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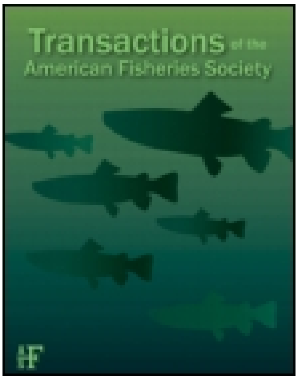

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Movements and Habitat Use by Grass Carp in a Large Mainstream Reservoir

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Movements and Habitat Use by Grass Carp in a Large Mainstream Reservoir[1]

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Abstract.—Triploid grass carp *Ctenopharyngodon idella* were experimentally stocked in a large, open, mainstream reservoir on the Tennessee River so we could describe their movement and dispersion patterns and determine if areas infested with hydrilla *Hydrilla verticillata* were preferentially used. Radio transmitters were surgically implanted in 25 immature grass carp in 1987 and 10 mature fish in 1988. Dispersion and use of vegetated habitat were analyzed separately for summer (warmwater) and fall–spring (coldwater) periods for grass carp stocked in 1987. The fish moved an average of 2.2 km (0.5–6.3 km) during summer 1987 and 0.4 km during the fall–spring period. The grass carp marked in 1987 tended to move upstream during the summer, ranged over an average area of only 0.10 km^2 (0.02–0.30 km^2), and moved even less during the fall–spring period. The submersed plant communities most used by the grass carp in 1987 were dominated by hydrilla and all relocated fish were in vegetated areas. The adult grass carp marked in 1988 moved an average of 32.7 km (0.7–71.1 km) during a 4-month monitoring period, did not reduce movements when water temperature declined, traveled both upstream and downstream, and ranged well beyond hydrilla colonies. The difference in behavior between fish stocked in 1987 and those stocked in 1988 appeared to be related to life history stage (juveniles versus adults). Thus, juvenile triploid grass carp seem more likely to provide effective hydrilla control in target areas than adults.

Extensive and dense populations of aquatic plants have serious consequences for human use of lakes and reservoirs. When biological methods of aquatic plant control are effective, they are preferable to physical and chemical methods (Mitchell 1974; Janik et al. 1980; Riemer 1984). Grass carp *Ctenopharyngodon idella* effectively control aquatic plants in various situations and climates (Shireman 1984; Taylor et al. 1984). They are voracious herbivores; the fish in a single heavy stocking sometimes eliminate all submerged aquatic plants in contained water bodies for several years (Stott and Robson 1970; Stott 1977; Sutton 1977; Van Dyke et al. 1984; Klussmann et al. 1988). Production of triploid grass carp has removed many concerns about introducing this exotic fish into open waters because triploids are functionally sterile (Clugston and Shireman 1987). Triploid fish and fertile diploids have similar behavior and they are about equally effective in consuming vegetation (Wattendorf and Anderson 1984; Wiley and Wike 1986). Nevertheless, important questions remain about whether grass carp can be used to manage aquatic weeds in large open systems like mainstream reservoirs (Noble et al. 1986; Allen and Wattendorf 1987).

The intent of aquatic plant management programs in large waters is control rather than eradication; eradication could cause other serious environmental problems. The utility of grass carp for effective but balanced vegetation control in large systems depends on behavioral factors such

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as the movements, habitat use, and feeding preference of the fish. Rapid and continual movement of grass carp can result in the large-scale dispersion of fish to connected waters where vegetation grazing may not be desirable. Also, if grass carp widely disperse soon after they are stocked, reservoir managers have little ability to maintain effective and balanced grass carp densities in vegetation control areas. Finally, grass carp must prefer habitats infested with plants and prefer the target plant species among the species available. Little information is available on grass carp behavior in open aquatic systems because the use of this fish has been restricted almost entirely to small and isolated waters.

Hydrilla *Hydrilla verticillata* is an exotic submersed aquatic weed that was first discovered in the USA in about 1960, in a canal near Miami, Florida (Haller 1976). By the mid-1980s, it had spread to several southeastern states, along the Atlantic coast to Maryland, and to Texas and California (Steward et al. 1984). In 1982, it was found in the Tennessee River system in Guntersville Reservoir, Alabama, and has continued to spread in the reservoir and other impoundments in the Tennessee River despite intensive control efforts. Hydrilla is considered to be an aquatic weed because it has a high asexual reproductive capacity and the ability to outcompete other submersed species in a wide range of aquatic habitats (Mitchell 1974; Spencer and Bowes 1985). The growth characteristics of hydrilla and the poor record of hydrilla control (Haller 1976, 1979) indicate that this plant will seriously affect the recreational use of Guntersville Reservoir and other Tennessee River impoundments.

We conducted a radiotelemetry study with experimentally stocked triploid grass carp in Guntersville Reservoir to investigate behavior in a large, open, and heavily vegetated system. The study was conducted to determine whether the behavior of grass carp would prohibit or seriously hinder their use for hydrilla control, and to supplement other information in determining the most effective combination of aquatic plant management methods. The specific objectives of this study were to describe the movement and dispersion patterns of radio-marked grass carp and determine if the fish prefer hydrilla-infested areas during the warmwater growing season.

Study Area

Guntersville Reservoir is a large, mainstream impoundment (27,479 hectares, 121.8 km long) on the Tennessee River in northeast Alabama (Figure 1). The physical and chemical limnology of the reservoir was described by Poppe et al. (1987). The impoundment is shallow (mean depth, 4.6 m), and has an extensive littoral area and stable water levels (annual fluctuation less than 1 m). The reservoir is fertile because nutrient levels are high (total $N = 0.59$ mg/L; total $P = 0.04$ mg/L) in the water entering the reservoir from the Tennessee River and the reservoir flushing rate is rapid (mean, 13 d). A shallow, stable, and fertile aquatic environment favors rapid plant growth and development of a dense, expansive, and diverse community of submersed aquatic plants. In 1987, 23% of Guntersville Reservoir (6,438 hectares) was colonized with aquatic vegetation (Burns et al. 1988). Eurasian watermilfoil *Myriophyllum spicatum* dominated the plant community, covering 3,626 hectares; hydrilla covered only 787 hectares in 1987, but more than 1,200 hectares in 1988. Hydrilla beds are primarily located in midreservoir areas in long, narrow beds on the submerged banks and islands of the Tennessee River. Dams at the upstream and downstream end of the reservoir would restrict, but not preclude, fish emigration during periods of floods and during the operation of navigation locks.

Methods

On 7 July 1987, radio transmitters (Advanced Telemetry Systems Inc.; 30 g in air; 45 × 15 × 15 mm; 356-mm teflon coated antenna) were surgically implanted in 25 triploid grass carp (1.8–2.7 kg; 51–60 cm, total length) purchased from an Arkansas hatchery and the marked fish were released at the edge of large hydrilla colonies (15 at Pine Island and 10 at Chisenhall, Figure 1). On 15 June 1988, five triploid grass carp (4.0–6.0 kg, 60–73 cm, total length) with transmitters were released at each of the two sites used in 1987. These fish were produced in an Arkansas hatchery in 1985, stocked (unmarked) in a hydrilla-infested 170-hectare Florida lake (Lake Miona, Sumter County) in 1986, and recaptured for release in Guntersville Reservoir.

Radio transmitters were surgically implanted in the body cavity by methods of Hart and Summerfelt (1975) and Southall and Hubert (1984). Each transmitter had a unique frequency and was inserted through an incision posterior to, and slightly dorsal of the pelvic fin base; the antenna protruded from the posterior end of the incision. Estimated life spans of the transmitters were 384 d in 1987 and 176 d in 1988; the 1988 instruments

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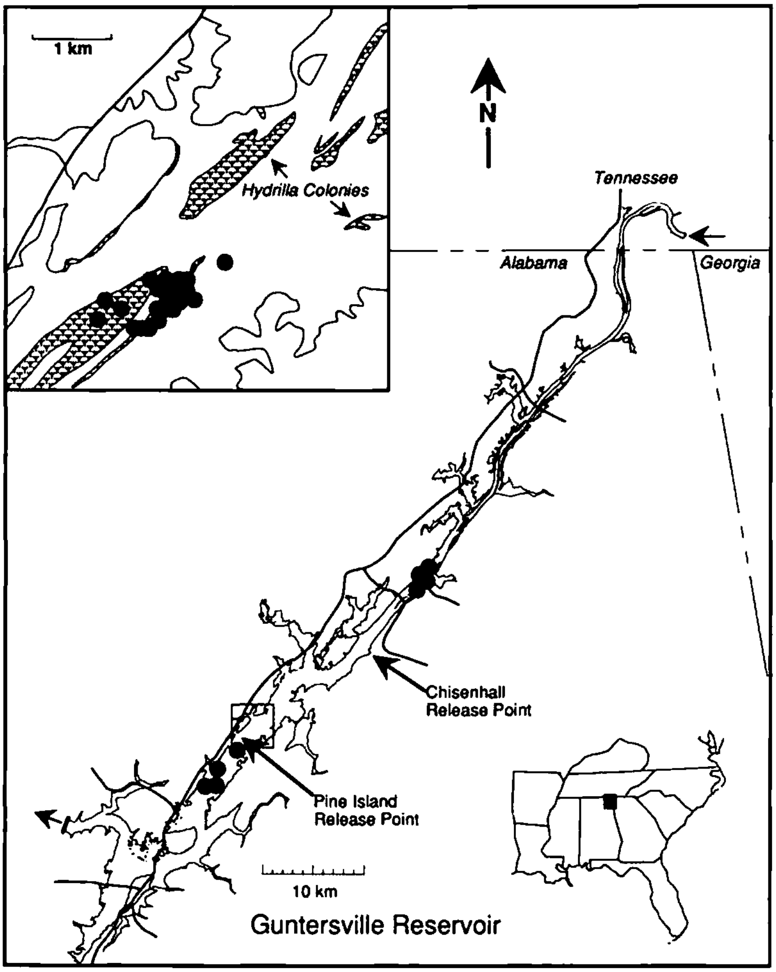

FIGURE 1.—Guntersville Reservoir, showing the release points for radio-marked grass carp. In the enlarged section of the reservoir map, 35 locations (July 1987 to March 1988) of a grass carp released in 1987 are shown as solid circles (overlapping locations are shown once); major hydrilla colonies are indicated by patterned shading. On the main reservoir map, 16 locations (June to October 1988) of a grass carp released in 1988 are shown as solid circles. The movements of these two grass carp were typical of fish released in 1987 and 1988.

had a greater signal output. In 1987, tracking began 3 d after the marked fish were released and was done most frequently (10–14 d/month) during the summer (surface water temperature ≥ 22°C) and less frequently (≤5 d/month) during the fall–spring portion of the year (≤21°C). Tracking began 1 d after the 1988 grass carp were released and was maintained at a higher rate for the first 2 months (9 d in July and 12 d in August) than during September and October (5–6 d/month).

Locations of radio-marked grass carp were established by periodic surveys of Guntersville Reservoir by boat. Surveys were conducted to regain contact with fish previously located and then to find fish that had not been located on the previous survey. All active transmitters were located during two aircraft surveys of the entire reservoir on 13 April 1988 and 2 August 1988. To establish and record fish locations, we used a hectare-grid map and triangulation (sightings by compass, Sunto KB-20/360R) from identifiable, mapped landmarks such as navigation buoys, hilltops, and islands. Frequently, a suspected signal source was verified by approaching it until the signal became very strong and nondirectional. For established fish locations, the following data were recorded: date and time, hectare coordinates, and dominant and subdominant plant species. Tennessee Valley Authority (TVA) reservoir vegetation maps prepared from detailed, large-scale (1:7,200) aerial photog-

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raphy were used to supplement and verify field observations. Plant community types were designated by species groups on the basis of dominant and subdominant species, or rarely by the presence of a species (e.g., *Chara zeylandica*) in a colony. The following community types were used in this study: hydrilla, Eurasian watermilfoil, hydrilla and Eurasian watermilfoil, spinyleaf naiad *Najas minor*, Eurasian watermilfoil and spinyleaf naiad, chara, chara present, and other.

The dispersion of radio-marked grass carp was described and analyzed according to direction and distance moved and range area. Dispersion was estimated as the maximum distance recorded from an initial known location (generally the release site) for each marked fish. Maximum recorded movement appeared to be a consistent measure, even though contacts with most fish were irregular. Compass directions of known movements (lines between locations) were computed and categorized by 90° groups (northeast, southeast, northwest, southwest). Fish range was estimated as the area of the minimum polygon that surrounded the known fish locations for a given time period and therefore was a measure of the minimum known range. Vegetation use was analyzed as counts of locations by plant community type. All analyses were done separately for grass carp released in 1987 and 1988, which are hereinafter referred to as 1987 grass carp and 1988 grass carp. Analyses for the 1987 grass carp were divided into the warmwater summer period (July, August, September 1987; average temperature 27°C, range 31–22°C) and the coldwater fall–spring period (November 1987 to March 1988; 11°C, range 21–4°C) because previous investigators (Nixon and Miller 1978; Kilambi and Robison 1979) reported differences in behavior and movement between warm and cold seasons. No tracking surveys were conducted during October 1987.

Results

Of the 25 grass carp marked with radio transmitters in 1987, 2 were not located on any of the 64 d of tracking from July 1987 to June 1988. Contact with the remaining 23 fish varied from consistent to rare; the number of monitored fish gradually declined until only one transmitter was detected in June 1988. One transmitter was recovered in shallow nearshore water. The extent of marked fish mortality could not be determined from our observation because some fish that seemed to be stationary later moved a substantial distance. We detected erratic transmitter signals (rapidly fluctuating pulse rates) from five fish before we lost contact with them, suggesting that some transmitters failed. The 13 April 1988 aircraft survey located one fish known to have an active transmitter but failed to locate others. Surveys downstream from Guntersville Dam in April 1988 failed to detect any marked grass carp. It is likely that most transmitters quit functioning by the end of March 1988; consequently we used tracking data collected before March 1988 in the analyses for 1987 grass carp.

During the summer of 1987, the average distance grass carp moved from their initial release points was 2.2 km (range, 0.5–6.3 km; $N = 23$). Most movement distances were short (<1.5 km) and most fish did not travel more than 3.0 km (Figure 2). During fall–spring, grass carp movement from the first location recorded during this period was very limited (average, 0.4 km; $N = 10$) and no fish moved more than 2.0 km (Figure 2). The overall extent of movement from release sites (both periods combined) averaged 2.96 km, which was only slightly more than that recorded for the summer alone and largely attributable to one fish that moved 16.5 km between the two seasonal periods.

The 1987 grass carp movements had a significant directional trend to the northeast during summer (chi-square test; $P < 0.0001$) whereas there was no significant directional trend during the fall–spring period ($P = 0.0678$). Movement to the northeast reflects an upstream dispersal trend because Guntersville Reservoir is narrow and oriented in a southwest–northeast direction (Figure 3).

The average range recorded for 1987 grass carp was 0.45 km^2, but much of this area was attributable to rapid, postrelease movements recorded during the first month of tracking (July 1987). Consequently, we deleted the July 1987 positions from the range estimates, which reduced the estimated range size by an average of 77%. Without the July locations, the measured range for grass carp during summer averaged 0.10 km^2 (range, 0.02–0.30 km^2; $N = 23$). During fall–spring, range estimate averaged 0.07 km^2 (0.01–0.21 km^2; $N = 11$). A comparison of estimates between summer and fall–spring indicated that the 1987 grass carp occupied ranges of similar size (t-test; $P = 0.2572$) when the first-month movements were not included. Correlating the number of locations recorded per fish and estimated range size provided no evidence that the number of location points

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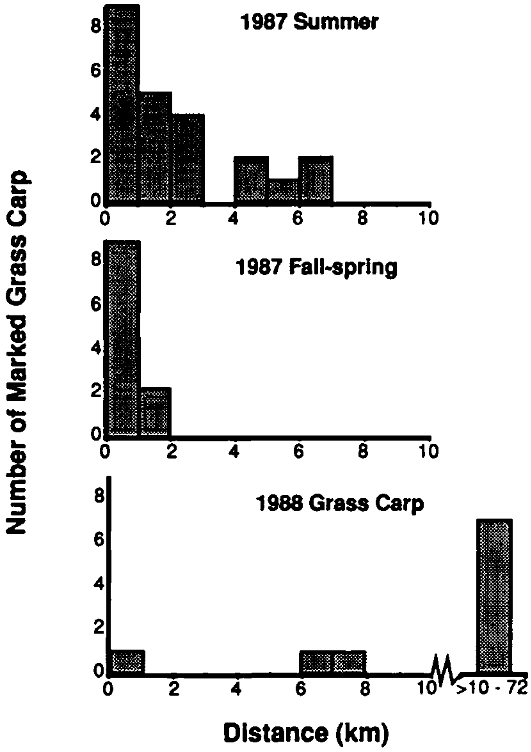

FIGURE 2.—Maximum measured movements by grass carp released in 1987 and 1988. The 1987 grass carp movements are shown separately for summer (July, August, September 1987) and fall–spring (November 1987–March 1988).

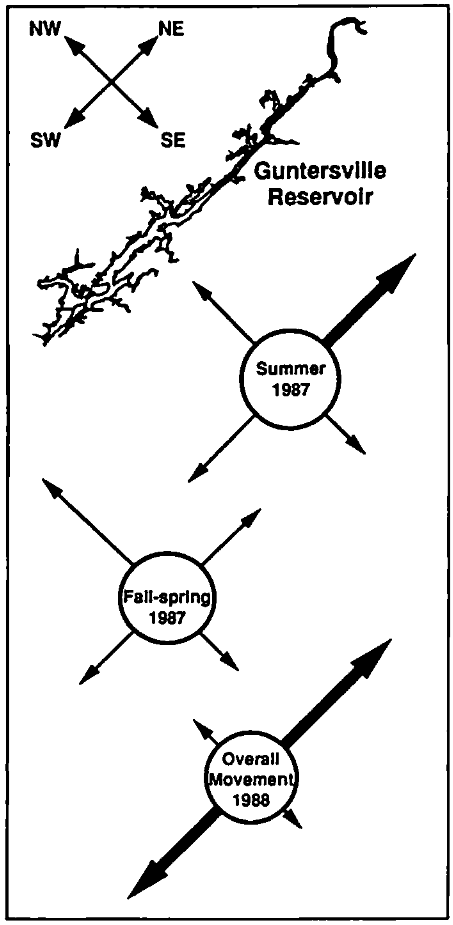

FIGURE 3.—Movement directions for 1987 and 1988 grass carp by 90° quadrant. Heavier lines and arrows represent significant directional trends and line length corresponds to the number of observations in a particular direction. Movement of the 1987 fish during summer indicated an upstream dispersion trend. The 1988 fish tended to move both upstream and downstream.

significantly affected range estimates (r = 0.027; $P > 0.05$).

The submersed plant community type associated with the locations of 1987 grass carp was dominated by hydrilla, and all contacts with fish occurred in vegetated areas. A chi-square test for a uniform distribution of fish locations across plant community types was highly significant ($P <$ 0.0001), strongly suggesting that grass carp were concentrated in hydrilla (Figure 4). Although hydrilla colonies were associated with 43% of established grass carp locations, pure hydrilla stands constituted a relatively small area of the reservoir (3%). Eurasian watermilfoil was the second most commonly used plant community type (20%).

Behavior of the 1988 grass carp differed markedly from those of the 1987 grass carp. The 1988 fish moved extensively (range, 0.7–71.1 km; N = 10; Figure 2), averaging 32.7 km for the monitoring period. One fish traveled 53.0 km in a 9-d period in October 1988 (6.0 km/d). There was no apparent change in movement when water temperature declined because the greatest recorded movements were roughly similar early and late in the 1988 tracking period (mean before and after October, 28.8 km and 37.7 km, respectively). Consequently, we did not separate dispersion results by warmwater and coldwater seasons.

The 1988 grass carp had a statistically significant trend of movement along an upstream (northeast) to downstream (southwest) axis (chi-square test; $P < 0.0001$; Figure 3), but there was no clear difference in the frequency of upstream and downstream movements. Despite the statistical significance of the chi-square test, there was no real directional trend in movement because of

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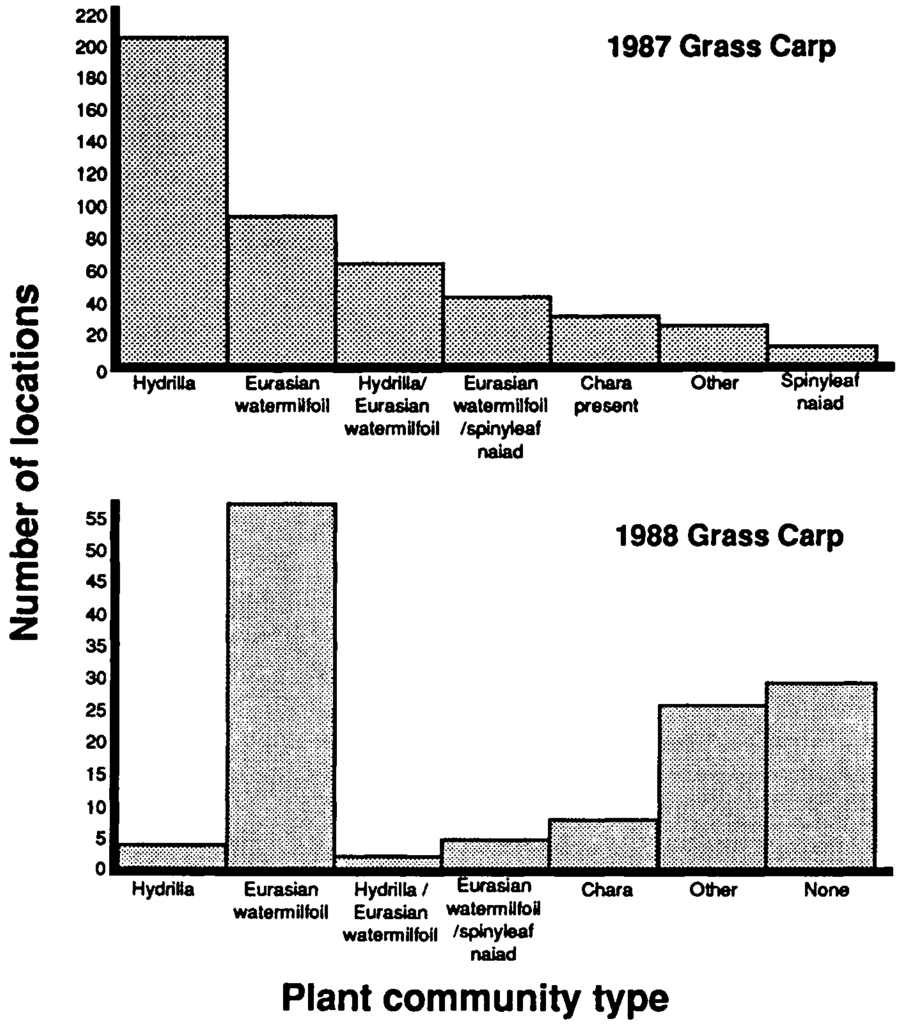

FIGURE 4.—Locations of grass carp by plant community type for fish released in 1987 and 1988. Soon after release, the 1988 fish moved well outside the distribution of the preferred community type (hydrilla) of the 1987 fish.

the narrow width and southwest–northeast orientation of Guntersville Reservoir and the great distances moved by the 1988 fish. Due to the extensive dispersion and continual movement of the 1988 fish, home range size was not computed because grass carp ranges generally covered major sections of the reservoir.

The extensive movements of the 1988 grass carp took most fish far from hydrilla colonies. Consequently, vegetation use was different from that of the 1987 fish and tended to be associated with the most common plant community type (Eurasian watermilfoil) and a variety of mixed plant colonies (Figure 4). Also, a substantial portion (22%) of the fish locations were in unvegetated areas.

Discussion

Grass carp released in summer 1987 moved little and generally did not move beyond hydrilla colonies in Guntersville Reservoir. Movements that were detected occurred during the first month after release and tended to be upstream. After the first month, the fish tended to remain near hydrilla colonies, foraged within small areas (average, 0.10 km^2), and showed no directional trend in movement. During fall–spring, grass carp generally remained sedentary and had no clear directional movement trend. For 57% of the contacts, 1987 grass carp were in hydrilla or mixed Eurasian watermilfoil and hydrilla. Behavior of the 1987 fish

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indicated that these immature grass carp remained near release sites and in colonies of preferred plant species for at least one growing season.

Mitzner (1978), who used radiotelemetry to monitor the movements of nine grass carp (mean weight, about 0.5 kg) in a 29-hectare Iowa reservoir, also noted that fish were sedentary most of the time and that behavior was consistent among marked fish. Nixon and Miller (1978), in a similar telemetry study of 12 grass carp in a 2,025-hectare reservoir in northwest Florida, showed that early movements of most fish were in an upstream direction, like the movements of our 1987 fish in Guntersville Reservoir; they also found that grass carp movement declined in cold weather and that the fish moved into deep, flooded creek channels. Grass carp feed little at water temperatures below 13°C (Kilambi and Robison 1979), and movement into deep water may be related to extended periods of low activity. The studies by Mitzner (1978) and Nixon and Miller (1978) indicated that grass carp primarily used shallow vegetated areas during warm weather, as we found (neither study provided estimates of range size).

Several studies have shown that grass carp are selective foragers that feed primarily, or exclusively, on the most preferred plants before eating less desirable species (Edwards 1974; Vinogradov and Zolotova 1974; Terrell and Terrell 1975; Colle et al. 1978; Fowler and Robson 1978; Mitzner 1978). Generally, these feeding preference studies involved a variety of plant species and the preferred ones depended on the species available. Leslie et al. (1987), who reviewed 10 years of vegetation control efforts with grass carp in Florida, classified plant species into three grass carp preference groups: preferred, intermediate, and nonpreferred. Hydrilla was listed as a preferred plant, whereas Eurasian watermilfoil was among the nonpreferred species. Van Dyke et al. (1984) also found that grass carp had a strong preference for hydrilla in lakes with mixed plant communities. Consequently, the heavy use of hydrilla colonies and mixed plant communities containing hydrilla by our 1987 grass carp is consistent with several previous studies that identified this plant as a preferred food.

The 1987 grass carp used areas dominated by Eurasian watermilfoil (20%) to a greater extent than anticipated from past studies that identified this plant as a nonpreferred species (Van Dyke et al. 1984; Leslie et al. 1987). Use of areas dominated by Eurasian watermilfoil may be due to the expansive distribution of this plant (over 50% of the total vegetated area) and the availability of small amounts of preferred plant species (for example, filamentous algae, *Najas* spp., and *Potamogeton* spp.) in areas that we classified as Eurasian watermilfoil. Although we assumed that grass carp feed on common plants in occupied areas, it is doubtful that Eurasian watermilfoil was being eaten, inasmuch as previous studies (reviewed by Leslie et al. 1987) have shown that this plant was avoided if other plants were available.

The rapid and continual movement of grass carp stocked in 1988 is in sharp contrast with the results obtained for the 1987 fish, although they are not unprecedented. Nixon and Miller (1978) found rapid grass carp movement (mean, 4.4 km; N = 12) during a brief tracking period (mean, 4 d) immediately after release. Pflieger (1978) documented extensive dispersion of grass carp in the Missouri and Mississippi rivers throughout the state of Missouri from a large release of grass carp in Arkansas (size range at capture in Missouri, 2.6–5.0 kg). Similarly, grass carp reproduction throughout the lower Mississippi River valley (Zimpfer et al. 1987) indicated that grass carp move extensively at some time during the life cycle. These accounts, our 1988 grass carp telemetry findings, and the observations of others (see Stanley et al. 1978) reinforce the reputation of grass carp for migrating long distances and congregating in areas far from the release sites. The 1988 grass carp were generally far from hydrilla colonies and their heavy use of areas dominated by Eurasian watermilfoil probably reflects the prevalence of that vegetation type and the presence of small amounts of preferred species with Eurasian watermilfoil.

The difference in movement behavior of the 1987 and 1988 grass carp may be explained by differences in fish size and sexual maturity. The biology of grass carp (reviewed by Shireman and Smith 1983) suggests that the 1987 fish were probably immature because their sizes were below the maturation size for females and at the maturity transition size for males (spring 1988 would be the predicted first reproductive season for males in the 1987 group). The larger grass carp released in 1988 generally exceeded the sexual maturity size for both males and females. Although there is little information on migratory behavior of grass carp of different sizes, the migrations of large grass carp reviewed by Pflieger (1978) and Stanley et al. (1978) indicated that extensive movements are not uncommon for adults. Therefore, the difference in behavior between the 1987 and 1988 grass carp could be attributed to their differences in sizes and life history status—the difference in behavior between juveniles and sexually mature adults.

The triploid grass carp stocked for aquatic plant management generally are 20–30 cm long for several reasons: grass carp producers market small fish (Wiley et al. 1987), fish at this length are more efficient than large fish at consuming weeds (Osborne and Sassic 1981), and predation on them by other fish is low at 30 cm (Shireman et al. 1978). The grass carp we used were much larger than would be used in routine operational stockings (roughly twice as large) because we needed fish large enough to accommodate radio transmitters with a 6–12-month life span. Our study, and studies by others, suggest that grass carp of stocking size may stay near their release points and feed on preferred plants such as hydrilla for at least one growing season. However, as these fish grow and reach sexual maturity (about 65 cm or 3.5 kg) they may undertake extensive migrations that could lead to concentrations of grass carp outside the target areas. Grass carp growth rates (Shireman and Smith 1983) indicate that typical stocking-size grass carp would reach sexual maturity within 2 years after stocking.

In general, our findings indicated that the behavior of triploid grass carp in this large open system did not prohibit their use in aquatic plant management programs. However, fishery biologists and aquatic plant managers should anticipate more difficulty in sustaining grass carp densities that are effective for maintaining balanced plant communities in large open systems than in contained water bodies. Annual stockings of grass carp on target plants may be required because fish stocked in previous years may disperse to distant areas. Because adult grass carp probably migrate long distances over time, we concur with the recommendation of Noble et al. (1986) that target areas not be viewed independently of upstream and downstream waters when the effects and consequences of grass carp use are being considered.

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