THESIS

MOVEMENT AND HABITAT USE OF TRIPLOID GRASS CARP IN A COLORADO IRRIGATION CANAL

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY DANIEL W. BEYERS ENTITLED MOVEMENT AND HABITAT USE OF TRIPLOID GRASS CARP IN A COLORADO IRRIGATION CANAL BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT OF THESIS

MOVEMENT AND HABITAT USE OF TRIPLOID GRASS CARP IN A COLORADO IRRIGATION CANAL

Movement and habitat use of 49 triploid grass carp in the South Platte Supply Canal (SPSC), Colorado, were monitored with radio telemetry during 1985 and 1986. The research was part of a study of the feasibility of using grass carp for biological control of aquatic plants in irrigation canals in temperate regions of the United States. Study of movements of grass carp in the SPSC in response to check-drop structures; time of day; available depth, velocity, substrate, and cover; aquatic plant biomass; discharge; and stocking site depth and velocity was emphasized.

Twenty triploid grass carp were introduced into the canal between July and September 1985, and 29 were released between May and September 1986. Fish were observed at 1, 2, and at least 7 days after release so that their response to environmental conditions at time of stocking (days one and two) could be compared to their response to environmental conditions after they had become acclimated to the canal (7 or more days after release). Twelve-hour telemetry sessions on consecutive days permitted observation of diel activity,

rhythmicity, movement near check-drops, and habitat use. Available habitat in the SPSC was estimated, and habitat preferences were calculated.

Aquatic plant biomass was the most important environmental condition effecting immediate post-stocking movement of grass carp. Higher biomass reduced grass carp movement and increased the length of time that fish remained in release sections. Higher discharges also decreased movement, as did release at stocking sites which provided low-velocity, relatively deep habitat. Stop logs, illumination, and time of day of stocking had no effect on immediate post-stocking movement of grass carp.

Grass carp were most active during daylight hours with peaks of activity at 7-8 hours after sunrise (HAS) and 13 HAS. During nighttime, grass carp repeatedly occupied specific locations (designated core areas) from which they dispersed during the day. Absence of aquatic vegetation at core areas indicated that grass carp fed most during daylight hours.

Check-drops were efficient barriers to upstream movement but poor barriers to downstream movement. However, five check-drop ascents were recorded.

Grass carp exhibited greatest preference for vegetated sand substrates and instream objects as cover. No preferences for depth or mean column velocity were calculated because turbidity prevented a visual estimate of fish position. Additionally, preference for depth and velocity was an artifact of preference for vegetated substrates and instream cover and not of real ecological significance.

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DEDICATION

To my parents Wayne and Ruth Ann.

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Introduction

The control of nuisance levels of aquatic vegetation in reservoirs and waterways used for irrigation has long been a problem for managers of aquatic systems. Swingle (1957) discussed benefits of herbivorous fish as a biological control of aquatic plants and suggested that the grass carp (*Ctenopharyngodon idella* Valenciennes) would be a wise choice. Other authors (Avault 1965; Stevenson 1965; Sills 1970) also advocated use of grass carp as an alternative to chemical and mechanical means of controlling aquatic vegetation. Since its introduction in 1963, the grass carp has been used as an effective tool for control and management of aquatic vegetation in lakes, reservoirs, ponds, and canals throughout North America. Its widespread acceptance has been largely due to its ability to consume more than its body weight per day of vegetation (Cross 1969; Opuszynski 1972), long life span (Krykhtin 1984; Gorbach 1972), inability to reproduce in lentic waters (Greenfield 1973; Stanley et al. 1978), and ability to tolerate extreme environmental conditions. Grass carp tolerate 0-39.3^{o}C (Bettoli et al. 1985), as little as 0.44 mg/l dissolved oxygen (Negonovskaya and Rudenko 1974), and up to 15 g/l salinity (Kilambi and Zdinak 1980). These same characteristics make wild populations of grass carp difficult to control, and many researchers have voiced fears that they may have deleterious effects on existing aquatic communities in North America (Stanley et al. 1978; Pierce 1983; Conner et al. 1980; Zimpfer and Bryan 1985). The controversy has fueled research which has resulted in a permit system to regulate the sale and distribution of grass carp, development of several types of sterile grass carp, and a better understanding of the implications of managing aquatic vegetation with grass carp. Unfortunately, descriptions of the grass carp's behavior and seasonal movements in its native range are largely incomplete and ambiguous. The most available sources are papers by Soviet authors and concern life history of grass carp in the Amur River, the northern extreme of the fish's natural distribution. Chinese research has emphasized culture and production of grass carp for human consumption. If thorough documentations of grass carp movement and behavior exist, they are either unavailable or lack English translations. This omission is especially disappointing since one way to understand the significance of movements of grass carp in an artificial situation is to first understand movements in their natural environment. Fortunately, an understanding of the natural distribution and life history of grass carp can provide some insight into the ties between the fish's natural environment and seasonal movement patterns.

Historical distribution

The original distribution of grass carp included low-gradient rivers and lakes on the Pacific coasts of the southern USSR and China. The distribution extended from 50° to 23° north latitude and included but was not restricted to the Amur, Yellow, Yangtze, and Pearl drainage basins. A monsoon climate characterized the native range, producing two high water periods each year and an annual yearly rainfall of 200 cm in southern China and 50 cm in northern China (Shireman and Smith 1981).

Life history

Grass carp typically attain a total length of 600 mm and weight of 6 kg at an age of 6 to 9 years. Reports of fish as large as 1220 mm and 32 kg can be found in the literature; however, maximum lengths and weights near 1100 mm and 15 kg are more common. Reliable reports indicate that grass carp often live in excess of 15 years in the Amur River (Gorbach 1972), and may live as long as 21+ years in that river (Shireman and Smith 1981).

The age at which grass carp reach sexual maturity is dependent on the local climate and ranges from 3 to 10 years. Grass carp in the Amur River mature in the sixth year of life (Fischer and Lyakhnovich 1973), while grass carp in the more temperate West River mature as early as 3 or 4 (Lin 1935). Females tend to be larger than males and may take an additional year to mature. Mature grass carp reproduce annually and may be intermittent spawners in tropical climates (Lin 1935).

Grass carp have rather constraining reproductive requirements, a quality which is partially responsible for their widespread acceptance. Flowing water is an important environmental stimulus; in its absence, grass carp will not spawn (Lin 1935; Stanley et al. 1978). Length of breeding season varies with climate. In temperate climates, the season is limited, but in tropical areas the breeding season is expanded and less distinct. The breeding season in the middle Amur River (temperate) begins in late May and ends in early August. In the more tropical Pearl and West rivers, the breeding season extends from April to September. Migration to the spawning grounds appears to be initiated by rising water. Lin (1935) noted a 1.2 m increase in stage within 12 hours was followed by several days of grass carp spawning. Rising water is caused by heavy rains associated with monsoons, and the runoff warms the rivers. At the start of migration, water temperature is typically 15-17^{o}C (Aliev 1976). Fish move in an upstream direction, and length of waterway may be important for physiological preparation of adults as well as development of drifting fertilized eggs and larvae. Aliev (1976) observed spawning in adults that swam a distance of at least 80 km, while fish whose migration had been prevented after only 2 km did not spawn.

The spawning site is typically in the primary channel of a river or large canal just below extensive rapids, islands, sandbars, or tributary junctions (Lin 1935). Spawning sites must meet three main requirements: 1) the waterway must be of sufficient length to allow incubation of semibouyant fertilized eggs, 2) temperature must be over 18^{o}C (Stott and Cross 1973), and 3) current velocities must range from 0.6 to 1.8 m/s (Lin 1935; Stanley et al. 1978; Leslie et al. 1982). A fourth requisite for spawning site selection may be related to discharge. Grass carp only spawn in large rivers with an average discharge of approximately 400 m^3/s (Stanley et al. 1978).

Grass carp are polyandrous with two or three males typically courting a single female (Lin 1935). Spawning takes place near the surface in the center of the river channel. Absolute fecundity estimates range from several thousand to 1,687,000 eggs per female depending on body size (Gorbach 1972). Fertilized ova are semibouyant and are kept suspended by current and turbulence at the spawning site. A minimum velocity at the spawning site of 0.6 m/s is required to prevent fertilized ova from sinking to the bottom where they may suffocate (Leslie et al. 1982). Greater turbulence may be required during the first 30 to 45 minutes after the eggs are released because they are less bouyant than after they become fully water hardened (Stanley et al. 1978). Eggs generally hatch in 32-40 hours at 26-30^{o}C. During this time, ova may drift between 50 and 180 km, depending on water temperature and velocity (Shireman and Smith 1981). Newly hatched larvae are pelagic and alternately swim up and passively sink down in the water column. This behavior results in their being carried downstream and eventually out of the mainstream (Stanley et al. 1978). Larvae enter adjacent lentic water bodies, ie., lakes, reservoirs, and floodplains, which serve as nursery areas. Nursery areas must have an abundance of aquatic or submerged terrestrial vegetation on which the larvae rest. Young grass carp feed on zooplankton and phytoplankton until they reach a length of 30-50 mm. Then the fish shift the major component of their diet from plankton to aquatic vegetation (Shireman and Smith 1981; Stanley et al. 1978). With the approach of winter, juvenile and adult fish leave shallow marginal waters and migrate to the main channels of rivers. The fish overwinter in deeper portions of the river channel. During this period, grass carp do not feed, and their bodies become covered with a thick layer of mucous (Fischer and Lyakhnovich 1973).

Use in irrigation canals

Grass carp have been successfully used for biological control of aquatic plants in irrigation canal systems throughout the world. In the USSR, extensive canal and reservoir systems are being managed with grass carp. In several of the systems, the fish have established reproducing populations and made management of aquatic vegetation far more cost effective than with mechanical or chemical means (Aliev 1965; Charyev 1984).

Several sterile forms of grass carp have been developed for use in areas where naturally reproducing populations are undesirable. The most useful sterile form of grass carp that has been developed is commonly referred to as a triploid. In grass carp, the normal genetic condition is to have two copies of each chromosome, a condition known as diploidy. Triploid grass carp have three copies of each chromosome, a condition which renders them functionally sterile (Malone 1984). Triploidy can be induced with a variety of methods, but those most commonly used include thermal shock and the use of hydrostatic pressure on fertilized eggs from diploid parents. These procedures result in failure of fertilized ova to exclude the second polar body from the nucleus or suppress first cleavage, thereby causing a normally functioning diploid zygote to become triploid (Cassani and Caton 1986).

In the U.S., triploid grass carp have successfully controlled aquatic vegetation in small irrigation canals in citrus groves in Florida (Sutton 1977) and in the All-American canal in southern California (Stocker and Hagstrom 1985). Studies with diploid grass carp in a cool-water irrigation canal in northeastern Colorado demonstrated that the fish can effectively control aquatic vegetation in temperate regions of the United States (Thullen and Nibling 1986). During the course of these studies, Thullen and Nibling noted significant occurrence of downstream movement by grass carp. Numbers of grass carp moving downstream, out of study areas, were high enough to have an effect on desired levels of aquatic plant control. However, poor water clarity and high canal discharge prevented estimation of numbers and times of movement.

To obtain a better understanding of grass carp movements in relation to biotic and abiotic factors, a research program was developed. The objective of the research was to determine movements of triploid grass carp (hereafter referred to as grass carp) in the South Platte Supply Canal (SPSC) in relation to check-drop structures; time of day; available depth, velocity, substrate, and cover; aquatic plant biomass; discharge; and stocking site characteristics. Preliminary studies in 1985 resulted in the formation of the following hypotheses to be examined during 1986.

1. Grass carp regularly move downstream over check-drop structures but rarely move upstream over the same structures.
2. Grass carp demonstrate diel periodicity of movement.
3. Grass carp demonstrate diel periodicity of feeding.
4. Grass carp show preference for certain microhabitats.

5. The abundance of aquatic vegetation effects the liklihood that grass carp remain in a section where they are released.
6. Water depth effects the liklihood that grass carp remain in a section where they are released.
7. Stocking site characteristics (depth, velocity, and cover) effect the liklihood that grass carp remain in a section where they are released.
8. Time of stocking effects the liklihood that grass carp remain in a section where they are released.
9. Discharge effects the liklihood that grass carp remain in a section where they are released.

Study Area

The South Platte Supply Canal was north-centrally located in Colorado, approximately 32 km north of Denver. It originated at a gated diversion dam from Boulder Creek and extended in a northeasterly direction for approximately 50 km before terminating in Sand Lake near Fort Lupton, Colorado. The SPSC was privately owned and operated. It was part of the Colorado-Big Thompson Project and provided water for agriculture and municipalities in northeastern Colorado (USDI 1957).

The portion of the canal comprising the study area began at the diversion dam and extended downstream for 5.4 km (Figure 1). Upstream and downstream extremes of the study area were equipped with bar screens to prevent escape of grass carp into local waters. The study area was partitioned into six sections, of varying length, by check-drop structures (Figure 2) and one check-drop siphon (a conduit which carries water under a road). Both structures were designed to maintain the desired water-surface elevation upstream while dropping the elevation of the canal downstream so that the water surface could conform to the landscape. The degree of elevation drop over structures varied from 0.5 m to 1.5 m (Figure [illegible]

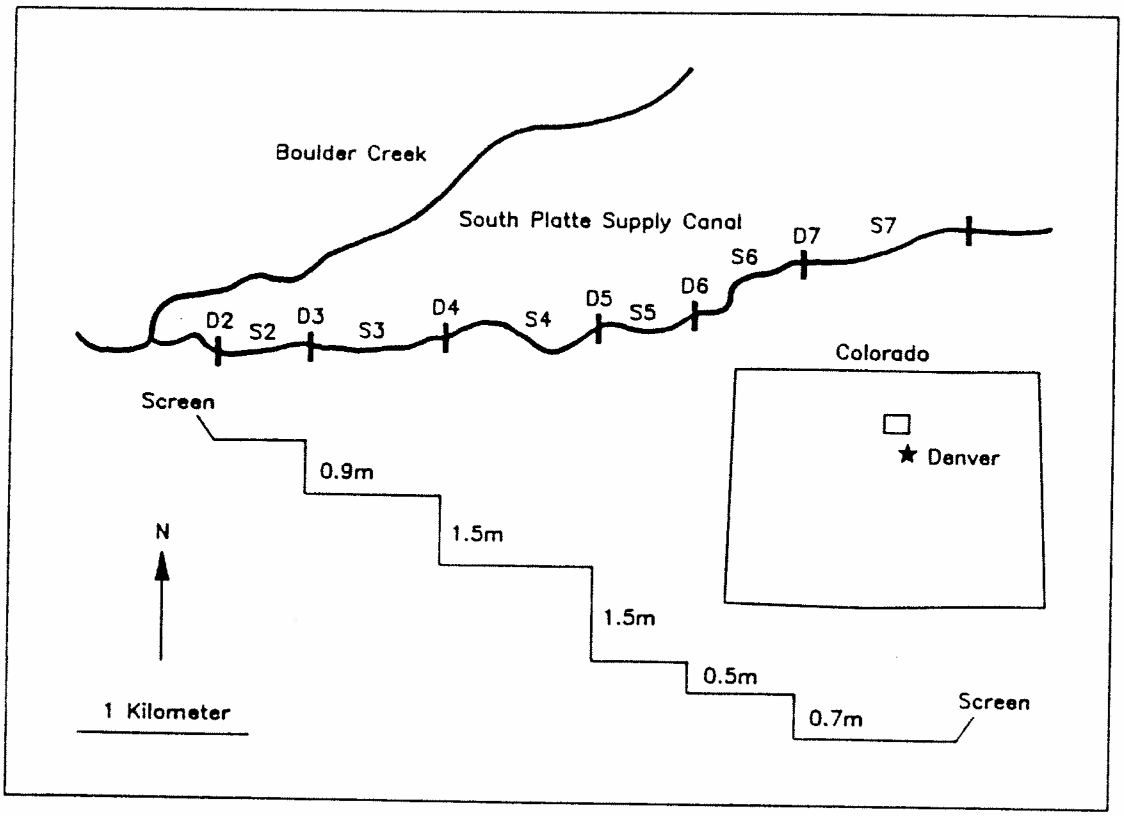

Figure 1.-South Platte Supply Canal plan view (top) and profile (bottom). Direction of flow is from west to east. D2-D7=check-drops; S2-S7=canal sections. Distance measures on profile represent vertical drop over each check-drop structure.

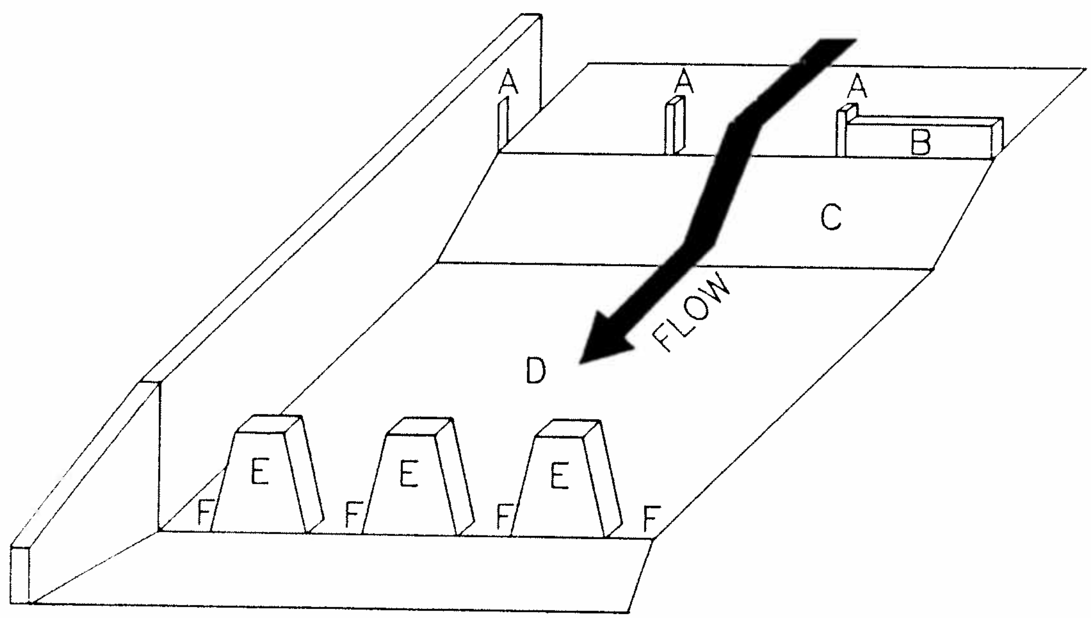

Figure 2.-Cutaway view of typical check-drop structure on the South Platte Supply Canal. A=stop log support; B=removable stop log; C=incline; D=plunge pool; E=baffle plates; F=outlets.

and proved to be a major factor in regulating grass carp movements.

The SPSC was reconstructed in 1957 with a mean gradient of 0.5 m/km, a flat canal bed 6.1 m wide, and side slopes of 2:1. Portions of the canal near water-control structures were lined with riprap as were other areas prone to erosion; however, the majority of the canal was unlined, compacted earth. By 1985, deterioration due to bank erosion, bank slumping, and repositioning of substrates had produced a canal bed which ranged from 6.1 to 12 m wide and occasional eroded banks which were vertical or undercut.

Small diversions from the canal for irrigation purposes were called laterals and occurred throughout the length of the canal. Access to laterals by grass carp was prevented by control gates.

Vegetation along the margin of the canal was largely comprised of reed canarygrass (Phalaris arudinacea) and smartweed (Polygonum spp.). Cattail (Typha latifolia) occurred in scattered patches but was less common. Cottonwood (Populus spp.) and willow (Salix spp.) occurred occasionally but were usually too far from the canal to provide shade or overhead cover. Submergent vegetation growing throughout the canal included, in order of abundance, waterweed (Elodea canadensis), leafy pondweed (Potamogeton foliosus), sago pondweed (Potamogeton pectinatus), and horned pondweed (Zannichellia palustris). Less common aquatic plants were the submergent buttercup

(*Ranunculus* spp.), the floating duckweed (*Lemna minor*), and the emergent speedwell (*Veronica* spp.).

The canal flowed through rural and residential areas. In rural areas, vehicular traffic was minimal, but livestock were allowed to graze canal banks or wade into the water. Traffic along the canal was heavier in residential areas and included automobile traffic, recreational use of all-terrain vehicles, and jogging.

The SPSC was not used to convey water during the winter months; however, groundwater and local runoff sustained a minimal flow of approximately 0.3 m^3/s. Typically, demand for water started in mid-May and continued until early October. Mean monthly flows during May, June, July, August, September, and October 1986 were 2.2, 1.6, 4.1, 2.6, 1.1, and 0.6 m^3/s, respectively (Figure 3). The minimum discharge during the 1986 irrigation season was 0.6 m^3/s, and the maximum was 5.2 m^3/s. The greatest daily change in discharge, 1.0 m^3/s, occurred on 15 May and 15 August. Adjustments in water delivery were made instantaneously, and when made on consecutive days, produced a highly fluctuating hydrograph. These abrupt changes in discharge effected depth and velocity and may have had considerable impact on grass carp movement.

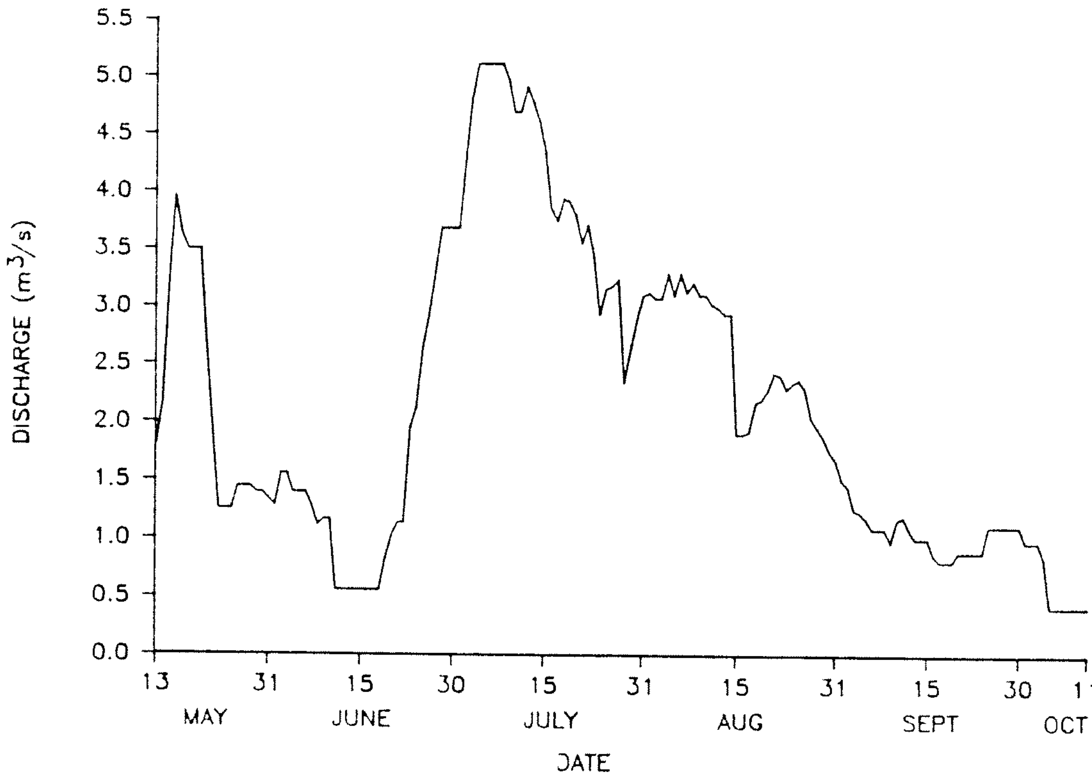

Figure 3.-Discharge in the South Platte Supply Canal during 1986.

Methods

Radio transmitter implantation

Because of high velocity and turbid water conditions, radio telemetry was chosen as the most efficient means of monitoring fish movements. The mobility provided by radio telemetry allowed quick surveys of fish without the risk of approaching the canal and disturbing study animals. Radio transmitters were surgically implanted within the abdominal cavities of grass carp. Transmitters were purchased from Custom Telemetry and Consulting, Athens, Georgia. Transmitters were 32 mm long and 16 mm in diameter, had a mass in air of 7.6 g, and were designed to operate for 9 months. Transmitters were supplied with a coating of beeswax by the manufacturer to provide an inert surface which would not irritate the implanted fish. Twelve frequencies between 30 and 31 MHz were available. A combination of frequency and radio signal pulse rate allowed each transmitter to be identified, even in the presence of other transmitters.

The surgical implantation procedure was refined during 1985, and the procedure outlined here is the method used to implant the 1986 study fish. Twenty-nine grass carp having a mean weight of 1536 g (range = 1100g - 2515 g) were radio-implanted in 1986. Study fish were provided by the

Imperial Irrigation District, Imperial, California. The grass carp were originally purchased from J. M. Malone and Son Enterprises, were verified triploids, and had been used in irrigation canals in southern California for 1 year before we obtained them. Fish were anesthetized in a 121 l plastic pail containing 15 l of water at a temperature of 17^{o}C and 200 mg/l tricain methane sulfonate (Argent Chemical Company). Sufficient anesthesia was attained in approximately 3.5 minutes; fish were removed from the anesthesia when they displayed a loss of reflex activity (ie., when they showed no response to handling) and opercular movement appeared labored but constant (Piper et al. 1982). Anesthetized fish were transferred to an operating board and positioned, ventral side up, on a 7.9 mm bar mesh net (Figure 4). The net suspended the fish and provided a non-skid surface on which to operate, while allowing water and mucous to drain away. An area of scales, three scale rows wide and approximately 50 mm long, was removed along the ventrum of the fish posterior to the pelvic girdle and anterior to the anus. The body wall near the incision was grasped with tissue forceps and held away from the viscera while the incision was made with a hook-shaped scalpel (Figure 5). Once through the body wall (dermis, muscle, peritoneum) the incision was extended by placing the scalpel into the opening and cutting as the scalpel was withdrawn. Incisions were approximately 30 mm long, beginning near the pelvic girdle and extending

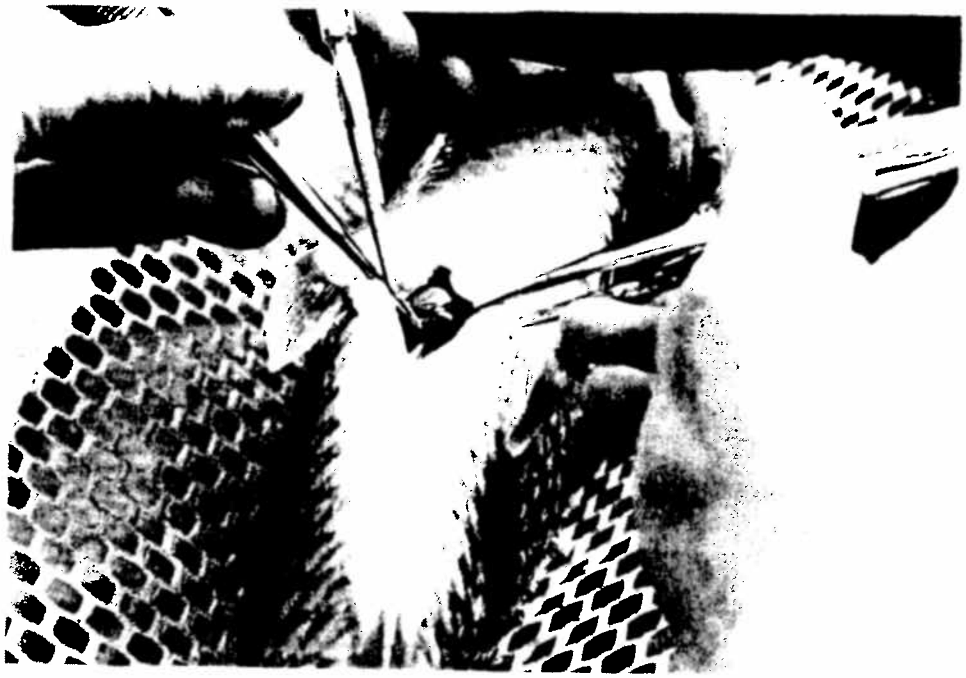

Figure 4.-View of grass carp during radio transmitter implantation. Transmitter had just been inserted into the abdominal cavity; note transmitter near tip of probe and position of incision.

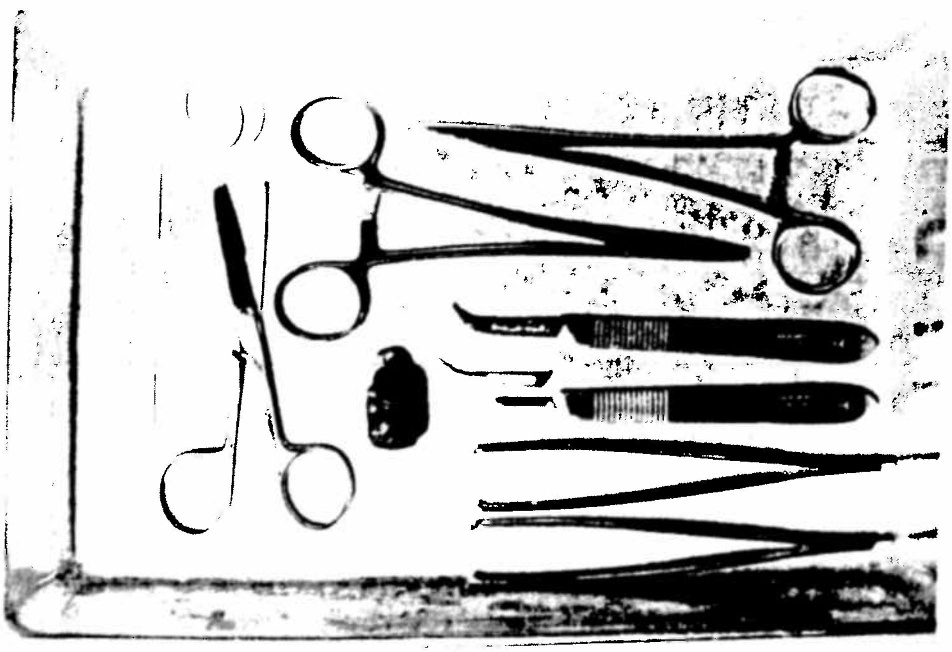

Figure 5.-Surgical instruments used to implant radio transmitters into grass carp. From top left in a clockwise fashion, instruments are: 3/8-circle reverse-cutting needles, needle holders, hook-shaped scapels, tissue forceps, radio transmitter and blunt-point scissors.

posteriorly. A spatula of crystallized Furacin (Argent Chemical Company), an amount equal in size to a small pea, was placed in the body cavity and followed by insertion of the radio transmitter, antenna-end first. Transmitter positioning involved pushing the transmitter forward within the abdominal cavity until it was anterior to the pelvic girdle, ventrally located midway between the pectoral and pelvic fins. The incision was closed with 4-0, non-absorbable, multifilament polyamide sutures (Braunamid, B. Braun Melsungen AG, West Germany) attached to 3/8-circle reverse-cutting needles. Three or four simple, interrupted sutures, 5-8 mm apart, were used and left in place for the duration of the study. Care was taken to realign tissues of the body wall. Transmitters and surgical instruments were soaked in a tray of isopropyl alcohol during surgery to reduce the liklihood of infection. Following closure, fish were weighed, measured, Floy-anchor tagged, and placed in a freshwater recovery tank. Total time required to perform surgery on individual fish (starting when the fish was removed from the anesthesia and ending when the fish was placed in the recovery tank) was 5-6 minutes. Short time out of water eliminated the need to irrigate the gills during surgery. Recovery from the anesthesia took 5-10 minutes. Fish were held in circular tanks at a temperature of 17^{o}C for at least 30 days before being released.

Equipment and methods of radio telemetry

Radio receivers were purchased from Custom Telemetry and Consulting. Receivers were CE-12 type, equipped with the same 12 frequency settings as the radio transmitters. Antennae were attached via a BNC coupler and could be connected and disconnected quickly. Two antennae were typically used, a portable 254-mm square-loop directional antenna and a truck-mounted 3-m omnidirectional whip antenna.

Radio telemetering was a two-step procedure. First, a search using the omnidirectional antenna was conducted to obtain an approximate location for each fish being studied. Once all study fish had been located, the second step of the telemetering routine commenced. This involved obtaining an accurate estimate of each fish's position on an hourly basis. The principle of triangulation was used to pinpoint transmitter locations by use of the directional antenna (Figure 6). Two bearings were made approximately 90 degrees to each other. A third bearing, taken perpendicular to the shoreline and bisecting the 90-degree angle between the first two, was taken to reduce triangulation error (Bovee 1986; Kenward 1987). A rope marked every 100 mm and weighted with a piece of wood was thrown over the canal at the same angle as the third bearing and used as a reference for triangulation bearings. Care was taken to observe fish before and after this procedure to ensure that they were not disturbed by my approach or deploying of the reference rope.

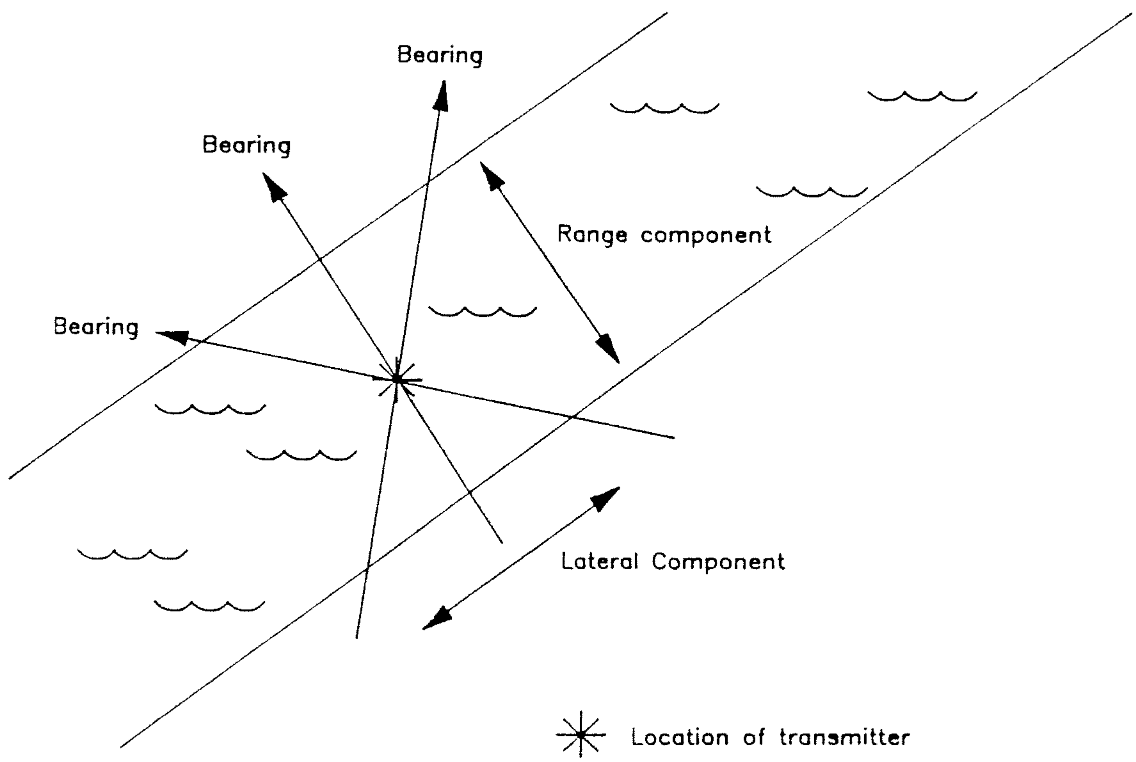

Figure 6.-Principal of triangulation (using multiple bearings) used to estimate grass carp positions in the South Platte Supply Canal.

An exercise to determine accuracy and precision of my ability to locate transmitters, using radio telemetry, in the canal was conducted. A radio transmitter was attached to a brick, and an assistant placed the brick in the canal while I waited with my back turned at a distance of approximately 120 m. On my assistant's signal, I located the transmitter using the triangulation method. The distance from my estimate to the radio transmitter was measured to the nearest tenth of a meter and recorded. Sample size was determined with an iterative technique which took into account the estimated sample mean, standard deviation and desired confidence limits (Green 1979). A sample size of ten was used. The exercise was carried out in a portion of the ditch where I commonly telemetered grass carp.

Movement

Movements of grass carp in the SPSC were not migrations as defined by Smith (1985). Migrations require a preparatory phase regulated by priming stimuli, a narrow time window during which releasing stimuli initiate migratory behavior, specific adaptations for migration, and termination at an appropriate location. Movements of grass carp in the SPSC were either directed movements (foraging trips) or accidental displacements (long-distance downstream movements). Such movements, although not migrations, are subject to similar selection pressures and can be discussed and explained using information provided by migration studies and migration literature.

Throughout this discussion, day and daytime refer to the time of day following sunrise and prior to sunset, night and nighttime refer to the time of day following sunset and prior to sunrise, and diel refers to the 24-hour cycle. Times of sunrise and sunset were provided by the Nautical Almanac Service, U.S. Naval Observatory, Washington, D.C.

The basic unit of measure of movement for all studies was the distance moved during the time interval between successive radio telemetry contacts. Grass carp were usually located hourly and sometimes every 0.5 hours if the fish were moving. Slight movements, less than or equal to 2 m upstream or downstream from a position estimate, were not considered movement.

Movements of grass carp in the SPSC can be divided into two general categories; those of non-acclimated and acclimated fish. Movements of non-acclimated fish occurred during the 7-day period immediately following the introduction of fish into the canal and were a result of handling during stocking and the fish's response to environmental factors in the canal at the time of stocking. Although somewhat arbitrary, the 7-day time period was an approximation of the amount of time required for grass carp to become accustomed to the canal environment. During that time, grass carp explored the canal, searched for food and cover, and adjusted to the diel patterns of temperature and light. **Movements of acclimated fish** were movements by fish which were accustomed to the canal and were a response to changing environmental factors, ie., food availability, light, temperature, discharge, and cover. All fish released during my studies were stocked in Section 2, and at the same location within the section unless otherwise noted. Although this stocking regime resulted in production of a majority of data from fish in Section 2, it also served to reduce the amount of variation in grass carp movements that would be produced if fish were stocked in different sections. Additionally, habitat measurements were time consuming, and by concentrating study in one or two sections, it was possible to collect more reliable habitat information.

To identify factors responsible for **movements of non-acclimated fish**, grass carp were stocked on seven occasions (15 May, 20 May, 10 June, 17 June, 27 June, 28 July, and 29 July 1986) under different environmental conditions which are summarized in Table 1. The number of fish stocked on these occasions ranged from two to four depending on the environmental factors being studied. Releases which were likely to result in immediate abandonment of the study section were typically studied with fewer fish. Releases which were expected to produce relatively short-distance movements over a long period of time were typically studied with four fish. Environmental conditions studied included plant biomass, effects of stop logs, discharge, water velocity at stocking site, illumination, and time of day. Aquatic plant biomass estimates were provided by J. S. Thullen and F. L. Nibling (USBR, Denver, Colorado, pers. comm.) using methods outlined by Thullen and Nibling (1986). The effect of the environmental condition of interest was studied by monitoring movements of grass carp immediately following their introduction into the canal and at 1, 2, and 7 or more days after stocking.

Table 1.-Environmental conditions at time of stocking for the study of movements of non-acclimated triploid grass carp in the South Platte Supply Canal, 1986. Conditions at time of stocking are marked X.

Stocking date	Number of fish	Variable[a] 1	2	3	4	5	6	7	8	9
15 May	3	X				X	X		X	
20 May	3	X				X	X		X	
10 June	4	X		X	X		X		X	
17 June	4		X		X		X		X	
27 June	4		X			X	X		X	
28 July	4		X			X		X	X	
29 July	2		X			X	X			X

[a]Variables:
1 plant biomass, low
2 plant biomass, high
3 stop logs in place
4 discharge, low
5 discharge, high
6 stocking site velocity, low
7 stocking site velocity, high
8 time of day, day
9 time of day, night

Grass carp which approached check-drops during telemetering sessions were closely monitored so that behavior near check-drops could be observed. Movements of fish which were moving downstream were predictable, and several downstream passes of check-drops were observed. Upstream ascents of check-drops were rare and unpredictable. When not actually observed, upstream and downstream passes of check-drops were documented by noting abandonment of previously occupied sections and residence in a new section.

Observations of movements of acclimated fish were made using 12-hour telemetering sessions. Fish studied during these sessions were located in Sections 2 through 6, although all had been released in Section 2. Stocked fish were allowed to acclimate to canal conditions for 7 to 10 days before they were telemetered, the assumption being that this was sufficient time for the fish to establish rhythmic patterns. Fish were telemetered every hour, and estimates of their position and activity were recorded. Data were collected from four fish telemetered on 10 and 11 July and five fish on 8 and 9 August, 1986. Data for the nine fish were pooled since discharges were similar (4.8 and 3.2 m^3/s, respectively) and differences in depth, velocity, substrate, and cover could be assumed to be negligible. Habitat measurements taken on 10 July and 8 August showed an average difference in depth of 96 mm due to declining discharge. Velocity, although not measured, probably had a similar minor decrease. It is unlikely that substrate and cover changed significantly from July to August. I assume that these changes had no effect on grass carp movement since grass carp were responding to abundance of aquatic plants and availability of cover, both of which underwent little change. Also, movements of the fish were similar during the two sessions, indicating no response to the changing conditions.

To investigate whether grass carp developed daily rhythms, fish were telemetered 1 day after stocking and 7 to 10 days after stocking. Fish telemetered 1 day after stocking should not have demonstrated daily patterns since they had not had time to adjust to fluctuating environmental conditions. Conversely, fish telemetered 7 to 10 days after stocking would be expected to demonstrate diel patterns, assuming 7 days is a sufficient amount of time for the behavior to develop. Twelve-hour telemetering sessions were conducted as described above on each occasion. All fish telemetered were not in the same section of the canal, and different fish were used to study arrhthymic and rhythmic behavior.

Habitat use

Habitat (depth, velocity, substrate, and cover) was measured at the conclusion of 12-hour telemetering sessions. Habitat use was based on the length of time a fish used a location and whether a fish was exhibiting feeding or nighttime resting behavior. A location was considered of value to a fish if the fish spent 15 minutes or longer at the location. If it did so, a "position estimate" was made via triangulation, marked along the canal, and recorded. No habitat information was collected from locations of moving fish. Habitat attributes were measured at every position estimate and then stratified on the basis of whether the fish had finished its daily foraging movements. Foraging was assumed to start when a fish left its nighttime location and to continue until it returned to the nighttime site and remained there overnight. Fish which passed through the nighttime site, or spent an hour or two at the site, were still considered to be foraging. This method of stratifying data was useful since data were stratified on the basis of fish behavior and not by such arbitrary criteria as time of day. Habitat was only measured for acclimated fish. Habitat use by non-acclimated fish was of little interest since it reflected habitat use by fish which were unaware of the environmental choices that existed.

Habitat measurements were made at estimated positions by wading into the canal and measuring dominant habitat types within a 0.5-m radius of position estimates. Water depth was measured using a wading rod and determining the distance from streambed to air-water interface to the nearest centimeter. Fish depth would have been a more desirable measurement but was impossible to measure because low transparency prevented visual estimates. Mean column velocity was measured with a Marsh McBirney flow meter using the method suggested by Bovee (1986). Substrate was categorized as suggested by Bovee (1986), using a modified American Geophysical Union particle-size classification. Mud and silt were grouped as fines (Table 2), and the following substrate types were added: smooth concrete, compacted clay, fines with vascular plants, sand with vascular plants, gravel with vascular plants, and cobble with vascular plants.

Table 2.-Substrate codes and definitions used to qualify habitat in the South Platte Supply Canal (modified from the American Geophysical Union particle-size classification system).

Code	Definition
1.	Fines (0.00024-0.062 mm)
2.	Sand (0.062-2.0 mm)
3.	Gravel (2.0-64.0 mm)
4.	Cobble (64.0-256.0 mm)
5.	Boulder (256.0->2048.0 mm)
6.	Smooth concrete
7.	Compacted clay
8.	Fines with aquatic vascular plants
9.	Sand with aquatic vascular plants
10.	Gravel with aquatic vascular plants
11.	Cobble with aquatic vascular plants

Substrate was classified by dominant particle size only and identified by feel and grab sample. Cover types were coded as: 0-no cover, 1-undercut bank, 2-overhanging riparian vegetation, 3-instream vegetative, and 4-instream object and were not quantified. No cover was identified when no source of visual isolation or current refugium was present. An undercut bank was defined as any bank having an undercut equal to or greater than 152 mm. Overhanging riparian vegetation, typically reed canarygrass, was defined as any vegetation hanging over the water column and within 304 mm of the water surface (Platts et al. 1983). When undercut banks and overhanging riparian vegetation occurred together, undercut was the classification assigned. Instream vegetative cover was defined as any mass of aquatic plants which was at least 100 mm wide (measurement made horizontally, perpendicular to the flow). Submerged mats of rooted aquatic macrophytes at least 300 mm deep (vertical measurement from substrate to plant mat-water interface) were common. Cover type 4, instream object, was defined as any object in the channel, other than plant mats (ie., rocks, pilings, slumped banks, and sandbars) that was at least 100 mm wide (measurement made horizontally, perpendicular to the flow) and capable of providing current refugia.

Habitat availability

Available habitat was quantified using a stratified-systematic method. The method involved identifying major types of habitat and then sampling locations on transects, with the number of transects in any one habitat being proportional to the fraction of total area of the study site that habitat comprised. Two types of major habitats were identified: 1) erosional habitats, which occurred immediately downstream of each drop structure and were characterized by a rocky substrate and relatively shallow, turbulent water; and 2) depositional habitats characterized by a shifting sand-gravel substrate, abundant aquatic macrophytes, and a deeper, low-velocity, water column. Erosional habitats comprised 16% of the entire study site, and depositional habitats comprised the remaining 84%. When quantifying habitat for the entire study site, eight transects were randomly assigned to two erosional habitats, and 44 transects were randomly assigned to four depositional habitats. When estimating available habitat in Sections 2 and 3 only, availability was determined with four transects in the erosional habitats and 13 transects in the depositional habitat. Habitat estimates were made on transects at 0.5 m from the ditchbank and at 1.5 m intervals along the transect. Available habitat in Sections 2 and 3 was estimated following each 12-hour telemetering session. Habitat in the entire canal was estimated at high (4.0 m^3/s) and low (0.4 m^3/s) discharges.

Habitat preference

Habitat preference curves illustrate habitat use relative to habitat availability. The reasoning used to develop a habitat preference function is the same as that discussed by Ivlev (1961) for determining food electivity. If a fish uses a habitat type in a higher proportion than that habitat type is available in the environment, the fish is assumed to be actively searching out and selecting that habitat in preference to others. Preference functions were calculated using the methods outlined by Bovee (1986). Each habitat variable had several components (habitat types) which were related by a proportion (relative frequency) to the other habitat types of that variable. A ratio of the relative frequencies of use and availability provided an index of habitat selection (suitability). Suitability values were normalized (scaled from 0 to 1) so that the most preferred habitat type was given a score of 1, and less preferred habitat types were proportionately less than 1.

Habitat preference functions have recently been a topic of controversy. Because preference functions consider habitat use relative to habitat availability, they theoretically eliminate environmental bias; ie., a preference function developed in one stream should be transferable to other streams. In fact, preference functions are transferable only under highly restricted conditions, and even then may require fine-tuning on a site-by-site basis (Bovee 1986; Mathur et al. 1985; Orth 1986; Orth 1987). This use of preference criteria, to improve transferability, is not my intent. I simply present preference functions for substrate and cover because the method provides an objective comparison of habitat use and availability. It not only illustrates habitat use, but when normalized, highlights the order of preference for habitat types. Considering this usage, the term "relative use" rather than preference, might be more apropos; however, I have retained the terms preference and suitability because methods used to determine relative use are the same as those for preference.

Results and Discussion

Surgical success and radio transmitter retention

Grass carp proved to be resilient subjects on which to conduct surgery. One of 19 fish died following surgery in 1985, and survival of 29 study fish was 100% in 1986. Incidence of disease following surgery was low. During 1985, several fish developed minor exterior fungal infections which eventually declined. No apparent infections occurred during 1986, possibly because holding water was cooler (17^{o}C as compared to 22^{o}C in 1985). Time required for incisions to heal varied with individual fish. At 14 days after surgery, some incisions appeared completely healed and normal, and others appeared closed but with considerable redness at the incision.

The fate of radio transmitter implants was examined using grass carp which were implanted during Spring 1985 and 1986. Transmitters had been in place for 12 to 17 months. Of five fish available for examination; four had encapsulated the transmitter within tissue. The radio transmitter in the fifth fish was lying free within the abdominal cavity, sandwiched between the gut and the body wall with no indication of being isolated within tissue. Marty and Summerfelt (1986) addressed encapsulation as it relates to channel catfish. They described the encapsulating tissue as a fibrous proliferation, highly vascularized, containing numerous myofibroblasts and acellular collagen. The encapsulating material in the grass carp I studied was largely mesentery composed of mature adipose tissue and endocrine cells. Some fibrosis (heavy fibrous connective tissue) of the mesentery was present, but there was a surprising lack of reactive tissue (D. H. Gould, Department of Pathology, Colorado State University, pers. comm.). Other observations on encapsulation in grass carp, 30 days after transmitter implantation, revealed radio transmitters entirely encapsulated in heavy fibrous connective tissue. Apparently the grass carp's immune system initially responds to the presence of the radio transmitter by isolating it within a capsule of heavy fibrous connective tissue which is gradually replaced by normal tissue. Marty and Summerfelt (1986) reported a transmitter expulsion rate of approximately 50% 23 or fewer days after implantation in channel catfish. Such a high rate of expulsion does not occur in triploid grass carp. All 1986 fish retained their transmitters for at least 7 months. Several of these fish were held for as long as 3 months before stocking, and no indications of body wall or incision exits were observed. Transmitter expulsion occurred at a higher rate in 1985, but I attribute this to improper transmitter size for the fish used. Radio transmitters should weigh no more than 2% of the fish's body weight in air (Winter 1983). The transmitters purchased in

1985 were designed for fish weighing at least 1150 g, but events beyond my control caused me to use triploid grass carp weighing an average of 542 g with an average total length of 355 mm. Radio transmitters implanted in these fish produced a bulge which was apparent on examination of a fish's midventral region. Marty and Summerfelt (1986) found that decreasing the transmitter-to-body-weight ratio significantly decreased the liklihood of expulsion; they identified excess transmitter weight as the primary cause of expulsion. The expulsion problem in grass carp was overcome during the second field season by using larger triploid grass carp with an average weight of 1525 g and an average total length of 517 mm.

Triangulation accuracy and precision

The exercise to determine accuracy and precision of triangulation position estimates showed that the distance from observed to actual transmitter locations, had a mean of 1.9 m, a standard deviation of 1.8 m, and a range of 0.0 to 6.0 m. Error in position estimates was due to inability to determine how far across the canal the transmitter was located, the range component in Figure 6. Prediction of the lateral position of the transmitter was 100% accurate. The difficulty in pinpointing the radio transmitter position was probably due to interference by canal banks on the signal produced by the transmitter. The farther away the transmitter was located from the near bank, the greater was my ability to accurately determine its location. During the exercise, radio transmitters were placed on the substrate, and this also may have influenced my ability to pinpoint position. Estimates of actual fish positions are probably better than those for transmitters alone because grass carp do not lie on the substrate but move up and down in the water column. Movement causes a change in orientation of the radio transmitter to the receiver. Transmitter orientation strongly influences the strength of the signal, and a moving fish provides more opportunities for an accurate bearing.

Overview of diel movement

The existence of daily movement patterns quickly became apparent during radio telemetering sessions. Telemetered fish consistently returned to specific locales (core areas) at night and dispersed throughout the canal during the day. The term "core area" refers to a portion of a home range (an area through which an animal regularly travels during its daily activities) which is used more intensively than the rest (Keenleyside 1979). The irrigation canal restricted movements of grass carp too much to allow identification of a home range (grass carp moved throughout entire sections), but the consistent use of core areas during nighttime implies the existence of a home range. In many cases, all telemetered fish in the same section converged on the same core area at approximately the same time of night and remained there until morning (Figure 7). An examination of a core area in Section 2 revealed the presence of a small seep originating from the canal bank. Drawings in the Designers' Operating Criteria for the South Platte Supply Canal (USDI 1957) indicated that the source of the water was a drainage tile, and the water was most likely groundwater. Slumping and erosion of the bank by the seep had produced an embayment which was approximately 1 m wide and 1.5 m long (Figure 8). Water from the seep was highly favored by grass carp in the canal. I observed fish attempting to take advantage of the input to the extent that their backs emerged from the water as they swam into the shallow water of the embayment (position A, Figure 8). Selection of locations where water inputs occurred was noted during 1985 as well. According to the Designers' Operating Criteria, a total of 12 water inputs are known to occur throughout the length of the canal, and only Section 7 does not receive an input.

Importance of freshwater inputs and core areas

To determine why freshwater input areas were so highly favored, I examined the seep in Section 2. The most obvious benefit provided by the seep was that the slumped bank on the upstream side provided current refugia. Slumping had produced a peninsula-like formation, and the resulting embayment was sufficiently large and deep to provide refugia for several grass carp.

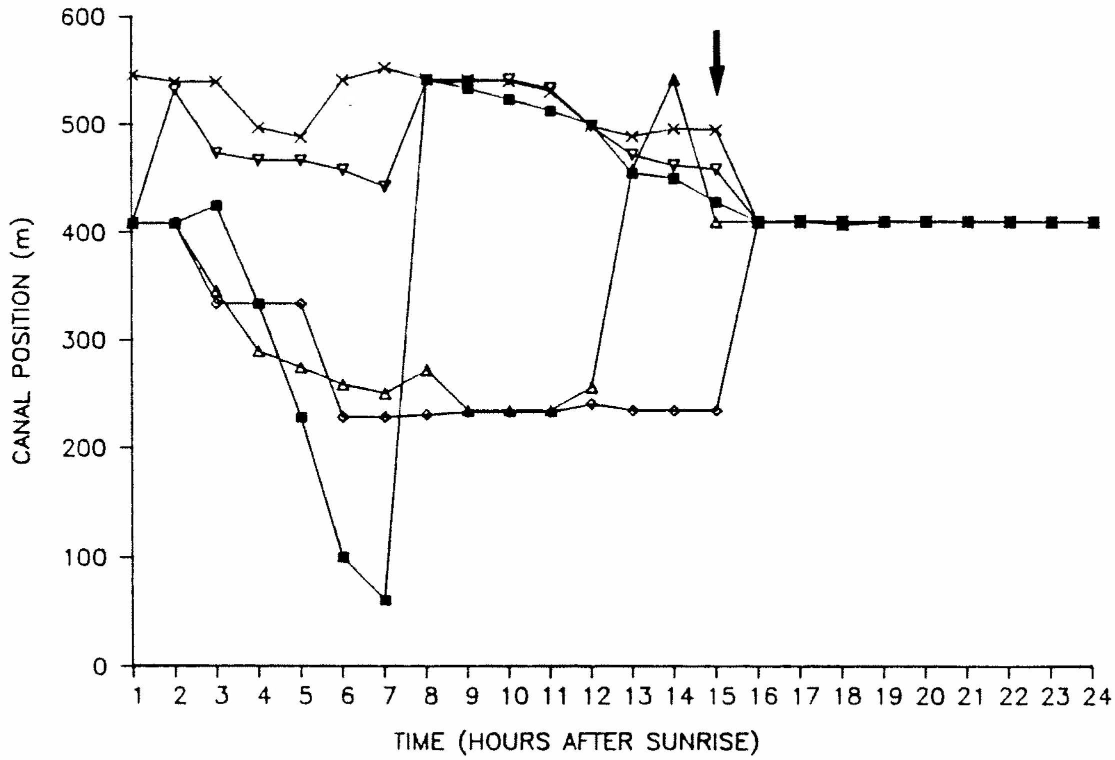

Figure 7.-Positions of grass carp in the South Platte Supply Canal as a function of hours after sunrise. Symbols denote hourly positions of five fish during the same day. Decreasing canal position values indicate upstream movement, and increasing values indicate downstream movement. A core area occurred at approximately 400 m. Vertical arrow indicates time of sunset.

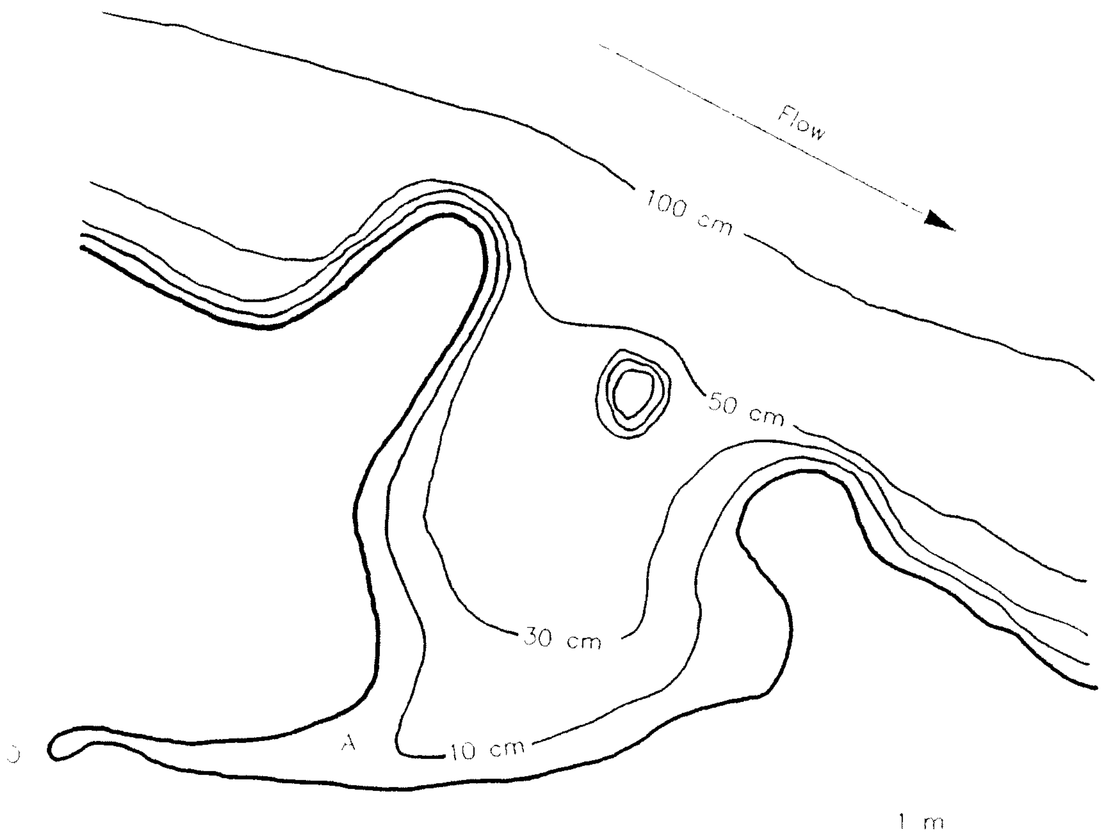

Figure 8.-A small embayment used by grass carp as a core area in Section 2 of the South Platte Supply Canal. A=shallowest position occupied by grass carp; O=origin of a seep in the canal bank.

A second possible benefit of the seep was that it modified the temperature of the water in that immediate area. Simultaneous temperature recordings made in the canal and seep (Figure 9) showed that the temperature of the seep equaled and then surpassed that of the canal 18 hours after sunrise and remained equal to or above the canal temperature until 10 hours after sunrise the following day. If grass carp showed a preference for warmer temperatures, they should have occupied the seep during these hours. Grass carp are known to prefer warm temperatures, having a temperature preference of approximately 25^{o}C (Bettoli et al. 1985). Discharge from the seep was approximately 2 l/min and, although it was not enough to effect the temperature of the canal, the temperature of water in the embayment was effected by the input.

A third possible benefit of the seep is that it may have been a major component of the "chemical landscape" of the canal, and as such, may have provided orientation (Smith 1985). Chemical information is available throughout the diel cycle, unlike visual information which is largely unavailable at night. Loss of visual stimuli during the night means that fish must rely on other senses if they are to remain in a suitable environment in a lotic system. The organs of chemoreception in many fish, including grass carp (Pashchenko and Kasumyan 1986), are acutely sensitive and may provide simple, accurate means of orientation when other senses are unable to function due to changing

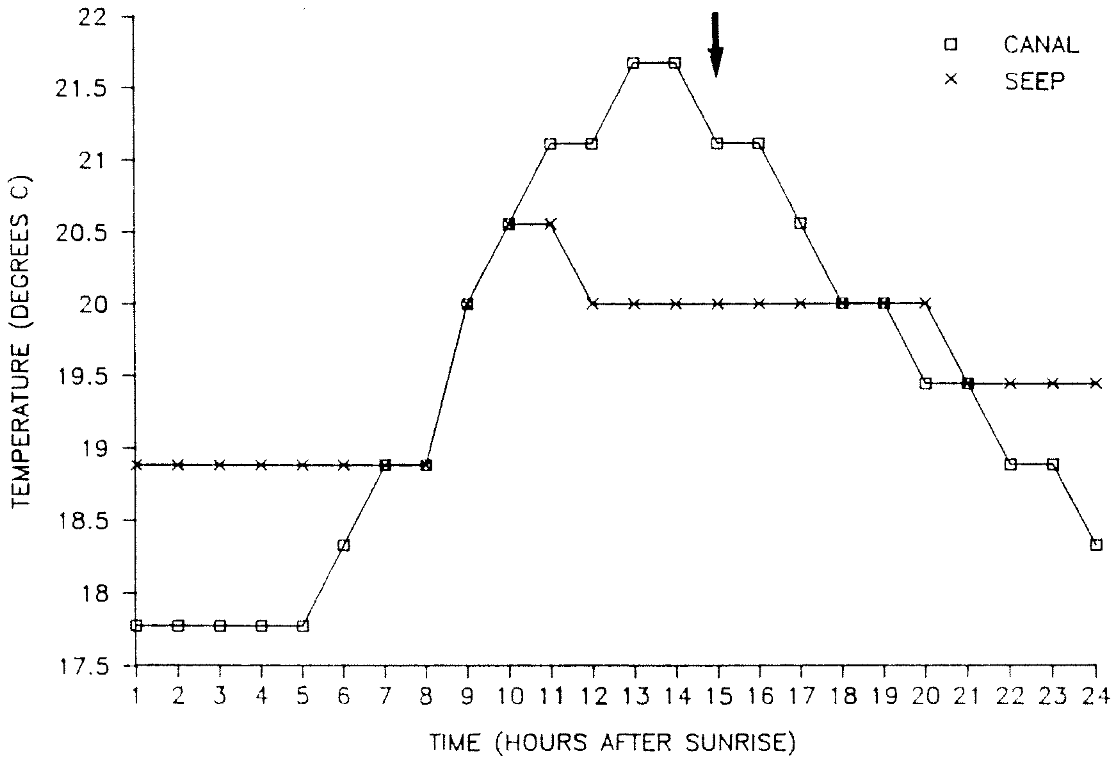

Figure 9.-Simultaneous temperature record of the South Platte Supply Canal and the seep in Section 2 as a function of hours after sunrise. Both measurements were taken on 10 July 1986. Vertical arrow indicates time of sunset.

environmental factors. With the onset of darkness, evening movements of grass carp may have been guided by a chemical path produced by the seep.

Lastly, grass carp may have used the seep, and other core areas, as a location at which to rendezvous and form a school in an effort to gain a hydrodynamic advantage or increase security. The hypothesized hydrodynamic advantages of schooling (Shaw 1978) include reduced energy demand for swimming, increased thrust, reduced oxygen demand, and friction reduction. Whether grass carp maintain proper orientation to take advantage of hydrodynamic conditions is not known and could not be observed in the SPSC.

The benefits of schooling as a response to threat of predation are not as well understood as hydrodynamic benefits, especially with regard to grass carp. Several authors (Gasaway 1977; Shireman et al. 1978) have discussed the apparent lack of a response to predators by juvenile grass carp. The circumstances surrounding the stocking of grass carp in their research may have been at least partially responsible for the observed behavior. In both cases, grass carp were obtained from a hatchery and stocked into ponds containing northern largemouth bass (Micropterus salmoides salmoides) or Florida largemouth bass (M. s. floridanus). Under such conditions, grass carp may have shown reduced ability to avoid predators because of their lack of previous exposure to predators. Many fish are suspected to have an innate repertoire of behavioral responses to predators (Pitcher 1986). Minnows from environments with and without predators (pike) displayed similar patterns of anti-predator tactics, but those from environments with sympatric predators performed the behaviors more effectively. This dulling of the ability to execute anti-predator tactics is probably a contributing factor to the observed susceptibility of grass carp to predation. Perhaps most importantly, grass carp may not equate bass morphology with that of a predator. If an innate response to a predator by prey fish does exist, it must be tied to an innate ability to recognize predatory species. The historical distribution of the family Centrarchidae is restricted to North America, making evolution of an innate response, specifically to centrarchids, impossible in grass carp. Shireman et al. (1978, p. 215) described a grass carp-bass encounter as:

> "...a bass slowly moving into a school of grass carp and ingesting an individual head first. The remaining grass carp in the school did not avoid the bass, but remained as they were prior to attack."

The description gives the impression that grass carp did not view the bass as a predator, even after an attack. That grass carp have evolved with predators is without doubt. The native rivers of grass carp contain an abundance of predators (Nikolski 1956; Shireman and Smith 1981; J. Q. Wang, Department of Fishery and Wildlife Biology, Colorado State University, pers. comm.), and the fish must have evolved anti-predator mechanisms. Grass carp school readily, especially in response to a threat. A school, a synchronized and polarized swimming group of fish, provides several means of countering predator attack via attack abatement, evasion, confusion, and detection (Shaw 1978; Pitcher 1986). Schooling, as a response to predation, would be most beneficial during periods when environmental constraints (darkness) prevent fish from improving their fitness through other behaviors (foraging). Coral reef fishes have adopted a similar strategy and seek shelter during inactive periods (Helfman 1986). Hobson (1972) suggested that these behaviors, even in waters depauperate of predators, may be a response to a "historic threat" from predators. Such innate behavior, although unnecessary in the irrigation canal, may cause fish to school during periods of inactivity so that they may maximize security.

Schooling also accomodates the transmission of chemical signals. Pashchenko and Kasumyan (1986) reported that grass carp possess and react to alarm phermone(s) found in many cyprinids and that they may be able to detect exometabolites of predatory fishes and respond with defensive behavior. Such a system would be more efficient if the fish being preyed upon were in a school. Not only would the liklihood of detecting a predator be improved but, should an individual be caught, chemical signals would be helpful in alerting the school.

Rhythmicity of diel movements

The importance of studying the development of diel rhythmic behavior is related to its link to acclimation of introduced fish to the canal environment. Rhythmic behavior is the response by living organisms to an oscillating environment. Changing environmental conditions (e.g., light intensity, light quality, and temperature) initiate a chain of physiological events which prepare an organism for the biological consequences of a changing environment. Documentation of grass carp rhythmicity in the SPSC indicates that the fish had sufficient time to acclimate to the canal and that the behavior observed probably occurs in other similar environments.

Typically, the daily light-dark cycle is the most prominent environmental stimulus responsible for entraining rhythmic behavior in fishes (Manteifel et al. 1978; Müller 1978; Helfman 1986). Behavior and movements of grass carp in the SPSC appeared to be consistent with this hypothesis. Grass carp were daytime feeders, a behavior which was probably regulated by light intensity. That grass carp show preference for certain types of aquatic plants provides support for this assumption. Sight must play an important role in finding and selecting preferred plants in the patchy environment of the irrigation canal. Grass carp X bighead carp (Hypophthalmichthys nobilis) hybrids fed most actively between 0400 and 2000 with feeding peaks at 0800 and 2000 in South Dakota ponds (Harberg and Modde 1985). In the town of

Dalian, Liaoning province, China, pond-cultured grass carp feed most actively during the day with feeding peaks at 1000 and 1800 (J. Q. Wang, Department of Fishery and Wildlife Biology, Colorado State University, pers. comm.). In the SPSC, absence of aquatic vegetation at core areas implied that grass carp did not feed during the night. During nighttime hours when grass carp occupied core areas, no foraging trips were recorded. Fish typically remained at core areas until sunrise, when increasing light levels probably made it possible for grass carp to find and select food.

A comparison of movements of non-acclimated and acclimated fish illustrates several interesting points. Unlike acclimated fish, non-acclimated fish did not display a high degree of synchrony in their movements. Figures 10 and 11 illustrate the relationship between number of non-acclimated and acclimated fish moving, and time of day. The number of non-acclimated fish moving during any hour of the day never exceeded two out of five, while acclimated fish showed a high degree of synchrony with as many as eight of nine fish moving during the same interval. Sunset, 15 hours after sunrise (HAS), and the onset of darkness (15-17 HAS) coincided with a marked reduction of number of acclimated fish moving as grass carp returned to core areas for the night. Beginning with this twilight period, and continuing until sunrise, distance moved by acclimated fish (Figure 12) was at a daily minimum. Conversely,

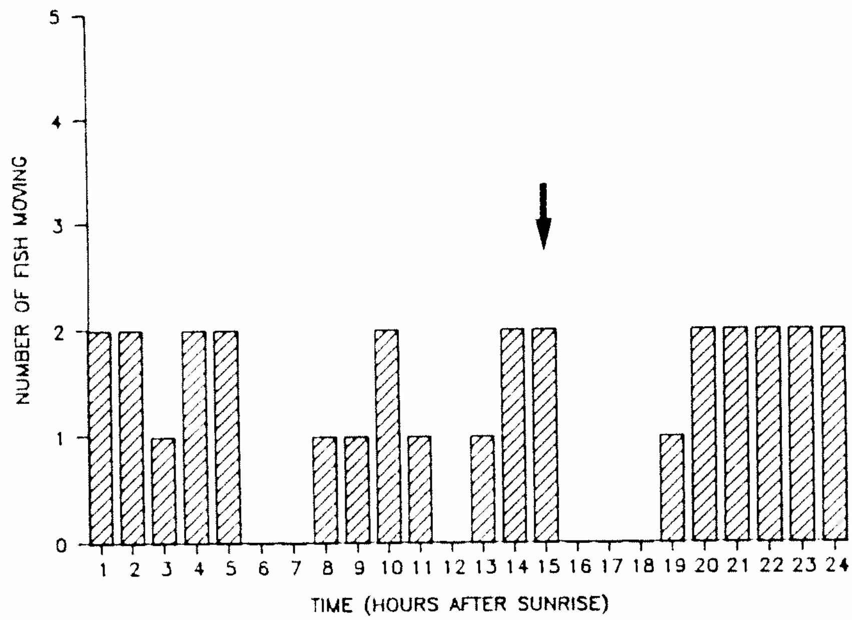

Figure 10.-Number of non-acclimated grass carp moving as a function of hours after sunrise in the South Platte Supply Canal (n=5). Vertical arrow indicates time of sunset.

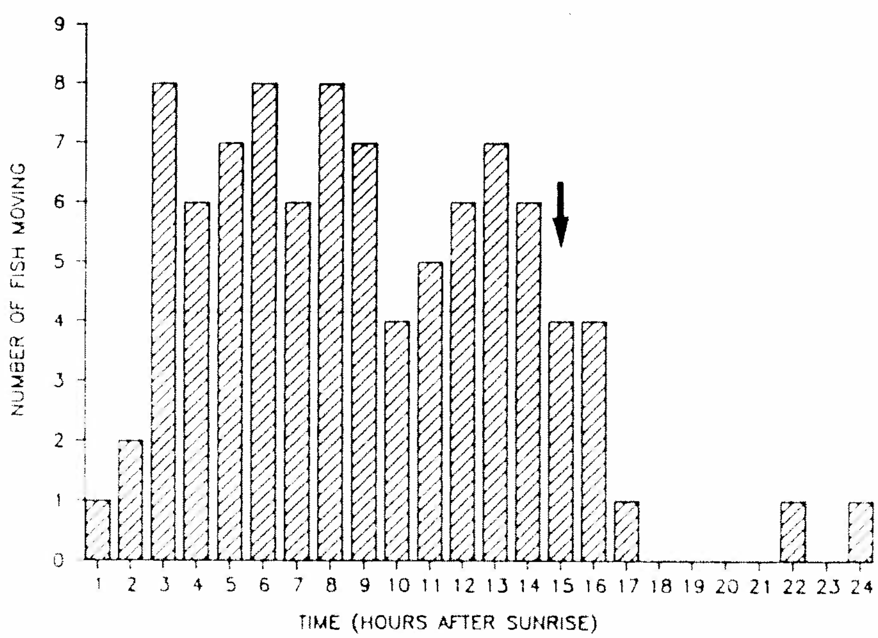

Figure 11.-Number of acclimated grass carp moving as a function of hours after sunrise in the South Platte Supply Canal (n=9). Vertical arrow indicates time of sunset.

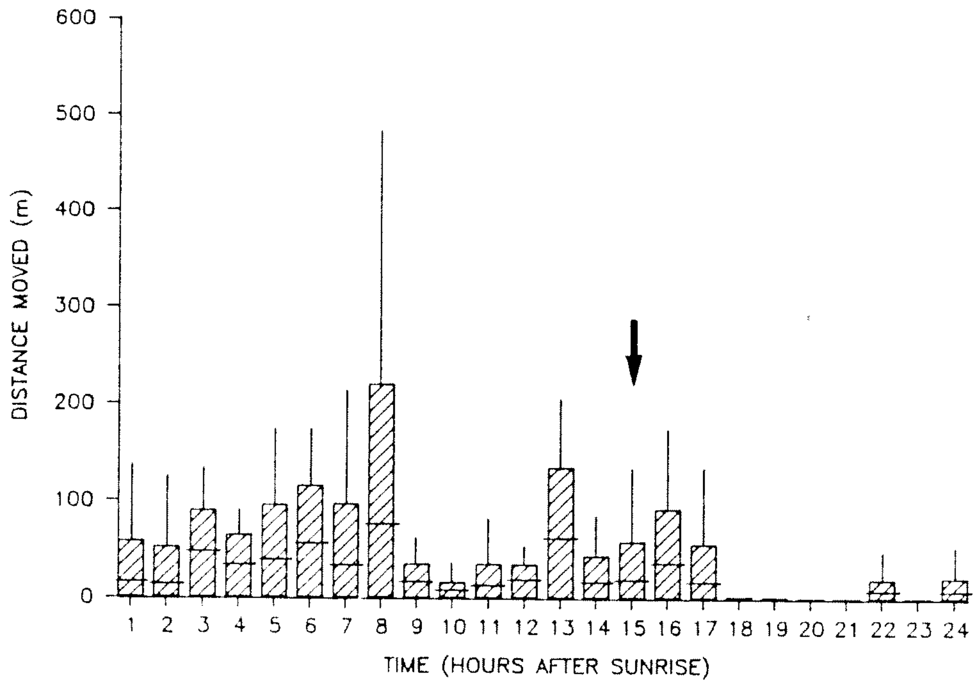

Figure 12.-Distance moved by acclimated grass carp (n=9) in the South Platte Supply Canal as a function of hours after sunrise. Tops of vertical lines represent maximum, horizontal lines represent mean, and hatched bars represent ±1 standard deviation of distance moved. Vertical arrow indicates time of sunset.

non-acclimated fish moved farther at night than during any other time of day (Figure 13). This tendency to move at night probably resulted from a loss of orientation due to lack of visual information. Acclimated grass carp did not lose position at night because they inhabited core areas whose characteristics made them identifiable. Non-acclimated grass carp had not learned the characteristics of these core areas and were subject to accidental displacement at night. The approach of dawn, and a corresponding increase in light intensity, permitted displaced, non-acclimated grass carp to locate suitable habitat (e.g., forage, current refugia) and resulted in decreased movement. This reduction of movement was in contrast to the behavior of acclimated grass carp. At dawn, acclimated grass carp began to move more frequently and greater distances (Figures 11 and 12), with peaks of movement occurring near midday, 7-8 HAS (1100-1200), and 13 HAS (1700). Peaks of activity coincided closely with the feeding peaks reported by Harberg and Modde (1985) and Wang (J. Q. Wang, Department of Fishery and Wildlife Biology, Colorado State University, pers. comm.) and may indicate a link between feeding and movement in the SPSC. Grass carp may have been actively seeking out food and probably were highly selective. Once a preferable plant was selected, it was quickly consumed and the search for forage was resumed. Although non-acclimated and acclimated grass carp appeared to behave differently in the canal, both

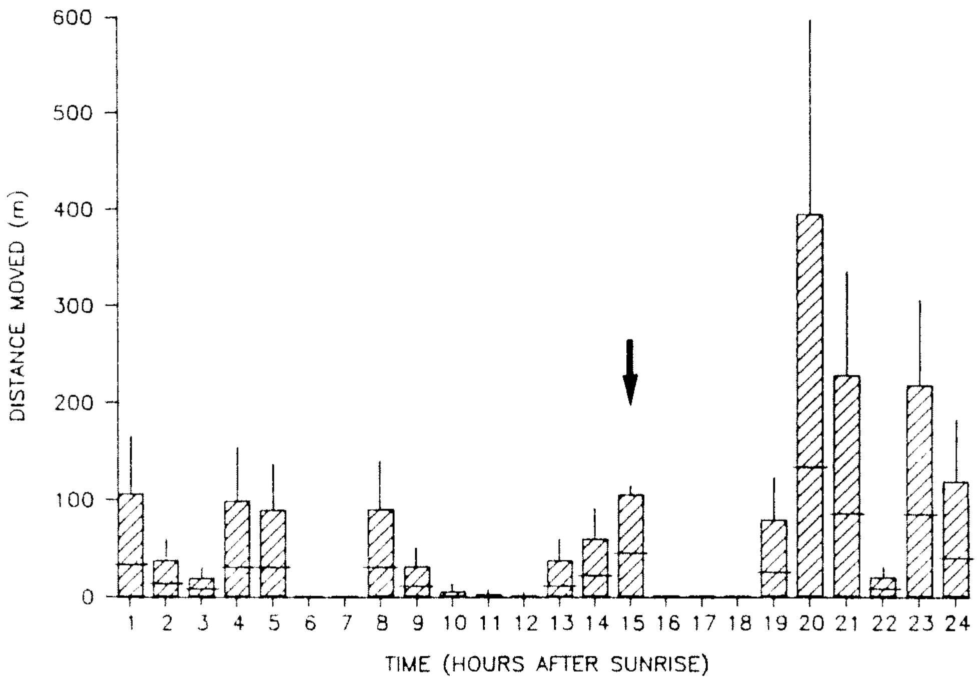

Figure 13.-Distance moved by non-acclimated grass carp (n=5) in the South Platte Supply Canal as a function of hours after sunrise. Tops of vertical lines represent maximum, horizontal lines represent mean, and hatched bars represent ± 1 standard deviation of distance moved. Vertical arrow indicates time of sunset.

groups showed decreased movement during mid-afternoon, at approximately 10 HAS (1400). Figure 10 implies an exception to this generalization, but the overall decline in number of fish moving before and after 10 HAS supports it. Distance moved (Figure 13) by non-acclimated fish was at a daytime low at 10-12 HAS, and the apparent increase in movement at 10 HAS in Figure 10 is an artifact of the small sample size and arrhythmic behavior. Many fish are less active during this time of day, and this is typically attributed to high light intensity. That both non-acclimated and acclimated fish responded in a similar manner, at a similar time of day, supports a hypothesis that the fish were attempting to escape brightly lit areas of the canal by restricting their movements to areas where light intensities were reduced (e.g., deep water, undercut banks). Although acclimated grass carp may have more experience in selecting such habitats, one would expect non-acclimated grass carp to show similar movement behavior since relatively darker microhabitats can be found in any area of the canal. Observations of grass carp on cloudy days revealed a noticeably higher degree of movement during midday than was normally observed on clear days, providing further support for the hypothesis.

Although light intensity was the principle environmental factor timing movements of grass carp in the SPSC, evidence of a second, less important factor, was found. Water temperature may have influenced the time of day when grass carp returned to core areas associated with freshwater inputs. As previously noted, the temperature of the water flowing from the seep in Section 2 surpassed that of canal water at approximately 18 HAS (Figure 9). At the same hour of the day, movement of acclimated grass carp decreased sharply (Figure 12) and the fish did not stray from the seep until sunrise. This pattern of movement is illustrated in Figure 7. As darkness approached, grass carp began moving back toward the seep, and in this instance, all arrived at approximately the same time (16 HAS). This arrival time is prior to the time when seep temperature surpassed canal temperature; however, the number of fish moving (Figure 11) and distance moved (Figure 12) indicated that, although the fish were near the seep, they were still making short movements and were not closely associated with the seep. The fish seemed to be "predicting" the time at which seep temperature would become preferable and timing their movements accordingly, but they did not occupy the water until it was warmer than the canal water. If this behavior was a result of temperature preference, one must ask "Why did grass carp abandon the seep environment at a time when the canal-seep temperature differential was maximized (sunrise)?" That behavior may have been a response to hunger. Wiley et al. (1986) concluded that grass carp may optimize caloric intake by maximizing "through-put" of edible plants. If so, it seems sensible that, as soon as sufficient light was available for them to feed, they would sacrifice the comfort of the seep for the benefits provided by feeding, especially after 7 hours without food.

Check-drops as barriers

Check-drop structures proved to be excellent barriers to upstream movement by grass carp. Unfortunately, check-drops did not prevent downstream movement, and the resulting unidirectionality of grass carp movements was problematic. Grass carp tended to accumulate in the most downstream section of the canal, Section 7, while upstream sections gradually became depauperate of grass carp.

Considerable effort was spent on observing grass carp movements near check-drops; although rare, upstream movement over check-drop structures was observed on one occasion in 1985 and on two occasions in 1986. During 1985, a single fish ascended Drop 6 (0.5 m). Maximum velocities over the drop were approximately 1.8 m/sec; however, water velocities near margins of the drop approached 0.0 m/sec. Several check-drop ascents were observed in 1986. As in 1985, a single fish moved upstream over Drop 6. In addition, three radio-implanted grass carp and a large number of untagged grass carp (F. L. Nibling, USBR, Denver, Colorado, pers. comm.) ascended Drop 7 (0.7 m). Drop 7 usually was a barrier to upstream movement. During the time period when grass carp ascended the drop, debris had accumulated in two adjacent outlets of the drop (the two left-most outlets in Figure 2) and caused an increase (approximately 300 mm) in depth of water in the plunge pool. Although an actual ascent of Drop 7 was not observed, coincidental occurrence of the flow modification by debris and the only instance of upstream movement over Drop 7, implies a cause-effect relationship. This finding is encouraging since it implies that simple, temporary modifications of drop structures may permit upstream redistribution of grass carp without use of expensive equipment or manpower.

Downstream-moving grass carp typically paused for a short time (20 to 120 minutes) before navigating drop-structures. Although check-drops did not prevent downstream movement, pauses indicated that existing check-drops acted as weak barriers. Given this predisposition, minor structural modifications may sufficiently improve barrier qualities of drops to discourage downstream movement of grass carp.

Habitat availability

The sampling protocol used to identify and quantify available habitat worked well. The stratified-systematic sampling strategy proved to be both efficient and easy to use. The strategy may have underestimated nearshore habitat, ie., habitat closer to the bank than 0.5 m, but maintained canal banks reduced the amount of deep nearshore habitat, and most habitat less than 0.5 m from the bank was too shallow to be available to grass carp.

Available habitat in the entire study site was measured at discharges of 4.0 m^3/s and 0.4 m^3/s (Figures 14 and 15). A comparison of available habitat at high and low discharges revealed the effects of discharge on mean column velocity, substrate, and cover in the SPSC.

As expected, depth and mean column velocity decreased at lower flows. Substrate patterns were similar at both discharges, but at lower flows, a greater proportion of gravel substrates was encountered. At low discharges, flowing water was restricted to the center channel of the canal, which was scoured free of sand at high discharges. Restriction of flowing water to the center channel coupled with dewatering of depositional nearshore habitats, was probably responsible for the greater abundance of gravel at low flows.

Observed differences of vegetated substrates were a result of timing of measurements. High discharge measurements were made in late July, when aquatic vegetation production was peaking; low flow measurements were made in October.

Cover underwent the greatest change with decreasing flow. Undercut banks (cover type 1) made up less than 5% of the observations at 4.0 m^3/s and more than 25% at 0.4 m^3/s. The difference could have been due to failure of the sampling strategy to measure undercut banks at high flows,

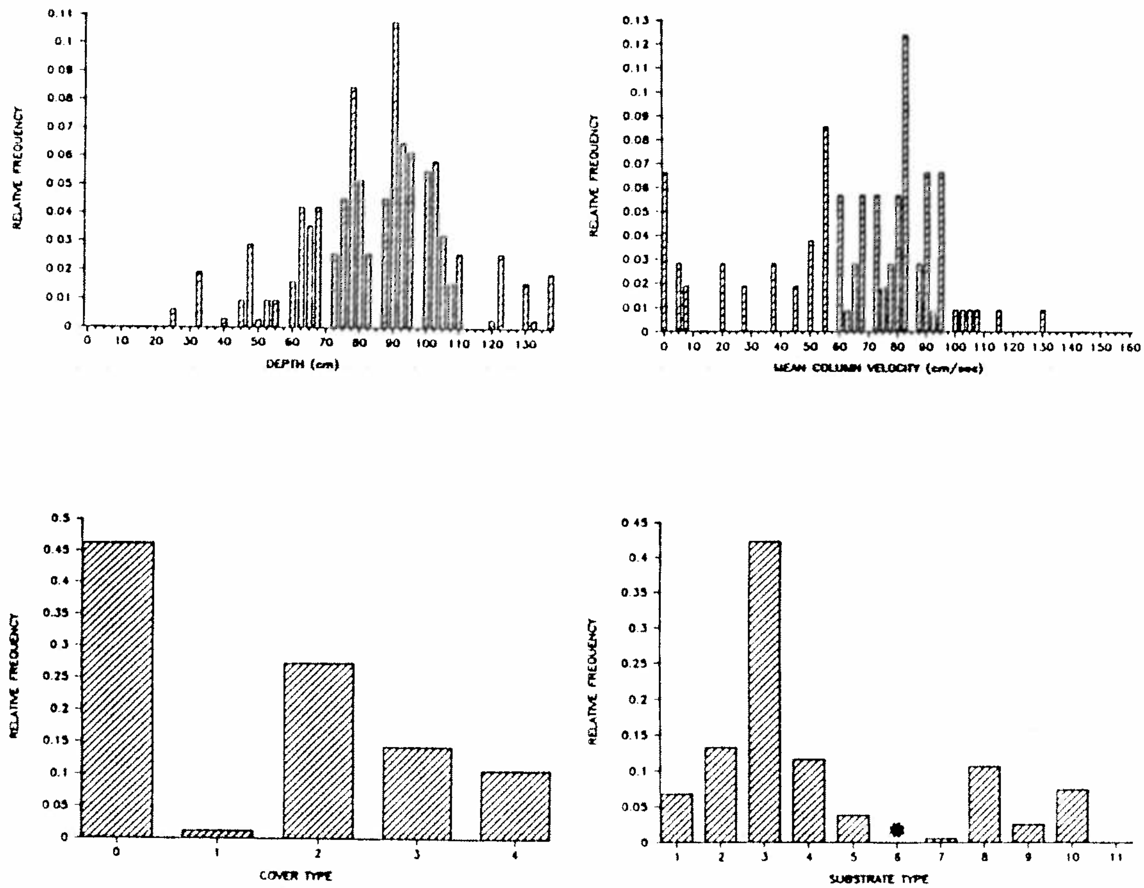

Figure 14.-Habitat availability at a discharge of 4.0 m^3/s in entire study area of South Platte Supply Canal. Habitat variables are (clockwise from top left): depth, mean column velocity, substrate, and cover. See page 29 for definition of substrate and cover types. ● =trace abundance.

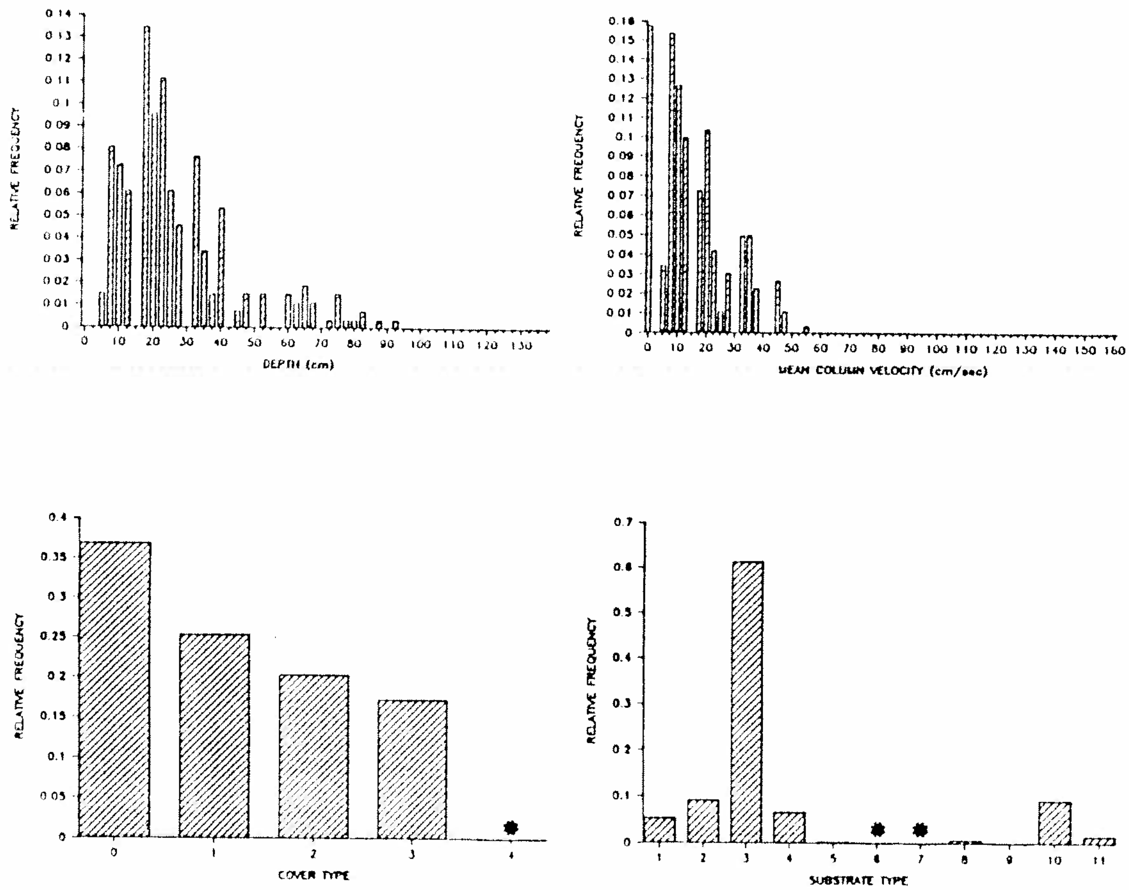

Figure 15.-Habitat availability at a discharge of 0.4 m^3/s in entire study area of South Platte Supply Canal. Habitat variables are (clockwise from top left): depth, mean column velocity, substrate, and cover. See page for definition of substrate and cover types. ✱ =trace abundance.

but a more likely explanation is that undercut banks developed as the canal operated. Bank slumping during the winter collapsed undercuts. When the canal began operation in May, undercuts were rare. Higher flows and velocities removed soft bank sediments, and undercuts developed as the summer progressed. The occurrence of cover type 4 (instream objects) decreased sharply with discharge and provided the best example of how changes in discharge can effect available habitat. The most common instream objects were large sandbars, many of which were dewatered at 0.4 m^3/s. Other sandbars tended to break down as flow patterns changed with decreasing discharge. Other instream objects (e.g., cobbles, boulders, debris) rarely occurred in the center channel and were probably washed out of the channel at higher discharges.

Comparisons of available habitat at low and high discharges demonstrate 1) how available habitat is effected by discharge and 2) how these changes may effect movements of grass carp in the SPSC. Mid-summer reductions in discharge, to levels as low as 0.5 m^3/s, occurred during the 1985 and 1986 field seasons. Dewatering of existing suitable habitats may cause fish to search for new habitats and encourage abandonment of occupied canal sections. To avoid this outcome, it may be beneficial to establish and maintain a minimum flow, or at least a minimum depth, in canals containing grass carp so that suitable habitats are not dewatered. An estimate of a minimum flow for the SPSC is beyond the scope of this study. In fact, I have not established that grass carp respond to large reductions of discharge by abandoning sections, but the scenario seems plausible and should be further studied.

In addition to estimates of available habitat for the entire study site, estimates of available habitat in Sections 2 and 3 were made following 12-hour telemetry sessions (Figure 16) because habitat use by telemeterred fish was estimated in Sections 2 and 3. By developing habitat use and availability data from the same canal section, a better comparison of habitat use and availability was assured.

Habitat use

Habitat use data were collected from fish in Sections 2 and 3 immediately following 12-hour telemetry sessions. Observations were stratified on the basis of grass carp behavior and grouped into daytime-foraging, or nighttime-core-area observations. Habitat use functions presented (Figure 17) only represent habitat use during daytime foraging movements. Nighttime observations of grass carp at core areas reflected use by grass carp of environmental characteristics which provide benefits other than those provided by depth, velocity, substrate, or cover. Core areas were selected during the night because they provided preferred temperatures, orientation, or the safety of a school. Unlike daytime habitat benefits, environmental is beyond the scope of this study. In fact, I have not established that grass carp respond to large reductions of discharge by abandoning sections, but the scenario seems plausible and should be further studied.

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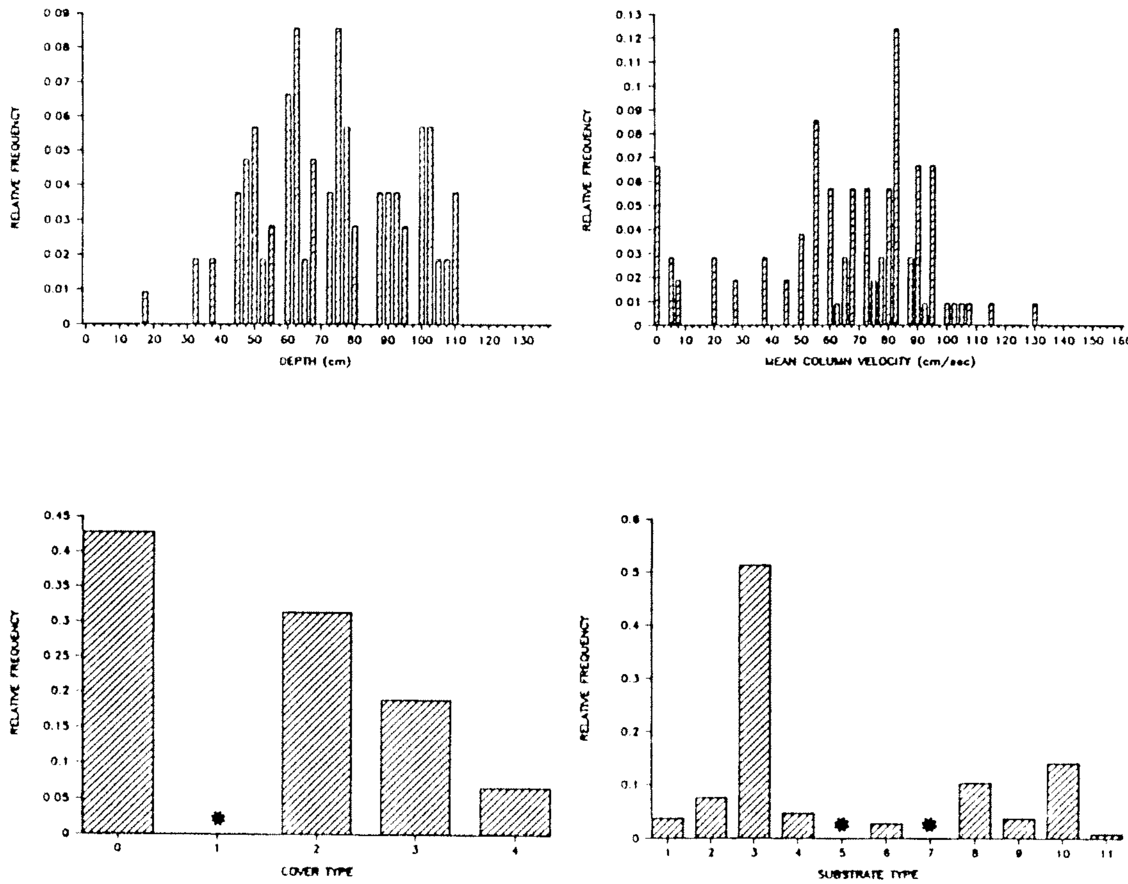

Figure 16.-Habitat availability at a discharge of 4.0 m^3/s in Sections 2 and 3 of the South Platte Supply Canal. Habitat variables are (clockwise from top left): depth, mean column velocity, substrate, and cover. See page 29 for definition of substrate and cover types. * =trace abundance.

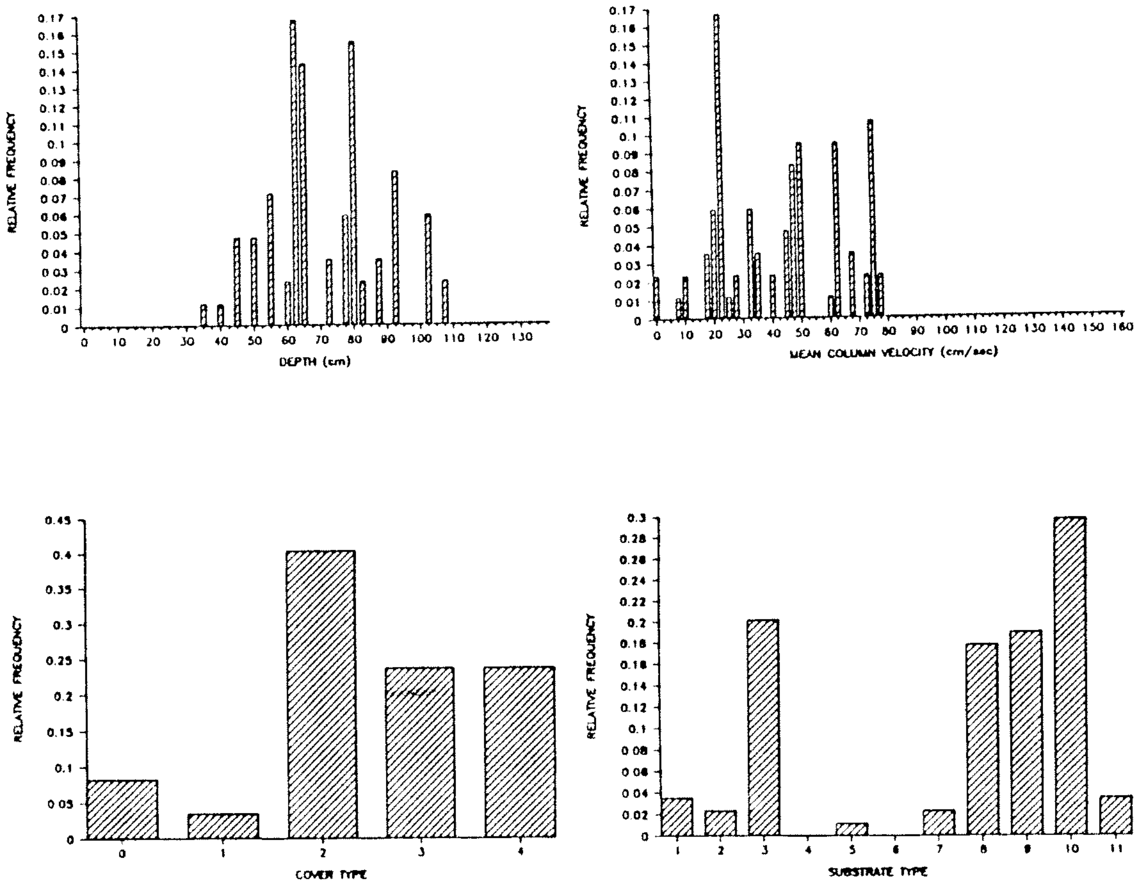

Figure 17.-Daytime habitat use by triploid grass carp at a discharge of 4.0 m^3/s in Sections 2 and 3 of the South Platte Supply Canal. Habitat variables are (clockwise from top left): depth, mean column velocity, substrate, and cover. See page 29 for definition of substrate and cover types.

factors which made core areas important to grass carp were not measured and were not incorporated into habitat use functions. Eighty-four non-moving daytime observations were made. By comparing habitat use with availability, one can begin to identify environmental factors that are important to grass carp in the SPSC.

Mean column velocity is most easily dealt with; it should be disregarded. It represents the mean column velocity at the position of the fish and not nose velocity. Had grass carp consistently inhabited exceptionally slow waters, where velocity remained fairly constant throughout the water column, the measurement may have been of some use, but this was not the case. Mean column velocity data tell little about grass carp in the SPSC.

Depth use and availability were very similar. The implication is that the fish were not selecting certain depths but were simply using depths as they occurred in the canal. This conclusion is consistent with previous observations of grass carp movement which suggest that grass carp selected habitats where food and cover were available without regard for depth.

A comparison of substrate use and availability reveals that grass carp used vegetated substrates (8-fines with vascular plants, 9-sand with vascular plants, 10-gravel with vascular plants, 11-cobble with vascular plants) in greater proportion than they occurred in the SPSC. This selection was expected since the fish feed over these substrates during the day.

Use of cover by grass carp was distinctly different from cover availability. The most apparent difference was avoidance of cover type 0 (no cover). Although 0-no cover was the most abundant cover type in the canal, less than 10% of grass carp observations were in areas with this environmental characteristic. Approximately 3% of grass carp observations were in areas with 1-undercut banks as cover. Undercut banks were extremely rare, and their relative scarcity and slow formation probably limited their use by grass carp. Grass carp used 2-overhanging riparian vegetation in slightly greater proportion than it occurred in the SPSC. Use of overhanging riparian vegetation as cover was probably a result of fish attempting to escape brightly lit water conditions during the day. The nearshore environment, where overhanging riparian occurred, also provided current refugia, making nearshore habitats more attractive to grass carp. The abundance of observations indicating use of bank cover may be an artifact of the width of the canal, triangulation error, and observer bias. The small width of the SPSC meant that riparian vegetation effected a greater percentage of the canal than it would in larger canals and rivers. The combination of increased effect of riparian vegetation, triangulation error, and observer bias for overhanging cover could have resulted in an artificially high ranking for bank cover use.

The last two cover types, 3-instream vegetative and 4-instream objects, were both used by grass carp, in greater proportion than they occurred in the SPSC. Instream vegetative was used only slightly (5%) more often, but other instream objects were utilized over three times more often than they were available.

Habitat preference

Like habitat use, habitat preference functions were calculated only for daytime foraging observations. Preference functions presented for grass carp in the SPSC should be considered highly specific and should not be used to predict grass carp behavior in other aquatic environments. The irrigation canal provided practically no truly preferable habitat for grass carp. Grass carp, natives of large rivers, should prefer to feed in lentic areas of rivers, utilizing the depth, velocity, substrate, and cover types associated with them. The SPSC did not provide those habitat types, hence, habitat use and preferences presented are specific for grass carp in the SPSC.

Grass carp in the SPSC preferred vegetated substrates over non-vegetated substrates (Figure 18). Sand with attached aquatic vascular plants was most highly preferred, followed by cobble, gravel, and fines with vascular plants. Large mats of aquatic vegetation were more abundant on sandy substrates than on any other substrate. Aquatic plant mats

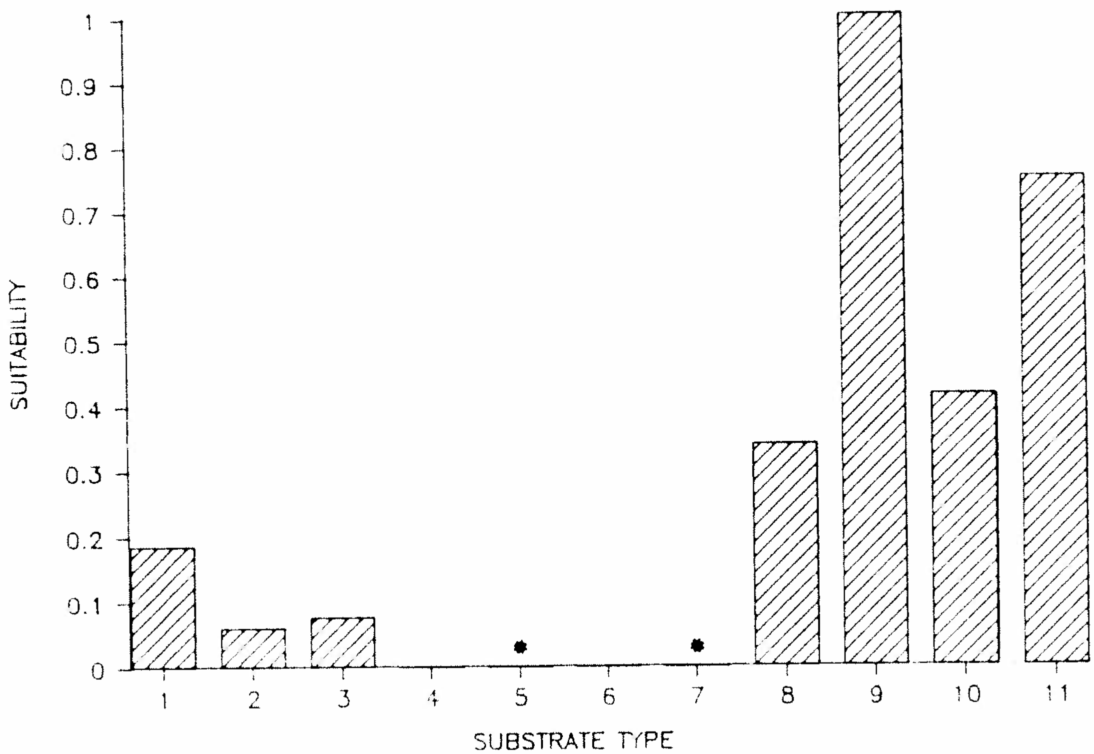

Figure 18.-Normalized suitability of substrate types at a discharge of 4.0 m^3/s for grass carp in Sections 2 and 3 of the South Platte Supply Canal. See page 29 for definition of substrate types. ● =trace suitability.

provided food and current refugia, properties which may explain their preferential use by grass carp. The high suitability rating for cobble with aquatic vascular plants may be an artifact of the rarity of that cover type. Due to the nature of the method used to calculate preference, habitats which occurred rarely, but were used by fish, received unduly high suitability ratings. Approximately 5% of grass carp observations occurred over cobble with vascular plants. Had the use of vegetated cobble substrates been more common, its suitability would not be in question, but this was not the case, and the high suitability rating for vegetated cobble should be cautiously regarded.

Cover preferences (Figure 19) of grass carp reflected the expected low preference for cover type 0-no cover. Undercut banks (cover type 1) had a high suitability score, possibly because they occurred so rarely. Approximately 3% of grass carp observations occurred at undercut banks. However, undercut banks were so rare that none were detected by habitat availability sampling in Sections 2 and 3. These conditions (availability equal to zero) prevented calculation of a suitability score. To calculate a suitability score, I have substituted the relative frequency for availability of undercut banks in the entire canal and recalculated preference. The resulting preference function indicates that undercut banks were more highly preferred than all other cover types except the most highly preferred cover type, [illegible]-other instream objects. As with the high

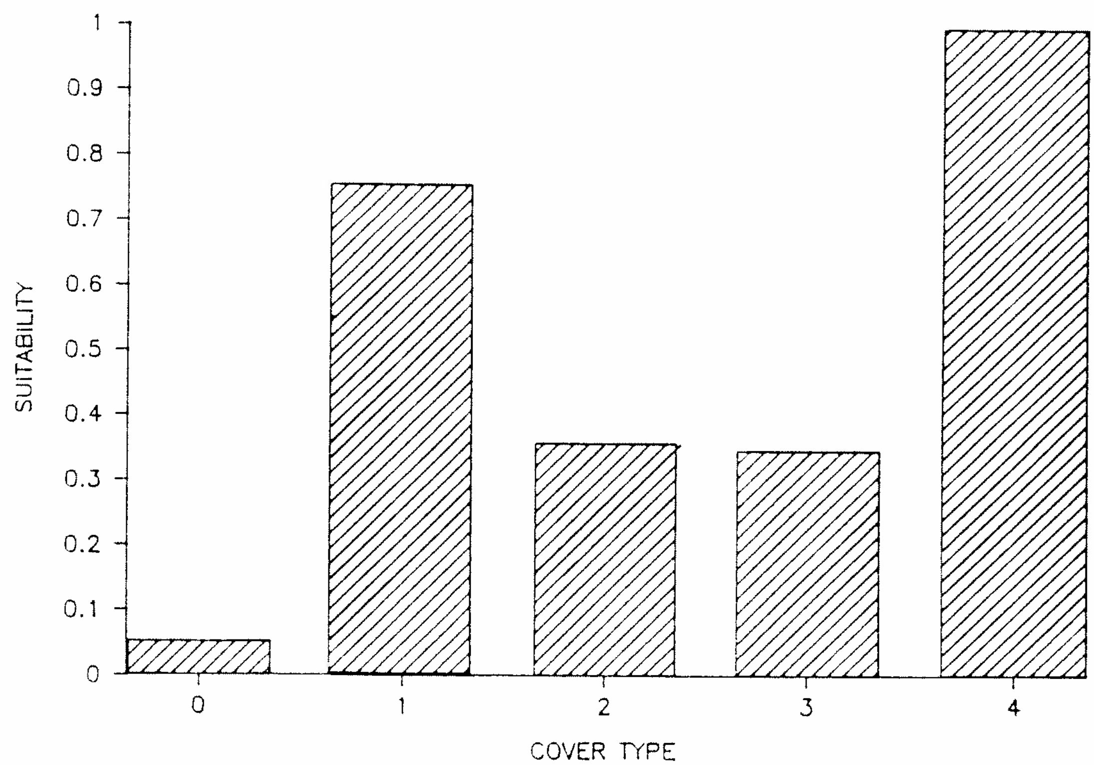

Figure 19.-Normalized suitability of cover types at a discharge of 4.0 m^3/s for grass carp in Sections 2 and 3 of the South Platte Supply Canal. See page 29 for definition of cover types.

rating for the substrate type cobble with aquatic vascular plants, it is possibile that the suitability score for undercut banks is artificially inflated by its rare occurrence. However, the use of undercut banks by other riverine species of fish support its high suitability score. Overhanging riparian vegetation (cover type 2) was moderately preferred by grass carp, as were instream plant mats (cover type 3). Both cover types were used in slightly greater proportion (5%) than they were available in the canal. Cover type 4, other instream objects, was most highly preferred. Instream objects comprised approximately 25% of cover-use observations and were probably used by grass carp as current refugia. The high suitability rating of instream objects supports the hypothesis that large discharge reductions may force fish to abandon previously suitable habitat and, possibly, occupied sections.

Because grass carp are a major tool for management of aquatic vegetation in irrigation canals, an understanding of their environmental requirements and preferences is important. Unlike chemical or mechanical controls, biological controls are long-lasting and respond to environmental stimuli. If managers are to develop a predictive index with which to assess the feasibility of using grass carp in an irrigation canal, habitat studies in small and large irrigation canals should be conducted and compared. The uniform nature of irrigation canals will probably improve the transferability of use and preference functions, and it should be possible to develop an environmental index which could be used by managers to predict the degree of success of grass carp in western irrigation systems.

Factors that affect movements of non-acclimated grass carp

Plant biomass

Grass carp were stocked on 15 May, 20 May, 10 June, 17 June, and 27 June 1986, mainly to study the effects of development of aquatic vegetation on grass carp movements (28 July and 29 July 1986 stockings were studied for comparison of day and night movement, see text). Downstream movement on the first three dates was greater than on the latter two (Figure 20). Dry weight biomass of macrophytes during the first three stockings was approximately 20 g/m^2 (J. S. Thullen and F. L. Nibling, USBR, Denver, Colorado, pers. comm.). By the fourth stocking, 17 June, biomass had increased to an estimated 60 g/m^2, and by 27 June dry weight biomass had increased to approximately 95 g/m^2. The increasing biomass was accompanied by an increasing liklihood that grass carp would remain in the section where released. Prior to the 17 June release, mean number of days spent in a section was 2.7. After and including the 17 June release, mean number of days that fish remained in a section was 19.2 and fewer fish left the release section on days 1 and 2 following their release (Figure 20). Although numbers of fish used were too low to permit useful statistical

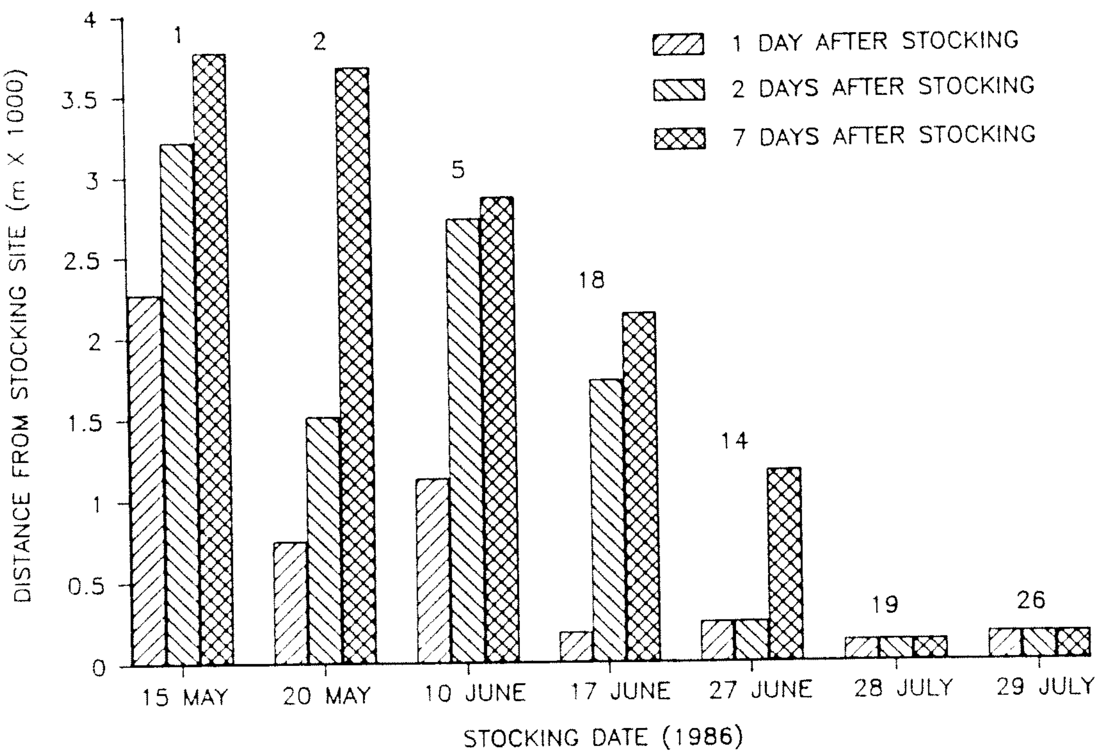

Figure 20.-Displacement of grass carp from stocking site in the South Platte Supply Canal, 1986, as a function of stocking date and number of days after stocking. Numbers above histogram groups are mean number of days grass carp remained in release sections. For stocking conditions see page 25.

analyses, a correlation between the liklihood that fish remained in a section and the abundance of aquatic vegetation was obvious.

A preliminary estimate of the abundance of aquatic plants necessary to improve the liklihood of grass carp remaining in a section where plant control is desired is at least 60 g/m^2 dry weight biomass of macrophytes. The species composition of the plants is likely to have an effect on the minimum plant biomass needed to encourage grass carp to remain in a section. In the SPSC, the most abundant aquatic plants were members of the genera Elodea, Potemogeton, and Zannichellia. All are moderately to highly preferred by grass carp (Harberg and Modde 1985; Swanson 1986; Wiley et al. 1986). In canals containing an abundance of less-preferred plants, grass carp may show a greater tendency to move as they search for more preferable plant species. Water temperature adds further complications because grass carp are less selective at higher temperatures (Opuszynski 1972).

Stop logs

To examine the effects of stop logs, boards that can be added to drop structures to impound water behind the drops (Figure 2), on movements of non-acclimated fish, grass carp were stocked on 10 June during a discharge of 0.5 m^3/s with one row of 250-mm-wide stop logs in place and again on 17 June at a discharge of 0.5 m^3/s without stop logs in place. I hypothesized that deeper water would improve access to bank cover and be reflected by longer residence times of released fish. Stop log conditions did not increase residence time. The mean number of days in Section 2 was much higher for the second release, 18 days compared to 5 days, for the release on 10 June. Although stop logs were not effective in this instance, I believe they may be useful in reducing movement under different circumstances. Grass carp stocked on 10 June were probably responding to lack of available food, rather than water depth or cover. Effects of stop logs could have been increased by using more of them, thereby increasing water depth 500 or 1000 mm. Use of stop logs is dependent on discharge and the capacity of the canal, but their careful use could keep canal depths constant during periods of declining flow, thus preventing a reduction of habitat which would encourage emigration.

<u>Discharge</u>

To examine the effects of relatively high and low discharges on movements of non-acclimated grass carp, four fish were stocked on 17 June and 27 June at discharges of 0.57 m^3/s and 3.51 m^3/s, respectively. Immediate movements of grass carp indicated that both groups reacted similarly to the discharge conditions, but during days one and two after release, grass carp stocked at the higher discharge showed less downstream movement than fish stocked at lower discharges. These results indicated that hatchery or laboratory fish which were accustomed to non-flowing conditions were capable of maneuvering at higher discharges and that higher discharges may provide more favorable environmental conditions for grass carp (e.g., deeper water, greater attenuation of sunlight, better access to bank cover).

Depth and velocity at stocking site

To test the effects of stocking-site velocity and depth on movements of non-acclimated grass carp, four fish were stocked on 28 July, approximately 30 m downstream of Drop 2. This portion of the canal had a uniform depth of 0.76 m, an average mean column velocity of 0.72 m/s, and a gravel-cobble substrate. Immediate movements of grass carp released at this site were compared to movements of fish released on 27 June and 29 July in a slower portion of the canal having an average depth of 0.90 m, an average mean column velocity of 0.58 m/s, and a sand-gravel substrate. Stocking at the higher-velocity location resulted in greater immediate downstream movement than was observed at the lower-velocity location. Two of four fish stocked at the high-velocity release site (group A) did not show increased downstream movement and remained near the stocking site, indicating that they were able to quickly adapt to the flowing-water environment. The other two fish (group B) independently moved downstream; by 2 hours after release, they had assembled approximately 300 m downstream of the release site. Twenty-four hours after release, one of the fish had moved upstream and had joined the group-A fish.

The other had moved downstream to within 45 m of the downstream limit of the section but did not leave the section for several weeks. I attribute greater downstream movement by group-B fish to effects of handling and disorientation. When stocking fish, I removed fish from a hauling tank and placed them in a 121-l plastic pail partially filled with water. I adopted the method as the least stressful means of moving fish to the stocking site. However, I noted that fish appeared to experience severe disorientation while in the pail. Loss of equilibrium was indicated as fish rolled over without attempts to right themselves. On release, I lowered the pail into the canal and allowed the fish to exit on their own. Occasionally, fish did not leave the pail for several minutes, (up to 20 minutes on one occasion). If fish suffer loss of equilibrium during stocking, the advantage of selecting a low-velocity stocking location becomes apparent. Slower-velocity sites may reduce passive transport of disoriented fish and allow them to reach cover with greater ease.

Illumination and time of day

To examine the effects of light levels and time of day on immediate post-stocking movement, two grass carp were released on a clear, moonless night (29 July) at approximately 2200 hours. The purpose of the release was to observe movements of the fish for comparison to day releases (28 July) and thereby gain some knowledge of which sensory systems (e.g., vision, acoustico-lateralis) the fish were relying upon when introduced into the canal. The experiment is important because, although it is unlikely that many grass carp will be released after dark, the fish must react similarly when introduced into highly turbid waters. Lack of light associated with a night release should have produced a higher degree of downstream movement due to the lack of visual stimuli, but night-released grass carp acted no differently than grass carp stocked at the same site during daylight hours. This is surprising considering that the fish had been in laboratory conditions before being introduced into the canal and then were not able to rely on vision as an aid to navigation in the relatively diverse, flowing environment. Apparently, the role of vision was minor compared to the role of the acoustico-lateralis sensory system in identifying suitable habitat at night. Fish stocked during the day may have used similar methods of navigation since current refugia cannot be seen, but must be felt, especially in turbid waters. Vision probably became more useful in identifying suitable habitat as a fish learned to visually recognize environmental characteristics associated with suitable habitat.

Another possibility is that night-stocked fish may have chanced upon resident grass carp and begun schooling with them. The released fish may have identified resident fish by sound communication. As members of the Superorder Ostariophysi, grass carp have a chain of small bones, collectively called the Weberian apparatus, which connect the swimbladder to the inner ear. Other fish in this superorder, catfishes and goldfishes, have an acute sense of hearing and respond to experimental alterations of this hearing system (Moyle and Cech 1982; Hawkins 1986). Sound production and reception may be highly developed in grass carp and may play a role in the social behavior of these fish, especially under turbid or lightless conditions. Grass carp produced grunting sounds while being handled.

Conclusions

Movements of 49 triploid grass carp in the South Platte Supply Canal (SPSC) were monitored with radio telemetry during 1985 and 1986. The objective of this study was to test several hypotheses (page 8) related to movements of triploid grass carp in response to check-drop structures; time of day; available depth, velocity, substrate, and cover; aquatic plant biomass; discharge; and stocking site characteristics. Tests of hypotheses were made by interpreting movement patterns of grass carp. Small sample sizes and failure to meet assumptions of independence precluded use of valid statistical tests. However, data typically showed overwhelming support for acceptance or rejection of specific hypotheses.

Hypothesis 1, that grass carp regularly move downstream over check-drop structures, but rarely move upstream over the same drops, was accepted. All telemeterred grass carp moved downstream over drops, but of 49 fish telemeterred during 1985 and 1986, only five were known to have ascended a check-drop. Of these, I suspected that three were successful only because an accumulation of debris in the check-drop had modified normal water flow through the structure.

Hypotheses 2 and 3, that grass carp demonstrated diel patterns of movement and feeding, were accepted. Acclimated grass carp in the SPSC did not feed and restricted their movements to core areas during the night. During the day, acclimated grass carp moved throughout their resident sections and returned to core areas in the evening.

Hypothesis 4, that grass carp show preference for certain microhabitats, was accepted. During daytime, grass carp preferred vegetated sand substrates, probably because of the food associated with them. Grass carp preferred instream objects (e.g., rocks, pilings, slumped banks, or sandbars) as cover and avoided areas of the canal which lacked cover. Preferences for depth and velocity were not calculated.

Hypothesis 5, that aquatic plant biomass would influence liklihood that grass carp remain in a section where they were released, was accepted. Grass carp abandoned release sections within several days of stocking until aquatic plant biomass levels reached 60 g/m^2, at which time a marked increase in residence time occurred.

Hypothesis 6, that water depth effects the liklihood that grass carp remain in a section where they are released was rejected. Manipulation of water depth with stop logs produced no effect when depth was increased 250 mm. Several factors confounded this experiment, and the decision to reject hypothesis 6 may be incorrect.

Hypothesis 7, that stocking site characteristics effect grass carp movement, was accepted. High-velocity stocking sites increased passive drift of disoriented grass carp and resulted in their immediate displacement downstream. Downstream movements of fish stocked at low-velocity locations were minimal.

Hypothesis 8, that time of stocking influences downstream movement, was rejected. Fish stocked at night showed the same patterns of movement as fish stocked during the day.

Hypothesis 9, that discharge effects the liklihood that grass carp remain in a section where they are released, was accepted. Grass carp stocked at higher discharges showed less tendency to move out of release sections than did grass carp stocked at lower discharges. Increased water depth, associated with higher discharges, may have improved habitat diversity and allowed grass carp greater access to suitable habitats, thus discouraging downstream movement.

Study of seasonal movements of grass carp in the SPSC was not possible. Grass carp were too strongly influenced by barriers to movement (check-drops) and canal discharge to display seasonal patterns.

Recommendations

Several recommendations for handling and stocking of grass carp into irrigation canals can be advanced. Although these recommendations are a product of observations of behavior of grass carp, they cannot be expected to hold true in every situation and should be reevaluated with each use.

1. Use of anesthesia while transporting grass carp to stocking sites should be avoided. Effects of anesthesia encourage disorientation and increase the tendency for passive drift immediately after stocking.

2. Grass carp should not be stocked until aquatic vegetation is abundant. A preliminary estimate of minimum biomass of aquatic macrophytes needed to improve the liklihood of grass carp remaining in a release section in the SPSC is 60 g/m^2 dry weight. Water temperature and species composition of aquatic plants probably affect the minimum biomass value; if higher macrophyte biomasses can be allowed, they should be permitted.

3. High discharges do not encourage downstream movement of recently stocked fish. Grass carp

accustomed to laboratory conditions immediately adjusted to lotic conditions of the SPSC. High discharges are desirable because they promote habitat diversity for grass carp.

4. Grass carp should be stocked during periods of anticipated constant discharge. By allowing grass carp to acclimate to the canal environment during periods of constant discharge, development of core areas is encouraged. Grass carp which are accustomed to a daily foraging routine and core area occupation are less likely to abandon occupied sections.

5. Grass carp should be stocked at low-velocity locations. Stocking at low-velocity sites allows grass carp to regain their equilibrium and orientation with a minimum of passive drift.

6. High turbidity does not increase immediate post-stocking downstream movement. Fish stocked on a moonless night moved like those stocked during daylight hours, indicating that a reduction of visual stimuli due to environmental conditions does not adversely effect a fish's ability to complete oriented movements immediately following release.

7. Grass carp should be stocked as early in the day as possible. If grass carp have several hours of daylight during which to acclimate, they have

more time to identify habitat they will be able to successfully occupy during the night.

8. Stop logs can be used to minimize effects of large discharge reductions. Care will be required to ensure that discharge modifications and stop-log distribution are coordinated.

9. Modification of existing water-control drop structures, to permit upstream movement by grass carp, should be considered. Simple modifications, like those described in the text, could be used to permit grass carp to redistribute themselves with a minimal manpower investment.

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