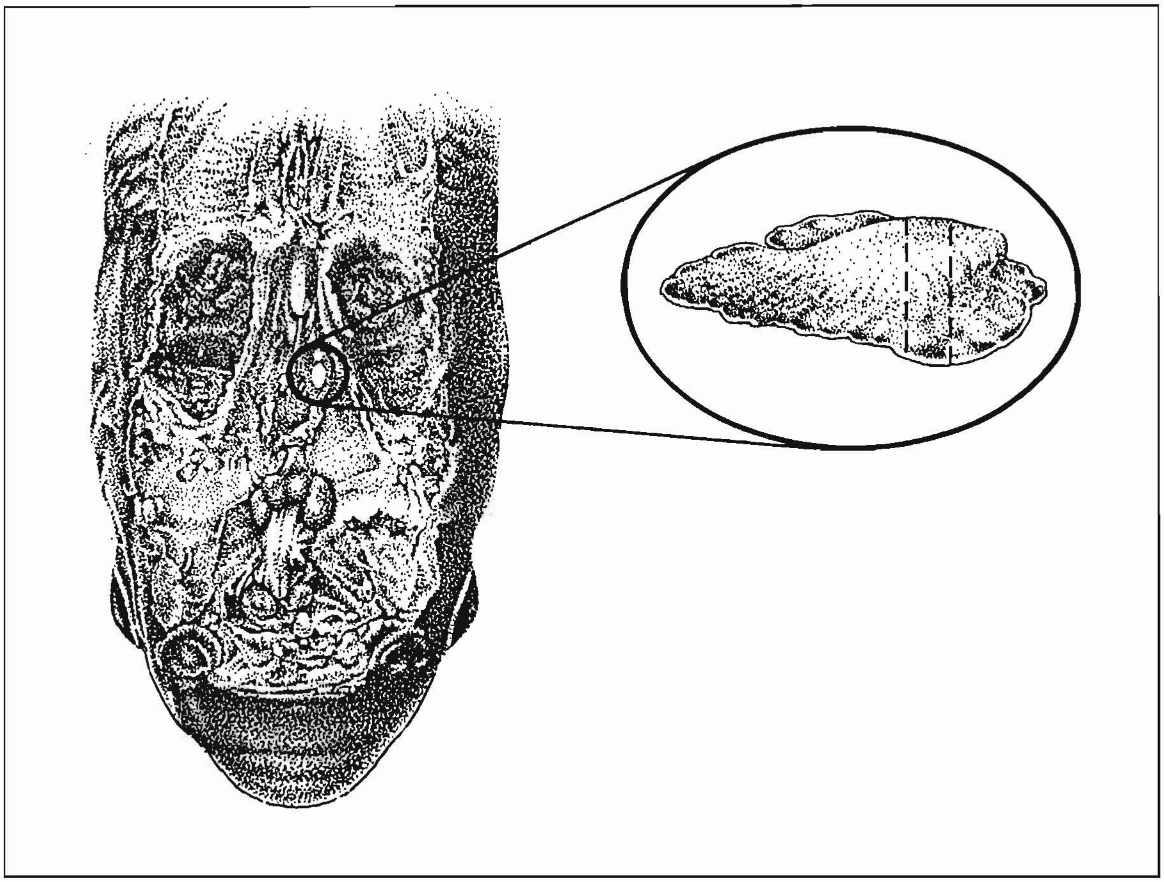

Figure 6. Position of utricular otoliths (lapilli) and location to section otolith

otoliths was counted and evaluated to determine the month of annulus formation. An arbitrary spawning date of 1 January was assigned to every fish. Fish captured between 1 January and annulus formation were assigned an age equal to the number of annuli plus one. Fish captured after annulus formation were assigned an age equal to the number of annuli.

After age determination using otoliths, known age scales were examined using a Ken-O-Vision microfiche projector. Distances from the focus to each annulus and the scale margin were measured using a sonic digitizer mounted on top of the projector. The Frazer-Lee method was used to backcalculate lengths (Carlander 1982). The correction factor was figured by regressing fish length against scale radius for a sample that covered the entire size range.

A catch curve (Ricker 1975) was used to estimate mortality. The population of triploid grass carp was estimated using the following relationship (Ricker 1975): $N_t = N_0 e^{-Zt}$. The number of fish stocked yearly (N_0), the instantaneous rate of total mortality (Z), and the number of years since stocking (t) were used in calculations. Growth of triploid grass carp as of 1994 was described by fitting a von Bertalanffy growth equation (von Bertalanffy 1938).

Results

A total of 69, 125, and 160 triploid grass carp were collected by bowfishermen during 1992 through 1994. During 1994, the most successful collection year, fish were collected from late winter through early fall; generally, the greatest catches occurred on calm nights with clear water conditions.

Scales became difficult to age after age 4; sectioned lapilli were relatively easily read, and first-time reader agreement was 80 percent for fish collected in 1994. Marginal increment analysis of fish collected in 1994 indicated that annuli were laid down during May-June. All fish collected after 30 June had detectable annulus.

Age specific weights ranged from 0.39 to 15.68 kg for ages 1 through 6, respectively (Table 1). The rate of growth in weight was linear (Figure 7) and described by the following equation: weight (kg) = -2.3 + 3.02 × age (r^2 = 0.99). The length-weight relationship pooled for all years was weight (g) = 0.00000425 × length$^{3.18}$. The length-weight relationship varied little during the study (Kirk et al. 1992; Kirk, Morrow, and Killgore 1994). Growth in length was rapid during ages 1 through 3 (approximately 150 to 200 mm/year) but decreased to 60 to 70 mm/year during ages 4 through 6. A von Bertalanffy growth equation was fitted as follows: $L_t = 1044 (1-e^{-0.615(t - 0.590)})$.

Table 1
Age-Specific Lengths and Weights of Triploid Grass Carp Collected in Santee Cooper Reservoirs, South Carolina, During 1994

Age	Total Length,[1] mm	SE, mm	Weight, kg
1	321	4	0.39
2	646	9	3.68
3	800	11	7.26
4	872	12	9.55
5	954	15	12.72
6	1,019	21	15.68

[1] Indicates mean backcalculated total length at annulus formation.

The instantaneous rate of total mortality (*Z*) in 1994 was estimated as -0.246, which converts to an annual rate of survival (*S*) of approximately 80 percent (Ricker 1975). Using this information and weights associated with backcalculated lengths, a triploid grass carp population of approximately 350,000 was estimated to weigh about 2,000,000 kg as of August 1994 (Table 2).

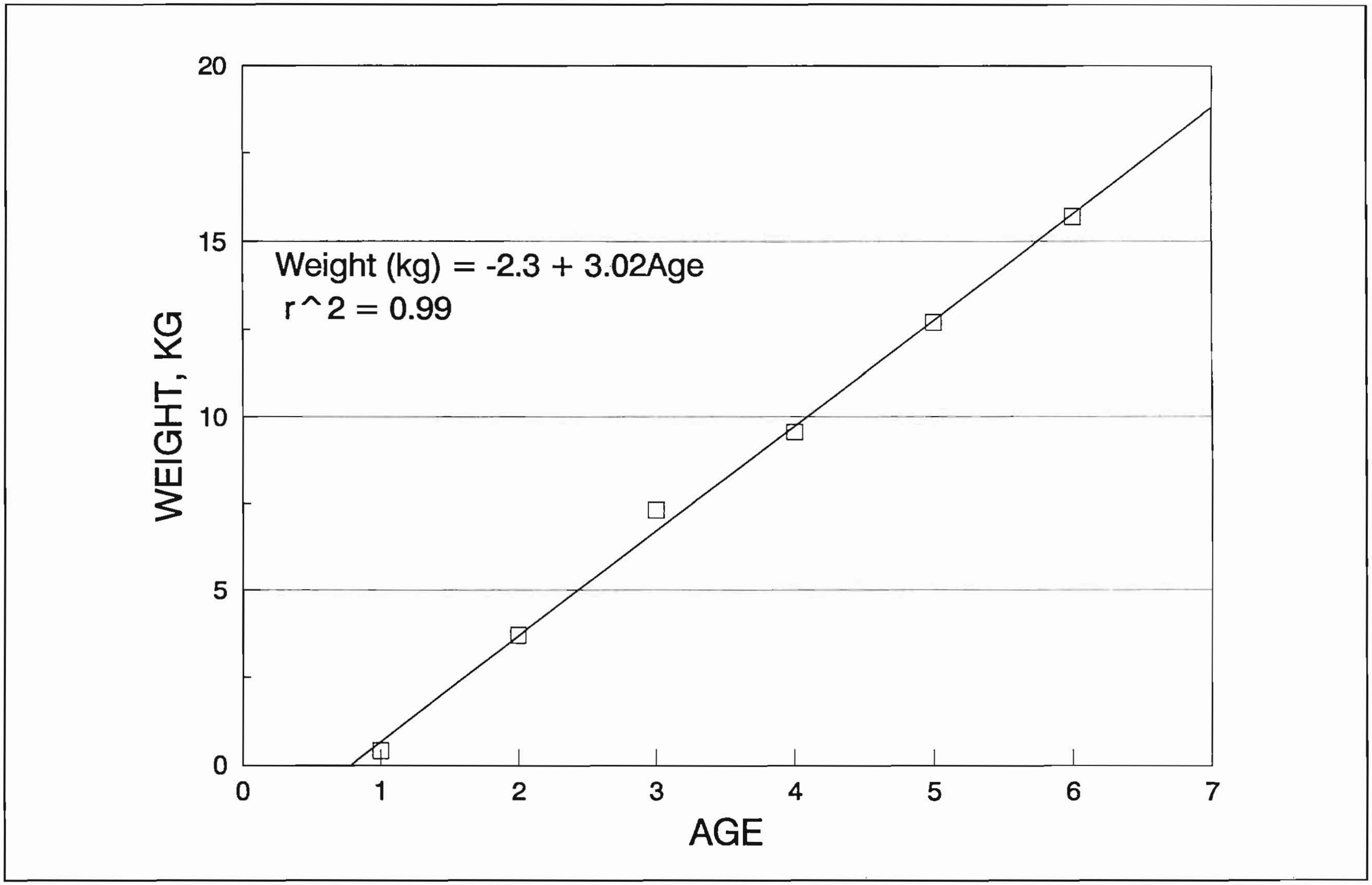

Figure 7. Mean weight of triploid grass carp collected in 1994 in Santee Cooper reservoirs, South Carolina, by age class

Table 2
Survival and Biomass Estimates of Triploid Grass Carp in Santee Cooper Reservoirs, South Carolina, as of August 1994

Age Class	Number Stocked	Surviving	Estimated Biomass, kg
1	152,500	134,850	53,670
2	50,000	39,096	143,873
3	100,000	61,140	444,183
4	100,000	47,806	456,556
5	100,000	37,381	475,340
6	100,000	29,229	458,373
Total		349,504	2,031,998

Discussion

The management implications of this study are that triploid grass carp can be cost-efficiently collected in large reservoirs, that suitable aging structures exist, and that stocking density and growth can be monitored. Triploid grass carp may have potential as a biocontrol agent where a palatable exotic, such as hydrilla, exists along with large stands of less palatable vegetation (Bain 1993). Grass carp sequentially eliminate aquatic plants in order of decreasing palatability (Leslie et al. 1987). Triploid grass carp could be incrementally stocked at densities sufficient to control hydrilla but too low to eliminate nontarget species (Sutton and Vandiver 1986; Leslie et al. 1987). Where triploid grass carp are conservatively and incrementally stocked—with the goal of maintaining intermediate levels of aquatic vegetation—estimates of growth and density would be critical in determining the degree and extent of future stockings.

Electrofishing was found to be unproductive in both the Santee Cooper reservoirs and Lake Guntersville, Alabama (Kirk, Morrow, and Killgore 1994). While effective, Shireman and Maceina (1981) found electrofishing in Florida time-consuming and expensive. Routine gill netting and rotenone sampling was performed by the South Carolina Department of Natural Resources to monitor fish populations in the Santee Cooper reservoirs and produced few grass carp (Kirk et al. 1992). Skilled bowfishermen operating individually or in tournaments collected adequate samples for $US50.00 a fish in both the Santee Cooper reservoirs and Lake Guntersville, Alabama (Kirk, Morrow, and Killgore 1994). Because skilled bowfishermen are both selective and cost efficient, these authors believe that bowfishing may be the technique of choice for collecting grass carp in large systems.

Scales and utricular otoliths appear to work well as aging structures. Scales became difficult to read past age 4, but sectioned lapilli were easily read. To improve backcalculations, triploid grass carp were aged using otoliths and then backcalculations performed using scales of known age. Marginal increment analysis demonstrated that annuli are laid down during May-June, and lengths backcalculated for age 1 fish fall within the size range of known age fish stocked by distributors.

Growth of grass carp can be affected by a number of factors including temperature, density, and food availability (Gasaway 1978; Bonar et al. 1993). Surprisingly, growth of triploid grass carp remained nearly linear (Figure 7) through age 6, although similar findings have been reported by Shireman, Colle, and Maceina (1980). The fish were growing approximately 3 kg/year suggesting that hydrilla (a preferred food item) may not yet be limiting; indeed, hydrilla continued to spread through the system during the period of this study. With a maximum life span of 10 years and at this growth rate, triploid grass carp in this system could approach 30 kg.

Mortality estimates need to be carefully monitored. The annual survival rate of approximately 80 percent was based upon collections made in 1994. The estimate of survival may have been skewed upward as a result of abnormally high survival of the first year class stocked in 1989, and further population monitoring should be considered. This rate of survival is significantly greater than studies performed in small impoundments (Kirk 1992) and may be due to the size of fish stocked (approximately 250 to 350 mm). The population estimate using this survival rate was approximately 350,000 fish, which equates to a stocking density of 5 fish per surface hectare of water or 17 fish per vegetated hectare in August 1994.

Use of a catch curve for total mortality estimation was based upon the assumption that fish are not emigrating from the system (Ricker 1975). These authors are reasonably certain based upon telemetry studies that triploid grass carp followed and remained near hydrilla as it spread throughout the reservoirs (see Chapter 2) and that few left through downstream dams or fishways. However, telemetry studies of Bain et al. (1990) suggest the potential for larger grass carp to emigrate.

Because of the controversial nature of grass carp stockings to control nuisance vegetation, modelers and decision makers should use the best information possible on growth and densities as the basis for their decisions. Collection of grass carp in large systems using bowfishermen and aging using utricular otoliths should allow modelers and decision makers to acquire the density and growth information needed to make informed decisions and increase the opportunity, where appropriate, to use this fish as a biocontrol agent.

4 Conclusions and Recommendations

Conclusions and recommendations are as follows:

a. Triploid grass carp do not move out of the area targeted for plant control if preferred food (i.e., hydrilla) is present in sufficient quantity. Other studies, however, suggest that grass carp will migrate if preferred food becomes limiting.

b. Shallow, open-water flats with hydrilla growing on the surface was the preferred location of triploid grass carp. Cypress swamps were not highly used and possibly avoided during periods of low dissolved oxygen.

c. The use of skilled bowfishermen is the most cost-effective approach to collect large numbers of grass carp. Other techniques, such as electroshocking, netting and cove rotenoning, may be effective in some cases, but they are usually more expensive and the results are not consistent.

d. Triploid grass carp can be aged using scales and utricular otoliths. However, scales are difficult to read past age 4.

e. Food appeared not to be limiting, and triploid grass carp exhibited linear growth through age 6 at a rate of approximately 3 kg/year.

f. Assuming that stocking rates of triploid grass carp are known and fish do not emigrate, population size can be estimated using a catch curve. In the study herein, triploid grass carp stocked at lengths greater than 250-mm total length had an annual survival rate of approximately 80 percent. The population estimate as of August 1994 was approximately 350,000, which translated to a system-wide density of 5 fish per surface hectare or 17 fish per vegetated hectare.

g. The techniques to estimate population attributes that were derived from these studies can be used to estimate the extent of future stockings with the goal of maintaining specified levels of aquatic vegetation in the water body.

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13. ABSTRACT ***(Maximum 200 words)***

A 5-year study of triploid grass carp movement and population attributes was conducted in the Santee-Cooper reservoir system. Radiotelemetry showed no long-distance migrations, and fish did not move into the river channel. Triploid grass carp remained on upper Lake Marion (target control area), exhibited local movements averaging 0.10 to 0.29 km/day, and preferred open flats with hydrilla. Fish apparently avoided or moved away from areas with low dissolved oxygen. Skilled bowfishermen were used to collect triploid grass carp for age and growth analysis. Utricular otoliths (lapilli) and scales were successfully used to age triploid grass carp. This population exhibited linear growth through age 6 at a rate of 3 kg/year with 80-percent survival. Extrapolation of population models showed densities of 5 fish per surface hectare of water or 17 fish per vegetated hectare as of 1994. The study concluded that grass carp can be efficiently collected in large reservoirs, suitable aging structures exist, and efficacy of stocking can be successfully monitored using telemetry, population-density estimates, and growth rates.

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