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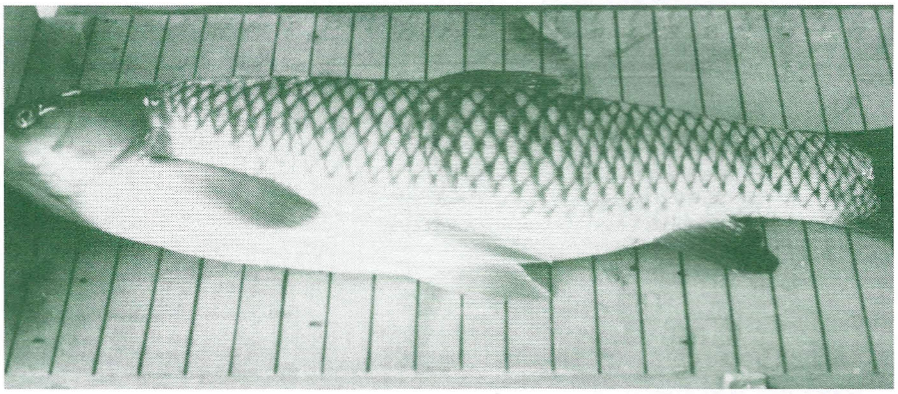


Triploid grass carp

Triploid Grass Carp as a Biological Control of Aquatic Vegetation

by

Larry Sanders, Jan Jeffrey Hoover, and K. Jack Killgore

The grass carp (or white amur), *Ctenopharyngodon idella*, is a large (125-centimetre) herbivorous minnow from lowland rivers of Pacific slope drainages of eastern Asia. It superficially resembles the common carp (*Cyprinus carpio*), but differs in several characteristics. Its body is more streamlined, its mouth is terminal, and it lacks a stiff dorsal spine and barbels. The grass carp has large, grooved pharyngeal (throat) teeth and a long intestine which allow it to effectively shred and digest aquatic plants as its principal food. The grass carp, as a biological control of aquatic plants, is considered an attractive long-term method for control of submersed aquatic plants.

The cost of aquatic plant control using grass carp in small waterbodies is less than $250 per hectare with benefits extending more than seven years (Shireman, Colle, and Canfield 1985). Because using grass carp to control aquatic vegetation is inexpensive and longer term compared to other control techniques, there is widespread interest in expanding its use throughout the United States.

The diploid grass carp has been used for biological control of aquatic plants from the 1970s until the 1980s. Numerous studies have been conducted to evaluate its potential for reproduction, feeding preferences, stocking rates, and impacts on other aquatic resources (Smith and Shireman 1983). Based on a five-year study at Lake Conway, Florida, practical guidelines for the use of diploid grass carp to manage aquatic plants in ponds and lakes were developed (Miller and Decell 1984). However, the potential of the diploid grass carp to naturally reproduce caused considerable controversy over its use as a biological control agent. This eventually led to the production of sterile, triploid grass carp which most states allow to be used for the control of aquatic plants, at least for experimental purposes.

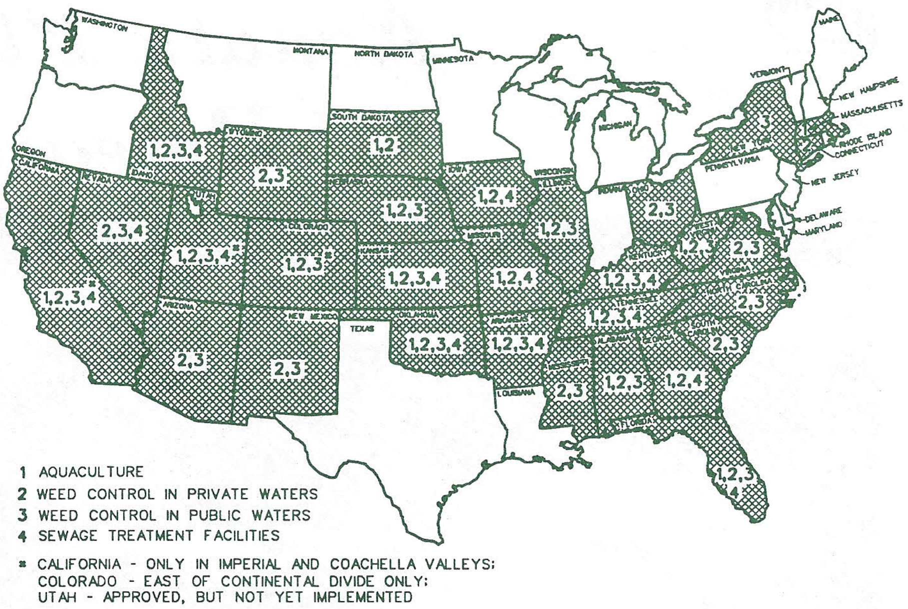
This article reviews the development and biology of the triploid grass carp and provides recommendations for its use as a biological control of nuisance aquatic vegetation. Triploid and diploid grass carp are morphologically identical and, reproduction notwithstanding, are assumed ecologically similar. Therefore, most data obtained from studies of diploid fish should be applicable to triploid fish (Sutton 1985).

Development of the Triploid Grass Carp

In 1963, the grass carp was first introduced at Stuttgart, Arkansas; subsequent introductions and dispersal rapidly expanded its range to at least 35 states (Guillory and Gasaway 1978, Clugston and Shireman 1987). Successful spawnings of grass carp in United States waters were predicted (Stanley, Miley, and Sutton 1978) and the potential for negative impacts on aquatic ecosystems influenced many states to prohibit or restrict the use of grass carp. Consequently, there has been a concerted effort to produce a low-risk control agent, that is, a nonreproductive grass carp.

Grass carp, like most fishes, are diploid. They possess two sets of chromosomes (one from each parent) and are capable of sexual reproduction. Triploid fish, however, have three sets of chromosomes and are incapable of normal sexual reproduction and the production of viable offspring. The use of triploid grass carp would severely limit the likelihood and magnitude of any negative impacts, but still allow benefits of its use, that is, long-term, low-cost plant control and the production of harvestable fish (Sutton 1985, Sutton and Vandiver 1986).

Triploid fish were first produced in the United States in 1979 as interspecific crosses between female grass carp and male bighead carp,



Triploid grass carp permitted and utilized (modified from State of Louisiana, Department of Wildlife and Fisheries 1989)

Aristichthys nobilis (Malone 1982). These fish contained an extra set of chromosomes and were incapable of reproduction, but were hybrids of the two species and not true grass carp; successful plant control was limited. Later, triploid grass carp were produced intraspecifically, by physically shocking fertilized eggs with heat, cold, or hydrostatic pressure; this stimulated the retention of a set of chromosomes that would normally be expelled during cell division (Clugston and Shireman 1987, Cassani and Caton 1986, and Allen and Wattendorf 1987).

Physical shock techniques induce polyploidy with apparent yields of 100 percent triploids (Cassani and Caton 1986). Because of this high success rate, this technique is being used to produce large numbers of fish. Concern exists, however, that induced polyploidy could result in the production of some reproductive grass carp (that is, diploid or reproductive triploid fish). Consequently, triploidy in each individual must be verified prior to stocking. Ploidy is most often determined by a Coulter Counter, which electronically measures the volume of a red blood cell after the cell membrane has been chemically removed (Allen and Wattendorf 1987, Clugston and Shireman 1987). Since triploids have larger red blood cells (and nuclei) than diploids, cell size differences are used to confirm triploidy (Allen and Wattendorf 1987).

Stocking of triploid grass carp will increase with greater availability of fish and greater confidence in their use. Six hatcheries in the United States are commercially producing triploid grass carp, and the number is likely to increase. As production techniques are perfected, cost ($4.00 per 20-centimetre fish) should decrease (Clugston and Shireman 1987). On December 2, 1985, in response to a request from South Carolina, the US Fish and Wildlife Service (FWS) issued a "Biological Opinion," stating that female triploid grass carp are functionally sterile and that the sperm of male triploid grass carp is probably nonfunctional; this document was not intended to promote the use of grass carp but was forwarded to all FWS regional offices for states that wish to implement studies on grass carp using federal funds.

Size at Stocking

Large grass carp provide more effective plant control than smaller individuals (Sutton 1985). Small fish suffer high mortality due to predation by birds, snakes, and other fish, and although feeding rates of small fish are high, quantities of plants eaten by smaller fish are not necessarily higher than those eaten by larger individuals. The difference in consumption rates between small and large fish is also a consideration. Fish weighing less than 3 kilograms (approximately 600 millimetres long) eat 100 percent of their body weight daily, but substantially larger fish (3 to 6 kilograms) eat 75 percent of their body weight. Because of their larger body weight, use of larger fish can result in larger absolute quantities of plant eaten per fish (Clugston and Shireman 1987). Large triploid grass carp, however, are difficult and more costly to obtain commercially, so this often necessitates the stocking of smaller fish and the use of alternative controls. Considering these reasons, the stocking size of triploid grass carp usually ranges from 200 to 300 millimetres.

Time of Stocking

Plant control strategy, water quality, and availability of commercial fish determine the time of year to stock grass carp (Sutton and Vandiver 1986). If grass carp are used in conjunction with herbicides or mechanical methods, they

Grass Carp Feeding Preferences

Plants consumed preferentially or controlled

Sagittaria graminea, coastal arrowhead
Hydrilla verticillata, hydrilla
Cabomba caroliniana, fanwort
Chara spp., muskgrass
Najas quadalupensis, southern naiad
Lemna spp. and *Spirodela* spp., duckweeds
Egeria densa, Brazilian elodea
Wolffia spp., watermeal
Elodea canadensis, elodea
Utricularia gibba, eastern bladderwort

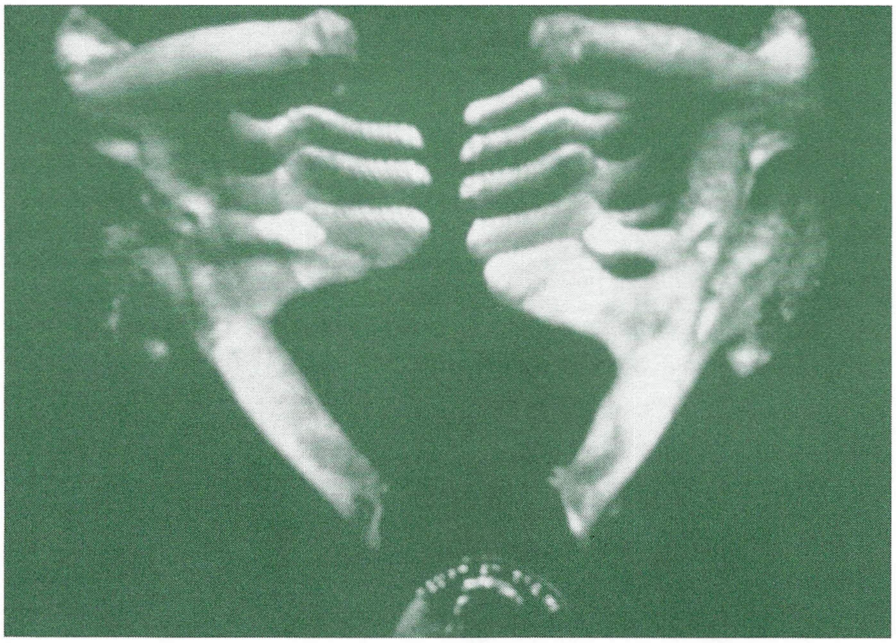
Plants sometimes preferred or controlled

Eleocharis, slender spikerush
Azolla caroliniana, azolla or water-fern
Potamogeton spp., pondweeds
Nasturtium officinale, watercress
Bacopa spp., water hyssop
Spirogyra sp., algae

Plants not preferred and sometimes not controlled

Najas flexilis, stonewart
Ceratophyllum demursum, coontail
Typha spp., cattail
Nuphar spp., spatterdock
Nymphaea spp., water lily
Myriophyllum spicatum, Eurasian watermilfoil
Vallisneria americana, tapegrass or eel-grass
Myriophyllum aquaticum, parrot-feather
Eichhornia crassipes, water hyacinth
Hydrocharis morsus-ranae, frogbit
Carex Pseudo-Cyperus, sedge
Scirpus spp., bulrush
Ludwidgia repens, water primrose
Myriophyllum heterophyllum, variable leaf milfoil

Information based on Sutton and Vandiver (1986), Fedorenko and Fraser (1978), Theriot and Sanders (1975), Miller and Decell (1984), and Pauley and others (1986).



Pharyngeal teeth used to macerate plant tissue

should be stocked after the effects of these treatments have been achieved and before regrowth of the plants. Otherwise, cooler months of the year are the best time for moving and handling triploid grass carp because fish are less susceptible to injury and disease (Sutton and Vandiver 1986, Thomas and others 1990). Spring is the most common time that commercial hatcheries have adequate numbers of triploid grass carp available for transport and stocking. Pine, Anderson, and Hung (1990) suggest that triploid grass carp be stocked in spring in order to match fish consumption with increases in plant production in canals. In summary, grass carp are usually stocked in spring when the problem aquatic plants begin to emerge.

Stocking Densities

To achieve effective control of problem plant species, triploid grass carp must be stocked in sufficient number such that the rate of total plant consumption by the fish is equal to or exceeds growth rates of those plants (Sutton and Vandiver 1986). Consumption and stocking rates depend on several factors, including the size of the fish, the density of the plant or plants to be consumed, the size of the waterbody, the water temperature during the growing season, and whether mechanical or herbicide treatments were used prior to the stocking of the fish. Several simulation models are available that consider these factors and help determine stocking rates. One model was developed from pond studies in Illinois using diploid grass carp (Wiley and others 1985) and another model developed from data collected at Lake Conway, Florida, over a five-year period (Miller and Decell 1984). The latter model was further modified for triploid grass carp (Boyd and Stewart 1990).

An additional consideration for stocking large waterbodies, such as reservoirs, is the movement of grass carp. If grass carp move away from target control areas, they would be ineffective for aquatic plant management. Grass carp of stocking size may stay near their release points, but as these fish grow and reach sexual maturity (about 650 millimetres or 3.5 kilograms), they can undertake extensive migrations that lead to dispersal of grass carp outside the target areas (Bain, Steeger, and Tangedal 1989). Therefore, annual stockings of grass carp may be required in large waterbodies because fish stocked in previous years may disperse to distant areas. Poor water quality conditions (such as low dissolved oxygen and high water temperature) in vegetated areas may also influence grass carp movement, causing the fish to move away from dense plant beds (Chappelear and others, in preparation).

Given the number of variables that must be evaluated, stocking rates are extremely variable and range from 2 to 500 fish per vegetated hectare (Stocker and Hagstrom 1985, Bonar, Thomas, and Pauley 1987, and Bates and Webb 1986). However, the most common rates are 25 to 60 fish per hectare (Allen and Wattendorf 1987) using fish approximately 300 millimetres long (0.5 kilogram per fish). Stocking rates should be based on the amount of vegetation (for example, number of fish per vegetated acre), rather than using the size of the waterbody as a determining factor.

Feeding Habitats and Growth Rates

Grass carp preferentially feed on or control many species of aquatic plants. Feeding habitats are influenced by vegetation composition, water temperature, and the size of the fish (Bowers, Gilbert, and Thornton 1987, Clugston and Shireman 1987). Fiber content, which varies among plant parts and plant species, can significantly influence palatability of the plant to grass carp. Low-fiber plants are generally preferred but fibrous plants may be controlled by stocking in the spring when the fish can feed upon the new shoots and buds (Prowse 1971).

Temperature affects the rate of feeding by grass carp; feeding stops when the water temperature reaches 11 degrees Celsius, declines at temperatures above 30 degrees Celsius, and is optimum at temperatures from 20 to 30 degrees Celsius (Young, Monaghan, and Heidinger 1983, Wiley and Wike 1986). The daily consumption rates of grass carp are relatively high compared to other herbivorous fishes. Small grass carp (<400 millimetres) can consume up to two times their body weight under optimal conditions, a rate which decreases to 80 percent of their body weight as the fish grow (Miller and Decell 1984, Clugston and Shireman 1987).

Growth rates for the triploid grass carp vary, but rates are generally lower than those of diploids, possibly because triploids exhibit lower feeding rates than diploids (Osborne 1982, Young, Monaghan, and Heidinger 1983). Although the triploid is a very close energetic match to the diploid in assimilation efficiency and metabolic rate, it exhibits a 10 percent lower rate of ingestion which is manifested as a 16 percent decrease in growth (Wiley and Wike 1986, Wiley and Gorden 1984). Growth of triploid grass carp ranges from 0.19 to 3.36 grams per day compared to a range from 0.64 to 14.62 grams per day for diploid grass carp (Wiley and Wike 1986).

Future Use of Triploid Grass Carp

Triploid grass carp are currently used for vegetation control in many states throughout the country, although restrictions vary among the states. Alabama and Arkansas, the initial importers of the fish, along with 12 other states, allow triploid and diploid grass carp to be stocked in their waters. Fifteen states issue special permits that allow the use of triploid grass carp for vegetation control (Allen and Wattendorf 1987). Four states permit experiments with triploids, and 19 states still technically prohibit importation, but several of the 19 may issue limited experimental-use permits.

The most important factor in the selection of triploid grass carp as a control agent for aquatic macrophytes is its functional sterility. Absolute guarantees that a triploid will never reproduce are tenuous, given longevity (10+ years), variability in size (four orders of magnitude), and the absence of long-term studies (Wiley and Gorden 1984). The chances of reproduction among triploid individuals are certainly negligible. Managers, however, must balance the risk with the beneficial results of biological control of nuisance plants. With the technology available today, triploid grass carp may be monitored and controlled and a decision for using them possibly reversed (Allen and Wattendorf 1987).

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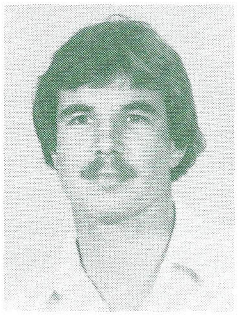

This issue reports on the development and use of the triploid grass carp for aquatic plant control. The most effective use of the triploid grass carp, considering size at stocking, time of stocking, and stocking densities, is discussed.

AQUATIC PLANT CONTROL RESEARCH PROGRAM

This bulletin is published in accordance with AR 25-30 as one of the information dissemination functions of the Environmental Laboratory of the Waterways Experiment Station. It is principally intended to be a forum whereby information pertaining to and resulting from the Corps of Engineers' nationwide Aquatic Plant Control Research Program (APCRP) can be rapidly and widely disseminated to Corps District and Division offices and other Federal and State agencies, universities, research institutes, corporations, and individuals. Contributions are solicited, but should be relevant to the management of aquatic plants, which are, providing tools and techniques for the control of problem aquatic plant infestations in the Nation's waterways. These management methods must be effective, economical, and environmentally compatible. The contents of this bulletin are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such products. This bulletin will be issued on an irregular basis as dictated by the quantity and importance of information to be disseminated. Communications are welcomed and should be addressed to the Environmental Laboratory, ATTN: J.L. Decell, US Army Engineer Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199, or call AC 601/634-3494

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