

4.

Rivers and Impounded Waterways

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Concerns about establishing wild populations of grass carp in United States waters have been largely removed by the development of functionally sterile, triploid grass carp (Clugston and Shireman 1987). Nevertheless, significant questions remain about the ability to manage aquatic plants with grass carp in large, open systems (waters without barriers to emigration) such as mainstream reservoirs (Noble et al. 1986; Bain et al. 1990). In a review of triploid grass carp use, Allen and Wattendorf (1987) stated that research is needed to determine if these fish can effectively control aquatic vegetation in large water bodies (> 200 ha) and open systems. In addition, the potential for undesirable effects of grass carp in open systems is not known, but significant impacts will need to be identified and mitigated for successful applications of grass carp.

The best guidance for open-system use of grass carp will come from operational stockings in large systems where follow-up studies (system monitoring) have taken place. Large releases (100,000 to 300,000 fish) of triploid grass carp began in reservoirs on the Tennessee River (TVA 1990) and the Santee River, South Carolina (de Kozlowski 1991). Management agencies conducted extensive monitoring in these systems, and they expect to modify future stockings based on their results. Finally, grass carp are now routinely stocked in irrigation canals of the western United States (Sport Fishing Institute 1991 see Chapter 5) and experiences in these waterways may be valuable for future applications.

Until retrospective information is available from the current applications of grass carp in open systems, future use of grass carp in open systems will be

tenuous and experimental. The main uncertainties about the effectiveness of grass carp for vegetation control in open systems will be reviewed in this chapter, followed by a review of the biology of grass carp relative to the major environmental concerns for open waters. As water resource managers inevitably practice adaptive use of triploid grass carp in large waters, the utility of this fish as a biocontrol agent in open systems may be resolved.

OUTSTANDING QUESTIONS ON EFFECTIVENESS

The intent of aquatic plant management programs in large waters is control rather than eradication. The utility of grass carp for effective but balanced vegetation control in large, open systems hinges on maintaining effective densities of fish on target species of vegetation. Water resource managers already have a poor record of achieving intermediate plant control in closed systems (Noble et al. 1986; Leslie et al. 1987). Open systems present two additional complications that make intermediate vegetation control an even greater challenge: loss of fish from target areas by emigration, and generally diverse aquatic plant communities.

MAINTAINING EFFECTIVE FISH DENSITIES

At present, managers of open waterways will have no choice but to base stocking rates of grass carp on the recommended ratios of fish and vegetation (fish/vegetated hectare) developed for closed systems (see Chapter's 2 and 3). Fish and vegetated-area ratios for open systems will eventually need adjustment for behavioral factors such as the movement patterns and feeding preferences of the fish. Rapid and continual movement of grass carp can result in large-scale dispersion of fish from target areas. In an open-system study of grass carp, Bain et al. (1990) found that juvenile grass carp (stocking-size fish) remained in and near hydrilla (*Hydrilla verticillata*) colonies, but larger, adult fish dispersed well

beyond target areas. These findings indicate that grass carp of stocking-size (20-30 cm total length, Wiley et al. 1987) may stay near their release points and feed on preferred plants such as hydrilla for at least one growing season. However, as these fish grow and reach sexual maturity (about 65 cm or 3.5 kg) they may undertake extensive migrations. Grass carp growth rates (Shireman and Smith 1983) indicate that maturity would normally be reached by 2 years after stocking. Therefore, annual or biannual stockings of grass carp on target plants may be required because fish stocked in previous years may disperse to distant areas.

FEEDING HABITS IN DIVERSE PLANT COMMUNITIES

Several studies have shown that grass carp are selective foragers that feed primarily, or exclusively, on the most preferred plants before eating less desirable species (Edwards 1974; Vinogradov and Zolotova 1974; Terrell and Terrell 1975; Colle et al. 1978; Fowler and Robson 1978; Mitzner 1978). Generally these feeding preference studies involved a variety of plant species and the preferred ones depended on the species available. Leslie et al. (1987), who reviewed 10 years of vegetation control efforts in Florida with grass carp, classified plant species into three grass carp preference groups: preferred, intermediate, and nonpreferred. Managers of open waters should identify the relative palatability of target plants and anticipate a sequential grazing effect on the plant community. If non-target plants are common and include preferred species, grass carp are likely to reduce or eliminate these plants before grazing on target species. The rate and frequency of stocking will need to accommodate this grazing pattern. If target species are relatively low in palatability within the local plant community, grass carp may not feed on them to any measurable extent prior to dispersion from target areas. Finally, managers of closed systems have succeeded in eradicating

unpalatable species such as Eurasian watermilfoil (*Myriophyllum spicatum*) with heavy stocking, but this strategy does not appear viable in open waterways where fish can disperse.

ENVIRONMENTAL CONCERNS

Triploid grass carp have potential for being a nuisance in open aquatic systems because the species is capable of consuming large volumes of aquatic vegetation (Bennett 1974; Guillory and Gasaway 1978), inhabiting large rivers, tolerating a wide range of environmental conditions, and dispersing widely from target waters. In the United States, grass carp have migrated up to 1,700 km (Guillory and Gasaway 1978) and have developed harvestable concentrations in rivers far from release points (Pflieger 1978). Because adult grass carp apparently migrate long distances over time, Noble et al. (1986) and Bain et al. (1990) recommended that target areas be viewed as a system that includes upstream and downstream waters when the effects of grass carp use are being considered.

Although most introductions of fish seem to have resulted from stock-and-see planning, past problems require that introduction decisions follow an objective assessment of potential impacts. Accounts of many problematic species indicate that objective, pre-introduction assessments could have identified most of the serious and undesirable consequences (Bain 1991). Water resource managers cannot with certainty predict the consequences of using grass carp for vegetation control, but by conducting an objective, thorough, pre-introduction assessment they are likely to expose potential problems and identify practical mitigation. Guidelines for assessing the introduction of fish have been developed for management (Bain 1991). Because fishery biologists often introduce species, the American Fisheries Society adopted a policy (Kohler and Courtenay 1986), that outlines a pre-introduction review. Below I have reviewed data and studies on grass carp

for assessing the potential problems that could occur in open systems. This information is grouped by topic of concern for introductions of fish, and the main points are summarized in Table 1 with published sources.

POPULATION CONTROL

Triploid grass carp are now widely available and methods for reliably producing triploid fish and verifying ploidy have been developed (Allen and Wattendorf 1987; Thompson et al. 1987). Although control of triploid grass carp populations seems secure, undesirable effects of fish congregations may occur at distant sites from plant control areas. In their native river habitats, grass carp make extensive spawning migrations and congregate in turbulent habitats associated with rapids, falls, and dams (Shireman and Smith 1983). Pflieger (1978) and Stanley et al. (1978) documented extensive dispersal and distant congregation of grass carp after the first large-scale introduction in the United States. Bain et al. (1990) reported that adult grass carp can move well beyond plant control areas in one season. Managers can control the number of triploid grass carp in an open system, but dispersal and distant congregations can be significant through time and difficult to manage. Consequently, the possibility for undesirable effects of triploid grass carp in non-target areas of open systems need to be identified and considered in program decisions.

DISEASES AND PARASITES

Shireman and Smith (1983) listed a large number of diseases and parasites of grass carp, and introductions of grass carp have spread parasites to new countries and continents (Musselius and Strelkov 1968; Ivasik et al. 1969). Because all triploid grass carp are raised in hatcheries, maintenance of disease-free facilities appear necessary. Sindermann (1986) described practical measures to

maintain disease-free hatcheries and to reduce the likelihood of introducing diseases and parasites. Inspection and treatment of fish in shipment are additional mitigation measures. Finally, open systems are connected to a wide range of aquatic habitats and sources of fish diseases and parasites. Therefore, open systems should have limited vulnerability to new diseases and parasites.

HABITAT ALTERATIONS

Grass carp can change the characteristics of aquatic habitats by consuming and processing large volumes of aquatic vegetation. When stocked at high densities, grass carp can eliminate all vegetation in even large aquatic systems (e. g., 8,100-hectare Lake Conroe, Klussmann et al. 1988). Impacts associated with vegetation grazing include alteration of water quality, reduction in the amount of cover provided by plants, and altered structural characteristics of aquatic habitats. Although aquatic plants are a biological component of an aquatic system, vegetation changes are discussed here in the context of water quality. Changes in plant cover and habitat structure are discussed later because the effects vary by organism group.

The killing and decay of large volumes of aquatic vegetation can elevate nutrient levels in water, induce phytoplankton blooms, reduce water clarity, and decrease oxygen levels (Boyd 1971). Plant grazing and biological processing by grass carp can have the same effects (Vinogradov and Zolotova 1974; Canfield et al. 1983; Klussmann et al. 1988). However, the effects of grass carp on water quality are more moderate than the effects from chemical control (Shireman and Smith 1983; Shireman 1984; Taylor et al. 1984; Leslie et al. 1987), for three reasons. First, vegetation is reduced more slowly by grass carp than by herbicides (Hestand and Carter 1978). Second, a significant portion of the nutrient content of consumed plants is retained in the fish (Lembi et al. 1978). Third, grass carp

selectively consume plant species in order of their palatability (Leslie et al. 1987), thereby leaving some species unaffected if stocking rates are not excessive. Despite differences between the effects of grass carp and herbicides, water quality is often primarily influenced by the rates of external nutrient loading, regional geology and land use, and the extent of plant removal (Canfield et al. 1983; Richard et al. 1984, 1985).

BIOLOGICAL EFFECTS

Like most herbivores, grass carp have a direct and profound effect on plant communities. Other biological effects are mostly secondary consequences of vegetation changes. Major concerns about the disruption of biological communities by grass carp involve reductions in desirable plants, macroinvertebrates, fish, and waterfowl. When grass carp are stocked at densities that largely eliminate vegetation, serious ramifications are likely for food resources, shelter, and spawning substrates for fish and wildlife (Taylor et al. 1984). A review of grass carp impacts tailored to a vegetation reduction program rather than to vegetation eradication is most appropriate here because water resource management agencies strive for vegetation management.

Grass carp are particularly selective in their consumption and preference for plant species (Van Dyke et al. 1984; Leslie et al. 1987; Chapter 1). They consume the most palatable species until it is scarce and then the next most palatable species until it is scarce and so on. Leslie et al. (1987) ranked the relative palatability of 23 plant species and reviewed the effect of grass carp on different plant communities. They reported that hydrilla, an exotic and nuisance plant in North America, was the most preferred species and the most common target of grass carp in the United States. Leslie et al. (1987) also concluded that when moderate densities of grass carp were used to control a highly palatable species,

less palatable species were not significantly reduced. If grass carp were used to control relatively unpalatable species, desirable species were drastically reduced before the target species was controlled, and in some cases, the target species increased in coverage. Finally, Leslie et al. (1987) reported that many desirable plant species can be reduced if the density of grass carp is not controlled relative to the availability of a palatable, target species. Stott and Robson (1970), Stott (1977), Fowler and Robson (1978), and Shireman and Maceina (1981) also cautioned water resource managers that the abundance of desirable plants will usually be reduced sharply when waters are stocked with densities of grass carp sufficient to control some unpalatable plant species.

Altered composition and reduced diversity of macroinvertebrate species have been documented in some studies of vegetation control with grass carp (Vinogradov and Zolotova 1974; Martin and Shireman 1976). However, a variety of studies reviewed by Shireman and Smith (1983) and Leslie et al. (1987) indicate that responses of macroinvertebrates to reduced vegetation vary from decreases to increases in density and diversity due to the counteracting effects of reduced plant surface habitat, increased invertebrate food supplies (i.e., plant detritus), altered substrate conditions, and increased dissolved oxygen in large vegetation colonies. In general, vegetation grazing by grass carp reduces the density and species diversity of phytophilous (plant dwelling) invertebrates, but benthic invertebrates tend to increase in density and diversity.

Changes in the composition and structure of the fish community have been documented repeatedly (e.g., Ware and Gasaway 1976; Klussmann et al. 1988) when grass carp substantially reduced or eliminated vegetation in lakes and reservoirs. Pelagic fish usually increase in density after grass carp reduced vegetation (Klussmann et al. 1988; Bettoli et al. 1990, 1991) and littoral, structure-oriented species (e.g., sunfish [Centrarchidae]) typically decline or

exhibited no clear response (Ware and Gasaway 1976; Bettoli et al. 1990). Changes in the fish community seem related to changes in the availability (including capture vulnerability) of food items caused by changes in plant density. Of all littoral fishes, those adapted to feeding in vegetated habitats decline most and open-water feeders flourished when plant density are reduced (Klussmann et al. 1988; Bettoli et al. 1990, 1991, 1992; Petridis 1990).

Aquatic vegetation is a key component of waterfowl habitat, and many studies confirm its importance for attracting and supporting waterfowl populations (Leslie et al. 1987). Hydrilla seems to be especially valuable for waterfowl because it supports a very high density and diversity of birds (Esler 1990), and its spread seems to have affected the distribution of wintering waterfowl in the southeastern United States (Johnson and Montalbano 1984, 1987). Significant local declines in waterfowl abundances have been attributed to removal of hydrilla by grass carp (Gasaway and Drda 1976; Gasaway et al. 1977). Impacts of grass carp on waterfowl are not limited to hydrilla control. Swanson (1986) identified considerable overlap in plant preferences of grass carp and several waterfowl species. Johnson and Montalbano (1987) urged that waterfowl habitat be considered in programs of plant control, and Leslie et al. (1987) recommended that grass carp not be used in water bodies with managed waterfowl habitats.

In summary, grass carp have significantly altered the food chains and trophic structure of aquatic systems by inducing changes in plant, invertebrate, and fish communities. Impacts are largely secondary consequences of reductions in the density and composition of aquatic plant communities. Organisms dependent on limnetic habitats and phytoplankton-based food chains tend to benefit from the presence of grass carp. In contrast, declines have occurred in the diversity and density of organisms that are dependent on structured littoral habitats and food chains based on plant detritus, macrophytes, and attached

algae.

MANAGEMENT ISSUES

Although biocontrol of aquatic plants in open systems with triploid grass carp is promising, it is controversial. Some users of water resources prefer abundant aquatic vegetation (e.g., many fishermen, waterfowl hunters) and dislike grass carp because of their ability to eliminate all aquatic plants. Other users prefer plant-free waters and view grass carp as the most desirable alternative to herbicides. Noble et al. (1986) described conflicts about the use of grass carp in Lake Conroe, Texas. Disagreements among user groups became intense, politicized, and litigated. Finally, the Texas legislature mandated stocking. Noble et al. (1986) recommended public education and open planning to minimize conflict and to maintain broad support for management of aquatic vegetation with grass carp.

Sport fishing is the most common water resource use thought to be jeopardized by grass carp, and many studies have been conducted to evaluate this issue (Shireman and Smith 1983; Taylor et al. 1984; Leslie et al. 1987). Aquatic vegetation is an important component of productive fishery habitats (Noble 1980; Bain and Boltz 1992), and optimal coverage seems to be about 30% for common sport fish such as largemouth bass (*Micropterus salmoides*, Colle and Shireman 1980; Wiley et al. 1984). Major reductions in plant coverage have been associated with large declines in sport fish populations (Ware and Gasaway 1976) and altered size structure of fish populations (Klussmann et al. 1988). However, other studies (e.g., Bailey 1978; Colle et al. 1987) revealed little or no effect of vegetation reductions on the abundance and harvest of sport fish. Therefore, whether vegetation reduction by grass carp is likely to cause a serious disruption of sport fishing remains unclear.

The biology of grass carp has been well studied, and the effects of operational stockings have been documented several times in closed systems. How-

ever, little is known about the behavior of grass carp in large, open systems, and stocking of open systems has not been thoroughly evaluated. Consequently, managers will continue to face significant uncertainties about the impacts and effectiveness of grass carp in open systems. Even in isolated lakes, controlling aquatic plants at desirable, intermediate levels seldom has been achieved because the optimal density of grass carp is often not known (Noble et al. 1986; Leslie et al. 1987). In open systems, managing stocking rates and densities of grass carp will be an even greater challenge. Conservative, incremental stockings and monitoring of vegetation seem necessary to balance the positive and negative effects of grass carp and achieve intermediate plant densities.

Table 1. Biology and environmental effects of grass carp for review in planning open-system stockings.

Sources	General conclusions or observations
Population Control	
Pflieger 1978; Stanley et al. 1978; Shireman and Smith 1983; Bain et al. 1990	Extensive movements and migrations by grass carp have been documented in their native range and in the U.S.
Diseases and Parasites	
Ivasik et al. 1969; Shireman and Smith 1983	Introduced grass carp transmitted parasites to other fish species, but detailed information and preventative measures are available.
Habitat Alterations	
Van Dyke et al. 1984; Wiley et al. 1987; Klussman et al. 1988	Stocking with grass carp can cause major reductions and eliminations of aquatic plants.
Vinogradov and Zolotova 1974; Canfield et al. 1983; Shireman and Smith 1983; Klussman et al. 1988	Reductions in vegetation by grass carp were associated with changes in water quality including increased nutrient concentrations and phytoplankton densities, reduced water clarity, and changes in dissolved oxygen concentrations.
Hestand and Carter 1978; Lembi et al. 1978; Leslie et al. 1983; Richard et al. 1984, 1985	Changes in water quality have been moderate especially in comparison with water quality changes from chemical forms of aquatic plant control.
Biological Effects	
Van Dyke et al. 1984; Leslie et al. 1987	Grass carp are very selective in consumption of plants and sequentially eliminate species in order of decreasing palatability. The relative palatability of plant species has been established for many plant communities.
Stott and Robson 1970; Stott 1977; Fowler and Robson 1978; Shireman and Maceina 1981	Grass carp often alter the composition of plant communities and eradicate some species from host systems. Depending on species composition, plant communities can be reduced considerably by grass carp present in densities needed for target plant control.

Table 1. Biology and environmental effects (cont.).

Sources	General conclusions or observations
Biological Effects (cont.)	
Vinogradov and Zolotova 1974; Martin and Shireman 1976; Leslie and Koblyinski 1985; Klussman et al. 1988	Species Composition and diversity of macroinvertebrates have been changed by grass carp. Diversity and abundance of benthic species are usually enhanced, whereas phytophilous species can be substantially reduced and eliminated.
Ware and Gasaway 1976; Klussman et al. 1988; Bettoli et al. 1991; Maceina et al. 1992	Control of vegetation with grass carp can alter fish communities. Abundance of species using structured, littoral habitats tends to decline, whereas species living in limnetic habitats often increase.
Forester and Lawrence 1978; Shireman and Smith 1983; Petridis 1990; Bettoli et al. 1992	Grass carp can indirectly alter feeding habits and spawning behavior of some fish species
Gasaway and Drda 1976; Johnson and Montalbano 1984, 1987; Leslie et al. 1987	Grass carp can significantly reduce waterfowl populations because of overlap in preferred aquatic plant species.
Forester and Avault 1978; Klussman et al. 1988; Bettoli et al. 1990	Vegetation reduction by grass carp has been associated with altered food chains and trophic structure of host systems. Abundance of algae and limnetic-dwelling organisms increased, whereas the abundance of organisms living in littoral areas and feeding on plant material declined.
Management Considerations	
Noble et al. 1986	Stocking with grass carp can be controversial because of conflicting interests of water resource users.
Noble et al. 1986; Shireman and Smith 1983	The life history of grass carp has been extensively analyzed except in large, open systems.
Noble et al. 1986; Leslie et al. 1987	Management of vegetation at intermediate densities has been rarely achieved with grass carp.
Bailey 1978; Colle et al. 1987; Klussman et al. 1988	Effects of grass carp on the quality of sport fishing remain uncertain and variable.

5

Agricultural Canal Systems

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The use of grass carp to control aquatic vegetation in canals, focusing on agricultural irrigation canals in the Southwestern U.S., will be the theme of this chapter. Grass carp have been used very successfully in the supply canals of the Imperial Irrigation District, Imperial, California (Stocker and Hagstrom 1986). This system consists of approximately 2,575 km of canal and 2,250 km of drain, and provides Colorado River water to over 182,250 ha of farmland in southeastern California. It is a closed system where drain water accumulates in the land-locked Salton Sea.

AGRICULTURAL CANAL CONDITIONS

Canals vary in width from the widest, the All-American Canal (34 m) (Figure 1), to smaller secondary canals (1.5 m) (Figure 2). Irrigation canals are typically constructed with flat bottoms and V-shaped sides. Some slumping of side slope material occurs over time, resulting in steeper banks and shallower depths. Water velocity varies among irrigation districts, and within an irrigation system, but typical values fall between 0.15 and 1.5 m/second. Faster water velocities occur near the center of the canal (as high as 2-3 m/second), with slower velocities (typically 0.1-0.5 m/second) near the sides of the canal, behind obstructions, and within plant mats. Plant growth usually occurs on the sides of canals having rapid flow, and on the sides and bottoms of canals with slow flow. Turbid water is very common in canals in the southwest U.S., and plant growth in canals deeper than 2 m is often limited by the amount of available light.



Figure 1. All-American Canal, near Calexico, California. Canal width is approximately 30 m.



Figure 2. Standard Canal, Imperial Irrigation District. Center gate in "open" position allows all water to pass downstream. Closed gate ("checked" position) would allow pond to build up, and delivery of water through gates 13 and 14.

Irrigation canals are typically found in areas with high water demand and less than adequate rainfall, and where crops can be grown that justify the higher expense of irrigation (versus dryland farming). A broad range of climates can be included in this group, but high water demand is frequently a result of high solar radiation, with corresponding high water temperatures. In addition, the banks of canals and drains (Figure 3) act to reduce wind effects on water surfaces (Sutton et al. 1986), thus reducing wave action. These same factors are frequently conducive to high rates of aquatic plant growth.



Figure 3. Culvert under roadway discharging to a drain, Imperial Irrigation District.

GRAVITY FLOW SYSTEMS - While grass carp have been used successfully in flowing water systems, consideration must be made for components of the system that may cause additional cost. Gravity flow irrigation and drainage systems usually have few impediments to fish movement, at least in the downstream direction. This can improve management efficiency if it allows greater fish

movement and reduces the need to stock specific parts of canals. It is much cheaper, for instance, to stock fish more heavily at the upstream ends of the system and to depend on general downstream movement of the fish to "distribute themselves."

PUMPED SYSTEMS - Pumped systems, or systems with many short sections between barriers of some kind, require more attention to stocking of fish because fish are less able to disperse throughout the waterways. This translates into additional cost to the program. Barriers to fish movement can be more subtle than gates or screens (Figure 4 and 5): culverts (Figure 3), pipes, and road crossings can greatly reduce fish movement. This can be an advantage if only certain areas require aquatic plant reduction; confined spaces keep the fish in the area where control is needed. In bigger systems, barriers usually mean more time is required to stock fish into each part of the system.

IMPEDIMENTS TO USING GRASS CARP - Any system must be reviewed for possible fish mortality components. Intakes for municipal water systems, or even large commercial water users, can suck water so vigorously that fish are pressed against screens or other physical barriers. This is especially important to consider when first stocking the fish. They are usually transported under anesthetic, and, until they recover, can easily be swept into areas they would avoid under normal conditions.

Under many irrigation system conditions, the competing demands on fixed amounts of water, or seasonal operating practices, will mean water is not always available. It is very important that the decision to develop a grass carp program is made with the full understanding and cooperation of the water users involved. Water users will not always be aware of the many changes to water flow that can



Figure 4. Rockwood Canal, Imperial Irrigation District. Full pond (to the right in the photograph) maintained by closed gates on left and center, and nearly closed gate on right. Overpour on right gate provides water for downstream users. Effective upstream barrier to grass carp movement while gates in "checked" position.



Figure 5. Bar screen on canal returning flow to Colorado River. Five cm bar spacing prevents large grass carp from leaving the irrigation system.

adversely affect the grass carp. For instance, rapid reintroduction of large volumes of water at high velocity to a partially dewatered canal can sweep the fish from the system. The cost of more slowly bringing up water flows must be compared with the cost of redistributing, or repurchasing, grass carp.

PREDATION - Grass carp can be highly susceptible to predation by piscivorous fish and birds and appear to attract such predators due to their schooling and "flashing" behavior as they feed on aquatic plants. Agricultural canals can harbor large populations of both piscivorous birds and fish and may present a problem to an effective plant management program with grass carp. Largemouth bass, for instance, can consume grass carp which are up to 60% of the bass' total length (Hatton 1977). Shireman et al. (1978) developed "calculated maximum lengths of grass carp that can be ingested by largemouth bass of various sizes" (Table 1). Stocking a grass carp over 198 mm total length would be necessary to avoid predation by largemouth bass up to 325 mm total length.

Bass are often found in agricultural canals, but usually they are smaller and in lower densities than in static water. Other predatory fish species, however, may be even greater problems. Channel catfish and flathead catfish grow very large in the warm waters of southern California and Arizona, and catfish, especially flathead catfish, can be fierce predators of small grass carp.

Some indication of predatory fish populations and representative size ranges should be obtained prior to developing the management plan. Canal outages give an excellent opportunity to observe fish species, numbers, and size. Canals that are devoid of water for significant periods of the year may merely reflect what comes in with the upstream water. End of the "water year" inspections should provide adequate information about fish in the system.

Where significant number and sizes of predatory birds and/or fish are found,

Table 1. Calculated maximum lengths of grass carp that can be ingested by largemouth bass of various sizes. From Shireman et al. 1978b.

Largemouth bass		Grass carp
Total length (mm)	Mouth width (mm)	Total length (mm)
50	5	21
75	7	39
100	10	51
125	12	56
150	15	74
175	17	86
200	19	100
225	24	115
250	28	141
275	32	160
300	36	179
325	40	198
350	44	218
375	48	237
400	52	256
425	56	275
450	59	294
475	63	314
500	67	333
525	71	352
550	75	371
575	79	390
600	83	410

larger grass carp should be stocked. It is possible that higher stocking rates will also be necessary.

INCIDENTAL LOSS OF GRASS CARP - Loss of grass carp in California's Imperial Valley irrigation system is also related to the degree of angling in the water body, and enforcement of regulations preventing possession of grass carp. Illegal net fishing may result in loss of more fish than incidental take by "legal anglers". The current California regulations make possession of grass carp illegal; all grass carp caught by anglers must be returned to the water. Publicity surrounding a few isolated instances of illegal net fishing and illegal possession of grass carp has educated the local public about the consequences of illegal take. One unfortunate angler went to the local newspaper with his prize catch, only to have his trophy picture lead wardens to cite him for illegal possession. Probably even more effective has been the District sponsored school program which teaches students about hydrilla, the grass carp, and the benefits of biological control programs.

CHEMICAL RUNOFF - Flowing water canals are typically very near the borders of agricultural fields, and those fields often have aerially applied pesticides. Label restrictions seek to avoid direct pesticide applications to waterways, but misplacement and/or drift can result in fish loss. Certain materials that can be aerially applied are extremely toxic to fish.

OUTAGES AND MAINTENANCE DRAWDOWNS - Outages and maintenance drawdowns are a fact of life for an irrigation district. While some systems in the warmest parts of the southwest U.S. operate every day of the year, most systems are dewatered for at least the winter months. This "down time" can be used to the

manager's advantage to inspect canals and evaluate the effectiveness of grass carp, to relocate fish from overstocked or dewatered areas, and to estimate the number of fish in a given canal.

Any system has periodic maintenance requirements that result in dewatering at least part of the system. Use of grass carp may reduce the number of outages necessary for a given canal, especially if outages were used to dry up aquatic vegetation as a means of aquatic plant management. Having fewer plants in a canal results in lower water levels, with less seepage and erosion.

CONDITIONS FOR SUCCESSFUL UTILIZATION OF GRASS CARP

The first thing that should be decided by a water manager is whether or not grass carp are suitable for the water and type of aquatic vegetation being managed, and for the specific goals of the vegetation management program (e.g. fishery enhancement, boating channels, irrigation, etc.).

Grass carp have been shown to be extremely effective in reducing standing biomass of submerged aquatic vascular plants of many genera and species. Typical goals for aquatic plant management in irrigation canals are reduction of plant biomass to levels where plants do not interfere significantly with water flow, do not increase sediment deposition by slowing water flow, and do not accumulate on screens, pump intakes, and irrigation pipe.

PLANT PREFERENCE - In general, grass carp prefer soft tissue submerged plants (*Hydrilla*, *Elodea*, *Potamogeton*, and others) that do not have a heavy gelatinous coating (e.g. *Nymphaea*), and smaller floating plants (*Lemna*, *Azolla*). Observations indicate that consumption preference probably does not change in flowing water. Pine and Anderson (1989) found that plant preference by triploid grass carp was variable among sago pondweed, American pondweed, and Eur-

asian watermilfoil, including a possibility of difference between static and flowing water as affected by water temperature.

FILAMENTOUS ALGAE - Filamentous algae are among the most frequently encountered aquatic plants that cause problems in western irrigation systems, and "stocking size" grass carp (over 20 cm) are usually not effective, especially if other more preferred vegetation is present. Very small grass carp (7-12 cm) will feed on algae (Zonneveld and Von Zon 1985), but are subject to predation and quickly grow to a larger, less effective size.

CONSUMPTION RATES - Very little work has been done to determine consumption rates for grass carp under actual conditions in agricultural canals. Pine et al. (1989, 1990) conducted a series of studies of plant preference, consumption, and feeding efficiency in concrete lined raceways very similar to some irrigation systems, although the system uses well water instead of surface water. While the

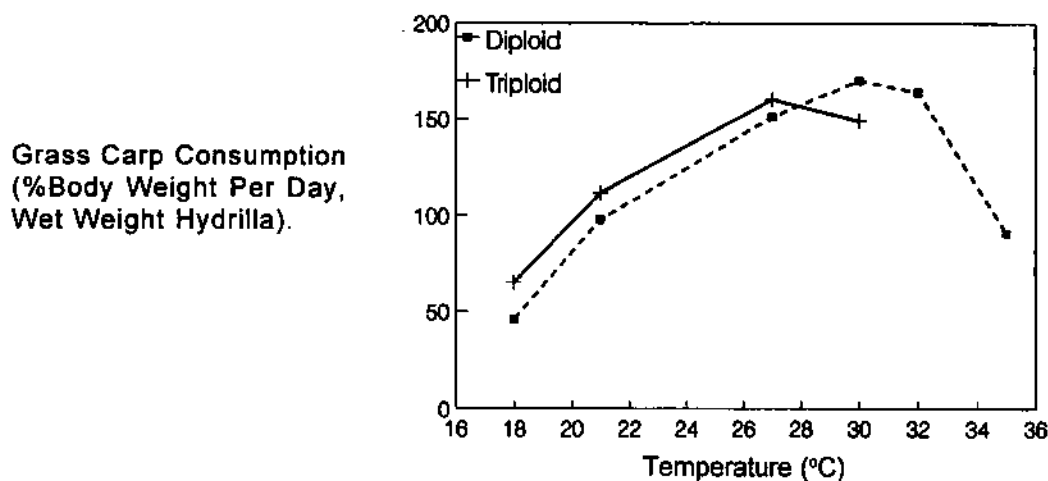


Figure 6. Consumption rates for diploid and triploid grass carp of hydrilla at varying temperatures.

studies clearly showed grass carp prefer certain plant species over others, the overall consumption of aquatic plants was much lower than what is typically observed in actual agricultural canals.

In June 1985, 7,800 triploid grass carp (average weight 122.4 g, $\pm$ 35.4 SD; average fork length 200.8 mm, $\pm$ 20.2 SD), direct from Malone & Son Hatchery in Lonoke, AR., were placed at the upstream end of the hydrilla infestation in the All-American Canal in the Imperial Valley, CA. (Stocker and Hagstrom 1986). Water temperature was approximately 27-29°C at the time of stocking. A partial draw-down of water elevation was conducted shortly after the fish were stocked, but sampling was conducted to separate the effects of the drawdown from the effects of the fish. Approximately 67,300 kg (wet weight) of hydrilla were removed during a seven week period. Ignoring weight gain, movement of fish out of the target area (observed, but not countable), and hydrilla that was removed but not consumed, approximately 1.4 kg of hydrilla (wet weight) were consumed per kg of grass carp (initial weight) stocked. In canals, then, it is likely that grass carp, under favorable conditions, are easily able to consume their own body weight each day.

Fish acclimated to warmer water temperatures appear to do very well during summer months. Laboratory comparison of diploid versus triploid grass carp consumption of hydrilla resulted in peak feeding by diploids at 30°C., and peak feeding by triploids at 27°C. (Figure 6).

CANAL PREFERENCE - Grass carp attempt to move out of canals with water depths of less than 0.5 m. Experience in Florida canals has shown the grass carp to be reluctant to move into vegetated shallow canals (less than one meter deep) even when food plants are no longer present in adjacent deeper water (Sutton et al. 1986). Grass carp will also move out of concrete lined canals if earthen canals can be found. Concrete lined canals usually have a smoother and higher velocity

flow over the entire wetted perimeter, and lack the quieter water edges and vegetation common to older earthen canals.

Some deposition of silt usually occurs on the concrete (Figure 7), and a heavy growth of plants can follow. Grass carp are often able to rest in the slower water velocity among the plants, facilitating excellent plant control. The loss of the "quiet water" areas after vegetation reduction results in grass carp moving to other locations. Restocking may be necessary each time plants recolonize the overlying sediments of concrete lined canals.



Figure 7. Standard Canal, Imperial Irrigation District. Dewatered concrete lined canal (approximately 1.8 m top width), with sediment accumulation.

CONTROL OR ERADICATION

Successful aquatic vegetation management depends on clearly defining the type or level of management desired. Management can include efforts targeting

enhancement of native plant species, enhancement of native species with reduction in exotic species, general reduction in all vegetation, eradication of one species, or eradication of all aquatic vegetation.

ERADICATION - Complete elimination of aquatic vegetation is viewed as a drastic step under most conditions, but is actually easier with grass carp than more subtle management efforts. While grass carp prefer some plant species to others, they should be considered more of a general feeder than a selective pressure agent where eradication is the objective. Plant reduction in the short term is proportional to the number of fish stocked and the conditions under which they are stocked. Relatively high stocking rates (50-200 fish/vegetation ha) will be required for plant eradication.

Grass carp are not a "classical" biological control agent, where populations of predator and prey fluctuate over time, and where numbers of predators usually fall fast enough when prey are reduced so that total elimination of the pest species rarely happens. Grass carp are long-lived (15 years or more), and they will provide nearly constant grazing pressure on the plant resource. Seasonal fluctuations in water temperature and light availability play a dominant role in predicting the long term impact on aquatic vegetation by grass carp. Because of the variability of temperature and light, it is very difficult to use grass carp to provide precise reductions in aquatic plant biomass to predetermined levels, unless there is a mechanism to remove fish.

The decision to eradicate any pest species is usually dependent upon some state and/or federally mandated eradication order. Hydrilla (*Hydrilla verticillata*), for instance, is a pest scattered in waters of California, and one that is on California's "A List" for eradication; whenever and wherever it is found within the state, an eradication program is initiated. Grass carp have provided the basis of

a hydrilla eradication program in the Imperial Valley, California. Grass carp are capable of removing all aquatic vegetation in ponds as well (Sutton and Vandiver 1986).

Costs of these eradication programs are higher than costs for general aquatic plant control because higher stocking rates are used, and because of parallel survey and detection programs typical of eradication efforts. While 10 grass carp per vegetated hectare will provide excellent long term (5 to 10 years) suppression of aquatic plants in small stock ponds in Imperial Valley, 75-100 fish per vegetated hectare have been stocked in the same ponds for hydrilla eradication. The higher rates are needed if immediate elimination of all vegetation is the goal. In this case, eradication costs are about 10 times the cost of a vegetation suppression program.

While these hydrilla eradication costs are high for the size and time length of the program, successful eradication reduces the need for continual funding for longer term programs to manage the hydrilla growth. In addition, eradication reduces the chance of spread of the noxious weed to other water bodies. These two factors are important for state and federal agencies, and less so for individuals. Expensive eradication programs should save agencies and taxpayers money over time, but "control" programs will be less costly than eradication programs to individual users of grass carp.

The need to keep water flowing in an irrigation system often results in establishing completely "clean" canals as a management goal. Eradication may be a more appropriate strategy under the flowing water conditions of agricultural canals, since there is often a very high dollar value attached to the use of the water.

Eradication using grass carp requires maintaining pressure on the plant populations at all times, but special care must be taken to ensure that as few propagules as possible are produced by the existing plants. The stocking strategy

must consider the particular biology of the plant in question. This is less important for plants which flower and set viable seed, or vegetative propagules, under many different types of conditions. However, for plant species that produce propagules only under a few specific sets of conditions, there is a greater reward for efforts spent preventing propagule formation, and every effort should be made to minimize the chance of reproduction. For example, if a particular targeted plant species only sets seeds in early fall, and if grass carp are available for stocking throughout the summer and fall, every effort should be made to stock grass carp so flowering and seed set does not take place. Grass carp stocked a month or two prior to seed set might save an entire year in the eradication effort, versus fish stocked immediately after seed set.

Grass carp alone may not eradicate plants in flowing water. Smaller canals and areas between rocks where grass carp can not reach may have to be handled with mechanical control methods, or by hand.

CONTROL - The starting point for developing a control (versus eradication) program is establishing the goals of the program, including an acceptable level of aquatic plant growth. Available funding is another important consideration; biological control programs require most of the financial input at the beginning of the program, with reduced costs for subsequent years. Typically the savings that can occur using grass carp can be shown within two or three years.

In small ponds in the southwestern U.S., stocking any number of grass carp usually results in eventual elimination of all but the least preferred (to the grass carp) vegetation. This is because the fish get larger each year, while the plant population diminishes. The principal difference between a control program and an eradication program under these conditions is the length of time required to eliminate the target species. The benefit of a control program is the reduced cost

associated with stocking fewer fish.

STAFF REQUIREMENTS

Use of grass carp means new jobs: determining the aquatic plant management strategy; assessing the impact of the grass carp program; inspecting canals to determine if minimum water level needs are being met; conducting fish removal, either during maintenance periods, or at the end of the water season (in seasonal irrigation areas); coordination with resource agencies (if required); permitting; and education of users and public information. Different organizations will develop different ways of handling these jobs, but efficiency and success may be increased if one individual has overall program responsibility.

Often the biggest challenge is in adjusting existing staff to new responsibilities associated with grass carp use. Extra care may need to be taken to ensure adequate water levels are maintained. Screens over intakes may have to be inspected regularly. Under some conditions, it may be worthwhile to hire the services of individuals experienced in grass carp and aquatic plant management, for guidance in developing and assessing the program, or for actual hands-on implementation of the management plan.

Where many peripheral personnel are involved, education about program goals and requirements will help generate the staff commitment necessary to ensure that all parts of the program are successful. For example, special attention is usually required to prevent canal equipment from injuring fish during maintenance operations.

TRIPLOID VERSUS DIPLOID

There are two types of grass carp used for aquatic plant reduction. The difference between the two has to do more with the potential for reproduction

than any difference in how they act as aquatic plant consumers (Sutton et al. 1986; Chapter 1).

Many laboratory and field studies have been conducted comparing sterile triploid grass carp with the normal diploids. Triploids may consume up to 10% less vegetation than diploids, depending on water temperature, but in an operational aquatic plant management program there should be no appreciable difference between the two fish.

POTENTIAL FOR REPRODUCTION - Potential reproduction by grass carp has been a subject of concern ever since the first proposed introductions of grass carp into this country in the 1960's (Stanley et al. 1978, Allen and Wattendorf 1988). This is a riverine fish, typically spawning in floodplain areas in its native Asian rivers. The narrow range of acceptable temperature, water level, time and flowing water requirements for eggs to hatch, etc., make reproduction unlikely in all but the major river systems in the U.S. However, resource agencies are often reluctant to permit additional exotic impacts to already overly impacted river systems.

Many states require the use of triploid grass carp to minimize the potential reproduction in any waters of the state (Chapter 7). The use of triploid grass carp does not eliminate any possibility of unwanted impacts to nontarget areas, since fish can be moved intentionally or unintentionally to non-permitted areas. Use of triploid grass carp does help ensure that grass carp introductions into nontarget waters will result only in plant reduction in proportion to the number and size of grass carp introduced: potential for self-replacing or expanding populations would not be the problem.

The advantages of using sterile triploid grass carp include the reduced likelihood that a program will be blamed for development of self-replacing populations of grass carp downstream of your program. Resource agencies in states

where grass carp use is not currently permitted may be more willing to discuss the use of sterile triploid grass carp.

PROGRAM EVALUATION

After determining the goals of an aquatic plant management program using grass carp, an agreement must also be reached about how the success of the program is to be measured. Visual inspection of canals may provide enough positive feedback if the program receives universal support, and is implemented in a reasonable fashion. Some actual measurement of plant reduction may be necessary if doubters are to be convinced.

MONITORING PLANT POPULATIONS - Measuring the amount or coverage of aquatic plants both before and after grass carp introductions provides feedback on the progress of the program. These measurements can take many forms, but some periodic evaluation is necessary to determine if the stocking rate was appropriate, both for possible restocking of the same areas in the future, and for any expansion of the program into new water bodies.

Measurements of plant growth can be made in "treated" and "untreated" canals. Photographs of plants under clear water or low water conditions can be used for comparison, but better assessment can be made with actual measurements. Numerous methods are available, ranging from collecting plants under water within fixed sized plots, to dragging various hooking devices through the water to collect plants (Dennis and Isom 1984; Sliger et al. 1990).

PROGRAM COST COMPARISONS - One criteria that is often as revealing as any other is reporting of aquatic plant control costs for years before the initiation of the grass carp program, and for subsequent years. If comparable sites are available,

better comparisons can be made if part of the system uses grass carp and the remaining areas use other methods of plant control. One complicating factor typical of many agricultural areas is that aquatic plant control often is merely part of a larger project to remove sediment from canals and drains. It is common for hydraulic excavators to be used to remove sediment and vegetation from the center of a relatively deep drain, and for that material to be dragged up the side slope to widen the drain during the same pass of the boom and bucket. In these situations, it is extremely difficult to separate the costs of plant control from other routine canal maintenance costs.

Cost (1992 dollars) for mechanical plant removal in Imperial Valley varies from about \$36-60 per km for anchor chain dragged along the canal bottom or for disking, to \$360-600 per km for hydraulic excavation. "Chaining" and disking provide substantial control of hydrilla for 6-8 weeks. Excavation can provide control for 3-4 months. All mechanical methods used in Imperial Valley must be repeated many times during the year to adequately control hydrilla regrowth. Stocking 20 grass carp per km of canal, and restocking 10% per year costs about \$50 per km.

Program costs prior to introduction of grass carp for the Imperial Irrigation District were \$250,000-\$400,000 per year to control enough hydrilla to keep water flowing through the system. This provided for machines and labor to attack the worst parts of the problem each year, but did not include the labor cost farmers incurred keeping irrigation pipe, pumps, etc., free of hydrilla fragments. The eradication/control program (hydrilla eradication in the western half of the valley where hydrilla formerly occurred, and general aquatic plant control in the remaining areas) currently (1992) costs about \$250,000 per year to provide plant-free water flow in 2,575 km of canal (approximately \$97 per km).

A small program, using imported grass carp, could expect annual costs

(fish only) of approximately \$161 per kilometer (1993 dollars) of canal vegetation controlled, over a ten year period. This would provide about 120 fish per kilometer, and assumes restocking 10% each year. A system that was heavily infested would approach this "vegetated canal kilometer" cost for each kilometer of canal controlled. A system with scattered patches of dense plants, or lightly infested throughout, could expect costs as little as 10% of this value per km of canal.

Personnel costs are extremely variable depending on the type of individuals hired for the position, but a biologist with some experience in handling warm water fish could probably manage most small programs, at an annual cost of perhaps \$25,000 to \$40,000 (1994 dollars), plus benefits.

Larger programs should have lower unit costs, since expanded area usually does not mean correspondingly expanded personnel and equipment cost. The exception would be if significant efforts were required to prevent fish movement (e.g. mechanical and/or electric screens), and expanded use meant additional barrier construction costs.

Significant additional expenses have been incurred by several western irrigation/municipal water systems where state regulations have required use of physical barriers to reduce fish movement. While no screening effort can prevent people from moving grass carp intentionally, bar screens and electric screens can reduce movement of fish through the water system. To reduce debris accumulation on bar screens, much larger grass carp (over 45 cm in the Yuma County Water User's Association, Arizona) have been used so that wider spacing of the screen bars is possible without loss of fish. Costs for screens can vary from several hundred dollars for a 1 m X 2.5 m, 5 cm space between bars, bar screen, to several hundred thousand dollars for larger screens, and screen/electrical barrier combinations.

OBTAINING FISH

Grass carp can be obtained from commercial suppliers in many southeastern U.S. states, including Arkansas and Florida. Shipping from these locations has been conducted successfully to locations at least 2,400 km distant. Single-truck shipments of over 20,000 fish have been made by truck to California from Arkansas, and air shipments of small numbers of fish (10 to 100) have been made from Florida to California. It is likely that additional hatcheries will develop in the future.

PLANNING FOR IMPORTING GRASS CARP - The biggest problem with not having an instant supply of grass carp is that plans have to be made that consider the growth of the particular plant species involved, the water use cycle (dry canals during winter?), and the size and number of grass carp available at the hatcheries. One consideration for seasonal canals is stocking fish as soon as possible in the year to provide the maximum opportunity for fish to consume plants before rapid plant growth starts in mid-summer. This will reduce the number of fish that have to be stocked to provide a desired level of plant control. Shireman et al. (1978) suggest that "if small grass carp are used (<200 mm TL) they should be stocked when water temperatures exceed 20°C. Below this temperature predation is prolonged because grass carp grow more slowly."

In canals that do not have a dry-out period, stocking date may not be critical in the long run. If grass carp can not be stocked in April of one year (in advance of the bulk of the growth which occurs in summer and early fall), the fish may not be able to keep up with aquatic plant growth during that same year, but they will be much larger the following year, and will provide much better control, assuming that grass carp mortality has not significantly reduced the population size.

Serious problems have occurred because of the timing of the grass carp

introductions. At commercial hatcheries, fish are typically loaded into compartmentalized sections of a hauling truck during daylight hours. Depending on the destination, a truck leaving a hatchery in late afternoon may arrive during the night at its destination. Because the fish have to be kept relatively cool (ice and liquid oxygen are typical methods of lowering water temperature) and anesthetized during shipment, there is strong motivation (in addition to transportation cost) for getting the fish to their destination as quickly as possible.

Unless the entity utilizing the grass carp has considerable previous experience with handling transported fish, any number of problems can arise, especially if the hauling truck arrives at 3:00 A.M. The night-time hours mean extra care must be taken when using ice picks, when determining the number of fish to be off-loaded at any particular location, etc. For these reasons, it may be better to off-load the fish at a temporary storage facility, with stocking to be done later. However, it is usually easier on the fish to stock directly into the desired locations, since this reduces the amount of handling to which each fish is subjected.

Thorough familiarity with the water system is also a requirement. The middle of the night is not the time to learn that the intake pumps for a large pumping station come on at variable times. The fish are groggy for several minutes after they are off-loaded into the receiving waters, and fish can easily be swept into pumps, screens, etc. When they are fully recovered from transportation, grass carp will actively avoid these same pump and screen facilities, if they are physically able to do so.

Depending on the size of the shipment, the number of stops the hauling truck will make, and the distance from the hatchery, it may be possible to schedule a delivery time that maximizes the opportunity for successful distribution of grass carp. Communication between the shipper and the receiver during the haul will also help the scheduling process.

DISTRIBUTION FROM THE HAULING TRUCK - If all of the fish are going into a relatively few places, the stockings can be made from the hauling truck. Ordinarily the company that hauls the fish will have a time limit on how long the truck can be used for distribution without extra charges. The contract can include a provision for payment for extra time required. This option may not be available if part of the fish shipment is bound for a different location. Possibly it could be arranged so that your load was the last of that shipment.

If plans include the use of the hauling truck, the contract must stipulate exactly how it is to be done, including the following:

- Will the truck driver be expected to physically help distribute the fish? Conversely, will anyone else be allowed to get in or on the truck?
- Will the fish be shot out the gate into a pvc pipe (20 cm diameter pipe is frequently used), or will hand netting of fish be necessary?
- Will accurate counting of fish be required at many different locations?
- Will the truck driver make adjustments of water temperature during the final few hours of transporting so the fish will arrive at the destination at nearly the same temperature as the receiving waters (more than 2° C difference may result in fish stress).
- Will dead fish count toward the total, and if not, how will mortality be determined? Count can be made of dead fish during distribution, or in receiving waters for the subsequent 48 hours (enough time must be allowed for dead fish to float to the surface). Mortality is fairly predictable, and suppliers may

simply add the mortality factor and deliver a few more fish than ordered.

After the first time, the process will get much easier, as local ways of solving problems are developed, but the first time is usually far more problematic than most people assume. If receiving staff are working from the truck, they must be sufficiently familiar with how the shipping compartments are handled to avoid making serious mistakes that could kill the fish. The working surfaces are usually wet, and frequently slippery. It is often not easy to get to the top of the shipping tanks, and considerable dexterity and physical strength may be required. If frequent stops are necessary, and the distances preclude remaining on the top of the shipping tanks between stops, the physical strain of climbing up and down the rig must be taken into consideration. The truck driver may have driven a considerable distance, and her/his unfamiliarity with your facility may result in unanticipated obstacles.

SUB-HAULING - If the fish are simply dropped off at one location for later distribution, some local system for transporting fish will be necessary. Successful short-distance (less than 3 hours) hauling during the cooler part of the year has been accomplished using rectangular nalgen® plastic basins (0.6 m width, 0.9 m length, 0.3 m height), with ice to keep water temperatures from rising. A pick-up truck can be used to haul several hundred kg of water and fish, but a more substantial vehicle is required for larger loads.

If fish are stored at some central location for subsequent distribution, mechanisms for temperature and oxygen control may be needed. Unless small numbers of small fish are being handled by experienced individuals, anaesthetic will also be needed; grass carp are "nervous" under such conditions and may jump out of their holding tank.

Advantages for sub-hauling include the ability to stock fish at times of the day and year different than the arrival of the hauling truck. Holding facilities could allow for a single shipment each year rather than multiple shipments as more fish are needed. Disadvantages for sub-hauling include the need to provide food for the fish, filtration to remove waste products if small tanks are used, possible aeration requirements, and security for the facilities.

CONTRACTING THE FISH STOCKING - If the process of receiving and distributing the fish appears to be more effort than the receiving entity is able or willing to provide, it may be possible to contract the process to a local aquaculture interest if regulations allow. This has been done successfully, and can even include the opportunity to stock fish at specifically desired times of the year, with known quantities and sizes of fish.

It is possible to purchase smaller fish than needed, and contract with the local aquaculture company to provide both temporary storage and growth for the fish. Programs have been developed where the local aquaculture company is paid some amount per fish for each fish going into the facility, or for each fish that comes out of the facility, and so much a kg (or cm) for growth. While these types of programs can work, it is important to find an aquaculture company that has a high degree of interest in successfully producing fish of the desired number and size. Since most grass carp introductions are not routine enough to be regular money-makers, fish farmers may not dedicate the resources necessary to produce the desired fish.

IN HOUSE PRODUCTION OF TRIPLOID GRASS CARP - At the other extreme, the management entity may want to construct a grass carp hatchery. Grass carp are relatively easy to produce; the most difficult part becomes the care and feeding

of young grass carp, and the staff and pond space required.

On the down side, public agencies may be criticized for competing with aquaculture interests if business is taken away from local fish farmers. There is also added risk: when the financial investment is in the hatchery, a failure during any given year may mean no stocking of grass carp that year. For normal plant management in canals, one year may not dramatically affect the overall program and this may be an acceptable risk. If sterility is required there is the added expense of ploidy verification, and possibly substantial risk if diploids are found in the system. In some states, discovery of diploids may jeopardize the entire program. It is possible that a local hatchery could be blamed for introductions of diploids even if the fish were from a different source. There are currently no practical markers to distinguish grass carp from different hatcheries.

Requirements for security of broodstock, fry, and fingerling ponds facilities vary among the states. California requires a security fence around any ponds that contain, or may contain, diploid grass carp (broodstock and uncertified fry), and bird netting over the facility to prevent waterfowl from carrying diploid grass carp and dropping them in adjacent unsecured waters. In addition, all water leaving these ponds must pass through sand filters and/or mesh screening to prevent eggs, fry, and fingerlings from escaping.

GRASS CARP GROW-OUT REQUIREMENTS - Grow-out from fry to fingerling stage grass carp in the Imperial Valley is conducted in 0.04 ha ponds. Six ponds of this size are adequate to produce 20,000 to 60,000 fingerlings. Larger ponds are necessary to produce stockable size grass carp. Approximately 2,500 grass carp, 20 cm in length, can be produced each summer in each ha of .8-1.0 m deep ponds. Grass carp in these ponds are fed pelleted fish food and fresh plants from canals, and aerators are used to supplement the water flow that is maintained at

all times through the ponds.

If grass carp needs are heavy for the first several years, and expected to be much less over time, investment in a hatchery is probably not warranted. The grass carp hatchery constructed in Imperial Valley, California, was developed to maintain exceptionally high stocking rates of grass carp for the hydrilla eradication program over a relatively long period.

Production of triploid grass carp is fairly simple, and very little more expensive than production of diploids (Cassani and Caton 1986). Unfortunately, the treatment is also less than 100% effective in producing sterile fish. Therefore if 100% sterility is required, all fish produced have to be checked for ploidy level prior to introduction into the system, and setting up this "ploidy verification" is neither cheap nor easy. Current technology includes the use of a Coulter Counter® to measure the size of the nucleus of red blood cells of small fish (Wattendorf 1986), or of cell density in whole tissue suspensions (Cassani 1990), although other methods are available (Allen et al. 1986; Pine and Anderson 1990).

Triploid fish have red blood cells with nuclei that are measurably larger than nuclei of regular diploid fish. A small amount of blood is extracted from the head region (chin) of each fish, the blood is diluted in standard quantities of appropriate solutions, and the nuclear size is measured. Fish with nuclei larger than a predetermined size are considered to be triploids. Cost for sampling and analysis, including staff time, adds about \$1.00 (1993 dollars) per fish to production costs.

GRASS CARP DISTRIBUTION

POST-STOCK MOVEMENT BEHAVIOR - Typically the fish arrive under anaesthetic, and have been at cooler temperatures during the haul, although the water temperature should be brought up to existing ambient temperature of the receiving water prior to stocking. After a fish hits the water, it usually makes some

motion as it tries to restore equilibrium and right itself. Within 30 seconds, most of the grass carp will have recovered, although some may take as much as several minutes. After recovery, the fish often swim vigorously in random directions in an apparent effort to avoid danger in their new habitat. Within a few minutes the grass carp are fully able to resist downstream drift, unless water velocities are greater than about 2 meters per second.

Typically, the fish gather into one or more schools, and begin feeding in and around plant beds. In gently flowing water (about 1 meter per second or less), most of the grass carp will move upstream until they find: An area with lower velocity water; an area with denser vegetation that provides food and relief from resisting the current; a culvert that may provide hiding places and protection from the sun; or a bridge or other structure that crosses the canal.

From this upstream location, the bulk of the fish movement over the next several months will be downstream (Stocker et al. 1991). This general downstream movement should influence decisions about where to stock fish within the system. Recovery from shipping conditions (temperature and anesthesia) and general downstream movement are the two biggest factors to consider in designing the stocking scheme. It is important to pick stocking locations so the fish distribute into desired locations when they come out of the anaesthetic.

This pattern of fish movement can be completely altered by plant density and water depth. Studies in very slow flowing canals in Florida have documented limited fish movement in areas of dense aquatic plant growth, upstream movement through culverts to new food sources, but avoidance of downstream movement to new areas of plant growth that would require going through a culvert or water control structure (Sutton et al. 1986). The canals in these investigations were shallow (under one meter), and plant control in the smallest laterals was much less than in larger main canals.

MOVING AND REMOVING GRASS CARP - There are several reasons why it may become necessary to move or remove grass carp after the initial stocking. Frequently the reason for moving fish is to reduce consumption of aquatic vegetation, or to move fish out of areas where all plants have been consumed. Less often, the need is to concentrate a number of grass carp in the area of desired plant reduction. In addition, it may be necessary to remove a sample of grass carp for some monitoring purpose (e.g. random inspection to assure triploidy, disease inspections, etc.).

If distances from one location to another are very short, and if water can be removed from the canal or pond, relocation of grass carp can be a fairly simple process. Under more typical conditions, however, many factors must be taken into consideration during the planning process. Handling and moving of grass carp in agricultural canals is very different than in static water bodies because the use of nets is complicated by the force of moving water, and is frequently impossible.

Condition of the fish should be monitored during transport and temporary storage in tanks or basins. Oxygen and temperature are interrelated factors in fish health. Temperature is easily monitored and a rapid temperature increase of more than 5° C should be avoided. It is advantageous to load fish into tanks with the same water temperature as the receiving water. If necessary, ice can be then added for further cooling. Temperatures above 25° C can be difficult to work in unless fish are to be held for only 20 minutes or so (warmer water holds less oxygen than cooler water). Grass carp are more tolerant of warm water and corresponding low oxygen than many fish species, but any movement of grass carp in temperatures above 30° C can be fatal. The density of fish in the tank also determines how much oxygen is available for the fish. A suggestion for warm water (20-22° C) without aeration of any kind is 0.12 kg of fish per liter of water for a maximum of 10 minutes. Half this amount of fish can be held for 20 minutes, one

third for 30 minutes, etc.

Aerators are relatively inexpensive and provide a mechanism to hold larger quantities of fish for longer times. Air stones are frequently connected to pressurized tanks of normal air (SCUBA tanks). These tanks can provide from 10 minutes to several hours of adequate aeration, depending on tank size and holding conditions. Oxygen can be bubbled into tanks to provide a more concentrated oxygen source. Prices probably vary widely from region to region, but both compressed air and oxygen can be obtained for about \$8-\$12 for a cylinder holding 7.47 m³ of compressed gas.

While it is critical that oxygen concentrations be maintained at adequate levels, monitoring oxygen is not as cheap or easy as monitoring temperature. Oxygen analysis equipment is available, but even with monitoring equipment the condition of the fish must be checked regularly. As oxygen levels fall, blood rich tissues of the gills turn from a bright red to a pinkish color.

Grass carp usually do better when thoroughly anesthetized for handling and shipping/moving. They handle 5-10° C changes in temperature better, and probably consume less oxygen than when fully alert. Dosage for anesthetics depends on the chemical being used, water temperature, fish size and number, and length of time in transit. It is not possible to provide a specific recommendation because different states may have different rules about which anesthetics can be used. In addition, federal laws apply, especially if there is the possibility that the fish may later be consumed. Fishing does not always have to be a legal activity to preclude the use of chemicals not labeled for human consumption.

To date, efforts to remove grass carp from canal systems with water present have been labor intensive, expensive, and/or only partially successful. In fact, in some situations it is probably less expensive to obtain additional grass carp from suppliers than to catch and redistribute them, or to store grass carp from canals

that are dewatered in the winter months. Where canals are dewatered for maintenance or annual dry-up periods, grass carp will concentrate in the remaining watered areas. In smaller canal systems, culverts under roadways often provide good locations for fish to remain during outages. Unfortunately, culverts often have rocks and other debris which make pulling nets difficult. In complete outages, it can be difficult to capture and remove all grass carp before low water affects survival.

In some situations, removal of fish may be conducted to decrease pressure on remaining aquatic vegetation where "control" is the management objective. This usually means that grass carp will have to be removed while the canals are under full operation. Some success has been obtained simply by installing a bag seine at the downstream end of the target canal section, a block net at the upstream end, and moving the block net downstream toward the bag seine. This can be a dangerous process for both humans and fish as water forces build on the nets, especially nets full of grass carp.

Grass carp are notorious jumpers, sometimes creating dangerous situations to personnel working in close proximity. Successful recapture programs are usually those that have developed methods to keep the fish from simply jumping over the nets. In many cases, elevating the nets 1-2 meters above the water has been effective. Some very innovative systems have been designed to reduce fish loss from jumping. In Arizona's Salt River Project, a mechanical bubbler has been used in the canal upstream of bag and seine nets, with fish being herded downstream away from the curtain of small bubbles as the air curtain is moved toward the nets. The nets are placed across the canal in pairs, so fish jumping over the first net are almost certainly caught in the second net. Additional nets are placed upstream of the bubbler and follow the bubbler downstream to contain any fish not herded by the bubbles. See Chapter 6 for

an evaluation of other recapture techniques.

DISTRIBUTION STRATEGIES - Under conditions of low to moderate flow (0-2 m/second), managers of systems with few, if any, barriers to fish movement may be able to stock all of the grass carp into the upstream end of the system, and depend upon general downstream distribution tendencies of the grass carp to move them throughout the system. If retaining fish in a given area is essential, mechanical barriers (screens) may be necessary, although problems with screens may be worse than those caused by the vegetation. Some adjustment of grass carp numbers may be necessary due to inability to accurately predict where fish will remain within the flowing water system. After "favored" and "avoided" areas are determined through experience, stockings can be adjusted.

Common physical attributes of canal systems that are often related to fish "avoidance" include high velocity water flow, concrete lined canals, and turbulence from drops, hydroelectric plants, gates, culverts, siphons, and other structures. If the individual designing the fish introduction plan is thoroughly familiar with the physical setup, use can be made of the structures to manage ultimate fish distribution.

Fish can be maintained in "avoided" areas by screens (including electrical barriers to reduce upstream movement). Many different types are available commercially, and many inventive farmers have designed and built their own. Typically some type of automated trash and plant removal mechanism is desirable to reduce the labor hours required to keep screens free of debris.

Additional fish can be stocked into, or upstream of, depending on the local pattern of fish movement, "avoided" areas during the year. Unless conditions are very unfavorable (water velocities above 2 meters/second, for example), some plant consumption will probably occur before all grass carp leave the target area.

This approach usually requires restocking several times during the year.

STOCKING RATES

Rapid and complete removal of aquatic vegetation in southwestern U.S. irrigation systems has been obtained using 50-187 fish per vegetated hectare in water velocities of less than 2 meters per second. The principal difference in impact between the extremes of this range of stocking densities is how quickly the vegetation is eliminated. The high end of the range can result in total plant removal in a matter of several weeks in lower density plant stands. At the lower end of the range, complete removal of plants may take several months to a year, again depending on plant density, water temperature, flow velocity, etc.. Fewer fish than this will usually result in partial vegetation removal, but the type of removal (small patches of open space versus general reduction) depends greatly on canal conditions. In larger canals where water velocities vary from 0.3-1.2 meters per second, as few as 12 fish per vegetated hectare can provide over 75% vegetation removal within 2 years. If complete removal of vegetation is the management goal, it is often necessary to supplement stockings in areas where fish are disinclined to remain.

Studies in Florida have found 25 to 623 fish per surface (canal) hectare prevented regrowth after chemical applications (Sutton et al. 1986). Rates of 623 fish per surface hectare stocked after limited mechanical plant removal resulted in total plant elimination within several months.

INTEGRATED CONTROL - Stocking rates can be reduced if significant amounts of the target vegetation are removed prior to introduction of grass carp. Care must be taken to ensure that decay of affected plants does not reduce oxygen to lethal (approximately 0.5 mg/L) levels. Mechanical removal of plants may be

more suitable since the vegetation is normally removed during the treatment.

Copper based herbicides have been used effectively in Imperial Valley stock ponds and reservoirs to reduce standing biomass of aquatic vegetation and give the grass carp a consumptive advantage. Grass carp can tolerate fairly high levels of copper in relatively hard waters, but may be more sensitive in softer waters. Again, care must be taken to ensure that oxygen problems are not created by decaying vegetation. Delaying a week or two before stocking grass carp will probably avoid oxygen problems.

Agricultural canals are usually too narrow and shallow, and have too high water velocity for floating mechanical plant harvesters to be used. Instead, buckets attached to backhoes and hydraulic excavators are used to lift out sediment and plants, and agricultural disks, pulled by a tractor from the bank, or anchor chains dragged by a tractor on each bank, are used to cut plants loose from the sediment. While these mechanical tools themselves (with the possible exception of disks and harrows) do not cause fish mortality, increase in suspended materials caused by mechanical control can also reduce oxygen availability dramatically. In high summer water temperatures, mechanical control can indirectly reduce the oxygen concentration enough to cause considerable fish mortality.

IMPACTS TO RESIDENT FISH

Use of agricultural canals as a sports fishery varies widely among irrigation districts. In some locations like Imperial Valley, favored canals are well utilized for recreational angling. Other districts prohibit fishing, often because of liability issues related to allowing access to canal banks. Districts that distribute water from large river systems usually import river fish with their water, unless specific measures (screens) are taken to reduce fish diversion. Because of routine

maintenance and periodic outages, canals do not usually provide high quality habitat for sports fish species, but larger canals where outages are less frequent and where maintenance activities affect a smaller portion of the waterway, can develop fishery resources attractive to anglers.

Because of the extreme variability among and between canal systems, it is very difficult to clearly demonstrate the type and magnitude of grass carp impacts, both direct and indirect, on resident fish populations. Studies of angling success in Imperial and Coachella Valleys, California (Stocker et al. 1989; Thiery 1990), did not indicate that grass carp introductions have directly affected the sport fishery (bass, channel catfish, bluegill). However, removal of the aquatic plants definitely changed the number of fish caught, and the best fishing locations.

Sport fish species that populate irrigation canals are typically found concentrated in parts of the canal that provide some physical structure. For example, in canals without aquatic plants, bass are more frequently found near check gates than in the open water sections between these gates. In canals with aquatic vegetation, bass are more likely to be found throughout the canal. Removal of aquatic vegetation allows small fish to be more easily found by predatory fish, and with plants and prey species absent in the open water stretches, the predators return to the areas with structure. Anglers looking for bass in small openings within hydrilla mats had to move to canal structures (gates, drops, etc.) after the vegetation was removed. The concentration of bass at these structures frequently lead to very high catch rates during short periods. Subsequently, anglers felt that somehow the grass carp program had reduced the number of bass, until the success at the structures became better known, and the temporarily higher amount of take became obvious.