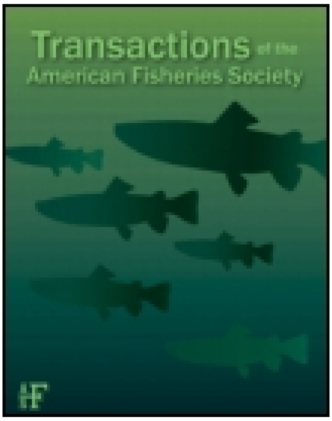

Transactions of the American Fisheries Society
Publication details, including instructions for authors and subscription information:
http://afs.tandfonline.com/loi/utaf20

Distribution and Movement Behavior of Radio-Tagged Grass Carp in Two Texas Reservoirs

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Published online: 09 Jan 2011.

Transactions of the American Fisheries Society 126:467–476, 1997

Distribution and Movement Behavior of Radio-Tagged Grass Carp in Two Texas Reservoirs

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Abstract.—Triploid grass carp *Ctenopharyngodon idella* with surgically implanted radio tags were stocked in two Texas reservoirs, Lake Texana (4,453 ha) and Lake Weatherford (445 ha), then tracked to determine magnitude and seasonality of movement patterns, diurnal changes in movement, and distribution relative to aquatic vegetation. After release, fish quickly became associated with macrophytes. More than 50% of observed movement during the first 3 months occurred within 1 week. Mean home range area was 3,234 ha (SE = 1,190), and mean core use area was 515 ha (SE = 193). Extensive movement was observed during 24-h tracking conducted immediately after release. However, five 24-h tracking surveys that were conducted at least 3 months after release showed little movement after acclimation. Somewhat elevated movement was evident from 0400 to 1200 hours. We conclude that immediately after stocking, an acclimation period with relatively intense movement occurs followed by an extended period of quiescence. Mean duration of the acclimation period was approximately 7 weeks for Lake Texana and 8 weeks for Lake Weatherford. Although both lakes in this study contained habitat considerably more heterogeneous than other sites where 24-h radio-tracking of grass carp had been done, individual fish did not appear to take advantage of the opportunity (via diel movement) to forage in different areas. Hence, daylight tracking alone should be sufficient to determine grass carp movement trends.

In recent years, aquatic plant growth has become a serious problem in many areas of Texas. Nuisance plants, primarily hydrilla *Hydrilla verticillata*, Eurasian watermilfoil *Myriophyllum spicatum*, waterhyacinth *Eichhornia crassipes*, and waterlettuce *Pistia stratiotes*, disrupt recreational use of water bodies including fishing and boating. Decaying plant material may also adversely affect the taste of public drinking water. Control of aquatic plants through mechanical means is both expensive and time consuming. Additionally, the mechanical harvest of aquatic vegetation may result in more than 30% fish mortality, and replacement costs of lost fishes can be high (Haller et al. 1980). Chemical control may be many times as expensive as biological control (Stott et al. 1971; Shireman 1982) and is often discouraged or restricted in waters used for drinking—either by livestock or humans. Further, some herbicides may remain in aquatic sediments for as long as 2 years after use (Engel 1990). As an alternative management tool, grass carp *Ctenopharyngodon idella* are effective as biological control agents for aquatic macrophytes in many situations (Van Dyke et al. 1984; Noble et al. 1986; Thompson et al. 1988; Chilton and Muoneke 1992). Although grass carp are certainly effective at controlling many types of aquatic vegetation in closed systems, movement is an important factor in the evaluation of their effectiveness in larger open systems where potential exists for emigration by the grass carp away from target areas. There has been much discussion about placing these fish in particular coves of large waterbodies to eliminate localized vegetation problems. However, fish that move extensively are likely to emigrate to other areas or other waterbodies where the fish are unneeded or unwanted.

To assess the movement of triploid grass carp, radio-tracking studies were performed in two Texas mainstream reservoirs. Although much information exists relative to grass carp feeding rates, feeding preferences, and reproductive biology, detailed observations of grass carp movement patterns are rare. These observations usually report on a limited number of fish (Nixon and Miller 1978; Hockin et al. 1989; Bain et al. 1990; Clapp et al. 1993) or provide only short-term tracking information (Nixon and Miller 1978). For example, data from studies by Hockin et al. (1989) and Beyers and Carlson (1993) included only 5 and 14 fish, respectively, whereas Nixon and Miller's (1978) study only lasted 1.5 months due to the short battery life of the radio tags used.

Information about diel movements is particu-

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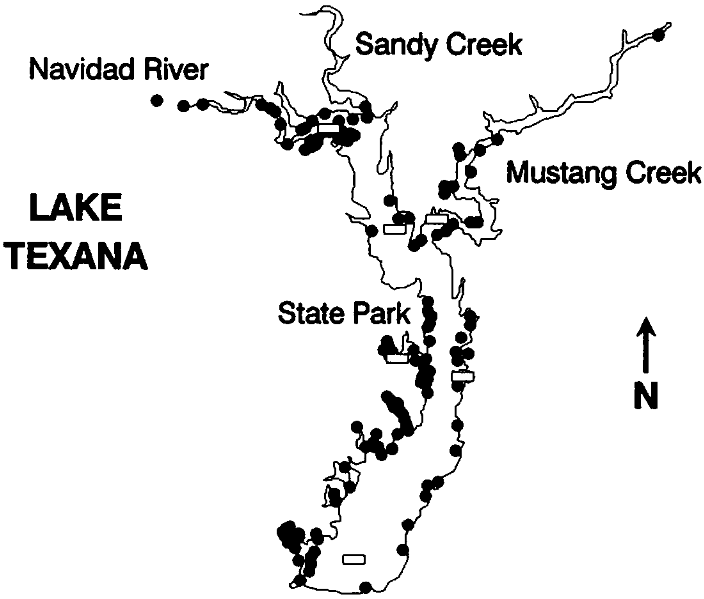

FIGURE 1.—Lake Texana, Texas. Solid circles indicate where radio-tagged triploid grass carp stocked in 1990 were found during 1990–1991. Open rectangles indicate stocking sites.

larly scarce, but it is vital to accurately assess the effects of movement on grass carp effectiveness. Daylight tracking alone may miss movement to secondary or even tertiary feeding beds at night. Unfortunately, only two studies, Hockin et al. (1989) and Beyers and Carlson (1993), have reported on grass carp movements during a 24-h period. Both studies were conducted under limited spatial conditions where habitat diversity was low. Hockin et al. (1989) used an enclosed section of the Lancaster Canal in Great Britain that was only 11 m wide and 1–2 m deep with slow-flowing water and uniform vegetation. Similarly, Beyers and Carlson (1993) used a small Colorado irrigation canal. It is difficult to assess the effectiveness of these studies in predicting the behavior of grass carp in larger water bodies where a two- or even three-dimensional range of movement is possible and where habitat diversity and complexity are substantially increased. Increased habitat diversity may afford fish the opportunity to forage in different areas as temperature and light regimes change during a 24-h cycle.

Objectives of this study were to determine (1) magnitude of triploid grass carp movements within each reservoir, (2) seasonal changes in magnitude and direction of grass carp movements, (3) distribution of grass carp relative to aquatic vegetation, and (4) diel changes in magnitude of grass carp movements.

Study Sites and Methods

Lake Texana is a 4,453-ha reservoir formed by the impoundment of the Navidad River about 50 km east of Victoria, Texas. Other significant inflows are from Sandy and Mustang creeks (Figure 1). Mean depth is 4.7 m and maximum depth is 13.4 m. During November 1989 Lake Texana was stocked with 15,300 triploid grass carp. Lake Weatherford is a 445-ha reservoir formed by impoundment of the Clear Fork of the Trinity River about 50 km west of the Dallas–Fort Worth area. Mean depth is 4.6 m and maximum depth is 12.5 m. During July 1990, Lake Weatherford was stocked with 1,100 triploid grass carp.

Ninety-five triploid grass carp (mean weight = 1.6 kg, mean total length (TL) = 503 mm, size range = 0.5–4.7 kg and 369–813 mm) were surgically implanted with radio tags equipped with internal loop antennas during June 1990 (only triploid grass carp were used in this study). Tag frequencies ranged from 48 to 50 MHz. Tags transmitting on the same frequency were distinguished by pulse rate differences (either 40 or 50 pulses/min).

The same implantation and postimplantation holding procedures were used throughout. Fish were anesthetized with either Quinaldine (Hypno®) or MS-222 (tricaine methanesulfonate) during implantation. A 3-cm longitudinal incision was made in the ventral wall about 7 cm anterior to the pelvic girdle, and a transmitter was inserted in the body cavity of each fish. Incisions were closed with either surgical staples or sutures of 1.8-kg-test fishing line combined with glue. After implantation fish were held in 1,700-L tanks for at least 2 d and given an antibiotic treatment of 29 mg nitrofurazone (Furacin®) per liter. Fish were then transferred to either a hatchery pond or a large raceway and held for a week before being transported to the reservoirs.

At Lake Texana, grass carp were divided into groups of 16 individuals and released at each of five stocking sites; a sixth site received only 15 fish (Figure 1). Tagged fish were tracked by boat at 1-week intervals for 3 weeks, 2-week intervals for the next 8 weeks, and 1-month intervals through June 1991 (although a number of tags prematurely stopped transmitting). To locate as many fish as possible, the entire reservoir was searched during tracking including several miles upstream in the three major tributaries. On several occasions the river was searched downstream from the dam almost to the coast (approximately 11 km).

To determine if diel movement was a factor in interpreting our tracking data, we conducted 24-h tracking studies in December 1990 and in February 1991. Unfortunately, many of the 1990 tags prematurely stopped transmitting, so the 24-h study planned for summer 1991 could not be conducted. Ten fish were tracked at 4-h intervals for 24 h on each occasion.

Because of difficulties with reception of signals from the original internal loop antenna tags, 26 additional triploid grass carp (mean weight = 3.75 kg, mean TL = 662 mm, size range = 5.34–9.31 kg and 586–688 mm) were implanted in April 1991 with tags with external whip antennas. Fish were released at each of the six original stocking sites in Lake Texana. All newly stocked fish were tracked after 1 week at 2-week intervals for the next 10 weeks and at 1-month intervals through October 28, 1991 (although some tags stopped transmitting before the last sampling date).

To determine grass carp movement immediately after stocking, 12 of the newly stocked fish were tracked at 4-h intervals for the first 24 h. The same 12 fish were located again 48 h after release. Another 24-h tracking study of the same 12 fish was conducted in July 1991 (3 months after release).

Ten triploid grass carp (mean weight = 1.5 kg, mean TL = 495 mm, size range = 1.4–1.8 kg and 482–506 mm) were implanted with internal loop antenna radio tags and released at one stocking site in Lake Weatherford during August 1990. They were tracked at 1-week intervals for 1 month, 2-week intervals for 2 months, and 1-month intervals through June 19, 1991 (7 of the 10 tags were still transmitting by the final sampling date). Twenty-four-hour tracking was conducted in October 1990 and March 1991 by locating five fish at 2-h intervals for 24 h on each occasion.

Throughout the study, locations of individual fish were marked on a grid map. Every location was assigned X and Y coordinates. Calculated changes of X and Y (ΔX, ΔY) between recording–monitoring dates were used to estimate straight-line distances traveled between dates. Average daily movement (ADM), in m/d, was calculated for each time interval between two tracking observations of a fish. We used ADM to analyze overall movement patterns through time, to compare movement between summer (May–October) and winter (November–April), and to compare movement among months. Only individuals located at least four times (three movement measurements) during each season were used in analyses of seasonal movement patterns. Data collected during the first 3 months after release were used to compare differences in movement patterns between the 1990 and 1991 releases. Only data from fish located at least four times were used; week 1 movement data for 1991 were excluded because week 1 data for 1990 were not available for comparison. Analysis of variance (ANOVA) was used to compare ADM between seasons (SAS Institute 1987). Data were log-transformed as $\log_e(n + 1)$ to stabilize variances. Core use area (95% confidence ellipse to a fish's mean location) and home range area (95% confidence ellipse to a fish's observed locations) were calculated for each fish (Sokal and Rohlf 1969; S. Kartalia and J. Foltz, Clemson University, personal communications). The SAS Institute's NPAR1WAY procedure (SAS Institute 1987), which includes a suite of nonparametric tests, was used to test for differences in patterns of grass carp movement and habitat use between lakes. A significance level of α = 0.05 was assumed for all tests.

Results

Lake Texana

Only 69 of the original 95 radio-tagged grass carp in Lake Texana were found. Six of these were located only once, 8 were located twice, and 10 were located three times. Eight of the 45 individuals that were located four or more times during

FIGURE 2.—Vegetation in Lake Texana, Texas. Solid circles indicate hydrilla and other submergent plant species. Open squares indicate emergent or floating vegetation (e.g., waterhyacinth and cattail).

the study exhibited two periods of concentrated movement. Eleven moved almost exclusively during the first few weeks after release. No fish were found downstream from the dam.

Fish released in June 1990 were always found at depths of 3 m or less and in association with littoral vegetation, primarily hydrilla. Association with coontail *Ceratophyllum demersum* was of lesser importance, and decreasingly so were associations with American lotus *Nelumbo lutea*, cattail *Typha latifolia*, smartweed *Polygonum hydropiperoides*, and pondweed *Potamogeton* spp., respectively. Some fish were found in vegetation stands as small as 1.8 m^2 in area. None were associated with waterhyacinth, although it was extremely abundant in certain areas of the reservoir. Grass carp distribution was skewed toward areas with the most abundant stands of hydrilla and coontail, such as the western shore of the lake, cove areas, and tributaries (Figures 1 and 2). In particular, the area just south of the Navidad River inflow, coves just south of the state park, and the large cove in the southwestern corner of the reservoir all had extensive hydrilla growth and a correspondingly high number of grass carp observations.

Overall ADM for fish released in June 1990 was 31 m/d (Table 1). Similarly, mean ADM during the first 3 months after release was 28 m/d (Table 1). However, in general, ADM decreased sharply through time (Figure 3). Location data from 22 fish (214 movement observations) were used to compare differences in movement between summer (1990) and winter (1990–1991). The mean ± SE of ADM was 32 ± 7 m/d for 101 summer movement observations and 7 ± 2 m/d for 113

TABLE 1.—Average daily movement (ADM; SE in parentheses) in Lake Texana and Lake Weatherford of radio-tagged triploid grass carp found at least four times during the first 3 months of each study period. Sample size (N) is the number of movement periods—time intervals between observations—summed for all fish observed in the period (e.g., N = 3 indicates a fish was located four times so three ADMs could be calculated).

Year tagged	Study period	Mean ADM (m/d) for: First 3 months after week 1	Full study period after week 1	Full study including week 1	Percent of total movement for study period during: First 2 d	First 7 d
		Lake Texana				
1990	Jun 1990–1991	28.4 (10.3) N = 21	30.7 (5.5) N = 63			
1991	Apr–Oct 1991	116.2 (15.9) N = 24	44.7 (8.0) N = 26		34.3% (4.3) N = 25	49.2% (4.8) N = 25
		Lake Weatherford				
1990	Aug 1990–Jun 1991		19.5 (7.4) N = 10	36.0 (11.5) N = 10		

winter observations. The ADM was significantly different between seasons (F = 10.47, model df = 1, error df = 212, $P < 0.002$).

Most of the observed movement of fish released in April 1991 occurred very soon after release. During the first three months, 33% of movement occurred within the first 2 d after release and 56% occurred within the first week. During the entire study (April–October 1991), 34% of movement occurred within the first 2 d, and 49% occurred within the first week (Table 1). After release, fish tended to swim either back and forth or in a spiral pattern until vegetation was encountered; thus, as in 1990, grass carp quickly became associated with vegetation. The mean ADM during the first 48 h was 1,255 ± 166 m/d (N = 25) and during the first week was 409 ± 48 m/d (N = 25). After the initial period of high movement, a quiescent period ensued. Twenty-one of the 26 fish released in April 1991 exhibited such behavior. The mean time to onset of quiescence was 28 ± 3 d (range, 2–52 d). Mean length of the period was 47 ± 7 d (range, 14–138 d). Mean ADM during the first 3 months after release was 116 ± 16 m/d (N = 24), and overall ADM was 45 ± 8 m (N = 26) (Table 1). Mean ADM for fish released in 1991 was 45.6% greater than for fish released in 1990 (Table 1).

As a group, fish released in June 1990 exhibited

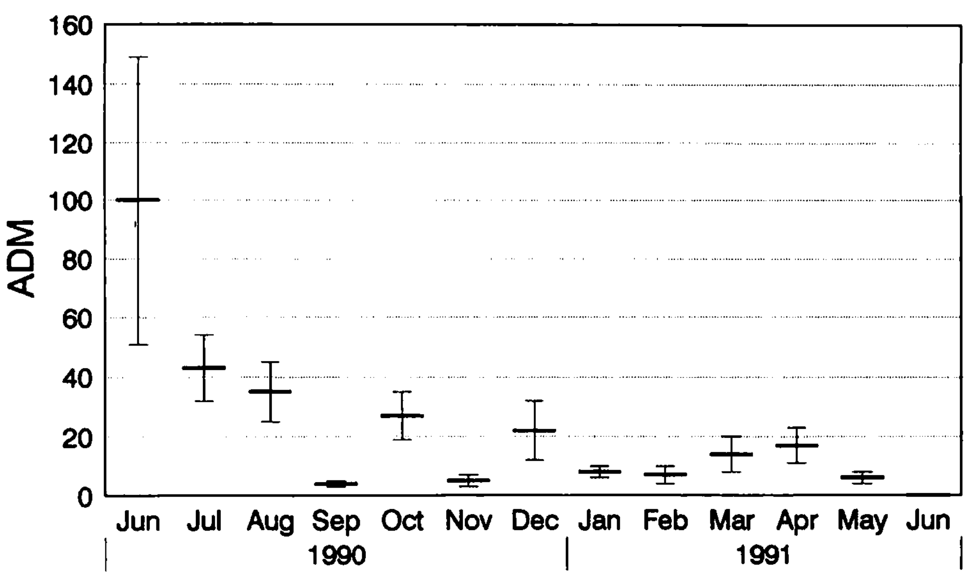

FIGURE 3.—Average daily movement (ADM, expressed in m/d) of triploid grass carp stocked during 1990 in Lake Texana, Texas. Error bars represent standard errors.

no pattern of upstream movement. In fact, two fish traveled downstream 13.6 km and 8.0 km, respectively. Similarly, fish released in April 1991 exhibited little directionality in their movement patterns during the course of the study. After 3 months, 15 of 26 radio-tagged fish had moved upstream from their initial stocking location; two of these moved downstream initially and remained there until late in the study period. Seven fish exhibited no directional movement pattern, and four moved downstream. A number of fish moved relatively long distances in a short period of time, irrespective of direction. For example, two fish moved downstream 6.5 km and 5.7 km, respectively, within 2 d of release. In contrast, two other fish moved upstream 3.6 km and 6.5 km, respectively, during the same period. Often individuals reversed direction. One fish was found 1.3 km upstream of release in Mustang Creek after 2 d, then it changed direction and moved more than three times that distance downstream into the reservoir during the next 6 d. During the study, mean home range for Lake Texana fish was 3,869 ± 1,439 ha, and mean core use area was 620 ± 233 ha.

Grass carp moved extensively during the first 24 h after release in 1991. Average movement during that time was 3.0 ± 0.6 km (range, 0.47–7.41 km). However, after fish had been acclimated to their new environment for 3 months, 24-h tracking studies revealed little or no diel movement for most individuals. During the two 24-h tracking studies in winter 1990–1991, 54% of our observations indicated no movement and 87% indicated movement less than 200 m. Forty of the 48 observed movements were the result of fish moving back and forth between frequently used sites. Only one fish moved more than 400 m during any one tracking period, and that fish moved back to its original position during the next period. Movements occurred between 0400 and 1200 hours for 57% of the time. Movement was not positively correlated to water temperature changes. Daily water temperature was always greatest between 1500 and 2300 hours. Similarly, during the July 1991 24-h tracking study with fish released in April 1991 (after fish had acclimated), 79% of all observations indicated zero movement, and four of the nine observations that indicated movement were the result of back-and-forth movement between established sites; 56% of all movements occurred from 0800 to 1200 hours. Again, time of increased movement was not positively related to mean water temperature, which was greatest between 1500 and 1900 hours.

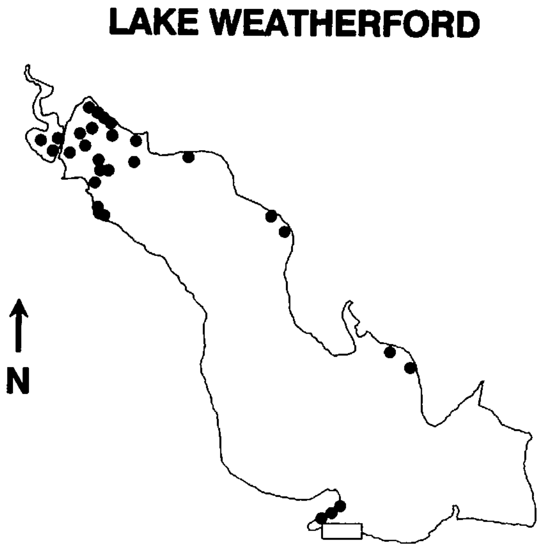

FIGURE 4.—Lake Weatherford, Texas. The rectangle on the southern edge of the lake indicates the stocking site in 1990, and solid circles indicate where triploid grass carp were found during 1990 and 1991.

Lake Weatherford

All ten fish were located at least once during the course of the study, and all were associated with bulrush *Scirpus* spp. primarily in the upstream portion of the reservoir (Figure 4). Movement was most intense during the first week after release; the mean ADM overall (including the first week's observations) was almost twice as great as the mean ADM overall with the first week discounted as an acclimation period (Table 1). Only two fish exhibited movement more than 200 m after the first week. Minor movements occurred in a pattern similar to that in Lake Texana. After an initial period of high movement, 7 of 10 fish began a quiescent period. The mean time to onset was 15 ± 2 d (range, 10–24 d), and the period lasted 55 ± 15 d (range, 6–116 d). Some, fish didn't move after the initial period. For purposes of calculation, the quiescent period ended December 31, 1990, for those fish.

Mean core use and home range areas for Lake Weatherford were 43 ± 23 ha and 373 ± 135 ha, respectively. Although the areas were smaller than for Lake Texana, they were not significantly different between lakes, probably due to the high number of zero values. Mean core use and home range areas for the two lakes combined were 515 ± 193 ha and 3,234 ± 1,190 ha. Regression analysis with combined data indicated core use area (F = 4.7, r^2 = 0.08, $P < 0.05$) and ADM (F =

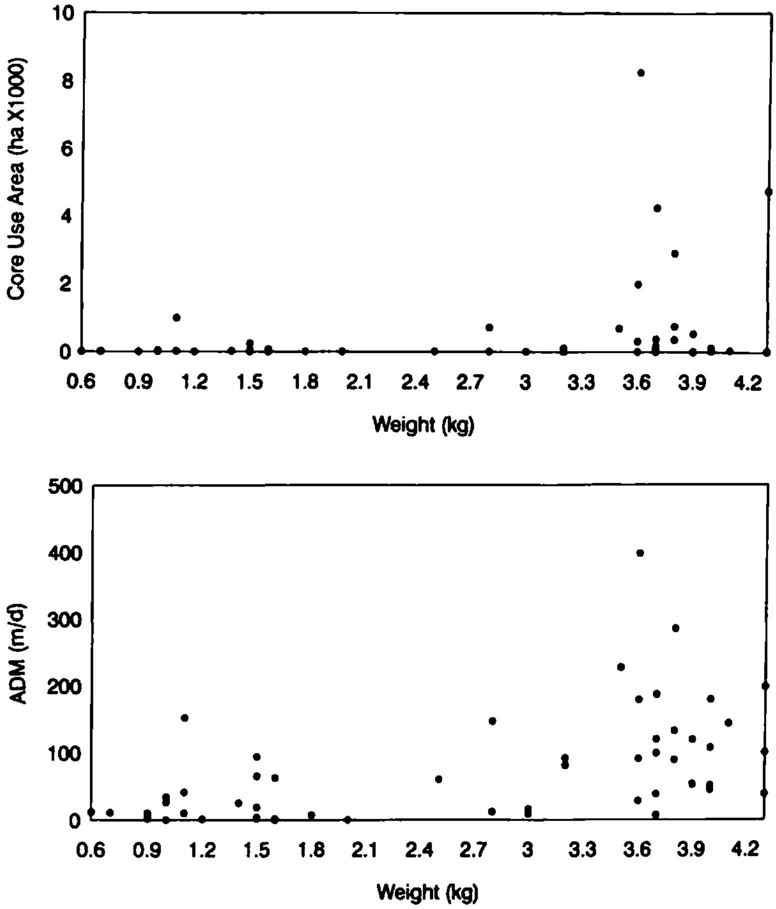

FIGURE 5.—Core use area (1,000s of hectares) and average daily movement (ADM) versus triploid grass carp stocking weight. Data for Lake Texana and Lake Weatherford were combined.

20.5, r^2 = 0.28, $P < 0.001$) were significantly and positively related to fish weight at stocking (Figure 5).

During the two 24-h radio-tracking studies in Lake Weatherford, the only recorded movement was by one fish that moved less than 15 m.

Discussion

In the two Texas reservoirs, grass carp exhibited a period of rapid movement and dispersal immediately after release and then a long interval of relative inactivity. Nixon and Miller (1978) and Kartalia and Foltz (personal communications) similarly reported periods of extreme activity immediately after release. Unfortunately, this period, which may last a number of weeks, and the quiescent period that follows can make it difficult to interpret tracking data. For example, Nixon and Miller (1978) found movement in grass carp increased with increased temperature, and Bain et al. (1990) similarly reported greater activity during summer than winter. However, although our data agree with these previous findings, it is difficult to determine whether declines in movement with the onset of cooler temperatures in fall were exacerbated by the overall trend of declining movement (across time) during the first year after release. Because fish at both reservoirs were released in summer (June 1990 in Lake Texana, August 1990 in Lake Weatherford), the summer movement data might have been enhanced by the tendency to move a great deal during acclimation; and declines in movement during winter might have resulted not only from temperature effects but also partly from natural declines in movement as preferred plants were encountered and acclimation ended. During the first year, acclimation behavior—initial high movement followed by declining movement—probably influenced movement data to a greater degree than did seasonality. Although it is possible that small May and June sample sizes ($N = 4$) might have been a factor in reduced ADM, standard errors were small. The 1991 data support the contention that initial reaction patterns to stocking may affect first-year movement more than season does.

In 1991 fish were stocked in April, before the onset of the summer period, so we should have seen increased movement as the summer progressed. But after an initial period of activity, a period of decreased movement began in early summer and, in 12 of 21 cases, extended through the end of June or later. Apparently, anticipated seasonal increases in movement were obscured by decreased activity following acclimation.

Our core use and home range data are consistent with findings by Kartalia and Foltz (personal communications), who reported 8.7 km^2 of core use and 49.0 km^2 of home range from Lake Marion, South Carolina, compared with our areas of 5.2 km^2 (core use) and 32.3 km^2 (home range). Perhaps home range and core use areas were somewhat larger in Lake Marion because its size (44,000 ha) provides more room for movement. However, if a loose relationship exists between home range and lake size, it is not linear; otherwise we should have observed areas only one-tenth the size of those reported from Lake Marion. In our study, both core use area and ADM were positively related to the stocking size of fish, but the relation was weak, indicating factors other than size have a crucial role in determining movement and range of grass carp during the first year after release. However, the subtle tendency for larger fish to move more extensively than small ones is evident. Presumably because they are more capable of greater movement, larger fish maintain larger feeding areas, or perhaps older mature fish are compelled to greater activity related to spawning.

The inactivity by grass carp after acclimation as well as the relationship between movement and size are both consistent with their behavior in native streams and rivers. Gorbach and Krykhtin (1988) reported juvenile grass carp feed for as long as 5 years in the lower reaches of the Amur River before they begin to move upstream into spawning areas (presumably minor movements take place during this time). Lack of strong directionality in movement patterns has significant management implications. In their native habitat, juvenile grass carp undergo a period of growth and relative inactivity in the lower portions of the Amur River, after which they begin a slow northerly migration that eventually leads to their spawning grounds in the upper river. Fish have been reported to move 500 km upstream in the first 2 years of the migration. One specimen (610 mm) moved 155 km in 9 months (ADM = 574 m/d; Gorbach and Krykhtin 1988). Consequently, pond and lake managers often indicate to clients that grass carp won't move downstream from where they are stocked. In our study, fish (mean length, 662 mm) released in Lake Texana during 1991 were already well within the size range that would begin a normal upstream migration, yet no net upstream movement was observed. Although at least 60% of the fish released into Lake Weatherford moved upstream from the stocking site, the trend was probably a function of the fact that virtually all of the plant biomass (bulrush) was found in the upper reservoir.

It was difficult to document escapement from either reservoir. We cannot say for certain why 26 of the original 95 tagged grass carp we stocked into Lake Texana were never found. During Lake Texana surveys, a few fish were found several kilometers upstream in both the Navidad River and Mustang Creek, but no fish were ever located more than 100–200 m upstream in Sandy Creek. It is possible that some traveled so far upstream that their radio tag signals could not be picked up by our receiver. None were located downstream of the dam. Nevertheless, fish might have moved downstream and entered salt water, rendering their tags undetectable. A number of authors have reported that grass carp are somewhat saltwater tolerant (Liepolt and Weber 1969; Cross 1970; Kilambi 1980; Maceina and Shireman 1980; Trimm et al. 1989). Schools of grass carp have been found downstream of Lake Texana. A number of fish from these schools have been captured, and PIT tag readings indicated they were escapees from Lake Texana (all 15,300 grass carp placed in the lake initially were equipped with PIT tags). However, our difficulties with internal loop antenna transmitters in 1990 (fish released in 1991 with external whip antenna transmitters were readily located), combined with the fact that water did not go over the Lake Texana spillway for months after release of the fish suggest the low percentage of fish located in 1990 might have resulted from a combination of escapement and technical problems. Similarly, the high number of fish located in Lake Weatherford, their direction of movement, and the lack of water releases over the spillway again suggest that our inability to locate fish on various dates might have been caused by a technical problem with the transmitters.

The only instance of significant movement during a 24-h period was immediately following grass carp release in 1991. All our other 24-h studies indicated minimal diel movement, usually during the morning. This result is consistent with a report by Hockin et al. (1989). Although they found grass carp movement in an unnavigated portion of the Lancaster Canal was almost continuous, activity was greatest around dawn and remained high until noon. Despite minor increases in movement around dawn in our study, we expected more pronounced activity. The heterogeneous environment, with varied choices found in both Texas lakes, provided much more diverse habitat than the canals where Hockin et al. (1989) and Beyers and Carlson (1993) did their work. However, no pronounced diel movements were observed, and changes in habitat types was not based on time of day. As in our study, Hockin et al. (1989) reported diel movement was uncorrelated with water temperature; Cassani and Maloney (1991) found that water temperatures of 22.2–30.3°C did not significantly affect average swimming speed of grass carp. Therefore, temperature shifts that occur within a 24-h period are, in general, probably not of sufficient magnitude to significantly affect activity.

In conclusion, our data suggest that any tagging studies conducted with grass carp should be relatively long-term because neither the initial period of acclimation nor the ensuing quiescent period may be indicative of typical movement patterns. The 2–4-week acclimation period of extensive movement we observed indicates than stocking grass carp for vegetation control in particular areas, such as bays or coves, will probably prove ineffective because fish will roam widely and will likely encounter other suitable areas, if available, before the onset of the quiescent period. Additionally, if grass carp are used as vegetation control agents in reservoir systems, care should be taken to ensure acclimation takes place during a period of low flow rates. This precaution should help minimize escape potential during acclimation, when the fish are most active and the probability of emigration is high. However, as the fish grow, their tendency to move increases along with the probability of escape from target study or management areas. Because little evidence for diel shifts in movement activity exists, daylight tracking alone may be sufficient to monitor grass carp movement. Finally, although some managers claim grass carp do not move downstream, our data indicate these fish will move both upstream and downstream. Tagged fish were observed moving in either direction in the Navidad River, in Mustang Creek, and in the main body of Lake Texana. Management decisions should not be based on the assumption that grass carp will only move upstream. Prudence should be used when stocking sites are chosen and approved because downstream areas may be affected by grass carp moving out of upstream areas. In particular, special caution is probably warranted when threatened or endangered species' habitats or sensitive wetland areas are downstream of proposed grass carp stocking sites.

Acknowledgments

We thank John Chamberlain, Noeleonel Garcia, Todd Viola, and David Wilson for excellent technical support during the course of the study. We also thank Jeffrey Foltz and Steve Kartalia (Clemson University), Richard Luebke and Maurice Muoneke (Texas Parks and Wildlife Department), and Brian Murphy (Texas A&M University) for helpful reviews of the manuscript.

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Received July 19, 1993
Accepted December 16, 1996