MOVEMENT AND HABITAT USE BY TRIPLOID GRASS CARP IN THE LOWER

RIO GRANDE, TEXAS

THESIS

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INTRODUCTION

Aquatic macrophytes are important components of aquatic ecosystems, providing both biotic and abiotic resources, refuge from predation, and habitat for spawning (Matthews, 1998; Wetzel, 2001). In recent years, freshwater habitats have experienced increasing disturbance and declines in water quality due to intensive agricultural practices, urbanization, and increasing point and non-point source pollution. As a result, many aquatic ecosystems are more susceptible to exotic weed infestation, which are economically and biologically detrimental (Colle and Shireman, 1980; Colle et al., 1987; Bain, 1993; Langeland, 1996). Noxious weeds like hydrilla (*Hydrilla verticillata*) and water hyacinth (*Eichhornia crassipes*) decrease recreational use of water-bodies, out-compete native flora, and impede flow of waterways (Colle and Shireman, 1980; Colle et al., 1987; Beyers and Carlson, 1993). Dense infestation of water hyacinth can also result in large losses of water through evapo-transpiration. Water hyacinth evapo-transpiration rate is as high as 13 times that of an open-water surface (Singh and Gill, 1996; Makhanuk, 1997).

Water hyacinth is a freshwater, free-floating plant that has an extremely high growth rate, and exhibits a high degree of phenotypic and genotypic plasticity (Pearce, 1998; Tabita and Woods, 1962). Water hyacinth reproduces primarily through stolons, is capable of doubling in coverage every month during the growing season, and produces seeds that can lay dormant for up to 7 years (Tabita and Woods, 1962). Water hyacinth is native to South America and was first introduced into this country by a visitor returning from the World's Industrial and Cotton Centennial Exposition in 1884-1885 (Tabita and Woods, 1962).

The exotic plant hydrilla is the most dominant submerged weed in the southeastern United States and was originally misidentified as American elodea (*Elodea canadensis)* (Netherland, 1997; Les et al., 1997). Hydrilla has a growth form that allows it to out-compete native plants for nutrients and sunlight. Hydrilla can spread by fragmentation and can also propagate through tubers, turions, and seeds (Langeland, 1996). Hydrilla is native to Africa, Asia, and parts of Europe, it was first discovered in North America in Florida in 1960 and by the 1970's was established in all major drainage basins in the state (Langeland, 1996). Hydrilla now occurs throughout much of the southern United States, including all Gulf and Atlantic coast states (Langeland, 1996).

Increasing water use over the past decade and recent drought in southwest Texas and northeastern Mexico have reduced flow and has limited the amount of water that can be withdrawn from the Rio Grande for municipal and agricultural purposes. The amount of water available for use is regulated by two reservoirs, Lake Falcon, currently (22 May 2003) at 13% conservation capacity, and Lake Amistad, currently at 32% conservation capacity. Overall, United States ownership within the Rio Grande is at 25% capacity (personal communication, Earl Chilton, Texas Parks and Wildlife Department). Water shortage in the lower Rio Grande has been exacerbated by the invasion of hydrilla and water hyacinth. Currently, hydrilla and water hyacinth infest a large portion of the Rio Grande downstream of Falcon Reservoir from McAllen, Texas to Brownsville, Texas.

Methods used to control nuisance aquatic vegetation are mechanical, chemical, biological, or an integrated approach (Buck et al, 1975; Martyn et al., 1986; Kirk, 1992).

Mechanical removal (shredding) of water hyacinth was conducted on a 19 km stretch of the Rio Grande in 1998, 40 km stretch in 1999, and a 48 km stretch in 2000. The control proved reasonably effective for water hyacinth. However, shredding was deemed inappropriate for hydrilla due to its ability to grow from fragments, and mechanical harvesting was too costly, slow, and labor intensive. After the first year of shredding the population, water hyacinth was reduced and consequently the following year the Texas Parks and Wildlife Department was able to clear twice as many river miles at 60% of the 1998 cost (personal communication, Earl Chilton, Texas Parks and Wildlife Department). Unfortunately, areas cleared of water hyacinth had increased growth and coverage of hydrilla. Until recently, chemical control was a non-viable option for the Rio Grande because the laws governing chemical control methods differ between the United States and Mexico.

Efforts to use insects as biological control agents of exotic aquatic plants are under investigation (Langeland, 1996). Currently, a weevil (*Neochetina sp.*) for water hyacinth and a fly (*Hydellia pakistannae*) for hydrilla are being tested in the lower Rio Grande by the U.S. Bureau of Reclamation, U.S. Army Corps of Engineers, and the U.S. Department of Agriculture (personal communication, Earl Chilton, Texas Parks and Wildlife Department). However, grass carp (*Ctenopharyngodon idella*) are the most commonly used organisms for long term control of hydrilla, and are relatively inexpensive compared to mechanical and chemical methods (Bonar et al., 1993; Beyers and Carlson, 1993).

Because of grass carp ability to move long distances and potentially move into undesirable non-target areas, and reduce native plant abundance, (Chilton and Muoneke, 1992; Clapp et al., 1993; Chilton and Poarch, 1997) grass carp use for vegetation control is controversial. Grass carp were prohibited in Texas prior to 1981, but after a year of litigation the Texas legislature passed House Bill 556, which allowed the release of diploid grass carp in Lake Conroe to examine their effectiveness in controlling nuisance aquatic vegetation (Trimm et al., 1989). Diploid grass carp now occur in the Trinity River, Cedar Bayou, Baytown, Spring Bayou, and the San Jacinto River (Trimm et al., 1989; Howells, 1993; Elder and Murphy, 1997). Effects of grass carp on native fish communities are variable. In some cases, total fish biomass has remained similar before and after elimination of vegetation by grass carp (Killgore et al., 1998). In other cases however, there are reductions in fish species diversity and changes in fish composition where pelagic species flourish while littoral species decline with grass carp introduction (Kilgen and Smitherman, 1971; Forester and Lawrence, 1978; Bettoli et al., 1993; Bain, 1996). The introduction of grass carp can also increase nutrient levels, induce phytoplankton blooms, increase turbidity, and reduce dissolved oxygen levels in aquatic ecosystems (Bain, 1996).

In 1989 the Texas legislature allocated $750,000 to study the effectiveness and safety of triploid grass carp (functionally sterile) as opposed to diploid grass carp as vegetation control agents (personal communication, Earl Chilton, Texas Parks and Wildlife Department). The majority of male gametes or sperm cells (0.99999988%) produced by a triploid are aneuploid, thereby decreasing the probability of grass carp establishing self-reproducing populations (Allen and Wattendorf, 1987). Hybrid grass carp (grass carp female X bighead carp male *Aristichtys nobilis*) have also been used for vegetation control, but are not as effective (Osborne, 1982; Shireman et al., 1983; Wiley and Wike, 1986). In 1992 the recommendation was made to legalize triploid grass carp in Texas by obtaining a permit from the Texas Parks and Wildlife Department (Texas Parks and Wildlife Department, 1992).

Factors that influence triploid grass carp vegetation consumption are plant species and tissue composition and abundance (Fowler and Robson, 1978), fish size (Osborne and Sassic, 1981), water temperature (Kilambi and Robison, 1979; Cai and Curtis, 1990), and salinity (Kilambi, 1980; Routray and Routray, 1997). Factors that affect grass carp herbivory are generally well studied. However, effects of salinity on grass carp herbivory are seldom considered because grass carp are freshwater fish. Although little is known on how salinity affects herbivory, grass carp are able to withstand a wide range of salinities (Cross, 1970; Kilambi, 1980; Kilambi and Zdinak, 1980; Chilton and Muenoke, 1992; Routray and Routray, 1997). Grass carp may even survive up to several days at salinities up to 100 ppt (Liepolt and Weber, 1969). Because of their tolerance to salinity and ability to move long distances, one concern over the introduction of grass carp in the lower Rio Grande to control nuisance aquatic vegetation is their ability to move into bays and estuaries and impact seagrass ecosystems which provide nursery habitat for estuarine fisheries. Thus, it was important that a pilot study be conducted before any large-scale introduction of grass carp was initiated for control of nuisance aquatic vegetation in the lower Rio Grande. The purpose of this study was to determine the magnitude, direction, and movement patterns of grass carp from designated release points and subsequent relocation points, and to determine habitat characteristics (conductivity, stream depth, temperature, habitat type, and flow velocity) of relocated grass carp. Results of this study not only have an applied management application, they provided descriptive dispersal and distribution ecology of grass carp in the lower Rio Grande. The study also provided information about grass carp dispersal through weir or channel diversion dams and distance traveled from the designated release points and subsequent relocation points.

METHODS

Study Area—The Rio Grande originates in the San Juan Mountains in Colorado following a 1,885-mile course, draining 182,200 square miles of varied landscape, and serving as the boundary between the United States and Mexico for more than two-thirds of its length before finally entering into the Gulf of Mexico. Throughout the river basin there are many water structures that function to meet the regional needs for flood control, power generation, municipal, agricultural, and industrial purposes.

The lower portion of the Rio Grande, known as the Rio Grande Valley begins at Falcon International Reservoir, continuing down to the Gulf of Mexico and comprises Cameron, Hidalgo, Starr, and Willacy Counties. This subbasin of the Rio Grande is an agriculturally active area. In 1994, the Rio Grande Valley accounted for nearly 50% of surface-water irrigation withdrawals in Texas (Lurry et al., 1998).

The study area encompassed 97 km of the lower Rio Grande from McAllen, Texas to Progreso, Texas. This area is also used for agricultural and municipal purposes, and there are two large water diversion dams, Anzalduas Dam and Retamal Dam that are used for flood control. Overall, discharge below Anzalduas Dam was low during the study period (Fig. 1) and water depth was ≤ 2 m. In general, the water quality (increased salinity) of the Rio Grande progressively decreases downstream, and is associated with the intensive agricultural practices along this segment of the Rio Grande (Lurry et al., 1998). Hydrilla and water hyacinth are the dominant plant species within this segment of the river with localized populations of filamentous algae and water star grass (*Cynodon nlemfuensis*).

Grass carp telemetry—Twenty-five triploid grass carp ranging from 510 mm to 625 mm in TL and 1.5 to 2.7 kg in weight were obtained from Johnson Lake Management Services and transported to A.E. Wood State Fish Hatchery in San Marcos, Texas. Fish were lightly sedated in 460 ppm buffered MS222 solution (buffer mix = 7.5 g sodium bicarbonate and 1.5 g MS222 dissolved in 37.8 liters of water) to reduce stress during handling and transport.

Twenty-five dual coded transmitters were obtained from Lotek Wireless, Newmarket, Ontario, Canada for surgical implantation. The CART 16_1 series uses combined acoustic / radio transmitters with external antennas to provide tracking flexibility in case high conductivity in the river or near the estuary interfered with the radio signals. CART transmitters were coded so that different fish were identifiable. Radio and acoustic frequencies were 150.5 and 76.8 megahertz (MHz) respectively. Transmitter average weight in water was 16.3 g, battery life was 663 days, and programmed to run continuously. Each fish was assigned a tag with a specific code number and the corresponding transmitter was surgically placed into the abdominal cavity.

Abdominal surgery was performed by making a mid-ventral incision beginning 3 cm posterior of either pelvic fin, extending 5 cm and then transmitters were placed into the abdominal cavity. Incisions were closed with 5-8 sutures. Absorbable vicryl coated sutures swaged to semi-circle taper cutting needles were used for surgery and abraded body areas were disinfected with 2% providone iodine solution. After surgery was completed, each fish was dipped into 0.5-1.0% salt solution for 30 seconds. Fish were placed in a flow-through raceway for a 7-day period to allow for recovery from surgical stress (Prentice et al., 1998).

Fourteen triploid grass carp were released in the lower Rio Grande at the Hidalgo and Cameron County Irrigation District # 9 pump station located near Progreso, Texas (26°20'N 98°11'W) and eleven were released 0.6 Km below Anzalduas Dam (26°08'N 98°20'W) located in the town of Granjeno, Texas on 10 October 2001. Tracking periods consisted of searching for transmission of radio signals along a 97 km stretch of the river from Anzalduas County Park, Texas to the Rio Grande weir (26°03'N 97°49'W) located near Progreso, Texas (Fig. 2). Tracking also was conducted farther downstream near the towns of El Ranchito and Brownsville, Texas (25°57'N 97°35'W) where boat access was available. Tracking was conducted by running the river until a radio signal was detected. Upon detection, 3 to 5 boat passes were conducted in an effort to increase accuracy of fish location and to achieve transmission of highest possible signal power (highest = 232 MHz).

Once a fish was located as accurately as possible, its position was taken using a global positioning system (Omnistar 3000L DGPS; ± 5 m). Habitat type [characterized as hydrilla, water hyacinth, filamentous algae (*Spirogyra* sp.) or exposed sediment] and various physiochemical parameters [conductivity (μs/cm), temperature (°C), stream depth (m), dissolved oxygen (mg/L), and flow velocity (m/s)] were recorded once a fish position was located. Grass carp dispersal was examined 7 ways: 1) number of times each fish was located during each tracking period (n = 72), 2) distance traveled from release point by each fish after first location (km) was the distance traveled by each grass carp to first location (n = 20), 3) total movement (km) was the sum distance traveled of all relocated fish (n = 72), 4) mean movement (km) was the average distance traveled by all fish between relocations (n = 72), 5) mean daily movement (km) was the average daily distance traveled by all fish between relocations (n = 72), 6) Mean maximum movement (km) was the average of the largest traveled distance among relocation intervals for each fish (n = 20), and 7) monthly direction of grass carp movement. Total movement, mean movement, and mean daily movement were examined monthly, throughout the entire study, and by season. Ten tracking periods were conducted from 11 October 2001 through 19 May 2002 (3 weekly samples after release, followed by 7 monthly samples).

RESULTS

Twenty out of 25 radio-tagged triploid grass carp were located in the lower Rio Grande. Four fish were located once, 4 fish were located twice, and 12 fish were located 4 or more times (Table 1). Only 1 grass carp was located during the 3 tracking periods conducted in October after release, consequently this grass carp was only included in the distance traveled from release point after first location and mean maximum movement. For the 7 subsequent tracking periods, the most grass carp located during a single tracking event was 15 in January, and the lowest number was 3 in May. All fish were found in water depths 2 m or less (Table 2) and associated mainly with hydrilla (48%), sometimes in mats as small as 2 m^2. Fish were also associated with exposed sediment (Fig. 3), but were always within a few meters of vegetation.

Overall, distance traveled by grass carp from release point to first location ranged from 1.6 to 26 km (Fig. 4). On a monthly basis, total movement (Table 3), mean movement (Table 3; Fig. 5), and mean daily movement (Table 3; Fig. 6) by triploid grass carp had an initial high period of activity followed by a steady decrease through time. During the entire study, total movement was 411.3 km, mean movement was 5.7 ± 1.0 km, and mean daily movement was 0.2 ± 0.0 km/d (Table 4). Seasonally, grass carp exhibited a higher period of activity during the fall/winter months than in spring months (Table 4). Mean maximum movement was 14.8 ± 2.3 km (range, 1.6 to 41.8 km), with most activity occurring within the first half of tracking (Table 5).

During the entire study, directionality of grass carp movement was variable (Table 6). Thirteen of 20 fish exhibited no strong directionality in their movement patterns. Three fish moved upstream 11.6, 14.8, and 23.8 km from their stocking sites respectively, although no fish were located upstream of Anzalduas Dam. In contrast, 4 fish moved downstream 1.6, 3.5, 21.8, and 23.3 km from their stocking sites. Often times, grass carp located on consecutive separate tracking periods exhibited high movement activity followed by intermittent movement irrespective of direction. For example, one fish moved 63.3 Km upstream from its stocking site then moved downstream 0.3 Km from its previous location during a subsequent tracking period. After 3 months, some grass carp started to exhibit no directionality, instead fish activity decreased dramatically, eventually becoming stationary.

Discussion

Grass carp exhibited large dispersal within a month of release in the lower Rio Grande, followed by a period of little movement. Several authors have reported a similar pattern (Mitzner, 1978; Nixon and Miller, 1978; Bain et al., 1990; Cassani and Maloney, 1991; Chilton and Poarch, 1997). Nixon and Miller (1978) tracked twelve grass carp in a 2025-hectare reservoir in Florida and reported movement from 0.2 to 18.3 Km, and observed a "rest and go" pattern where some grass carp had reduced movement among tracking intervals and significant movement at other times. Clapp *et al.* (1993) reported a maximum distance of 17.1 km from the initial stocking site in Lake Harris, Florida and noted that 61% of movements greater than 1.0 km occurred during the first half of the tracking period. Temperature, food availability and acclimation have been suggested to play a role in grass carp dispersal behavior following release in which there is an initial period of high activity, followed by an interval of little directed movement. For example, Nixon and Miller (1978) reported an increase in grass carp movement with an increase in temperature. Bain *et al.* (1990) and Chilton and Poarch (1997) recorded more movement by grass carp in summer months when water temperatures are warmer, than in winter months, when water temperatures are cooler. Chilton and Poarch (1997) made a total of 214 movement observations for 22 grass carp in Lake Texana, Texas between summer (1990) and winter (1990-1991) and the mean movement per day was 32 ± 7 m in the summer (101 observations) and declined to 7 ± 2 m in winter (113 observations). Because I stocked grass carp in October, just before temperatures in the lower Rio

Grande began a winter decline, I expected to observe reduced activity during fall and winter if temperature affected dispersal behavior. Instead, the pattern was greater movement during cooler months and progressively decreased movement through spring (Hockin et al., 1989; Cassani and Maloney, 1991). This suggests factors other than temperature are stimulating high dispersal initially by grass carp in the lower Rio Grande.

Another factor that is suggested to influence grass carp dispersal behavior (an initial high period of activity followed by little to no activity) is plant composition and abundance (Fowler and Robson, 1978; Mitzner, 1978; Bain et al., 1990; Clapp et al., 1993). I found strong grass carp association with hydrilla stands in the lower Rio Grande. Bain *et al.* (1990) reported that hydrilla occurrence was 43% at grass carp relocations versus only 3% lakewide in Guntersville Reservoir, Alabama during the first year of the study, while Clapp *et al.* (1993) reported that hydrilla was dominant at 30% of fish locations and only 21% of lakewide locations in Lake Yale, Florida. Kirk *et al.* (2001) reported 70% of grass carp observations were associated with hydrilla in Cooper River, South Carolina. Several studies have shown that grass carp are selective foragers, feeding primarily on the most preferred species before consuming less desirable ones (Mitzner, 1978; Colle et al., 1978; Fowler and Robson, 1978). These studies usually involved a variety of plant types and preference depended on the species available. In several studies, hydrilla has been at the top of the list as a plant preferred by grass carp (Shireman and Maceina, 1981; Shireman et al., 1983; Chilton and Muoneke, 1992; Hanlon et al., 2000).

The grass carp in the lower Rio Grande rarely used areas dominated by filamentous algae and water hyacinth. Opuszinski (1972) reported that filamentous algae and floating aquatic plants are rarely eaten by grass carp, and that even during a massive algae bloom in Zabieniec, Poland, filamentous algae only comprised 9% of the total food intake. Catarino *et al.* (1997) reported that grass carp avoided water hyacinth when given the choice between more preferred plant species. However, the substantial use of unvegetated areas (exposed sediment) by grass carp (26%) was unexpected, although Bain *et al.* (1990) reported a similar finding.

Acclimation is a third factor that may be responsible for decreasing movement by grass carp after release. Numerous authors have suggested that that transportation of fish in hauling tanks cause an increase in physiological stress and can even cause an increase in mortality rate before and after stocking (Carmichael et al., 1983; Olla et al., 1998). Although there has never been any research conducted to suggest that stress contributes to fish dispersal behavior post-release, I hypothesize that transportation of fish to stocking sites and/or acclimation to a new environment may have been another contributing factor to the grass carp dispersal behavior observed on the lower Rio Grande. It is possible that when fish living in a hatchery environment are under controlled conditions for several months and then transported considerable distances to stocking sites and introduced, initial dispersal behavior may be a result of stress experienced during transportation or gaining experience in a new unfamiliar environment.

Absence of strong directionality patterns in the lower Rio Grande has management implications. Gorbach and Krykhtin (1989) report that grass carp have traveled as far as 500 Km upstream towards spawning grounds in the first 2 years of migration. Bain *et al.* (1990) reported upstream movement of fish in Guntersville

Reservoir, Alabama, while Nixon and Miller (1978) also reported 11 of 12 grass carp moved in an upstream direction. As a result, many lake and pond managers suggest to clients that grass carp will not migrate downstream from their stocking point (Chilton and Poarch, 1997). In my study, 29 of 72 movement observations recorded were in a downstream direction even though our fish (mean 568 mm) were fairly close to the size range (630 mm to 670 mm) that would begin a natural upstream migration (Chilton and Muoneke, 1992; Chilton and Poarch, 1997).

It is difficult to determine the fate of 5 radio-tagged grass carp that were not located in the lower Rio Grande. One possibility is that these grass carp traveled into areas where boat access was unavailable and were beyond equipment detection limits. Harvest of grass carp may offer another explanation for my inability to locate all fish. During several tracking periods hand-wrought gillnets were observed stretched along side and across river banks. Recreational fishing and cast netting was also observed along the banks of the river on numerous occasions.

In conclusion, my data suggests that temperature differences did not play a role in influencing grass carp dispersal behavior. Although, in regions where there are definitive seasons, temperature differences may contribute to grass carp dispersal behavior to a larger degree than were observed on the lower Rio Grande. Additionally, plant composition and abundance is an important issue if grass carp are used for vegetation control, close attention should be given to the plant species available within the specified target area. Attention should also be given to flow rate at the time grass carp stocking occurs. Although, flow was low in the lower Rio Grande during the duration of my study there is potential for grass carp to emigrate beyond specified target areas during periods of abnormally high flow. For example, Prentice *et al.,* (1998) reported an emigration rate of 3.5 % from home reservoirs (target areas) during low flow conditions (1.6 m^3/s to 15.9 m^3/s) compared to an emigration rate of 59 % during high flow conditions (> 23.5 m^3) in the Guadalupe River, Texas. Significant rainfall caused increased river flow conditions resulting in numerous dam-gate drawdowns. During the high flow period 57 out of 125 grass carp moved passed 1 to 10 dams covering a distance of 325 Km, compared to 13 out of 125 grass carp moving past 1 to 6 dams covering a distance of 106 Km during low flow conditions. In the Guadalupe River water passing downstream had to pass through hydropower generators, during the course of this study there was always a degree of unrestricted passage possible through Anzalduas Dam release gates, therefore if the lower Rio Grande were to experience a significant rainfall event causing abnormally high flow conditions, this may result in numerous dam-gate drawdowns. If emigration upstream through Anzalduas Dam were to occur, grass carp could potentially enter flood control channels that flow into the Arroyo Colorado, eventually entering the Laguna Madre and possibly impacting seagrass ecosystems. More research needs to be conducted to fully understand grass carp behavior and ecology in large open systems so that existing vegetation management strategies can be further expanded to include large river systems

LITERATURE CITED

ALLEN, S. K., JR. AND WATTENDORF, R. J. 1987. Triploid grass carp: status and management implications. Fisheries 12:20-24.

BAIN, M. B. 1993. Assessing impacts of introduced aquatic species: grass carp in large systems. Environmental Management 17:211-224.

BAIN, M. B. 1996. Rivers and impounded waters. In: Cassani, J.R., editor. Managing aquatic vegetation with grass carp: A guide for water resource managers. American Fisheries Society, Introduced Fish Section, Bethesda, Maryland. Pp. 65-75.

BAIN, M. B., D. H. WEBB, M. D. TANGEDAL, AND L. N. MANGUM. 1990. Movements and habitat use by grass carp in a large mainstream reservoir. Transactions of the American Fisheries Society 119: 553-561.

BETTOLI, P. W., M. J. MACEINA, R. L. NOBLE, AND R. K. BESTILL. 1993. Response of a reservoir fish community to aquatic vegetation removal. North American Journal of Fisheries Management 13:110-124.

BEYERS, D. W., AND C. A. CARLSON. 1993. Movement and habitat use of triploid grass carp in a Colorado irrigation canal. North American Journal of Fisheries Management 13:141-150.

BONAR, S. A., G. L. THOMAS, S. L. THIESFELD, G. B. PAULEY, AND T. B. STABLES. 1993. Effect of triploid grass carp on the aquatic macrophyte community of Devils Lake, Oregon. North American journal of Fisheries Management 13:757-765.

BUCK, D. H., R. J. BAUR, AND C. R. ROSE. 1975. Comparison of the effects of grass carp and the herbicide diuron in densely vegetated pools containing golden shiners and bluegills. Progressive Fish Culturist 37:185-190.

CAI, Z. AND L. R. CURTIS. 1990. Effects of diet and temperature on food consumption, growth rate, and tissue fatty-acid composition of triploid grass carp. Aquaculture 88:313-327.

CARMICHAEL, G. J., G. A. WEDEMYER, J. P. MCCRAREN, AND J. L. MILLARD. 1983. Physiological effects of handling and hauling on smallmouth bass. Progressive Fish Culturist 2:110-113.

CASSANI, J. R., AND D. MALONEY. 1991. Grass carp movement in two morphologically diverse reservoirs. Journal of Aquatic Plant Management 29:83-88.

CATARINO, L. F., M. T. FERREIRA, AND I. S. MOREIRA. 1997. Preferences of grass carp for macrophytes in Iberian drainage channels. Journal of Aquatic Plant Management 36:79-83.

CHILTON, E. W., II AND M. J. MUONEKE. 1992. Biology and management of grass carp (*Ctenopharyngodon idella*, Cyprinidae) for vegetation control: a North American perspective. Reviews in Fish Biology and Fisheries 2:283-320.

CHILTON, E. W., II. AND S. M. POARCH. 1997. Distribution and movement behavior on radio-tagged grass carp in two Texas reservoirs. Transactions of the American Fisheries Society 126:467-76.

CLAPP, D. F., R. S. HESTAND III, B. Z. THOMPSON, AND L. L. CONNOR. 1993. Movement of triploid grass carp in large Florida lakes. North American Journal of Fisheries Management 13:746-756.

COLLE, D. E., J. V. SHIREMAN, AND R. W. ROTTMAN. 1978. Food selection by grass carp fingerlings in a vegetated pond. Transactions of American Fisheries Society 107:149-152.

COLLE, D. E., AND J. V. SHIREMAN. 1980. Coefficients of condition for largemouth bass, bluegill, and redear sunfish in hydrilla-infested lakes. Transactions of the American Fisheries Society 109:521-531.

COLLE, D. E., J. V. SHIREMAN, W. T. HALLER, J. C. JOYCE, AND D. E. CANFIELD JR. 1987. Influence of hydrilla on harvestable sport-fish populations, angler use, and angler expenditures at Orange Lake, Florida. North American Journal of Fisheries Management 7:410-417.

CROSS, D. G. 1970. The tolerance of grass carp (*Ctenopharyngodon idella* Val.) to seawater. Journal of Fish Biology 2:231-233.

ELDER, H. S. AND B. R. MURPHY. 1997. Grass carp (*Ctenopharyngodon idella*) in the Trinity River, Texas. Journal of Freshwater Ecology 12:281-289.

FORESTER, T. S. AND J. M. LAWRENCE. 1978. Effects of grass carp and carp on populations of bluegill and largemouth bass in ponds. Transactions of the American Fisheries Society 107:172-175.

FOWLER, M. C. AND T. O. ROBSON. 1978. The effects of the food preferences and stocking rates of grass carp (*Ctenopharyngodon idella* Val.) on mixed plant communities. Aquatic Botany 5:261-276.

GORBACH, E. I., AND M. L. KRYKHTIN. 1989. Migration of the white amur, *Ctenopharyngodon idella*, and the silver carp, *Hypophthalmichthys molitrix*, in the Amur River basin. Journal of Ichthyology 28:47-53.

HANLON, S. G., M. V. HOYER, C. E. CICHRA, AND D. E. CANFIELD JR. 2000. Evaluation of macrophyte control in 38 Florida lakes using triploid grass carp. Journal of Aquatic Plant Management 38:48-54.

HOCKIN, D. C., K. O'HARA, AND J. W. EATON. 1989. A radiotelemetric study of the movements of grass carp in a British canal. Fisheries Research 7:73-84.

HOWELLS, R. G. 1993. Confirmed grass carp spawning. Fisheries 18:36

KILAMBI, R. V. 1980. Food consumption, growth, and survival of grass carp (*Ctenopharyngodon Idella* Val.) at four salinities. Journal of Fish Biology 17:613-18.

KILAMBI, R. V. AND W. R. ROBISON. 1979. Effects of temperature and stocking density on food consumption and growth of grass carp (*Ctenopharyngodon idella*, Val.). Journal of Fish Biology 16:171-175.

KILAMBI, R. V. AND A. ZDINAK. 1980. The effects of acclimation on the salinity tolerance of grass carp, (*Ctenopharyngodon idella* Cuv. And Val). Journal of FishBiology 16:171-175.

KILGEN, R. H., AND R. O. SMITHERMAN. 1971. Food habits of the white amur stocked in ponds alone, and in combination with other species. Progressive Fish Culturist 33:123-127.

KILLGORE, K. J., J. P. KIRK, AND J. W. FOLTZ. 1998. Response of littoral fishes in Upper Lake Marion, South Carolina following hydrilla control by triploid grass carp. Journal of Aquatic Plant Management 36:82-87.

KIRK, J. P. 1992. Efficacy of triploid grass carp in controlling nuisance aquatic vegetation in South Carolina farm ponds. North American Journal of Fisheries Management 12:581-584.

KIRK, J. P., K. J. KILLGORE, J. V. MORROW JR., S. D. LAMPERECHT, AND D. W. COOKE. 2001. Movements of triploid grass carp in the Cooper River, South Carolina. Journal of Aquatic Plant Management 39:59-62.

LANGELAND, K. A. 1996. *Hydrilla verticillata* (L.F.) Royle (Hydrocharitaceae), "The Perfect Aquatic Weed". Castanea 61:293-304.

LES, D. H., L. J. MEHROFF, M. A. CLELAND, AND J. D. GABEL. 1997. *Hydrilla Verticillata* (Hydrocharitaceae) in Connecticut. Journal of Aquatic Plant Management 35:10-14.

LIEPOLT, R. AND E. WEBER. 1969. Versuche mit phytophagen fischen *Ctenopharyngodon idella*) (Studies with phytophagous fish (*Ctenopharyngodon idella*)]. Revue Roumaine de Biologie-Zoologie. 14:127-32.

LURRY, D. L., D. C. REUTTER, AND F. C. WELLS. 1998. Rio Grande NASQAN Program-Monitoring the water quality of the nation's large rivers: U.S Geological Survey Fact Sheet FS-083-98.

MAKHANUK, K. S. 1997. Impact of water hyacinth on Lake Victoria. 23rd WEDC Conference, Durban, South Africa.

MARTYN, R. D., R. L. NOBLE, P. W. BETTOLI, AND R. C. MAGGIO. 1986. Mapping aquatic weeds with aerial color infared photography and evaluating their control by grass carp. Journal of Aquatic Plant Management 24:46-56.

MATTHEWS, W. J. 1998. Patterns in freshwater fish ecology. Chapman and Hall, New York, New York.

MITZNER, L. 1978. Evaluation of biological control of nuisance aquatic vegetation by grass carp. Transactions of the American Fisheries Society 107:135-145.

NETHERLAND, M. D. 1997. Turion ecology of hydrilla. Journal of Aquatic Plant Management 35:1-10.

NIXON, D. E. AND R. L. MILLER. 1978. Movements of grass carp, *Ctenopharyngodon idella*, in an open reservoir system as determined by underwater telemetry. Transactions of the American Fisheries Society 107:146-148.

OLLA, B. C., M. W. DAVIS, AND C. H. RYER. 1998. Understanding how the hatchery environment represses or promotes the development of behavioral survival skills. Bulletin of Marine Science 2:531-550.

OPUSZYNSKI, K. 1972. Use of phytophagous fish to control aquatic plants. Aquaculture 1:61-74.

OSBORNE, J. A. 1982. The potential of the hybrid grass carp as a weed control agent. Journal of Freshwater Ecology 1:353-360.

OSBORNE, J. A. AND N. M. SASSIC. 1981. The size of grass carp as a factor in the control of hydrilla. Aquatic Botany 11:129-136.

PEARCE, F. 1998. All-out war on the alien invader. New Scientist 158:34-38.

PRENTICE, J. A., W. J. DEAN JR., M. S. REED, AND E. W. CHILTON. 1998. Movement of triploid grass carp in small hydropower impoundments of the Guadalupe River, Texas. Proceedings Annual Conference Southeastern Association Fish and Wildlife Agencies 52.

ROUTRAY, P. AND M. D. ROUTRAY. 1997. Growth potential of grass carp (*Ctenopharyngodon idella,* Val) in saline water with an aquatic weed *Potamogeton pectinatus* as feed. Fishery Technology 34:7-10.

SHIREMAN, J. V., AND M. J. MACEINA. 1981. The utilization of grass carp, *Ctenopharyngodon idella* Val., for hydrilla control in Lake Baldwin, Florida. Journal of Fish Biology 19:629-636.

SHIREMAN, J. V., R. W. ROTTMAN, AND F. J. ALDRIGE. 1983. Consumption and of hybrid grass carp fed four vegetation diets and trout chow in circular tanks. Journal of Fish Biology 22:685-693.

SINGH, S. AND M. S. GILL. 1996. Evapo-transpiration loss of water hyacinth (*Eichhornia crassipes)* and chemical control of weed. Indian Journal of Agricultural Sciences 66:487-489.

TABITA, A., AND J. W. WOODS. 1962. History of waterhyacinth control in Florida. Hyacinth Control Journal 1:19-23.

TEXAS PARKS AND WILDLIFE DEPARTMENT. 1992. Application to stock triploid grass carp. Available: www.tpwd.state.tx.us. (1992)

TRIMM, D. L., G. GUILLEN, C. T. MENN, AND G. C. MATLOCK. 1989. The occurrence of grass carp in Texas Waters. Texas Journal of Science 41:413-417.

WETZEL, R. G. 2001. Limnology: lake and river ecosystems, 3rd edition. Academic Press, San Diego, California.

WILEY, M. J. AND L. D. WIKE. 1986. Energy balances of diploid, triploid, and hybrid grass carp. Transactions of the American Fisheries Society 115:853-863.

TABLE 1—Relocated triploid grass carp during each tracking period in the lower Rio Grande, Texas from November 2001 through May 2002.

	Tracking Dates (Periods)						
Code No	11/09-11/11	12/12-12/14	1/10-1/13	2/16-2/17	3/14-3/16	4/24-4/25	5/18-5/19
26	X	X	X	X	X	X	X
65	X	X	X	X	X	X	
31	X						
74	X	X	X		X		
60			X				
61	X		X	X	X		
25	X		X	X	X	X	
99							
75		X	X	X	X		
82			X	X			
106							
93	X	X	X	X			
17	X	X	X	X	X	X	X
88	X			X			
28	X	X		X	X		
101							
21		X	X				
102	X	X	X	X	X		
19		X					
89							
20	X	X	X		X	X	X
104		X	X	X	X		
33							
73	X		X				
39	X						
N =	14	12	15	12	11	5	3

TABLE 2—Range of physiochemical characteristics recorded at triploid grass carp relocation sites (N = 41) from December 2001 through May 2002 in the lower Rio Grande, Texas.

Parameter	Range
Conductivity (μs/cm)	765-1294
Temperature (°C)	14.6-28 1
Dissolved Oxygen (mg/L)	3 2-14 2
Current velocity (m/s)	0.0-0.5
Depth (m)	0 3-2 0

TABLE 3—Monthly total, mean, and mean daily movement by triploid grass carp from points of release and relocation from November 2001 through May 2002 in the lower Rio Grande, Texas.

Month	N	Total movement (Km)	Mean movement (Km)	Standard error	Mean daily movement (Km)	Standard error
November	14	185 1	13 2	2.6	0 4	0.0
December	12	97 7	8 1	3 6	0 3	0.1
January	15	76 3	5 1	1 6	0 2	0 1
February	12	50 9	4 2	1 7	0 2	0 1
March	11	0 3	0 03	0 0	0 0	0 0
April	5	1 0	0 2	0 2	0 2	0 0
May	3	0 0	0 0	0 0	0 0	0 0

TABLE 4—Total movement, mean movement, and mean daily movement by triploid grass carp from points of release and relocation from November 2001 through May 2002 in the lower Rio Grande, Texas.

Study period	Total movement (Km)	Mean movement (Km)	Standard error	Mean daily movement (Km)	Standard error
Nov 2001-Feb 2002	410.0	7.7	1.3	0.3	0 1
(Fall/Winter)	(N = 53)	(N =53)		(N =53)	
Mar 2002-May 2002	1.3	0.1	0.0	0.0	0.0
(Spring)	(N = 19)	(N =19)		(N =19)	
Nov 2001-May 2002	411.3	5.7	1.0	0.2	0.0
(Entire study)	(N = 72)	(N = 72)		(N = 72)	

TABLE 5—Summary of maximum movement by triploid grass carp (N = 20) in the lower Rio Grande, Texas from October 2001 through May 2002.

Code No.	Total number of observations		Maximum movement (Km)
60	1		1.6
21	2		3.2
104	4		3.2
39	1		3.5
102	5		5.3
28	4		7.4
82	2		9.0
26	7		10.5
17	7		10.6
*93	5		11.5
75	4		14.3
65	6		15.7
73	2		18.3
20	6		21.9
25	5		22.9
61	4		22.9
19	1		23.3
31	1		23.8
88	2		26.0
74	4		41.8
	73	Mean =	14.8
		Standard error =	2 3

*Maximum movement was recorded in October.

TABLE 6—Direction (%) of movement between relocation events for triploid grass carp from November 2001 through May 2002. U = upstream, D = downstream, S = stationary. Stationary is defined as little to no detected movement.

Month	N	Direction		
		U	D	S
November	14	64.3	35.7	
December	12	41.7	58.3	
January	15	26.7	73.3	
February	12	50.0	33.3	16.7
March	11	0.0	18.1	81.9
April	5	20.0	0.0	80.0
May	3			100.0

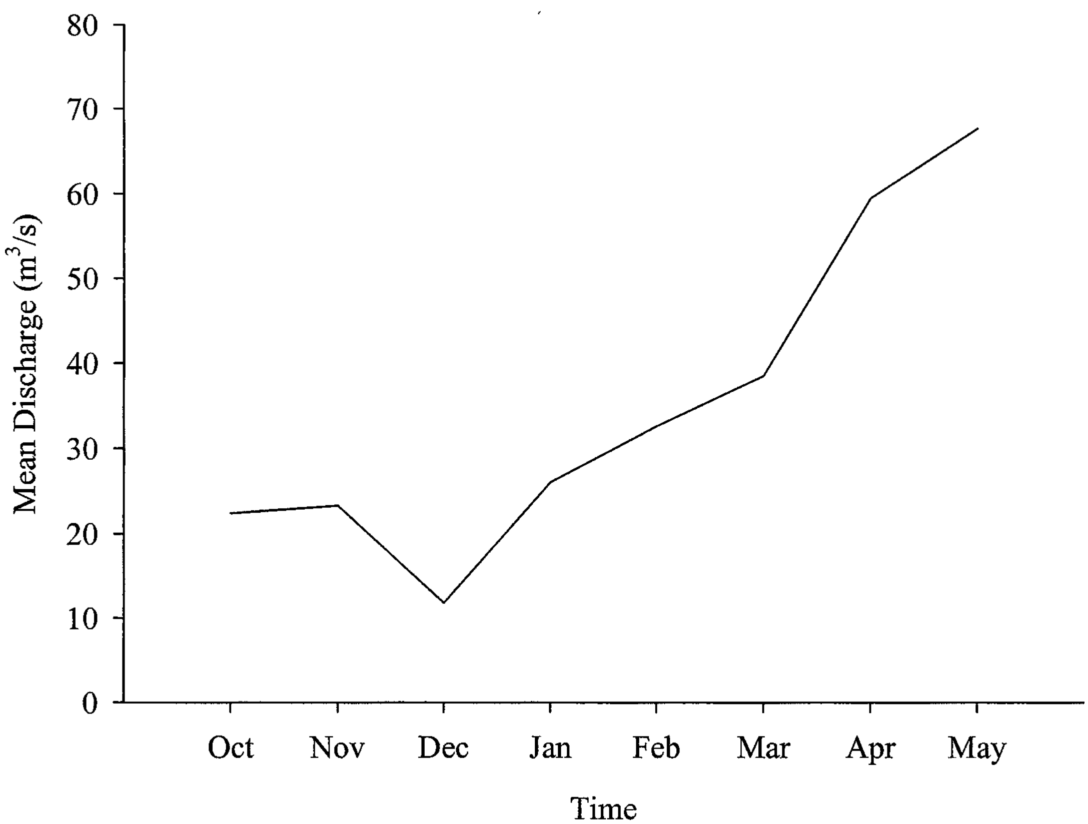

FIG. 1—Mean discharge below Anzalduas Dam from October 2001 through May 2002. (Data source: International Boundary Water Commission; available at: www.ibwc.state.gov.)

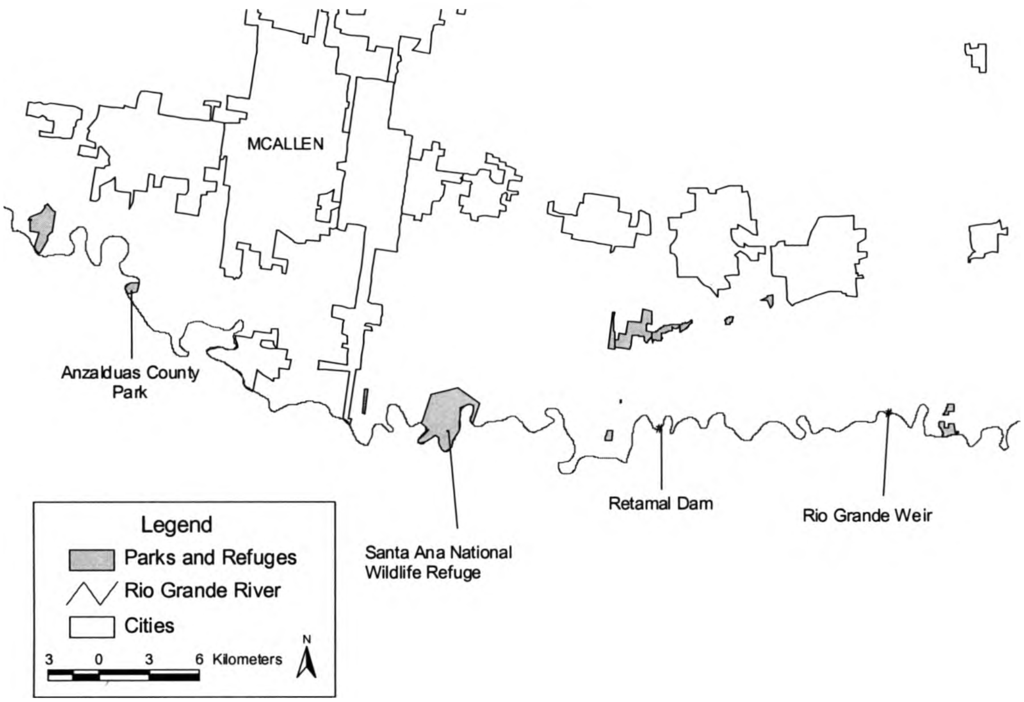

FIG. 2—Map of the lower Rio Grande from Anzalduas County Park (Anzalduas Dam) downstream to a Rio Grande weir located near Progreso, Texas where grass carp tracking was conducted from October 2001 through May 2002.

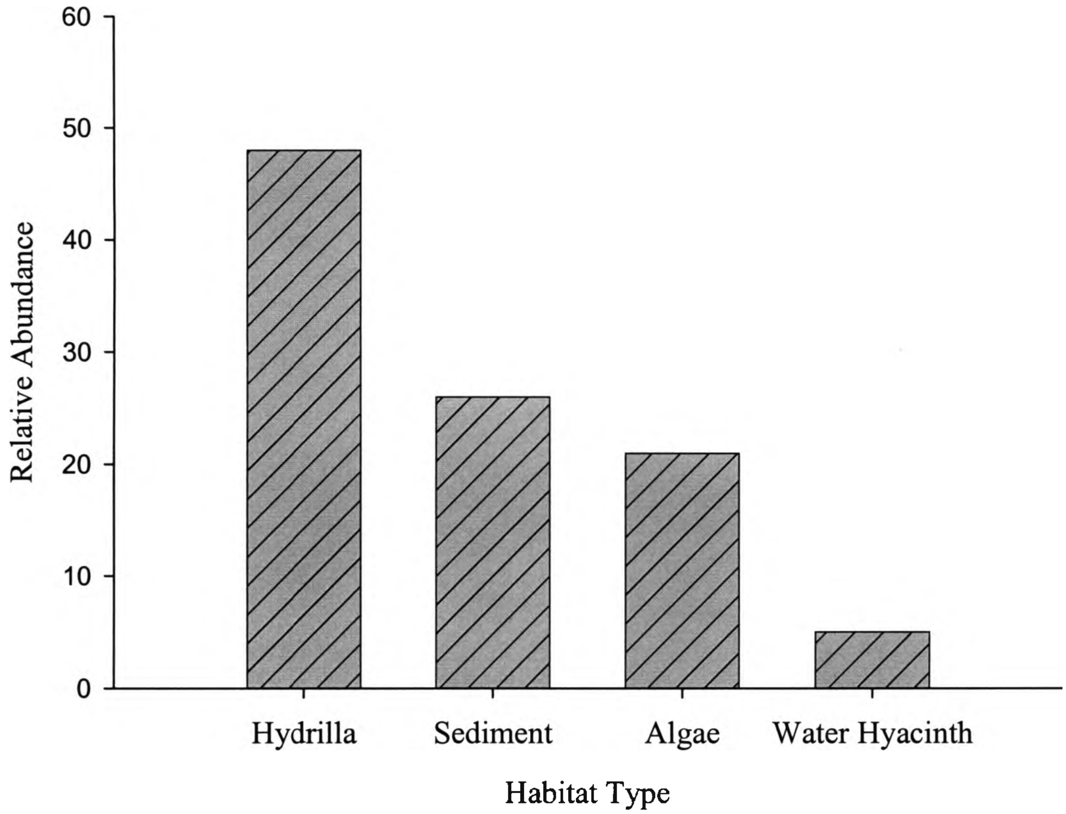

FIG. 3—Relative abundance of triploid grass carp (N = 72) located in each habitat type from November 2001 through May 2002 in the lower Rio Grande, Texas.

FIG. 4—Distance traveled from stocking site with corresponding date the first time each triploid grass carp (N = 20) was located in the lower Rio Grande, Texas from October 2001 through May 2002.

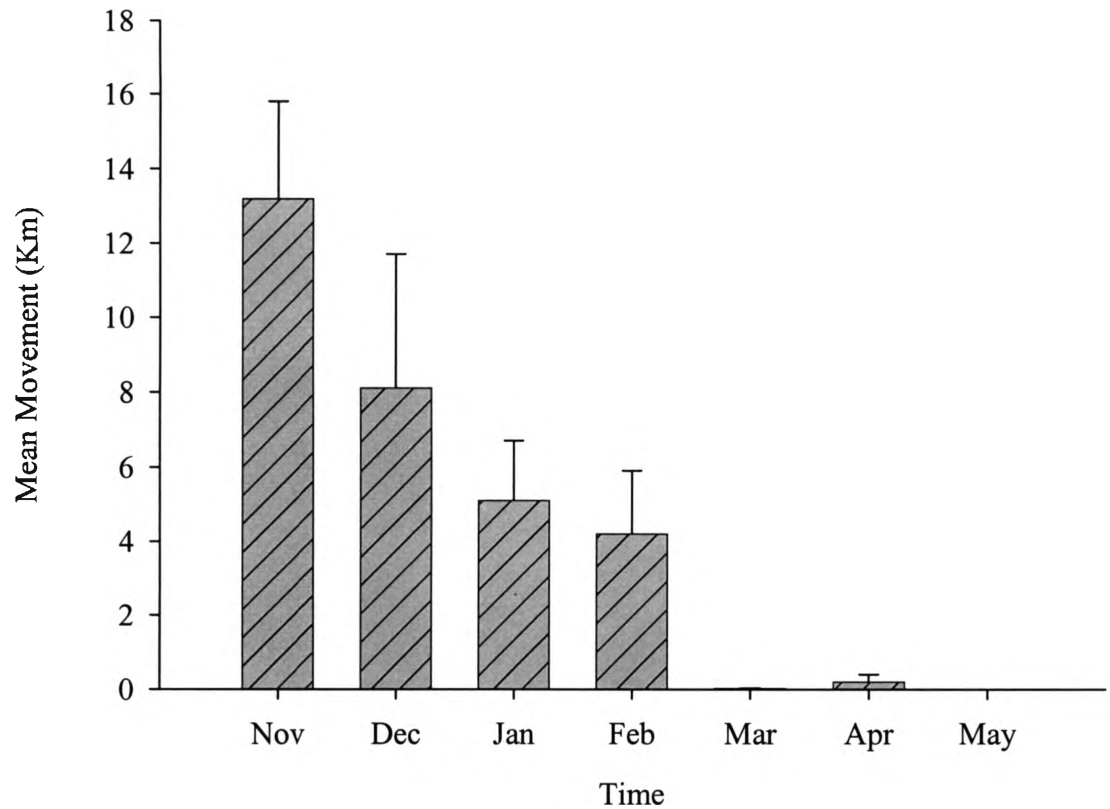

FIG. 5—Mean movement (± S.E.) traveled by triploid grass carp from release points and sequential relocation points from November 2001 through May 2002 in the lower Rio Grande, Texas.

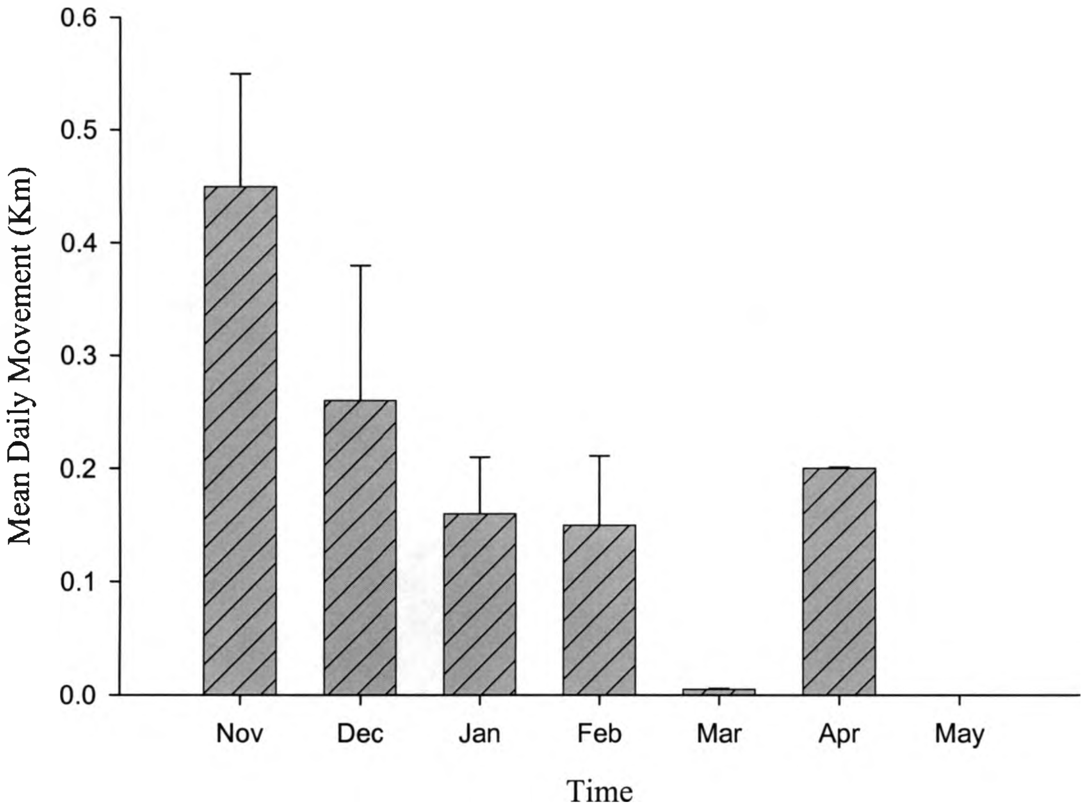

FIG. 6—Mean daily movement (± S.E.) of triploid grass carp from November 2001 through May 2002 in the lower Rio Grande, Texas.

VITA

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