Movement of Triploid Grass Carp Among Small Hydropower Impoundments of the Guadalupe River, Texas

John A. Prentice, *Texas Parks and Wildlife Department, Heart of the Hills Research Station, HC07, Box 62, Ingram, TX 78025*

Wilfred J. Dean, Jr., *Texas Parks and Wildlife Department, Inland Fisheries, 134 Braniff, San Antonio, TX 78216*

Michael S. Reed,[1] *Texas Parks and Wildlife Department, Inland Fisheries, P.O. Box 116, Mathis, TX 78368*

Earl W. Chilton II, *Texas Parks and Wildlife Department, Inland Fisheries, 4200 Smith School Road, Austin, TX 78744*

Abstract: Triploid grass carp (*Ctenopharyngodon idella*) (N = 125, 50.8–98.6 cm total length [TL]) were implanted with radio tags and released into 5 reservoirs (25 fish each in Dunlap, McQueeney, Placid, H4, and H5) on the Guadalupe River, Texas. These fish were located periodically to determine specific movement patterns in and among the series of riverine reservoirs and the Guadalupe River system to provide an evaluation of their use and safety as an aquatic vegetation control tool. All grass carp survived tag placement surgery and stocking into assigned reservoirs. However, beginning 7 months after release, stationary radio tags (no longer implanted in a fish and lying on the bottom due to tag loss and fish mortality) were located. Ultimately, 60 stationary tags were recovered and placed into other grass carp for release where each tag was found. Grass carp emigration from home reservoirs occurred throughout the study. Emigration was always observed in a downstream direction. Grass carp emigrated from these reservoirs at a rate of approximately 3.5% each 6 months during the first 18 months of study, which had low river-flow conditions. During high river-flow conditions, grass carp emigrated from these reservoirs at a rate of approximately 59% in 6 months. Seventy grass carp moved past 1–10 dams, emigrating a maximum 1-way distance of 325 km. Due to observed grass carp emigration, they are not recommended for vegetation control efforts in similar riverine aquatic systems.

Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 52:49–61

1. Present Address: Missouri Department of Conservation, St. Louis Regional Office, 2360 Hwy D., St. Charles, MO 63304.

Although grass carp have been extensively cultured in many areas around the world (Greenfield 1973, Avault 1990) for a variety of purposes, use in the United States has largely been for aquatic vegetation control (Cassani 1996). They are currently a legal management tool in some form in many states (Chilton and Muoneke 1992, Wattendorf and Phillippy 1996). In Texas, they were first legally introduced into the San Jacinto River system during 1981–1982 when grass carp were released into Lake Conroe as part of research to evaluate their vegetation control effectiveness (Klussmann et al. 1988, Trimm et al. 1989). In January 1992, triploid grass carp became legal in Texas for private water use with a permit from the Texas Parks and Wildlife Department (TPWD). They became legal for use in public waters with a TPWD permit in March 1993.

Various concerns over introduction of grass carp into aquatic ecosystems have been raised and must be balanced with the evidence that these fish offer a powerful tool for aquatic plant reduction or removal (Cassani 1996). A major concern over grass carp use in riverine, semi-riverine, and impounded waterway environments centers on the fish's propensity for movement. Grass carp were first used on an operational basis in Arkansas (Lake Greenlee) in 1970 (Bailey and Boyd 1972). By 1974, after introductions in Arkansas reservoirs open to streams or rivers and in other areas of the United States, there were numerous reports of grass carp in the Missouri and Mississippi rivers (Pflieger 1978). Grass carp movement has been observed in canals and open waterways (Beaty et al. 1986, Bain 1996, Stocker 1996). Fish movement was upstream, downstream, and through structures such as gates and siphons. Containment of grass carp at target areas in large lakes and impounded rivers has been difficult, causing dilution of original stocking at the target area and potential impact on vegetation at nontarget areas (Bain et al. 1990; Cassani 1995, 1996). Some studies indicated radio-tagged grass carp do not always move out of targeted areas (de Kozlowski 1991, Clapp et al. 1993); however, targeted areas were large (7,000–10,000 ha), sample sizes were small, and non-radio-tagged fish were collected downstream in nontarget areas. Additionally, questions remain on the extent of movement expected by grass carp out of a stocked reservoir and efficacy of their use in large systems (Noble et al. 1986, Bain 1996). Gorbach and Krykhtin (1988) found that although grass carp may remain in the downstream reaches of their native Amur River after hatching, they soon begin an upstream migration toward spawning areas. Grass carp may move 155 km during the first 9 months of life and up to 500 km during the first 2 years.

During 1993, hydrilla (*Hydrilla verticillata*) was discovered in Lake Dunlap, Guadalupe County, Texas. Lake Dunlap is upstream in a series of small hydropower impoundments along the Guadalupe River (Fig. 1). Aquatic plant management options included chemical, mechanical, physical and biological controls. Primarily, chemical control was used in spring 1994. During summer 1994, hydrilla returned to Lake Dunlap and was found in downstream Lake McQueeney. With the possibility of hydrilla spreading throughout the Guadalupe system, many concerned citizen groups requested use of triploid grass carp as a management option. Generalized grass carp behavior and movement potential, as discussed above, was not accepted as grounds

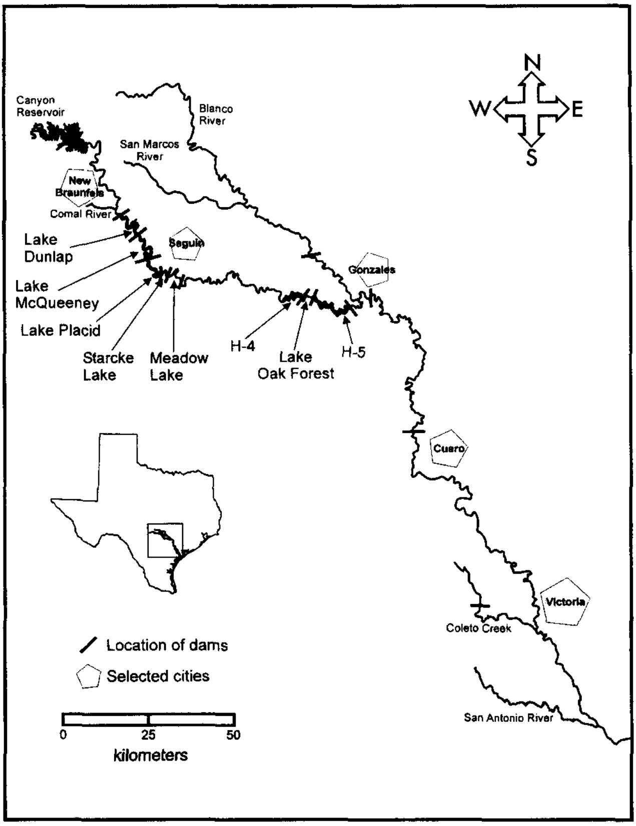

Figure 1. Area for triploid grass carp movement study on the Guadalupe River system, Texas, 1995–1997. River distances are shown to scale. Outlines of reservoirs and symbols for dams and cities are not shown to scale.

for dismissal of grass carp use, because of lack of specific fish movement data. Most citizen groups believed the impoundment dams at each end of these reservoirs would provide grass carp containment. Unfortunately, if triploid grass carp move out of vegetation control target areas, the benefits of grass carp as an inexpensive, long-term aquatic vegetation control and control without reliance on herbicide use would be negated and vegetation removal could occur in non-targeted areas where unwanted. Therefore, this study was conducted to determine specific triploid grass carp movement patterns in and among the series of riverine reservoirs and Guadalupe River system to provide an evaluation of their efficacy and safety as an aquatic vegetation control tool.

Financial support for this study was jointly provided by Friends of Lake McQueeney (lakeside property owners), the Guadalupe-Blanco River Authority (GBRA), and TPWD. We are especially thankful to GBRA staff who assisted with access to various water bodies and tabulated river flow and dam overflow data. We are also especially thankful to many TPWD staff for study assistance during tagging, stocking, and tracking of grass carp.

Methods

One hundred twenty-five triploid grass carp (50.8–98.6 cm TL; 1.7–11.2 kg) were obtained from TPWD hatchery and commercial sources and transported to the A. E. Wood Fish Hatchery in San Marcos, Texas. These fish were subdivided into groups of smaller (50.8–66.0 cm TL, $N = 38$) and larger (67.0–98.6 cm TL, $N = 87$) fish to enable observation of any differences in behavior by size. Relatively large individuals were obtained to facilitate surgical implantation of radio tags, provide an acceptable ratio of tag/fish body weights <0.02 (Nielsen 1992), and help avoid fish mortality due to predation when released. Fish were implanted with internal, abdominal radio tags (Advanced Telemetry Systems, Inc. [ATS], Asanti, Minn.; Model 5902; 18 g in air; 45 × 10 mm with a 30-cm teflon coated stainless steel antenna) on 3 August 1995. Radio tags transmitted in a frequency range of 48.021–49.994 megahertz (MHz). Each radio tag transmitted a unique, fixed radio frequency separated by at least 10 kHz from any other radio-tag frequency used in this study as suggested by Nielsen (1992). Each of the 5 reservoirs was assigned 25 radio frequencies, and fish implanted with those assigned frequency tags were stocked into respective reservoirs. Radio tags were programmed to activate on/off cycles (4 days on and 3 days off weekly for 6 weeks, followed by 5 days on and 25 days off for 5 months, followed by 6 days on and 85 days off continuing until batteries expired). Battery life expectancy was 1,460 total consecutive days.

Surgical procedures for internal abdominal placement of radio tags into fish were similar to those of Schramm and Black (1984) and Stoskopf (1992). Fish were fully anesthetized in a 460 ppm buffered MS222 solution (buffer mix = 7.5 g sodium bicarbonate and 1.5 g MS222 dissolved in 37.8 liters water). Each radio-tagged fish was weighed and measured. A midventral incision was made (beginning about 3 cm posterior of right or left pelvic fin origin extending posterior about 5 cm) for tag insertion. After the tag antenna was passed through the body wall and the tag body placed in the fish's body cavity, the incision was closed with 5–8 independent sutures perpendicular to and evenly spaced along the incision. Heavy absorbable coated vicryl (3.5 metric, Ethicon, Inc.) sutures swaged to half-circle taper-cutting needles (CT-1) were used. Any abraded body areas on fish were disinfected with a spray of 2% povidone iodine solution. After surgery, each fish was given a 30-sec dip in 0.5%–1.0% salt (NaCl) solution and then placed in a recovery tank of fresh water. Fish were allowed to recover from surgical stress for 4 days in freshwater flow-through raceways. Each day during recovery, fish were given 1 antiseptic treatment of 0.3% salt and 25 ppm hydrogen peroxide for 1–2 hours.

Grass carp were stocked into assigned (home) reservoirs (25 fish/reservoir in Dunlap [165 ha], McQueeney [160 ha], Placid [100 ha], H4 (200 ha], and H5 (198 ha], Fig. 1) on 7 August 1995 with fish released at various locations in each reservoir where submersed vegetation was growing. Tracking (locating) of radio-tagged fish began on 8 August 1995 using ATS Challenger 2000 and Lotek Engineering, Inc. (Newmarket, Ontario, Can.) model STR-1000 telemetry receivers with deck-mounted 1.5-m whip and hand-held, directional loop antennae. Tracking was conducted thereafter each time radio tags were in the active "on" mode. Tracking was to continue through at least 2 flood events, each of a magnitude of $\geq$127-m^3/sec and lasting $\geq$4 hours. The 127-m^3/sec flow level would cause study reservoir dam gates to be lowered $\geq$0.6 m to maintain constant level of each reservoir. Guadalupe River average daily water flow and hourly duration of water spills over hydropower dams were recorded by GBRA (Seguin, Texas) for each reservoir.

Tracking early in the study included searches for radio signals in all study waters (Fig. 1) from the towns of New Braunfels (Guadalupe County) to Gonzales (Gonzales County, including the lower San Marcos River) (169 river km). However, as the study progressed, search areas expanded upstream of New Braunfels to Canyon Dam (including the Comal River) and downstream of Gonzales to upper San Antonio Bay (total distance = 501 river km). Impoundment dams forming the series of study reservoirs had normal operating heights of about 9 m, with gates that were lowered to release increased flow, making upstream emigration of grass carp highly unlikely unless river flow became high enough to inundate the dam. Therefore, tracking through the river system and reservoirs started at the upstream-most end and progressed downstream (except when high river flow conditions caused the addition of upstream area searches for all fish that could possibly have moved upstream).

For each reservoir or river section, a tracking sample consisted of 2 complete passes by boat (launch site to each end of the water body and back to the launch site) listening for the radio frequencies assigned to that area. On 3 sample occasions, aircraft were also used to ensure more complete coverage of the river area searching for all unlocated radio frequencies. Aircraft flights covered river areas from the town of Seguin, Texas, to upper San Antonio Bay. The last 2 tracking efforts searched for all unlocated radio frequencies in all study waters. Whenever a pulsing radio tone for an assigned frequency was heard, the signal source location was identified as closely as possible ($\leq$50 m by boat; $\leq$1 km by aircraft) and marked on a United States Geological Survey 7.5-minute map.

Radio frequencies not found in a given reservoir after conducting a tracking sample were then added to the tracking sample list for the next downstream reservoir. Radio signals appearing to show no movement from 1 tracking sample to the next were given exacting location scrutiny by using progressively less sensitive antennas as we neared the source location. Signals from radio tags remaining in fish moved as we approached to within 10 m. However, signals not moving were located to within 10 cm by use of digitally displayed signal strength variation (measured by the STR-1000 telemetry receiver) response to a 4-cm exposed end of a coax antenna cable attached to 3- or 5-m wooden poles, depending on water depth. Radio tags located to within 10 cm were recovered by following the wooden poles to the tag and feeling by hand. Recovered radio tags were surgically placed into another fish from hatchery stock as described above and that fish was released where the tag had been found. Additionally, as tracking samples were being conducted, each actively operated boat observed throughout each reservoir was counted and recorded to determine if there was any difference in fish disturbance between reservoirs.

To follow grass carp reaction to the tagging process, additional, similar-size fish from hatchery stock were given surgical treatment and sham radio-tags (similar tags for which batteries were expired) similar to fish used in the Guadalupe River. Fish given sham tags were held 9–12 months in hatchery ponds. Upon pond draining and fish recovery it was determined if tagged fish survived and retained their tag, survived and lost their tag, or died.

Analysis of grass carp movement data involved determining 1-way distance by river between successive locations for each fish found during each tracking sample. Movement data for fish within home reservoirs were analyzed for the first 7 months before stationary radio tags were observed to avoid any movement differences that might be due to fish stocking time and acclimation differences. Fish locations could only be determined on the intervals that radio tags activated, therefore for analysis, monthly within-home reservoir fish movement data were expressed as proportions of the total available distance to move within each reservoir. Proportion data were normalized by arc sine-square root transformations. Movement data for fish emigrating from home reservoirs were analyzed for the entire study period. Logarithmic transformation was used to normalize distance/month emigration data and boat counts/tracking sample data. Using analysis of variance and Tukey's studentized range test ($P \leq 0.05$; SAS Inst. 1987), differences in fish movement between fish size groups, boat traffic, home reservoirs, and reservoir water spilling were compared.

Results and Discussion

All grass carp survived tag placement surgery, the surgical recovery period, and stocking into assigned Guadalupe River reservoirs. However, beginning 7 months after release, stationary radio tags (no longer implanted in fish and lying on the bottom, Table 1) were located. Stationary tags could have been due to fish mortality or tag loss, and probably resulted from both causes. Of the 60 stationary radio tags recovered (Table 1), 1 was found with the skeletal remains of a grass carp, 2 were found on the bank out of water, 2 were found in deep, mid-reservoir locations, and the remaining 55 were in shallow shoreline areas. A total of 29 grass carp surgically implanted with sham tags experienced 69% survival and tag retention, 14% survival and tag loss, and 17% mortality. Schramm and Black (1984) noted 20% loss of radio tags by grass carp due to ruptured sutures within 30-day observation periods. No radio tags in this study became stationary until 7 months after surgery.

During the first 18 months of this study, little rainfall occurred and Guadalupe River flows remained low (average daily river flow ranged from 1.6 m^3/sec on 5 Aug 1996 to 15.9 m^3/sec on 1 Nov 1995, Table 2). River flows first approached "normal" capacity in February 1997, when average daily flow increased from 14.1 to 23.5 m^3/sec. Beginning March 1997, rains caused frequent high river flows resulting in numerous dam-gate drawdowns and water spills (Table 2). All Guadalupe River reservoirs in this study were maintained at a constant level and dams for each reservoir

Table 1. Radio tracking dates and fish home-reservoir emigration findings for 125 triploid grass carp tagged and released in 5 hydropower reservoirs on the Guadalupe River (Comal, Guadalupe, Gonzales, DeWitt, Victoria, and Calhoun counties), Texas, August 1995–August 1997.

Tracking date	*N* found in home reservoir[a]	*N* emigrated	*N* not located	*N* of stationary tags[b]	% of fish emigrated[c]	Distance emigrated (km)[d]		
						Minimum	Maximum	Mean
8 Aug 95	120	0	5	0	0.0			
14 Aug 95	108	2	15	0	1.6	3	18	10.5
21 Aug 95	109	2	14	0	1.6	1	2	1.5
28 Aug 95	106	3	16	0	2.4	1	4	2.7
5 Sep 95	114	3	8	0	2.4	1	4	2.0
11 Sep 95	109	3	13	0	3.2	0	2	1.3
11 Oct 95	109	4	12	0	3.2	0	18	5.8
12 Oct 95	107	4	14	0	3.2	0	1	0.5
11 Dec 95	108	4	13	0	3.2	0	1	0.8
9 Jan 96	112	4	9	0	3.2	0	2	1.0
8 Feb 96	115	4	6	5	3.3	0	2	1.0
9 May 96	107	4	14	13	3.6	0	2	1.0
8 Aug 96	101	9	15	38[e]	10.3	0	69	15.1
7 Nov 96	83	13	29	14	11.7	0	82	64.0
6 Feb 97	87	13	25	22[e]	12.6	1	74	21.6
8 May 97	52	60	13	15	54.5	2	325	296.0
7 Aug 97	30	70	25	15	63.6	8	264	76.8

a. Home reservoir refers to the reservoir where a grass carp was originally stocked.
b. Stationary radio tags were no longer connected to a fish due to fish mortality or tag loss.
c. Percent of fish moved was the ratio of fish found moved out of home reservoirs in relation to the number available to move. Stationary tags were not counted unless they had been replaced in another fish which was restocked where the tag had been collected.
d. Distance moved includes all movement for fish that had left home reservoirs. Movements of fish remaining within home reservoirs were not included.
e. Thirty-eight stationary radio tags were recovered and implanted in new fish which were stocked September 1996 where the tags had been collected; 22 additional stationary radio tags were also recovered and implanted in new fish which were stocked April 1997 where tags had been collected.

were similar in that as increased river flow occurred, dam gates were lowered to allow more water to pass without affecting reservoir level. For example, in Lake Placid the spill in August 1995 (98 hours; 17.1 m^3/sec, Table 2) caused 1 of 2 dam gates to be lowered 0.4 m, while the spill in June 1997 (377 hours; 191.2 m^3/sec, Table 2) caused both dam gates to be lowered up to 1.22 m.

At the beginning of this study, lakes Dunlap and McQueeney contained large areas of submersed aquatic plant growth (44 ha [27% lake area] and 83 ha [52% lake area], respectively), Lake Placid contained limited areas (<2 ha; 2% lake area), and lakes H4 and H5 contained very little submersed aquatic plant growth. Submersed plant growth was largely composed of hydrilla. Total area herbicide treatments of lakes Dunlap and McQueeney during May 1996, with release of 5,000 additional grass carp in each of lakes Dunlap and McQueeney during June 1996, removed submersed aquatic plants from those 2 reservoirs during the remainder of this study. Submersed aquatic plant areas became very small in Placid and remained so in H4 by late 1996 through 1997. However, rapid growth of hydrilla was observed in H5 during 1996 and 1997, resulting in 32 ha of coverage (16% lake area).

Table 2. Guadalupe River (recorded at Lake Dunlap gauging station) monthly flow and Dunlap, McQueeney, Placid, H4, and H5 reservoir dam water spill data, August 1995–November 1997.

	River flow (m^3/sec)			Total hours of water spills (maximum hourly m^3/sec spill volume) over dams				
Month/Year	Average	Minimum	Maximum	Dunlap	McQueeney	Placid	H4	H5
Aug 95	11.2	9.1	15.2	0	0	98 (17.1)	0	0
Sep 95	10.4	9.6	13.4	0	0	0	5 (33.9)	0
Oct 95	10.9	9.2	13.5	0	0	0	0	0
Nov 95	13.5	12.9	15.9	0	0	0	0	0
Dec 95	12.6	11.3	13.9	0	0	0	0	0
Jan 96	10.8	10.2	12.0	0	0	0	0	0
Feb 96	9.9	8.8	11.7	0	0	0	0	0
Mar 96	9.1	8.3	9.7	0	0	0	0	0
Apr 96	8.8	6.9	10.1	0	0	0	0	0
May 96	7.1	3.9	8.7	26 (69.4)	0	0	0	0
Jun 96	4.4	2.6	8.3	0	0	16 (23.6)	0	0
Jul 96	2.3	1.8	2.8	0	0	0	0	0
Aug 96	3.5	1.6	10.3	0	0	0	0	0
Sep 96	8.4	6.8	13.2	0	0	0	0	0
Oct 96	7.7	6.9	11.4	0	0	0	0	0
Nov 96	8.8	7.2	13.2	0	0	0	5 (27.6)	0
Dec 96	11.1	8.8	14.1	0	0	0	0	0
Jan 97	11.1	10.3	11.8	0	0	0	0	0
Feb 97	16.0	9.0	38.9	0	0	0	0	0
Mar 97	32.9	27.4	50.0	0	60 (16.7)	61 (36.1)	0	37 (16.7)
Apr 97	56.1	22.7	134.2	235 (107.1)	255 (109.0)	289 (144.4)	251 (97.7)	293 (117.5)
May 97	42.2	29.3	112.3	130 (80.0)	119 (80.0)	126 (92.0)	118 (77.2)	121 (86.0)
Jun 97	72.4	25.1	157.8	285 (132.3)	360 (176.3)	377 (191.2)	385 (165.7)	422 (169.6)
Jul 97	149.9	141.4	159.4	744 (146.0)	744 (132.4)	744 (104.8)	744 (212.4)	744 (144.1)
Aug 97	44.2	21.8	142.9	99 (108.6)	164 (115.4)	170 (131.1)	162 (150.1)	230 (120.9)
Sep 97	21.2	14.2	27.4	0	0	0	5 (107.9)	5 (26.1)
Oct 97	15.3	13.6	18.8	0	0	0	0	6 (80.3)
Nov 97	14.5	13.1	16.1	0	0	0	0	0

Grass carp emigration from home reservoirs occurred throughout the study, even when no dam overflows occurred (Tables 1, 2). Emigration was always observed in a downstream direction. Study observations indicated grass carp emigrated from these reservoirs at a rate of approximately 3.5% each 6 months during the 18-month low-river-flow period when fish should have been most contained. During the low-flow period, 13 grass carp moved past 1–6 dams covering a maximum 1-way distance of 106 km (mean distances per sample ranged 1–64 km). During high-river-flow conditions, study observations indicated grass carp emigrated from these reservoirs at a rate of approximately 59% in 6 months (Tables 1, 2). During the high-flow period, 57 grass carp moved past 1–10 dams covering a maximum 1-way distance of 325 km (mean distances per sample ranged 77–296 km). Addition of retagged fish could have allowed a greater movement potential for newly introduced individuals which have been indicated in other research to exhibit frequent movement for some short time after introduction to a water body (Nixon and Miller 1978, Chilton and Poarch 1997). However, of the 22 fish most recently introduced before high-flow conditions (Table 1), 12 fish (55%) emigrated during the high-flow period which is similar to the emigration rate of the initially introduced fish. Addition in June 1996 of 5,000 grass carp into lakes Dunlap and McQueeney was expected to affect fish emigration from those reservoirs, but no effect was observed. During the 18-month low-flow period only larger size group fish emigrated, while during the high-flow period both size groups emigrated and fish from the smaller size group moved significantly ($P < 0.0001$; Table 3) greater mean distances (175 ± 32.3 km) than larger size-group fish (56 ± 8.8 km). Movement of only larger size-group fish during the low-flow period supports other observations that as grass carp reach larger sizes their propensity for movement increases (Bain et al. 1990, Chilton and Muoneke 1992, Bain 1996). When high-flow conditions occurred, the presence of submersed aquatic vegetation in study reservoirs had changed, as discussed above, and the greatest vegetated area was in H5. However, of the 57 grass carp emigrating during high-flow conditions, 36 moved through or away from the H5 vegetated area, while 11 moved to the vegetated area and 10 did not move far enough downstream to reach the vegetated area. The observation of many grass carp moving through the H5 vegetated area, coupled with the greater numbers and distances of emigration of fish of both size groups during high river flow periods, indicates water flow is a major factor affecting emigration and can apparently disrupt established home ranges (Cassani and Maloney, 1991, Chilton and Muoneke 1992).

Table 3. Analysis of variance summaries testing for differences in triploid grass carp emigration movement from reservoirs of the Guadalupe River, Texas, between smaller and larger size-groups, August 1995–August 1997.

Factor	Source of variation	df	Sum of squares	Mean square	*F*-ratio	*P* (>*F*)
Movement (km)	Size group	1	174,165.73	174,165.73	19.27	0.0001
	Error	120	1,084,521.21	9,037.68		
	Total	121	1,258,686.94			

Grass carp movement within all home reservoirs was frequent immediately after stocking. Groups of fish were observed at opposite ends of home reservoirs during the period of weekly tracking samples, and this behavior continued throughout most of the study timespan in lakes Dunlap and McQueeney, but to a lesser degree in lakes Placid, H4, and H5. Movement within reservoirs of larger size-group fish from all reservoirs combined was found to be greater ($P \leq 0.0147$) than for smaller size-group fish (Tables 4, 5). There were also differences in larger size-group fish movement among reservoirs ($P \leq 0.0001$) that were not found for smaller size-group fish ($P \leq 0.0651$) (Tables 4, 5), which again supports the idea that as grass carp increase in size their propensity for movement increases. Among study reservoirs, greater proportional movement by larger fish was observed in lakes Dunlap and McQueeney, followed by lakes Placid, H4, and H5 (Table 4). Within Lake Placid, 1 week after release and continuing, grass carp were regularly located in association with 2 submersed aquatic plant growth areas which were relatively small (1 near the upstream and the other near the downstream end of the reservoir). Lake H4 contained 71 km of river between the impoundment dam and the next dam upstream where 9 fish (36% of fish stocked) moved the entire distance within a 1-month time period; 6 fish completed the 142-km round trip within 2 months. Grass carp within H5 were observed moving sporadically throughout the lake until 1996 when fish were regularly located in association with submersed plant growth in the downstream end of the reservoir. Other research has indicated grass carp exhibit frequent and rapid movement for a

Table 4. Home reservoir sizes, mean boat counts (±SE), triploid grass carp mean monthly distance (MMD±SE) movement data, and movement expressed as percent of each total reservoir length (% distance±SE) for smaller and larger size group fish within home reservoirs on the Guadalupe River, Texas, August 1995–February 1996.

Parameter	Dunlap	McQueeney	Placid	H4	H5
Surface area (ha)	165	160	100	200	198
Length[a] (km)	12.9	12.9	9.7	70.8	25.8
Mean boat counts	17.7±3.08	17.7±2.74	11.9±3.16	3.7±0.70	4.5±0.78
Number of boat counts	10	10	10	10	10
Tukey's test[b]	A	A	AB	C	BC
Smaller fish					
MMD (km)	2.0±0.21	2.1±0.55	1.3±0.48	15.5±3.68	3.9±0.97
% distance	16.1±1.75	15.7±3.89	13.8±4.92	21.9±5.19	10.1±2.18
Sample size[c]	98	28	28	37	38
Larger fish					
MMD (km)	4.1±0.49	4.2±0.38	1.5±0.22	13.8±2.10	4.3±0.72
% distance	31.5±3.84	32.1±2.92	15.1±2.30	19.4±2.96	11.7±1.80
Sample size[c]	56	118	121	82	86
Tukey's test[b]	A	A	B	B	B

a. Length of each reservoir = length of river between impoundment dam and the next upstream dam.

b. Mean values without a letter in common below them are significantly different between reservoirs as indicated by Tukey's studentized range test, $P \leq 0.05$.

c. Sample size = number of radio-signal fish locations made for each fish size group in each reservoir.

short time after introduction followed by longer periods of relative inactivity, apparently in areas where aquatic vegetation was present (Nixon and Miller 1978, Chilton and Poarch 1997) similar to observations in lakes Placid and H5. Movement by grass carp of substantial distances observed within Lake H4 may be explained by the riverine nature of the reservoir and lack of submersed plants similar to observations of Pflieger (1978), Stanley et al. (1978), and Bain et al. (1990). However, prolonged and frequent movement of grass carp within lakes Dunlap and McQueeney was more difficult to understand because fish were associated with plants at almost any location in these 2 reservoirs until summer 1996. Boat traffic, observed to be significantly ($P \leq 0.0001$) greater in lakes Dunlap and McQueeney, followed by lakes Placid and H5, and again followed by Lake H4 (Tables 4, 5), may have caused grass carp disturbance in these narrow riverine reservoirs. Movement reaction of grass carp to noise has been noted to be strong enough to aid herding and capture in small impoundments (Bonar et al. 1993). In reservoirs with large areas of vegetation growth, grass carp might be easily disturbed and caused to move from place to place compared to reservoirs where vegetation is limited.

During the course of this study, grass carp exhibited movement both within reservoirs where they were stocked and downstream (emigration) throughout the Guadalupe River system. Fish movement may have been due to a variety of reasons, but river flow apparently ranks high as a factor influencing grass carp movement. During

Table 5. Analysis of variance summaries testing for differences in boat traffic among study reservoirs and triploid grass carp movement within reservoirs of the Guadalupe River, Texas, where stocked. Movement was observed between smaller and larger fish size groups (all reservoirs combined) and between reservoirs for each size grouping, August 1995–February 1996.

Factor	Source of variation	df	Sum of squares	Mean square	*F*-ratio	*P* (>*F*)
Boat traffic						
	Reservoirs	4	3.5265	0.8816	12.21	0.0001
	Error	45	3.2496	0.0722		
	Total	49	6.7761			
Movement (reservoirs combined)						
	Size groups	1	0.7233	0.7233	5.99	0.0147
	Error	690	83.3455	0.1208		
	Total	691	84.0688			
Movement (smaller size group)						
	Reservoirs	4	0.7390	0.1848	2.25	0.0651
	Error	224	18.4286	0.0823		
	Total	228	19.1676			
Movement (larger size group)						
	Reservoirs	4	6.9836	1.7469	13.98	0.0001
	Error	458	57.1942	0.1249		
	Total	462	64.1778			

high river-flow and dam overflow conditions, large numbers of grass carp emigrated downstream, although even during periods of low river flow when conditions would be most restrictive to emigration, grass carp emigrated downstream. Due to their demonstrated emigration, grass carp are not recommended for aquatic vegetation control in riverine systems.

Literature Cited

Avault, J. W., Jr. 1990. Species profile—Chinese carps, common carp. Aquacul. Mag. 16(2): 59–64.

Bailey, W. M. and R. L. Boyd. 1972. Some observations on the white amur in Arkansas. Hyacinth Control J. 10:20–22.

Bain, M. B. 1996. Rivers and impounded waterways. Pages 65–77 *in* J. R. Cassani, ed. Managing aquatic vegetation with grass carp, a guide for water resource managers. Am. Fish. Soc., Bethesda, Md.

———, D. H. Webb, M. D. Tangedal, and L. D. Mangum. 1990. Movements and habitat use by grass carp in a large mainstream reservoir. Trans. Am. Fish. Soc. 119:553–651.

Bonar, S. A., S. A. Vecht, C. R. Bennett, G. B. Pauly, and G. L. Thomas. 1993. Capture of grass carp from vegetated lakes. J. Aquat. Plant Manage. 31:168–174.

Beaty, P. R., R. G. Thiery, N. T. Hagstrom, and M. R. Mizumoto. 1986. Efficacy and environmental impact of grass carp in the Coachella and Imperial valleys. Final Rep., Aquat. Res. Group, Coachella Valley Water Dist, Coachella, Calif. 59pp.

Cassani, J. R. 1995. Problems and prospects for grass carp as a management tool. Pages 407–412 *in* H. L. Schramm, Jr. and R. G. Piper, eds. Uses and effects of cultured fishes in aquatic ecosystems. Am. Fish. Soc. Symp. 15, Bethesda, Md.

———, ed. 1996. Managing aquatic vegetation with grass carp, a guide for water resource managers. Am. Fish. Soc., Bethesda, Md. 196pp.

——— and D. Maloney. 1991. Grass carp movement in two morphologically diverse reservoirs. J. Aquat. Plant Manage. 29:83–89.

Chilton, E. W. II and M. I Muoneke. 1992 Biology and management of grass carp (*Ctenopharyngodon idella*, Cyprinidae) for vegetation control: a North American perspective. Reviews in Fish Biol. and Fish. 2:283–320.

——— and S. M. Poarch. 1997. Distribution and movement behavior of radio-tagged grass carp in two Texas reservoirs. Trans. Am. Fish. Soc. 126:467–476.

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 Am. J. Fish. Manage. 13:746–756.

de Kozlowski, S. J. 1991. Lake Marion sterile grass carp stocking project. Aquatics 13:13–16.

Gorbach, E. I. and M. L. Krykhtin. 1988. Migration of the white amur, *Ctenopharyngodon idella*, and silver carp, *Hypophthalmichthys molitrix*, in the Amur River basin. J. Ichthyol. 28:47–53.

Greenfield, D. W. 1973. An evaluation of the advisability of the release of the grass carp, *Ctenopharyngodon idella*, into the natural waters of the United States. Trans. Ill. State Acad. Sci. 66:47–53.

Klussman, W. G. and 7 coauthors. 1988. Control of aquatic macrophytes by grass carp in Lake Conroe, Texas, and the effects on the reservoir ecosystem. Texas Agricul. Exp. Sta., Texas A&M Univ., MP-1664, College Station. 61pp.

Nielsen, L. A. 1992. Methods of marking fish and shellfish. Am. Fish. Soc., Spec. Publ. 23, Bethesda, Md. 208pp.

Nixon, D. E. and R. L. Miller. 1978. Movements of grass carp, *Ctenopharyngodon idella,* in an open reservoir system as determined by underwater telemetry. Trans. Am. Fish. Soc. 107:146–148.

Noble, R. L., P. W. Bettoli, and R. J. Betsill. 1986. Considerations for the use of grass carp in large, open systems. Pages 46–48 *in* G. Redfield, J. F. Taggart, and L. M. Moore, eds. Lake and reservoir management, vol. 2. North Am. Lake Manage. Soc., Washington, D.C.

Pflieger, W. L. 1978. Distribution and status of the grass carp (*Ctenopharyngodon idella*) in Missouri streams. Trans. Am. Fish. Soc. 107:113–118.

SAS Institute, Inc. 1987. SAS/STAT guide for personal computers, version, 6th ed. SAS Inst., Inc. Cary, N.C. 1,028pp.

Schramm, H. L., Jr. and D. L. Black. 1984. Anesthesia and surgical procedures for implanting radio transmitters into grass carp. Prog. Fish-Cult. 46:185–190.

Stanley, J. G., W. W. Miley II, and D. L. Sutton. 1978. Reproductive requirements and likelihood for naturalization of escaped grass carp in the United States. Trans. Am. Fish. Soc. 107:119–128.

Stocker, R. K. 1996. Agricultural canal systems. Pages 78–112 *in* J. R. Cassani, ed. Managing aquatic vegetation with grass carp, a guide for water resource managers. Am. Fish. Soc., Bethesda, Md.

Stoskopf, M. K. 1992. Fish medicine. W. B. Saunders Co., Philadelphia, Pa. 882pp.

Trimm, D. L., G. Guillen, C. T. Menn, and G. C. Matlock. 1989. The occurrence of grass carp in Texas waters. Texas J. Sci. 41:413–417.

Wattendorf, R. J. and C. Phillippy. 1996. Administration of a state program. Pages 130–151 *in* J. R. Cassani, ed. Managing aquatic vegetation with grass carp, a guide for water resource managers. Am. Fish. Soc., Bethesda, Md.