Movement of Triploid Grass Carp in Large Florida Lakes

by

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Introduction

Grass carp (*Ctenopharyngodon idella*) are currently being used for aquatic plant control in large, open-lake systems in a number of States, including Alabama and South Carolina, and the ability to accurately predict the fish's vegetation control capabilities will become increasingly important as the use of grass carp in large systems becomes more widespread. Knowledge of localized movement patterns may aid us in determining stocking rates and developing plant control strategies. Nixon and Miller (1978) state that, "... Behavior of grass carp, particularly daily activity, seasonal activity, and distribution is closely allied with their ability to effectively control aquatic vegetation." For example, if we know how large an area that a grass carp will typically cover, and what might cause a fish to move or expand this area, we will be better able to predict the amount of vegetation control provided by that fish. In situations where grass carp are stocked in a system to control a single type or a limited area of aquatic vegetation, movement patterns may determine how well fish achieve this control (Nixon and Miller 1978). Desired plant control may not be achieved if fish move away from a target area of vegetation or never move to that area in the first place.

Vegetation control in an open system may be less than expected if fish emigrate from that system. Ellis (1974), Nixon and Miller (1978), and Hardin and Mesing[3] all provide evidence of grass carp emigration from a stocked system. As of 1978, grass carp had been found 1,690 km from the point of original introduction into the United States, the result of "widely scattered research projects, stockings to solve aquatic weed problems, interstate importation from private hatcheries, and dispersal from stocking sites" (Guillory and Gasaway 1978). Emigration from a given body of water also has the potential to cause undesired impacts on vegetation communities in connected waters (Stanley, Miley, and Sutton 1978), including damage to native aquatic plants and plants important to waterfowl as well as other wildlife food.

Some studies of grass carp movement and behavior have been conducted, but most of this work took place in small (less than 100 ha) lakes (Mitzner 1978), canal (Hockin, O'Hara, and Eaton 1989; Cassani and Maloney 1991), or reservoir (Bain et al. 1990) systems, or for short (less than 30 days) periods of time (Nixon and Miller 1978). Comparatively little research has been conducted to answer questions concerning the movement and long-term behavior of triploid grass carp in large, natural lakes. We conducted the present study to qualitatively and quantitatively describe long-term movement and aquatic plant selection by triploid grass carp in two types of Florida lakes, one open system (several lakes with navigable connections) with little submerged aquatic vegetation and one closed system with extensive submerged aquatic vegetation.

Study Area

Lake Harris (6,688 ha) and Lake Yale (1,636 ha) are part of a large natural chain of lakes in central Florida. Navigable connections exist between Lake Harris and Lake Denham (Helena Run) and between Lake Harris and Lake Eustis (Dead River) (Figure 1). A water

[1] Illinois Natural History Survey, Charleston, IL.
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[3] S. Hardin and C. Mesing, Unpublished Data, Florida Game and Fresh Water Fish Commission.

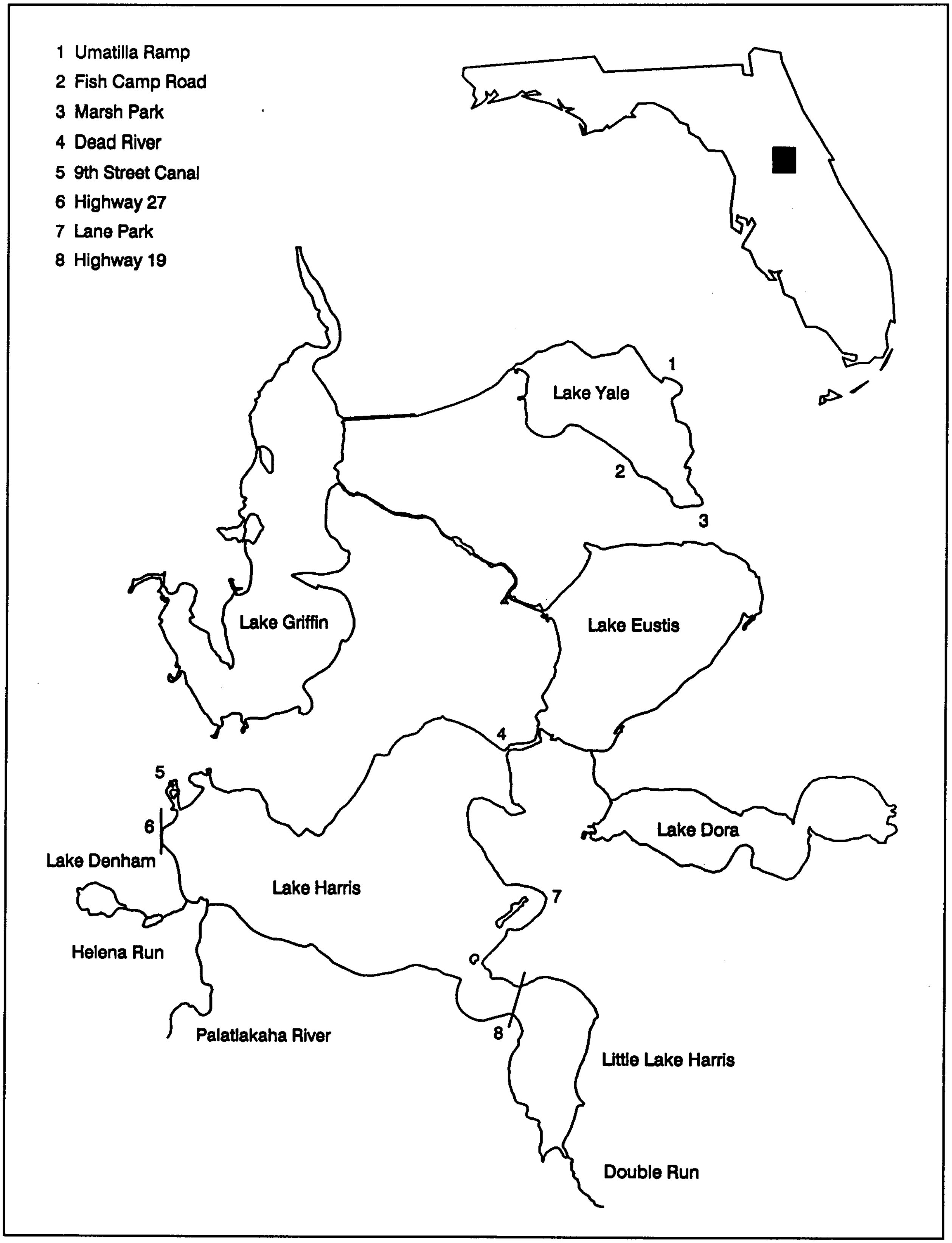

Figure 1. Harris Chain of Lakes, Lake County, Florida

control structure is located in the Palatlakaha River, approximately 2 km upstream from Lake Harris, preventing further movement of fish upstream. Double Run, a historic connection to lakes further up the chain, is now navigable only for approximately 2 km upstream from its entrance into Little Lake Harris. No navigable waterways exist between Lake Yale and other lakes in the system.

Lake Harris is a eutrophic lake, with vegetation limited primarily to a band of emergent plants (predominantly maidencane (*Panicum* spp.), cattails (*Typha* spp.), and arrowhead (*Sagittaria* spp.)) averaging 20 m in width and surrounding the lake to a depth of 2 m. Lake Harris contained significant amounts of hydrilla (*Hydrilla verticillata*) (500 ha) and Illinois pondweed (*Potamogeton illinoensis*) (100 ha) in 1987. A fluridone treatment in that same year was successful in removing the majority of these plants. During the period of this study, submergent plants, including hydrilla and egeria (*Egeria densa*), were limited primarily to Double Run and the Palatlakaha River. These two areas received periodic herbicide treatments during this study, and levels of submergent aquatic plants fluctuated. Lane Park, 9th Street Canal, and the south end of Little Lake Harris contain areas of spatterdock (*Nuphar luteum*) and fragrant water lily (*Nymphea odorata*) from 20 to 100 ha in size.

Lake Yale is a mesotrophic to slightly eutrophic lake with an abundance of rooted aquatic vegetation and occasional algal blooms (Mesing and Wicker 1986). Hydrilla covered approximately 1,200 ha of Lake Yale in 1983. A fluridone treatment in 1984 reduced coverage to a negligible (less than 10 ha) amount. Beginning in 1987, triploid grass carp were stocked at a rate of seven fish/hectare to control hydrilla regrowth in Lake Yale. During the time of this study, hydrilla was found in 150 ha (January 1988) to 500 ha (January 1990) of Lake Yale.

Methods

Radio transmitters from Advanced Telemetry Systems (ATS), Isanti, MN, (Model 5A), were surgically implanted in triploid grass carp following methods outlined in Summerfelt, Hart, and Turner (1972) and Peterson (1975), with minor modifications. Radio transmitters were chosen because signal characteristics are superior in heavy vegetation to those of ultrasonic transmitters (Nixon and Miller 1978). Average weight of the transmitters used was 50 g, and expected battery life was given as 400 to 600 days. The first transmitters used were approximately 9.5 cm long and had 45-cm external antennas. Later in the study, transmitters with coiled internal antennas and mortality circuits that would engage after a transmitter remained motionless for 8 hr were used. The length of these later transmitters was 15 cm. Fish were collected for tagging by electrofishing in lakes previously stocked for vegetation control.

Twenty-two radio-tagged grass carp were released at two locations in Lake Harris between August 1987 and February 1989 (Table 1). These fish were generally released within 8 hr of surgery together with four to five nontransmittered fish, so that transmittered fish would not form a single school. Fish weight ranged from 2.4 to 6.4 kg, and length ranged from 600 to 810 mm. Fourteen fish were radio-tagged and released at three locations in Lake Yale between June 1988 and April 1989 (Table 1). These fish ranged in weight from

Table 1
Radio-Tagged Triploid Grass Carp Stocked in Lake Harris and Lake Yale Between August 1987 and April 1989

Stocking Site	No. of Fish	Days Tracked	No. of Locations
Lake Harris (Aug 1987 - Feb 1989)			
Highway 27	8 (16)	105-546	15-78
Highway 19	4 (6)	38-528	2-66
Lake Yale (June 1968-Apr 1989)			
Umatilla	1 (3)	328	41
Marsh Park	3 (7)	77-432	11-54
Fish Camp Road	3 (4)	264-290	29-33

Note: Number of fish represents those grass carp tracked successfully; total number of radio-tagged fish stocked at a given site is shown in parentheses. Days tracked and number of locations are the range of values for fish at a given site, following a 10-day recovery period. Stocking sites are shown in Figure 1.

2.7 to 6.1 kg and in length from 661 to 827 mm. Since grass carp had been previously stocked in the lake for control of hydrilla, radio-tagged fish in Lake Yale were not released with other, nontransmittered grass carp. We classified a fish successfully tracked if the fish was located for 30 days or longer after a 10-day waiting period following surgery. Nineteen of the thirty-six fish implanted with transmitters were successfully tracked for between 38 and 546 days. In the 17 unsuccessful cases, fish died and were recovered, or transmitters were deposited on the lake bottom as a result of fish dying or expelling transmitters. Transmitters were recovered using a metal detector adapted for aquatic work.

Tracking was conducted by boat approximately once per week on each lake between 0700 and 1630 hr. Average time between locations was 7.2 days on Lake Harris and 8.1 days on Lake Yale. An ATS directional loop antenna (maximum range—800 m) was used for initial long-range location. After initial detection of a radio signal, the boat was maneuvered until a signal could be detected with a short (6-cm) length of coaxial cable or wire. Fish tracked in Lake Harris were located on a gridded map of the lake to the nearest 230-m square grid panel (0.125′ of latitude and longitude), with the center of that panel taken as the actual fish location. Precision of locations for fish tracked on Lake Harris was taken to be one-half the diagonal of a grid square, or 163 m. Later in the study, we obtained a Loran-C recorder, and locations of fish tracked in Lake Yale were recorded to the nearest 0.01′ using this unit. Field experiments using our transmitters showed a maximum reception range of 20 m using a 6-cm coaxial cable as an antenna, indicating that the precision with which we could locate fish in Lake Yale was somewhere between 10 m (Loran-C) and 20 m (worst case scenario with short antenna). Locations of fish in both Lake Harris and Lake Yale were plotted on base maps of each lake constructed from field-corrected Loran-C coordinates. Approximately once every 6 weeks, the entire chain of lakes was surveyed from a fixed-wing aircraft to check for emigration.

Maximum distance moved by a grass carp from the site of stocking and distance moved between consecutive radio locations of an individual grass carp were calculated as straight line movements and are considered minimum distances (Hockin, O'Hara, Eaton 1989; Cassani and Maloney 1991). Based on the above measures of movement, we defined percent maximum distance moved as the maximum distance moved by a fish from its stocking site divided by the distance from that stocking site to the most distant point in the lake, and movement rate as the distance moved by each fish over the course of the study (sum of distances moved between consecutive radio locations) divided by the time that fish was tracked. Differences in maximum distance moved from site of stocking, percent maximum distance moved, and movement rate between groups of fish from each lake were examined using the Mann-Whitney test (Conover 1971).

For fish with greater than 20 locations and tracked for periods longer than 180 days, we calculated a 100-percent minimum convex polygon home-range area using the University of Idaho's Program Home Range (Ackerman et al. 1989). This measure was chosen because we were interested in determining the maximum area that might be used by these fish, and because geometrically based estimates such as the 100-percent minimum convex polygon are more appropriate when subtracting areas (see below) and in cases where data may be autocorrelated (Swihart and Slade 1987). However, this type of geometrically based, rather than statistically based, measure can still be used in comparing home-range areas among categories of organisms (Swihart and Slade 1987).

Areas outside of lake or river boundaries are often included when plotting home ranges of aquatic organisms. To solve this problem, we plotted home ranges on Loran C-corrected base maps of Lakes Harris and Yale using SYGRAPH (Wilkinson 1988), then measured areas outside the lake boundary using a planimeter and subtracted these areas from the calculated home ranges (Dombeck 1979; Mesing and Wicker 1986). This correction resulted in an average reduction in home-range area of 24 percent from that given by the University of Idaho program. Both uncorrected and corrected 100-percent minimum convex polygon home-range areas are reported here and are hereafter referred to simply as total and corrected home-range areas. Differences in home-range area between groups of fish from each lake were examined using the Mann-Whitney test (Conover 1971). Relationships between sample size and home-range area for fish from each lake and for all fish combined were examined using a one-way analysis of variance (ANOVA) (Conover 1971).

Plant occurrence was measured at each fish location in Lake Yale by taking three "frotus" (a 5-m pole with hooks arranged radially at one end) grab samples at each location and recording plant species collected. The dominant plant at each location was defined as the plant occurring in the majority of these three grabs. These dominant plants were grouped by type, relative to plant management objectives for Lake Yale, as follows: target plant—hydrilla; nontarget plants—Illinois pondweed, southern naiad (*Najas guadalupensis*), coontail (*Ceratophyllum demersum*), cattails, eel grass (*Vallisneria americana*), milfoil (*Myriophyllum* spp.), chara (*Chara* spp.), bladderwort (*Utricularia* spp.), spikerush (*Eleocharis* spp.), spatterdock, fragrant water lily, maidencane, bacopa (*Bacopa* spp.), and nitella (*Nitella* spp.); combination—target and nontarget plants equally dominant; or bare—no plants present. Plant occurrence at fish locations was compared among individual fish using Fisher's exact test (SAS Institute, Inc. 1988). The Bonferroni procedure was used in partitioning P for these multiple comparisons. Plant occurrence in Lake Yale was also measured quarterly along six transects throughout the lake, using the same methods as described for measurement at fish locations. Temporal and seasonal changes in plant occurrence within the lake, in plant use for all fish combined, and differences between lake-wide plant occurrence and plant occurrence at fish locations were evaluated using the likelihood ratio chi-square test (SAS Institute, Inc. 1988). The study period was partitioned into summer (April-September) and winter (October-March) periods, as well as a first (October 1988-June 1989) and second (July 1989-February 1990) half for these analyses. No statistical comparisons were made between plant use by fish and plant occurrence in Lake Harris or between Lake Yale and Lake Harris plant communities since only qualitative visual estimates of plant occurrence (emergent plants, visible submerged plants, or open water) were made at fish locations in Lake Harris.

Results

Movement and behavior in a large, open system

Twelve fish were successfully (based on criteria described above) tracked in Lake Harris. All but one of these fish were tracked for periods longer than 80 days, and six were followed for longer than 300 days. The maximum distance moved from site of stocking for a fish in Lake Harris was 17.1 km (Table 2). Median maximum distance moved from site of stocking for this group was 10.4 km, and median percent maximum distance moved was 80 percent. Only 22 percent of locations were greater than 1.0 km from the previous location (Table 2); 61 percent of these movements

Table 2
Statistics Describing Movement of Triploid Grass Carp Tracked in Lake Harris and Lake Yale

Movement Statistic	Lake Harris	Lake Yale
Number of fish tracked	12	7
Median maximum distance, km	10.4 (1.6-17.1)	3.7 (1.8-5.9)
Median percent maximum distance	80 (13-100)	70 (23-92)
Median movement rate, km/day	155 (43-339)	126 (50-161)
Percent greater than 1.0 km	22 (489)	34 (246)

Note: Maximum distance from site of stocking is a straight line distance; percent maximum distance is defined in the text. Percent greater than 1.0 km is the percentage of individual grass carp movements that were greater than 1.0 km from a fish's previous location. Values in parentheses are ranges for fish in each group except percent greater than 1.0 km, for which the total number of measurements taken is given in parentheses.

greater than 1.0 km occurred during the first half of tracking. Median movement rate for Lake Harris fish was 155 m/day (Table 2).

Home areas for the majority of Lake Harris fish were in either or both of two widely separate areas in Lake Harris—Double Run and the Palatlakaha River (Figure 1). While radio-tagged fish did use some areas out of the main body of the lake, including dead-end and obstructed waterways associated with Lake Harris, they did not move through any of the navigable waterways connecting Lake Harris to other lakes in the Harris Chain. Median total home-range area for Lake Harris fish was 5,337 ha, and ranged from 79 to 8,256 ha (Table 3). Median corrected home-range area was 3,021 ha (range; 61 to 4,954 ha), or approximately 45 percent of the total lake area. There was no significant relationship between sample size (number of locations) and either total or corrected home-range area for fish tracked in Lake Harris (ANOVA, P = 0.9043 and 0.8834, respectively).

Table 3
Home Range Statistics for Triploid Grass Carp Tracked in Lake Harris and Lake Yale

Fish Number	Days at Large	No. of Locations	Total Area, ha	Corrected Area, ha
Lake Harris				
121	496	62	6,457	4,468
141	544	68	5,268	1,445
200	546	78	648	362
381	186	31	79	61
401	544	68	8,256	4,951
420	189	21	6,030	3,951
780	528	66	3,477	2,456
811	336	48	5,406	3,586
Median			5,337	3,021
Lake Yale				
190	279	31	160	159
440	328	41	336	310
460	290	29	626	594
610	432	54	306	302
660	264	33	461	445
950	400	50	508	478
Median			398	378

Note: Total area is the 100-percent minimum convex polygon area calculated using the University of Idaho's Program Home Range. Corrected area is the total area with areas outside the lake boundary subtracted using a planimeter. See text for further description.

While shoreline emergent vegetation was abundant in Lake Harris throughout the study, at the time fish were tracked, the Double Run and Palatlakaha River areas provided the only abundant submergent plant forage in the lake. Nine of the twelve fish tracked used at least one of these areas; three fish moved between the two areas on several occasions, a distance of approximately 16 km. Seventy-five percent of these long-distance movements occurred between October and April.

Movement and behavior in a large, closed system

Seven fish were tracked successfully in Lake Yale, and six of these fish were tracked for longer than 250 days. The maximum distance moved from site of stocking for one fish in Lake Yale was 5.9 km (Table 2). The median maximum distance from site of stocking for all Lake Yale fish was 3.7 km, and the median percent maximum distance moved for these fish was 70 percent. Median maximum distance moved from site of stocking for fish in Lake Yale was significantly less than that for fish tracked in Lake Harris (Mann-Whitney, P = 0.0423), but percent maximum distance moved by Lake Yale fish was not significantly different from that of Lake Harris fish (Mann-Whitney, P = 0.4715). Thirty-four percent of locations in Lake Yale were greater than 1.0 km from the previous location (Table 2); of these, only 39 percent occurred during the first half of tracking. The median rate of movement for triploid grass carp in Lake Yale was 126 m/day; this was not significantly different from that of fish tracked in Lake Harris (Mann-Whitney, P = 0.1280).

Median total home-range area for fish tracked in Lake Yale was 398 ha (Table 3), and was significantly smaller than that for fish tracked in Lake Harris (Mann-Whitney, P = 0.0201). Median corrected home-range area was 378 ha, about 23 percent of the total area of Lake Yale. The difference between corrected home-range area for fish tracked in Lake Yale and those tracked in Lake Harris, while large, was only marginally significant (Mann-Whitney, P = 0.0528). As with fish tracked in Lake Harris, there was no significant relationship between sample size and either total or corrected home-range area for fish tracked in Lake Yale (ANOVA, P = 0.8183 and 0.8155, respectively).

Plant selection

Distribution of plants in Lake Yale varied significantly from the first half of the study to the second (Likelihood ratio chi-square, P = 0.000, df = 3; Figure 2A), but was not significantly different between winter and summer when data from both halves were combined (Likelihood ratio chi-square, P = 0.816, df = 3; Figure 2B). The temporal change in distribution of plants was the result of increased growth of hydrilla in Lake Yale during the second half of the study period.

Triploid grass carp in Lake Yale were quite similar in their use of plants; only 2 of 21 possible comparisons between individual fish were significant and both involved fish #630 (Table 4). Hydrilla was the dominant plant at 15.4 to 53.3 percent of individual fish locations (Table 4). Comparisons between winter and summer use of plants by all fish combined were close to significant (Likelihood ratio chi-square, P = 0.067, df = 3; Figure 3B). Fish were more likely to use areas with a single dominant plant in summer than in winter, when they made more frequent use of areas with combinations of plants. Comparisons of plant use by fish between the first and second half of the study were not significant (Likelihood ratio chi-square, P = 0.8420, df = 3; Figure 3A).

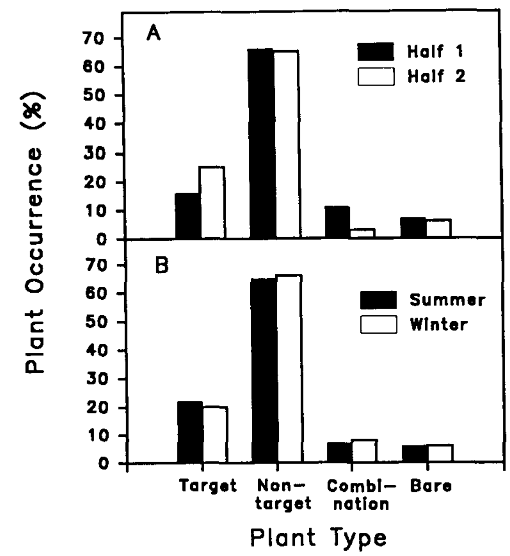

Figure 2. Temporal (A) and seasonal (B) comparisons of lake-wide plant occurrence in Lake Yale, Florida, between October 1988 and February 1990. Plant type groups (target, nontarget, combination, and bare) are based on aquatic plant management objectives; species included in each group are given in text. Temporal half #1 includes the sampling period between October 1988 and May 1989; half #2 includes sampling between June 1989 and February 1990. Summer sampling was conducted from April through September, and winter sampling was conducted from October through March

The distribution of plant types at all fish locations in Lake Yale combined was significantly different from the lake-wide frequency of these same plant types in both summer and winter, during the first and second half of the study, and for all data combined (Figure 4).

Table 4
Statistical Comparisons Involving Overall Plant Use by Individual Fish on Lake Yale

Fish	Target Plant	Nontarget Plant	Combination	Bare	Significant Comparison
190 (28)	39.3	39.3	17.9	3.6	None
440 (38)	21.0	44.7	13.2	21.0	w/630
460 (26)	15.4	30.8	38.5	15.4	None
610 (49)	24.5	26.5	40.8	8.2	None
630 (9)	33.3	0.0	66.7	0.0	w/440,950
660 (30)	53.3	13.3	23.3	10.0	None
950 (46)	30.4	45.6	13.0	10.9	w/630

Note: Values given are percent of fish locations for which the designated plant type was dominant. Description of plant categories is provided in the text. Values in parentheses are total number of locations for each fish. Significant comparisons are those for which plant use was different based on Fisher's exact test (P< 0.002). Critical values for Fisher's exact test were adjusted using the Bonferroni procedure to keep overall P ≤ 0.05. See text for further description.

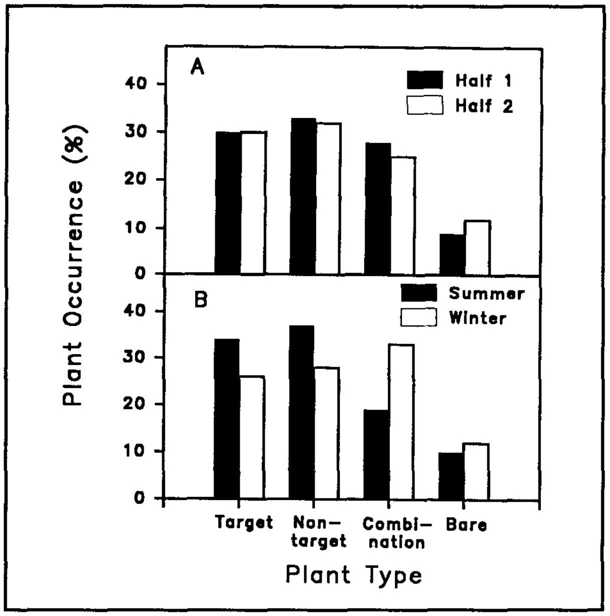

Figure 3. Temporal (A) and seasonal (B) comparisons of plant occurrence at sites used by triploid grass carp tracked in Lake Yale, Florida, between October 1988 and February 1990. Plant type groups and temporal and seasonal sampling periods are as described in Figure 2

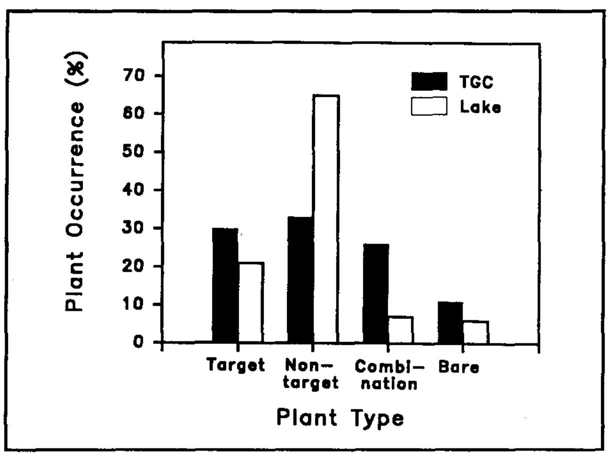

Figure 4. Plant use by triploid grass carp (TGC) tracked in Lake Yale, Florida, as compared with lake-wide distribution of plant types. Data presented are for all sampling periods combined

Hydrilla was the dominant plant at 30 percent of fish locations and only 21 percent of lake-wide sampling locations. Nontarget plants were dominant at 33 percent of fish locations, as compared with 65 percent of lake-wide sampling locations.

Lake Yale triploid grass carp were located in shoreline emergent vegetation, which comprised approximately 5 percent of the lake surface area, on fewer than 10 occasions. Lake Harris fish, on the other hand, were primarily found in association with littoral, emergent vegetation communities, or in canal or riverine environments. These were the only areas in Lake Harris that contained appreciable amounts of submergent vegetation.

Discussion

Distance moved

Distances radio-tagged grass carp moved in this study were within the range of values reported in the literature. Nixon and Miller (1978) observed displacements of 0.2 to 18.3 km, and Martyn et al. (1986) recaptured fin-clipped grass carp up to 9.1 km from the site of release. Grass carp tracked in Florida's St. Johns River were found to move considerable distances upstream and downstream. One fish was located 35 km from point of release.[1]

While statistical comparisons showed, for the most part, few quantitative differences in movement patterns between lakes (other than a difference in maximum distance from site of stocking), we did observe some qualitative differences in movement between the two groups of fish tracked in the present study. These differences may have been related to the distribution of aquatic vegetation in each lake, to seasonal influences, or to variations in water quality within one of the study lakes. In general, movement by Lake Harris fish was intermittent, little or no movement followed by extended movement between separate home areas. Three Lake Harris fish moved on several occasions between two areas approximately 16 km apart; these long-distance movements usually occurred during spring and autumn. Fish in Lake Harris had available to

[1] Personal Communication, F. Cross, Florida Game and Fresh Water Fish Commission.

them only patchy areas of submergent vegetation. When food becomes patchy, animals will tend to limit activity to areas in which food is readily accessible or move intermittently between distant food sources (Pyke, Pulliam, and Charnov 1977).

Stanley, Miley, and Sutton (1978) discuss the importance of temperature in triggering spawning movements, and even though fish used in our study were functionally sterile triploids, spawning instincts may still have played some role in determining movement patterns. Bain et al. (1990) observed different patterns of movement in two groups of triploid grass carp they tracked in Guntersville Reservoir, Alabama, and attributed these differences in movement to differences in fish size and maturity. During the first year of their study, grass carp movements were limited to 6.3 km from the stocking site, but fish tracked during the second year of the study were found up to 72 km from the site of stocking. Somewhat in contrast to our observations, Cassani and Maloney (1991) reported that water temperatures ranging from 22.2 to 30.3 °C did not have a significant effect on grass carp speed, and Nixon and Miller (1978) reported that lower water temperatures decreased rapidity of movement.

Water quality, including dissolved oxygen levels, may also influence movement of grass carp.[1] Previous studies by the Florida Game and Fresh Water Fish Commission have shown that fish will move out of areas with low dissolved oxygen levels.[2] Shireman and Haller reported a decrease in the number of fish locations in some areas of Lake Pearl, Florida, after herbicide treatments.[3] We observed fish to move out of areas of Lake Harris that had been treated with the herbicides endothall and fluridone, but the movements did not occur immediately after the treatments; we did not determine if these fish movements resulted from changes in water quality or changes in the quantity or quality of food available to grass carp in these areas.

Home range

Most studies of grass carp movement have reported some type of home-range tendency on the part of these fish. While Mitzner (1978) indicated that only two of nine fish tracked in Red Haw Lake, Iowa, showed homing to established activity centers, Shireman and Haller reported that 9 of the 10 grass carp they tracked established home areas.[3] Home-range areas were 2.0 to 14.0 ha, and core areas were 0.8 to 6.0 ha. Hockin, O'Hara, and Eaton (1989) described the use of three primary areas by grass carp in a British canal and indicated that fish moved quickly between these areas. Cassani and Maloney (1991) described two general behavior patterns, free-ranging activity and home-area use, and reported that seven of nine fish tracked established use of a home range for some period during their study. Schardt, Jubinsky, and Nall (1982) described home-range use by grass carp as soon as 7 to 10 days following release.

The different results reported above emphasize not only the need for consistency in describing fish behavior but also the importance of the duration of telemetry studies in determining fish behavior patterns. For example, by tracking fish in Lake Harris for over 2 years, we were able to observe use of and movement between two separate areas of the lake by several fish. In general, the longer a fish is tracked, the greater the variety of behaviors likely to be observed and the larger the area it is likely to explore, depending upon whether the requirements (i.e., food and spawning) of that fish can be met in large or limited areas of the system. Fish tracked in Lake Yale had abundant food available to them, and their home-range areas were generally smaller than those of fish in Lake Harris. Lake Harris fish

[1] G. Pauley and G. Thomas, Unpublished Data, Washington Cooperative Fisheries Research Unit.
[2] Personal Communication, F. Cross, Florida Game and Fresh Water Fish Commission.
[3] J. Shireman and W. Haller, Unpublished Data, University of Florida, Gainesville.

were forced to search over a much larger area or to use several different areas since submergent aquatic plants were scarce and patchy.

Home ranges we observed in both lakes were larger than those seen in other studies. One reason for this difference may have been that the lakes we were working on were larger than those in previous studies for which home-range areas of grass carp were reported. As a percentage of lake size, the home-range areas we observed were similar to those reported previously. Home ranges of fish tracked in Lake Harris ranged from 1 to 74 percent of the lake area and of fish tracked in Lake Yale from 10 to 36 percent. Home ranges reported by Shireman and Haller for fish tracked in 24-ha Lake Pearl ranged from 3 to 58 percent of the lake area.[1] Differences between the home-range areas calculated in this study and those reported in other studies may also have resulted from differences in the measures of home range that were used. We reported total and corrected 100-percent minimum convex polygon areas; others have used 95-percent areas or core areas. Our correction (subtracting land areas using a planimeter) resulted in an average reduction from the total home-range area of 38 percent on Lake Harris, but only 4 percent on Lake Yale. This difference was probably due to the increased use of shoreline areas by Lake Harris fish, as compared with those in Lake Yale, as well as their use of multiple areas. Different home-range measures (i.e., statistically based measures) may be more appropriate for studies of different animals or for investigating different research questions. We were interested in determining the maximum area that might be used by triploid grass carp under these conditions, and for this purpose, the corrected 100-percent minimum convex polygon seemed most appropriate.

Plant selection

Knowledge of plant selection by triploid grass carp is of critical importance when considering grass carp for a plant control or management application. Bain et al. (1990) found that grass carp in Guntersville Reservoir, Alabama, chose areas of hydrilla (43 percent at fish locations versus 3 percent lake-wide) and Eurasian watermilfoil (*Myriophyllum* spp.) (20 percent versus 13 percent) in the first year of their study; but in the second year, fish chose primarily Eurasian watermilfoil or mixed plant communities, and 22 percent of the locations were in areas devoid of plants. They attributed these differences in plant choice between years to changes in fish size and experience as well as changes in plant distribution between the first and second year of their study. In the present study, we also observed changes in plant distribution in Lake Yale over the course of the study, but changes in use of plants by triploid grass carp in Lake Yale were seasonal rather than temporal in nature. Fish in Lake Yale were more likely to use areas with a combination of target and nontarget plants in winter and areas with dominant coverage of either target or nontarget plants in summer. Fish in Lake Yale chose areas of hydrilla disproportionately to its abundance in the lake, and we located these fish in shoreline emergent vegetation on fewer than 10 occasions. However, in Lake Harris, where plants were limited to shoreline and lotic areas, fish made almost exclusive use of these areas.

There was some evidence that fish in Lake Yale made use of shoreline vegetation more often than we observed. This evidence consisted of fish collected in these areas by electrofishing, circular clearings in shoreline emergent vegetation, and visual sightings of grass carp in midlake areas, followed by collection of fecal material containing shoreline emergent vegetation at these midlake sites. We also found hydrilla in stomach samples taken from fish captured by electrofishing in shoreline emergent areas between 1900 and 2200 hr, indicating that fish may have been feeding in deeper, open-water areas on hydrilla during daytime and then migrating into nearshore areas at night when water temperatures were favorable and the threat of

[1] J. Shireman and W. Haller, Unpublished Data, University of Florida, Gainesville.

avian predation or of human disturbance (Swanson and Bergersen 1988) was minimal.

Additional tracking between 1800 and 0800 hr would help to answer questions concerning possible inshore nocturnal feeding migrations and use of emergent plants by grass carp. Previous studies of grass carp nighttime behavioral patterns have yielded variable results. Mitzner (1978) indicated that, with the exception of some surfacing behavior observed in evening, nocturnal and diurnal movements were not different. Hockin, O'Hara, and Eaton (1989) reported that grass carp in British canals were most active from 0200 to 1200 hr. Activity lessened somewhat in afternoon and was least in late evening. They indicated that water temperature was probably an important factor in these activity fluctuations. Nixon and Miller (1978) found fish to be more active during daylight hours than at night. However, the increased rest periods between movements at night they reported could have been associated with increased nighttime feeding activity by grass carp. Mitzner (1978) reported that fish were generally sedentary near vegetation and more active in open water areas. In general, activity and feeding are probably inversely related since a herbivorous animal cannot graze effectively when it is highly active.

Management recommendations

Based on the results of this study, we can begin to construct a picture of typical grass carp behavior in large Florida lakes. The fact that median percent maximum distance moved was greater than 50 percent in both of the current study lakes (80 percent in Lake Harris and 70 percent in Lake Yale) indicates that grass carp can potentially cover the majority of a lake from a single stocking site. When plants are present in abundance, grass carp can be expected to feed in an area from 250 to 750 ha in size and remain only locally active. If areas of abundant plants are smaller and/or widely separate, grass carp can be expected to occasionally move longer distances in search of plants and may have multiple home areas. In order to use low levels of fish to control problem plants in large lakes, grass carp stockings should be well-placed around a lake to allow fish to effectively cover areas of target plant abundance, based on the measures of movement described above. While all transmitter fish in this study remained in the open system, it is inevitable that, with a large-scale stocking, some fish will leave if a connection to other lakes is available, especially in a flowing-water situation. Situations in which grass carp have "escaped" from a system have generally been in association with flowing water (Ellis 1974; Nixon and Miller 1978; Hardin and Mesing[1]).

A number of questions remain concerning the use of grass carp for aquatic plant management in large lakes. Grass carp schooling behavior, described by Martyn et al. (1986) and Hockin, O'Hara, and Eaton (1989), could lead to high concentrations of fish in some areas of a lake and low concentrations of fish in other areas. When using grass carp at low rates to control regrowth of problem aquatic plants, a uniform distribution of fish throughout the lake may be more desirable. Increased knowledge of grass carp schooling dynamics may help us to achieve this type of distribution without overstocking a lake.

While studies have shown that grass carp feed preferentially on hydrilla, it is still difficult to predict the amount and timing of aquatic plant control to be expected on target and nontarget species when using this fish. Determination of the dynamics of all aquatic plant populations is paramount in being able to accurately predict grass carp plant control capabilities. We must also realize that because of the dynamic changes associated with aquatic systems, we may never be able to predict plant control success as accurately as we would like. The grass carp has been demonstrated to be an economically feasible plant management tool and should be used in conjunction with the other tools at our disposal to implement effective aquatic plant control programs.

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[1] S. Hardin and C. Mesing, Unpublished Data, Florida Game and Fresh Water Fish Commission.

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