

# An Overview of the Use and Efficacy of Triploid Grass Carp *Ctenopharyngodon idella* as a Biological Control of Aquatic Macrophytes in Oregon and Washington State Lakes<sup>1</sup>

by

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## Introduction

Considerable money and effort is expended annually to control excessive plant growth in Oregon and Washington State waters. Acceptable practices for controlling aquatic weeds in Washington State have included chemical treatments, mechanical harvesting, water level reduction, dredging, and bottom screening ("Grass Carp Use in Washington" 1990). With the advent of sterile, triploid grass carp (*Ctenopharyngodon idella*) in 1983, local, State and Federal agencies supported a study conducted by the University of Washington Cooperative Fish and Wildlife Research Unit on the efficacy of grass carp for aquatic plant control in the Pacific Northwest.

At the time this research was initiated, little information was available regarding the efficacy of grass carp in north temperate climates of the United States. The major objectives of this research were as follows:

- a. Evaluate current methods for determining separating triploid (sterile) grass carp from diploid (fertile) grass carp.
- b. Verify the sterility of triploid grass carp.
- c. Evaluate the efficiency of plant control by triploid grass carp in the Pacific Northwest.

- d. Determine the effect of triploid grass carp on the ecosystems of several Pacific Northwest lakes, primarily on the water quality and the fish populations.
- e. Develop a method for predicting grass carp stocking rates for Pacific Northwest waters.
- f. Develop methods for capturing grass carp from overstocked waters.

This research was concluded in 1991, and the following gives a broad overview of our results. Specific information from each of these studies is available through Bonar, Thomas, and Pauley (1987, 1988); Bonar (1990); Bonar et al. (1990); Bonar et al. (1993a, b); Bowers, Pauley, and Thomas (1987); Frodge (1990), Frodge, Thomas, and Pauley (1990, 1991); Pauley et al. (1985, 1987, 1991); Thomas et al. (1989, 1990); and Vecht (1993).

## Methods

We evaluated the efficacy of grass carp for aquatic plant control in the Pacific Northwest through field and laboratory studies conducted from 1984-1991 and a compilation of data from literature and questionnaire surveys. Seven Washington lakes and one Oregon lake were stocked with grass carp to evaluate their

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effect on aquatic plants, water quality, and fish communities, to examine grass carp growth, and to identify feasible grass carp capture techniques. Experimental lakes were divided by barrier nets to provide a reference area that was not stocked with grass carp and one or two treatment areas where grass carp were stocked. Two external control lakes, one on each side of the Cascade Mountain Range, were monitored throughout the study to provide controls in the event of barrier net failure. Experimental lakes were monitored before and after stocking to provide a before-after-treatment-control (BACI) design. In larger Devils Lake, areas of the plant community were cordoned off from grass carp grazing using nets (exclosures).

Laboratory studies were used to examine grass carp preference and consumption on Pacific Northwest macrophytes and to evaluate techniques to separate triploid and diploid grass carp. Studies were conducted in 4270 l outdoor tanks using both flow-through and recirculating filtering systems. Methods varied by experiment and will be discussed in the descriptions of the individual studies below.

Sterility of the triploid grass carp was not directly verified in these studies, but rather through contact with other researchers from warmer, southern climates where the fish matured more quickly.

## Overview Of Various Studies

### Genetics and growth of grass carp

**Origin of grass carp in the United States.** Literature searches and telephone surveys revealed that all grass carp in the United States currently are of Chinese origin.<sup>1</sup> Russian literature revealed that differences in genetics, age of maturity, and spawning times exist between the warmwater-acclimated Chinese

stocks and the more northern Russian stocks originating from the Amur River system. However, no directed experimentation has been conducted to identify temperature-related differences in feeding rates between the different stocks.

**Separation of triploid and diploid grass carp.** The external morphology of diploid and triploid grass carp was studied to determine whether the two types could be separated by differences in external characteristics (Bonar, Thomas, and Pauley 1988). In a comparison of 27 measurements, six scale counts and five fin formulae from two stocks of diploid and triploid fish obtained from commercial producers, analysis of covariance, and discriminant analysis indicated a classification accuracy of only 65 to 85 percent. Clearly, triploid grass carp differentiated by external morphology alone should not be stocked into waters where diploid fish are illegal or would cause management problems.

The accuracy of a Coulter counter, a Coulter counter with channelyzer, and a flow cytometer were also evaluated for separating diploid and triploid grass carp.<sup>2</sup> Using a Coulter counter with a channelyzer resulted in 100-percent correct classification of 167 fish, while using a Coulter counter alone resulted in 1 misclassification and 166 correct classifications. Costs of flow cytometry units (\$65,000 - \$212,000) and sample processing by flow cytometry (\$0.57/sample) were both higher than those for the Coulter counter and the channelyzer (\$25,490; \$0.36/sample).

**Growth rates of triploid grass carp in the Pacific Northwest.** Growth rates of triploid grass carp were studied from four Washington lakes (Vecht 1993). Growth was highest in East Pipeline Lake, where grass carp grew from an average of 144 to 6,032 g in approximately 4.3 years. In Keevies Lake,

<sup>1</sup> Unpublished Manuscript, 1994, S. A. Bonar, G. L. Thomas, and G. B. Pauley, "Origin of grass carp in the United States and differences in Asian grass carp stocks."

<sup>2</sup> Unpublished Manuscript, 1994, S. A. Bonar, G. L. Thomas, and G. B. Pauley, "Accuracy and cost comparison of flow cytometry and Coulter counter techniques for rapid ploidy analysis of grass carp (*Ctenopharyngodon idella*)."

two size classes of grass carp grew from an average of 144 and 732 to 4,419 g in approximately 4.3 years. In Bull South Lake, carp grew from an average of 144 to 3,701 g in approximately 4.3 years. In Big Chambers Lake, two size classes of grass carp grew from 282 and 223 to 2,363 g in approximately 1.3 years. Fulton condition factors of fish from all lakes ranged from 1.13 to 1.87. The length-weight relationship calculated for grass carp in this study (168 to 855 mm total length) was  $\log \text{ weight (g)} = -4.53359 + 2.87217 \log \text{ total length (mm)}$ . Scale increments were measured to back-calculate growth at annulus formation. When examining fish growth using regression analysis of back-calculated yearly growth increments, we found that 73 percent of the variation in fish growth was explained by fish age. Triploid grass carp growth rates were as high or higher than growth rates of diploid grass carp from their native range.

### Effects of triploid grass carp grazing on Pacific Northwest test lakes

**Effects on aquatic macrophytes.** In 1986 and 1987, triploid grass carp were stocked into five Washington lakes at rates ranging from 113 to 550 fish/vegetated hectare (4.7 to 15.1 fish/metric ton wet weight of vegetation). Three years after stocking, vegetative cover was reduced in all lakes in amounts ranging from 6 to 67 percent (Bonar 1990). Biomass surveys revealed that waterweed (*Elodea canadensis*) and Sago pondweed (*Potamogeton pectinatus*) were grazed first in eastern Washington lakes followed by coontail (*Ceratophyllum demersum*). Native watermilfoil (*Myriophyllum exalbescens*) exhibited no definite trends. In western Washington, floating-leaved pondweed (*Potamogeton natans*) was reduced or removed, but coexisting watershield (*Brasenia schreberi*) was not grazed appreciably.

Within 3 years of stocking Devils Lake, Oregon, with 27,090 sterile triploid grass carp (180 fish/vegetated hectare; 6.1 fish/metric ton wet weight vegetation), the total volume of vegetation declined by 30 percent, while the total vegetative biomass increased (Bonar et al. 1993a). This biomass increase was due

primarily to the expansion of short compact communities of the exotic plant Brazilian waterweed (*Egeria densa*). Comparison of the main lake with enclosure areas protected by net barriers and the results of feeding preference experiments suggested that the increased dominance of *E. densa* was caused by factors other than selective feeding. Furthermore, as the grass carp grew, they seemed to control the expansion of *E. densa* and to maintain species diversity in the plant community. Results from feeding experiments suggested that the size of the grass carp may influence feeding preference and should be considered when determining the palatability of the target plant species. Results indicate that although successful stocking rates will have to be higher for cool northern waters than for warm waters in the Southern United States, the grass carp can still be an economical and effective control of plants in temperate climates.

**Effects on water quality.** Introduction of sterile triploid grass carp into Keevies Lake and Bull Lake in Washington State resulted in a reduction of surface cover and biomass of the aquatic macrophytes, along with some improvements in water quality (Frodge 1990). In areas previously dominated by floating-leaved species, mean bottom dissolved oxygen (DO) increased from <1 to >3 mg/L. Mean conductivity increased from around 30 to 90  $\mu\text{siemens}$  and was associated with higher ion concentrations, primarily calcium, which increased from 2 to 4 mg/L. In areas previously dominated by submergent species, surface pH was reduced to <10, surface DO decreased from >20 to 10 to 15 mg/L, and mean bottom DO increased from 2.0 to 4.5 mg/L.

**Effects on fish assemblages.** Fish samples were taken from several Washington lakes in 1985, 1986, 1988, and 1990 and from Devils Lake, Oregon, in 1986, 1987, and 1988 (Thomas et al. 1989; Marino et al. 1994). Fish were taken by either electroshocking or fyke netting. Age, length, and weight data were collected for several species of fish, including largemouth bass (*Micropterus salmoides*), black crappie (*Pomoxis nigromaculatus*), pumpkinseed sunfish

(*Lepomis gibbosus*), bluegill sunfish (*Lepomis macrochirus*), warmouth (*Lepomis gulosus*), yellow perch (*Perca flavescens*), brown bullhead (*Ictalurus nebulosus*), and rainbow trout (*Oncorhynchus mykiss*). Proportional Stock Density Index (PSD) was used as a method of evaluating the quality of the fishery when appropriate. Numbers of largemouth bass in Keevies Lake declined two orders of magnitude 3 years after stocking grass carp. However, the decline occurred in the control area as well as the two treatment areas, suggesting a natural fluctuation and not a response to grass carp grazing. Growth of largemouth bass increased slightly, while pumpkinseed sunfish and black crappie exhibited no differences. In East Pipeline Lake, there were no changes in either growth or abundance of largemouth bass and pumpkinseed sunfish. The population of largemouth bass in Devils Lake declined from 1986 to 1988 by about 30 percent. However, this decline may have resulted from an increase in sport fishing mortality since increased fishing effort was observed following reductions in plant surface cover.

### **Effects of dense canopies of aquatic macrophytes on Pacific Northwest lakes**

#### **Effects on dissolved oxygen and pH.**

Dense mats of aquatic macrophytes partitioned the littoral zone of two shallow lakes in Washington State into different habitats of varying water quality (Frodge, Thomas, and Pauley 1990). Horizontal distribution of DO and pH in the lakes was associated with the patchy distribution of aquatic macrophytes in the lake, and the vertical distribution of DO and pH was associated with the location of the canopy in the water column. Elevated concentrations of DO and pH were observed in the canopies of submergent species, while lower DO and pH were observed both in the canopies of floating-leaved species and in the subcanopy water of both growth forms. Vertical mixing of the water column occurred in the open-water areas to a greater extent than within macrophyte beds, resulting in higher subsurface DO concentrations than beneath either submergent or

floating plant canopies. Diel changes in DO and pH were associated with the growth form of the macrophytes that formed the plant canopy. Diel pH and DO changes were significant within the canopy of the submergent species that formed in the near-surface waters. Diel changes were not seen in either the surface of floating-leaved macrophytes or in the subcanopy of either growth form. In Keevies Lake, western Washington, dense canopies of overlapping floating leaves of *B. schreberi* reduced summer surface and subcanopy dissolved oxygen to <2 mg/L without significantly changing pH. In canopies of *P. natans*, which has subsurface as well as floating leaves, the surface DO was higher than in adjacent open-water areas, but subcanopy DO was as low as beneath *B. schreberi* canopies. In Bull Lake, in eastern Washington, surface canopies of the submergent species *C. demersum* and *M. exalbescens* regularly had DO concentrations of >30 mg/L and pH > 10. Beneath these canopies of submergent plants, DO of <1 mg/L was common at 0.25 to 0.50 m, and pH was typically 1 to 2 units lower than at the surface.

**Sediment phosphorus beneath dense aquatic macrophytes.** Dense surface canopies of aquatic macrophytes were associated with significant changes in the physical and chemical water quality of two shallow Pacific Northwest lakes (Frodge, Thomas, and Pauley 1991). Internal loading of phosphorus (P) was observed at the sediment-water interface beneath canopies of *C. demersum* and *M. exalbescens* and in deep open-water areas when DO concentrations were  $\leq 0.4$  mg/L. Aerobic release of P was observed at sites with surface covers of green filamentous algae (*Pithophora* sp.) where concentrations of DO were >20 mg/L and pH > 9. An increase in surface P concentrations also was observed in sites dominated by the floating-leaved *B. schreberi* and appeared to be associated with leaf decay within the surface canopy. There was an apparent net loss of phosphorus to the sediments beneath both submergent and floating-leaved canopies when DO concentrations were  $\geq 0.4$  mg/L. The removal or reduction of the plant canopies could simultaneously reduce anoxic P release while increasing

aerobic P release. These P cycling mechanisms should be considered in the management of aquatic macrophytes.

**Effects on fish.** Concentrations of DO measured in dense beds of aquatic macrophytes in two western Washington lakes were below reported lethal limits ( $\leq 1$  mg/L for largemouth bass and steelhead trout (*Oncorhynchus mykiss*) (Frodge et al. 1994). Temperature, DO, pH, and conductivity were measured synoptically, with all parameters except DO within acceptable ranges for largemouth bass and steelhead survival. The impact of the observed low DO concentrations on endemic fish was examined by field observation, electroshocking, and 72 hr in situ cage bioassay. Largemouth bass were tested in Keevies Lake, a small, shallow, eutrophic lake in western Washington, and steelhead trout were tested in the large, deep, mesotrophic Lake Washington. No mortalities occurred over 72 hr in the open water or surface water in dense patches of Eurasian watermilfoil (*Myriophyllum spicatum*) in Lake Washington where DO concentrations were consistently  $>4.0$  mg/L. No significant mortalities occurred in the open-surface water of Keevies Lake or in the upper 1 m of water in patches of *P. natans* where concentrations of DO were consistently  $>2$  mg/L. Significant fish mortalities occurred at both the surface and at the 1-m depth in dense beds of the floating-leaved macrophyte *B. schreberi* and in the bottom water ( $<2.0$  m) of both floating-leaved and submergent plant species, where DO concentrations were  $<2$  mg/L. When the volume of water in Keevies Lake with DO concentrations  $> 1$  mg/L was recalculated during the period of maximum macrophyte biomass and compared with the total volume of the lake, a 50-percent reduction in available largemouth bass habitat was estimated. The observed lethal DO concentrations and high mortalities in the bioassay tests indicate that at high densities, aquatic macrophytes can have significant detrimental local effects on fish. Habitat degradation by these dense growths of aquatic macrophytes has significant implications for the management of aquatic macrophytes and littoral fisheries.

## Use of grass carp for aquatic plant control

**World usage of grass carp for aquatic plant control.** We used a questionnaire to obtain management and stocking rate information on the grass carp from 28 states in the United States and 11 European countries (Bonar 1990). Most responses indicated grass carp were effective in controlling some plant species but not others. Most respondents reported phytoplankton populations increased following the stocking of grass carp ( $P < 0.001$ ). The number reporting waterfowl population declines was not significant ( $P > 0.07$ ), but this may have been due to the small number of responses to this question. Respondents did not agree on changes in game fish population size, and no consistent changes were observed in either the population size ( $P > 0.52$ ) or body condition ( $P > 11$ ). However, the respondents reported that angling quality improved following stocking ( $P < 0.001$ ), which was primarily attributed to better access to the water. An analysis of grass carp capture techniques revealed angling and nets were more effective than electroshocking, nets only, or nets used in combination with electroshocking. Relationships between stocking rate needed for aquatic plant removal and plant morphology, air temperature of treatment site, and waterway type were developed from stocking rate recommendations provided by the respondents.

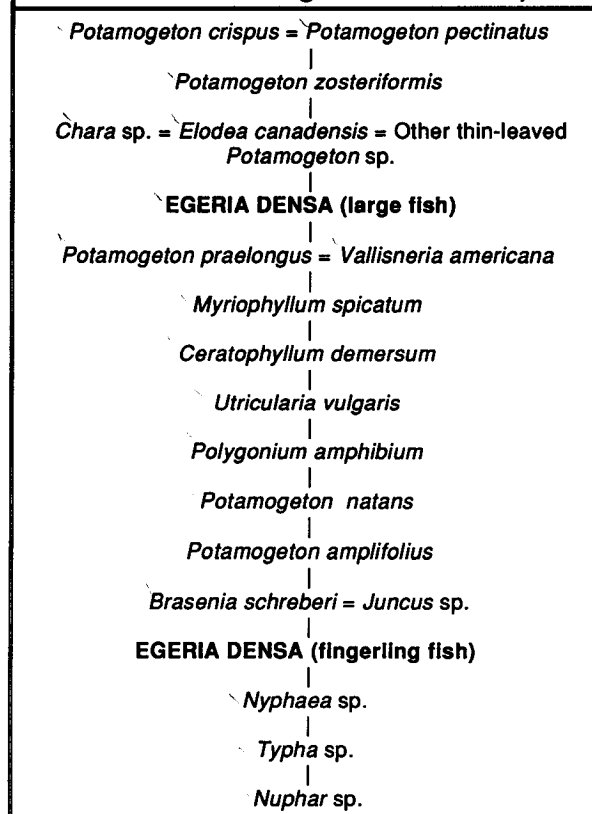
**Feeding preference of grass carp for Pacific Northwest plants.** The importance of 20 Pacific Northwest aquatic macrophyte species as food items for grass carp was evaluated (Bowers, Pauley, and Thomas 1987; Pauley et al. 1991). No significant difference in feeding preference was found between diploid and triploid grass carp. No significant differences were found in relative preference because of either fish density in the holding tanks or to water temperatures of 15, 20, and 25 °C. Feeding rates of triploid grass carp increased between 15 and 20 °C, but not between 20 and 25 °C. In paired two species plant preference trials using diploid and triploid

grass carp, there was a distinct difference in feeding preference between all plant pairs tested except for *P. pectinatus* and curly-leaved pondweed (*Potamogeton crispus*), which were selected equally by grass carp.

The preference for plants by fingerling (mean wt. = 269 g) and larger grass carp (mean wt. = 927 g) did not differ when consumption was tested for three different plant assemblages resembling those occurring in Lake Lawrence and Chambers Lake, Washington, and in a hypothetical nonpreferred plant community made up of species from both lakes (Pauley et al. 1991). However, large and fingerling triploid fish preferences did differ for a plant community consisting of *M. spicatum*, *E. canadensis*, *E. densa*, and tapegrass (*Vallisneria americana*) that resembled the community from Devils Lake, Oregon (Bonar et al. 1993a). Fingerling fish found *E. densa* almost unpalatable, while it was a highly preferred plant species when presented to the larger grass carp. When presented with the various multispecies plant communities, grass carp did not remove plants in a preferred species-by-species sequence. Instead they grazed simultaneously on several palatable plants of similar preference before gradually switching to less preferred groups of plants. The relative preference of many plants was dependent upon what other plants were associated with them. The relative preference rank for the 20 aquatic plants tested is shown in Table 1.

**Relationship between plant chemical composition and their consumption by grass carp.** The rate at which triploid grass carp consumed three plant species from different locations was measured and compared with the chemical composition of the plants. Grass carp fed on *E. canadensis* from three lakes at significantly different rates ( $P < 0.001$ ), but did not eat *E. densa* from two lakes at significantly different rates (Bonar et al. 1990). Feeding rate of the grass carp was positively correlated to the concentration of calcium ( $r = 0.976$ ) and lignin ( $r = 0.946$ ), but was negatively correlated to the content of iron ( $r = -0.808$ ), silica ( $r = -0.934$ ), and cellulose

**Table 1**  
Preference of Grass Carp for Pacific Northwest Aquatic Macrophytes (Preference declines moving down the table)



( $r = -0.922$ ). Multiple regression analysis revealed calcium and cellulose content were the most important predictors of consumption rate. These experiments demonstrate that water chemistry and plant chemical composition may affect plant palatability and could in part be responsible for some of the discrepancies in grass carp consumption rate and preference studies.

There were numerous differences in the tissue composition of Eurasian watermilfoil, *M. spicatum*, from two different lakes in Washington State (Pauley et al. 1991). Although calcium and magnesium did not differ between samples from the two lakes, significant differences were observed among samples of silica, cellulose, lignin, phosphorous, iron, zinc, and copper. No significant difference was exhibited between the consumption rates of *M. spicatum* from the two different lakes for either fingerling grass carp or larger carp.

Larger fish ( $927 \pm 148$  g;  $414 \pm 22$  mm total length) consumed approximately four to five times as much milfoil as smaller fish ( $269 \pm 18$  g;  $264 \pm 18$  mm total length).

**Disturbance and time of day effects on consumption rates.** The highest consumption rates in tank experiments were in the afternoon and at night, which corresponded to times when water temperatures were the highest ( $20$  to  $24$  °C; Pauley et al. 1991). These results indicate diurnal heating and cooling could affect grass carp consumption rate in small ponds and coves in lakes. Human disturbance did not affect consumption rates substantially. Feeding rate of grass carp disturbed at random times increased as grass carp acclimated to the disturbance.

**Prediction of grass carp stocking rates.** An empirical model for predicting grass carp stocking rates was developed from the stocking rate recommendations of 38 grass carp managers worldwide and data from over 100 field trials (Bonar 1990). Stocking rates are predicted by matching the desired plant control objective (eradication or partial control) and the accumulated air temperature units of a site to corresponding values on regression curves that are averages of successful stocking rates used by managers under similar conditions. One version of the model (COVER) predicts stocking rates based on the area of the waterway covered by vegetation (grass carp/vegetated hectare), while the other version (BIOMASS) predicts stocking rates based on the maximum total plant biomass found in the water at the height of the growing season (grass carp/metric ton wet weight of vegetation). The model was fine tuned with the results of the Pacific Northwest grass carp field trials.

**Capture of grass carp from vegetated lakes.** Seven techniques were evaluated as methods of capture for grass carp in five Washington State lakes containing aquatic vegetation (Bonar et al. 1993b). The capture methods included angling, pop-nets, lift nets, or traps in baited areas; angling in nonbaited areas; heating the water in small areas to at-

tract fish; and herding fish into a concentrated area and removing them with gill nets or seines. Herding fish into a concentrated area was the most effective of the techniques ( $P < 0.001$ ), followed by angling in baited areas. Herding is effective in lakes containing thick vegetation, submerged logs, and other underwater obstructions and may be effective for removing grass carp from overstocked waters or to monitor growth.

## Summary

The laboratory and field experiments, as well as an exhaustive questionnaire and literature survey, demonstrated grass carp could be an effective plant management tool in the Pacific Northwest. However, water managers in this area will have to stock grass carp at rates higher than those used in most other regions of the country to achieve adequate plant control. Even when stocked at these higher rates, grass carp are economical when compared with other methods of plant control.

Aquatic plants were not completely eradicated in any of the field sites 4 years after stocking. Monitoring should be conducted for longer periods in Northwest lakes to determine if partial control can be achieved over a longer time period or complete plant control results, a common situation reported by others (Leslie et al. 1987; Colle, Cailteux, and Shireman 1989; Bettoli et al. 1993).

With the levels of aquatic vegetation control we achieved using triploid grass carp, we did not see major adverse impacts on water quality or native fish populations. In fact, water quality improved in the lakes heavily infested with aquatic vegetation, primarily because of an increase in subsurface oxygen concentrations following the removal of aquatic plant canopies.

Triploid grass carp were legalized in Washington State, December 1990. Careful, controlled use of grass carp, strict verification of disease-free and sterile fish, and additional experimentation and monitoring to improve stocking rate predictions and capture techniques

will ensure the grass carp's place as a safe, effective component in region-wide aquatic plant management programs.

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