*J. Aquat. Plant Manage.* 28: 36-40

# Control of Aquatic Plants in Static and Flowing Water by Yearling Triploid Grass Carp

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## ABSTRACT

One year old triploid grass carp (*Ctenopharyngodon idella* Val.), ranging in weight between 90 and 224 g, were placed in canals having static or flowing water to determine their feeding preferences and ability to control curlyleaf pondweed (*Potamogeton crispus* L.), elodea (*Elodea canadensis* Michx.), and Eurasian watermilfoil (*Myriophyllum spicatum* L.) during winter, summer, and fall temperature regimes. Based on plant fresh weight consumed, preferences under static, winter conditions were: elodea = curlyleaf pondweed = Eurasian watermilfoil; and in flowing water: curlyleaf pondweed>Eurasian watermilfoil. Preferences in static water in summer were similar to those in winter. Preferences in flowing water were: curlyleaf pondweed-= Eurasian watermilfoil. Fall static water preferences were: Eurasian watermilfoil>curlyleaf pondweed. In flowing water, Eurasian watermilfoil = curlyleaf pondweed. Feed efficiencies (fish wet weight gain/plant fresh weight consumed) in static water in winter and summer were 0.11 and 0.35, respectively. For flowing water, efficiencies were 0.46 and 0.35 for winter and summer. Protein efficiency ratios (fish wet weight gain/dry weight protein consumed) in static water for winter and summer were 5.0 and 18.9, respectively. Ratios for fish in flowing water were 16.3 and 13.4 for winter and summer. The yearling fish did not show high levels of control of aquatic plants presented to them in this study.


*Key words*: biocontrol, curlyleaf pondweed, elodea, Eurasian watermilfoil, feed efficiency.

## INTRODUCTION

We have previously reported on the ability of triploid grass carp (*Ctenopharyngodon idella* Val.) ranging in weight between 350 and 550 g and stocked at 357 fish/hectare to control various species of aquatic plants in different seasons in static and flowing canals (Pine et al., 1989a). Depending on the season of stocking, this combination of size and stocking rate was effective in eliminating aquatic plants and showed differences in consumption rate. Diploid grass carp of similar weight range were used in a study by Van Dyke and Sutton (1977) in a static system. Others have also reported that this size-range of triploid grass carp stocked in flowing water can effectively reduce macrophyte biomass (Cassani et al., 1988). We examined the feeding characteristics of smaller fish ranging in weight between 90 and 224 g in this study. Although other authors have studied diploid grass carp in this size range, or smaller, in static systems (Fischer, 1968; Kilambi and Robison, 1979; Hajra, 1985), little work has been done in flowing systems where small triploid grass carp have been used.

The objectives of this study were 1) to test the ability of smaller triploid grass carp to control aquatic plants during different seasons and 2) to measure plant preferences and feed efficiencies of the fish using curlyleaf pondweed, elodea, and Eurasian watermilfoil.

## MATERIALS AND METHODS

Triploid grass carp were held in a 10,000-L fiberglass pool covered with 50% shadecloth prior to experimentation. The pool was supplied with aerated water at a flow rate to provide a 24-h turnover. Temperatures in the pool varied between 9 to 25 C and fish were fed *ad libitum* with an equal (by weight) mix of the three plants under study plus lettuce (*Lactuca sativa* L.) for at least a month before the start of each trial. A total of 36 fish were used, with a new group of 12 fish in each of three studies (winter, summer, fall). The triploid grass carp were one year old and weighed between 90 and 224 g.

Two canals having static and two canals having flowing water were used and each was divided in the middle to make two replicates (Pine et al., 1989a). Canals were 122 m long × 3 m wide (at the top), concrete lined, and trapezoidal in cross section, and filled with well water. Flow velocities were 0.67 $ms^{-1}$ upstream and 0.25 $ms^{-1}$ at the

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downstream end. Separate stockings were made in winter, summer, and fall so that the effect of temperature on consumption rate could be studied. Daily temperature fluctuated more in static water but showed an overall downward trend during the winter experiment similar to canals with flowing water. Temperatures were higher in static water during winter and summer but lower than flowing water in fall (Figure 1).

The aquatic plants utilized in our initial static versus flowing water study (Pine et al., 1989a) were sago pondweed (*Potamogeton pectinatus* L.), Eurasian watermilfoil (*Myriophyllum spicatum* L.), and American pondweed (*Potamogeton nodosus* Poir.). In this study, fish were fed curlyleaf pondweed (*Potamogeton crispus* L.), elodea (*Elodea canadensis* Michx.), and Eurasian watermilfoil which are common in northern California. These three plants have been used in other studies with both triploid and diploid grass carp (Fowler and Robson, 1978; Wiley et al., 1986). Eight containers of each species were placed in each canal section to acclimatize for one month in either static or flowing conditions. Before introduction of fish, plant biomass in each system was equalized through a non-destructive measurement of shoot length and plant count (Pine et al., 1989b).

Three triploid grass carp were placed into either upstream or downstream canal sections in each of the four canals with the other canal section serving as an unstocked control. Before stocking, fish wet weight was measured. Water quality variables of temperature, total alkalinity, total hardness, conductivity, pH, dissolved oxygen, and turbidity were determined as in Pine et al. (1989a). Low water temperature during winter and towards the end of fall slowed triploid grass carp consumption rate so that the experimental interval used was two months and one month, respectively, but the summer trial lasted only one week. Experiments were ended when visual inspection in-

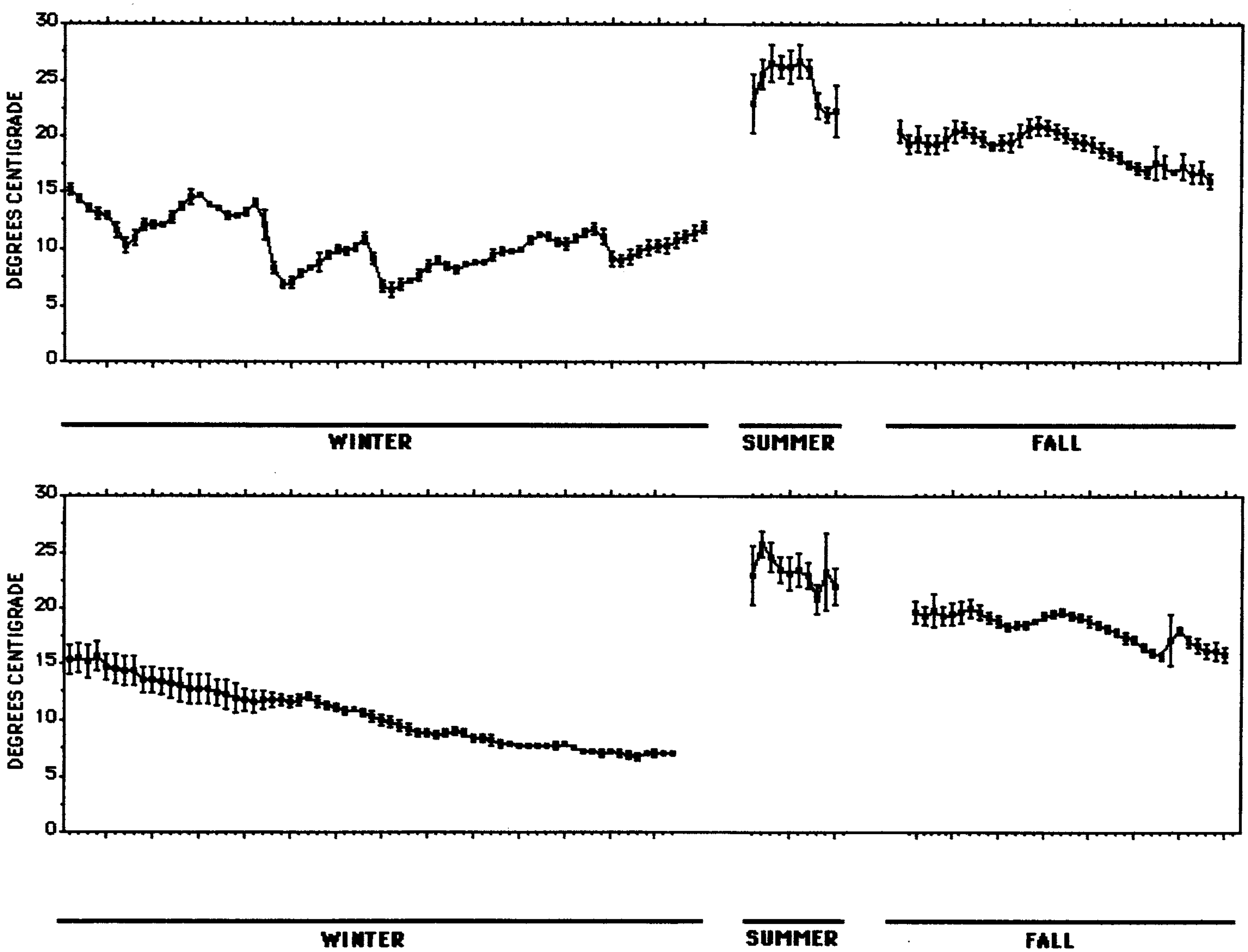


Figure 1. Mean daily temperatures of static (top) and flowing (bottom) canals in winter, summer, and fall trials. Bars show the range of six values taken at: 0200, 0600, 1000, 1400, 1800, 2200.

dicated the near elimination of the most preferred plant species. Fish were removed at this time and their wet weight determined.

All plants in each container from both treatment and control sections were cut at the soil surface and their total fresh and dry weight were determined. Fresh weight was used to estimate total amount of plant material consumed as a percent of plants in the unstocked control sections. Initial (pre-stocking) control values were substracted from final values to determine net plant growth during the experiment. Treatment values were then corrected using this information. Controls were averaged for both canals having static and flowing water in calculating the percent of control fresh weight biomass for the two systems, respectively. Dry weight was determined by drying plants in an oven for 24 hours at 100 C and was used in calculating gross energy, feed efficiency, and protein efficiency ratio. Feed efficiency was calculated as: fish weight gain/dry weight feed consumed and protein efficiency ratio was calculated as: fish wet weight gain/dry weight protein consumed (Robinson and Wilson, 1985). Proximate analysis was done by AOAC method (Jones, 1984), and acid detergent fiber by a method described by Van Soest and Wine (1967). Proximate analysis variables measured were: kjeldahl nitrogen, fat, and ash. Because of the large amount of sediment in the samples, filtering for the fiber measurement was impossible and fiber content was not measured. Gross energy was measured with a Gallenkampf bomb calorimeter. Gross energy consumed was calculated by multiplying the dry weight of a plant species consumed by the gross energy of the dried plant material.

Statistical analysis of percent of control fresh weight comparisons was done with arcsine transformed data using Duncan's multiple range test. Statistical comparisons of preference based on gross energy were done using ANOVA. All statistical tests were done at $P \leq 0.05$ significance level.

## RESULTS AND DISCUSSION

Comparison of plant fresh weight consumed in flowing water showed that feeding preference in the winter trial was: elodea = curlyleaf pondweed > Eurasian watermilfoil in canals having static water ($P \leq 0.05$). In flowing water during winter, plant preference was: curlyleaf pondweed < Eurasian watermilfoil (Figure 2). Biomass of elodea increased in the presence of fish (Table 1). This higher elodea biomass in the presence of fish was also indicated when percent of control fresh weight was used to compare preferences (Figure 2). Based on energy consumption, ranking in static water was: elodea > Eurasian watermilfoil = curlyleaf pondweed ($P \leq 0.05$); in flowing water, curlyleaf pondweed had the only measureable amount of gross energy consumed (Table 1). Eight times more energy was consumed in the canals with static water compared with the flowing water during the winter trial. A factor that may have influenced amount consumed was the differences in experimental interval for each season.

Based on fresh weight percent of control, preferences were similar in summer and winter under static conditions. However, the fish consumed less fresh weight than the

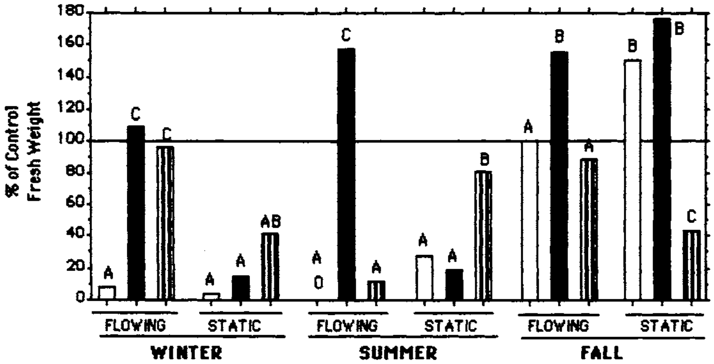


Figure 2. Comparison of triploid grass carp preference and consumption rate of three plant species using plant fresh weight percent of control as the variable of comparison. Fresh weight percent of control was calculated by dividing the mean of control fresh weight for plants in either flowing or static systems into the respective treatment fresh weight for each plant species and multiplying by 100. If a bar is replaced by a 0, all plants were consumed. Each bar represents the mean of 10 values. Letters above bars—within experiment comparisons are based on Duncan's Multiple Range Test done on arcsine transformed data ($P \leq 0.05$). Bars with similar letters within test groups are not significantly different.

winter trial. In flowing water, plant preference was similar for Eurasian watermilfoil and curlyleaf pondweed. Curlyleaf pondweed was completely consumed in the summer flowing conditions (Figure 2).

Preference determined by energy consumption in summer was: elodea > curlyleaf pondweed = Eurasian watermilfoil in static water; in flowing water preference was: Eurasian watermilfoil > curlyleaf pondweed ($P \leq 0.05$). In contrast to winter conditions, about one half as much energy was consumed in static water compared with flowing water.

In the fall trial, Eurasian watermilfoil was the only plant eaten sufficiently to produce measurable values for fresh weight or energy consumption. Other plants either had negative or zero values. Fish gained more weight in static water in the winter and summer trials; however, in the fall trial, fish in both systems displayed the same weight gain (Figure 3).

Proximate analyses indicated differences in plant composition in canals having static and flowing water for all three seasons (Table 2). In the winter trial, ash content in Eurasian watermilfoil was 34.6% and 43.5% in static and flowing water, respectively ($P \leq 0.05$). Curlyleaf pondweed, elodea, and Eurasian watermilfoil displayed significant differences among plant species between these systems with fat content of 0.5% and 2.0%, 0.4% and 2.6%, and 0.5% and 1.8%, respectively, in static and flowing water. Nitrogen content and acid detergent fiber analyses showed no significant differences among any of the plants in static and flowing water.

In the summer trial, percent ash was significantly different in curlyleaf pondweed and elodea in static versus flowing water with values of 50.1% versus 42.9% and 51.4% versus 56.1%, respectively. In curlyleaf pondweed, acid detergent fiber was significantly lower in canals having static versus flowing water, with values of 41.2% versus 49.0%, respectively. Percent ash in elodea in the fall trial was significantly lower in static and flowing water than in summer and winter. Fat and acid detergent fiber were not determined for curlyleaf pondweed in static or flowing sys-

TABLE 1. TOTAL FRESH WEIGHT AND GROSS ENERGY OF THE SPECIES OF PLANTS CONSUMED BY TRIPLOID GRASS CARP DURING THE WINTER, SUMMER, AND FALL EXPERIMENTS IN STATIC AND FLOWING WATER. VALUES CORRECTED FOR PLANT GROWTH DURING THE TRIAL BY THE FOLLOWING: TREATMENT VALUE – (INITIAL CONTROL VALUE – FINAL CONTROL VALUE). VALUES REPRESENT MEAN OF TWO REPLICATES (±SD). MJ = MEGA JOULES, FW = FRESH WEIGHT.

| PLANT TYPE | FRESH WEIGHT CONSUMED(G) | | | ENERGY CONSUMED (MJ/FW CONSUMED) | |
|---|---|---|---|---|---|
| | STATIC | FLOWING | | STATIC | FLOWING |
| | | | Winter | | |
| Curlyleaf pondweed | 477.4 ± 83.1 | 326.4 ± 15.7 | | 0.5 ± 0.0 | 0.3 ± 0.1 |
| Elodea | 950.2 ± 193.5 | –23.1 ± 8.5 | | 1.2 ± 0.4 | 0.0 |
| Eurasian watermilfoil | 304.3 ± 17.2 | 13.0 ± 1.1 | | 0.6 ± 0.1 | 0.0 |
| Total* | 1731.9 | 339.4 | | 2.3 | 0.3 |
| | | | Summer | | |
| Curlyleaf pondweed | 114.2 ± 36.9 | 110.3 ± 12.3 | | 0.1 ± 0.0 | 0.1 ± 0.0 |
| Elodea | 436.6 ± 191.1 | –119.3 ± 45.6 | | 0.4 ± 0.1 | 0.0 |
| Eurasian watermilfoil | 63.4 ± 40.2 | 440.4 ± 92.3 | | 0.1 ± 0.0 | 1.3 ± 0.2 |
| Total | 614.2 | 550.7 | | 0.6 | 1.4 |
| | | | Fall | | |
| Curlyleaf pondweed | –12.8 ± 6.2 | 0.0 | | 0.0 | 0.0 |
| Elodea | –177.6 ± 78.4 | –120.4 ± 30.5 | | 0.0 | 0.0 |
| Eurasian watermilfoil | 188.9 ± 52.9 | –302.2 ± 97.3 | | 0.3 ± 0.1 | 0.0 |
| Total | 188.9 | 0.0 | | 0.3 | 0.0 |

*Values having negative signs are treated as zero.

tems because contamination with sediment made filtering of samples impossible. Acid detergent fiber was significantly different for both elodea and Eurasian watermilfoil in static versus flowing water with values of 34.5% versus 39.0% and 41.9% versus 52.6%, respectively. All other values were not significantly different.

Nitrogen, ash, fat, and acid detergent fiber for each plant species were regressed against fresh weight consumed for each plant in static and flowing systems. Variables giving significant positive correlation were: fat and nitrogen in curlyleaf pondweed in static and flowing water, respectively, as well as fat in elodea in flowing water. A negative correlation was found with ash in elodea in static water. As the sample size was small (N = 3), statistical significance was low and so further studies are needed to verify these relationships. The studies should attempt to manipulate plant nutrient composition to determine effects on consumption.

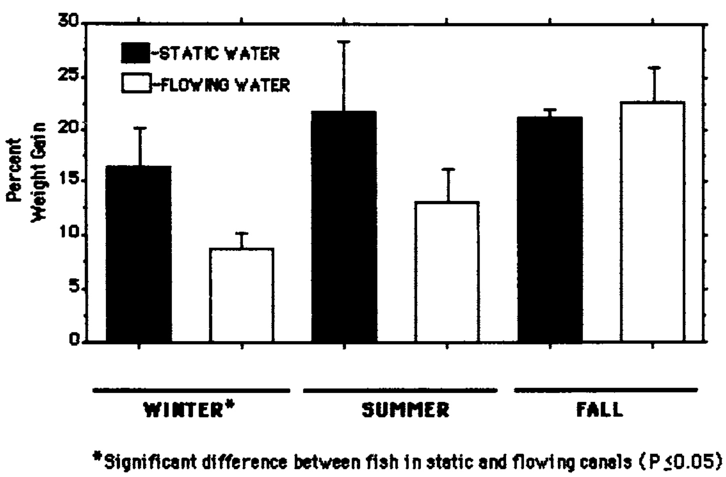


Figure 3. Percent of increase of triploid grass carp body weight in static versus flowing canal trials in winter, summer, and fall. Values were calculated by taking a mean of the initial fish body weight for static and flowing systems and dividing them by the final mean fish body weight after the end of the trial, and multiplying by 100. Data are means of six values. Vertical bars are standard deviation. Initial body weights (g) of fish were: 140±8, 100±11, and 93±9 for static; 149±22, 116±31, and 86±17 for flowing canals in winter, summer, and fall trials, respectively.

Fish in winter had significantly lower increase in body weight than in fall for both canal systems (Figure 3). Fish in winter in static water had a significantly higher percent weight gain than in flowing water.

Feed efficiency was different between the two canal systems. In winter and summer, feed efficiency in static water was 0.11 and 0.35, respectively, and in flowing water, efficiencies were 0.46 and 0.35, respectively. Protein efficiency ratios in winter and summer for canals having static water were 5.0 and 18.9, respectively, while for canals having flowing water it was 16.3 and 13.4, respectively.

Triploid grass carp consumption rate slowed at colder water temperatures. Stroganov (1963) had found that diploid grass carp cease to eat at water temperatures below 13 C. It may be possible to take advantage of the decrease in consumption rate at lower water temperatures by releasing cold water from the bottom of a storage reservoir to slow consumption of aquatic plants in canals during warm months. This method of influencing consumption rate may be useful in maintaining stocks of desirable aquatic plants used by waterfowl as a food source.

All three species appeared stimulated to grow faster by grazing in canal sections stocked with fish at various times in flowing water and in fall in static water. This effect was also observed in our previous study (Pine et al., 1989a) and is known as "over-compensation", where grazing stimulated growth in plants (Belsky, 1986).

Plants, especially elodea, also seemed to produce more biomass in flowing water compared with static water. Triploid grass carp consumed significantly higher amounts of

TABLE 2. PROXIMATE ANALYSIS AND VAN SOEST ANALYSIS OF CONTROL PLANTS FROM THE STATIC VERSUS FLOWING WATER IN WINTER, SUMMER, AND FALL. EACH VALUE REPRESENTS THE MEAN OF TWO REPLICATES (±SD) AND IS A PERCENTAGE BASED ON 100% DRY MATTER. ADF = ACID DETERGENT FIBER.

| | CURLYLEAF PONDWEED | | ELODEA | | EURASIAN WATERMILFOIL | |
|---|---|---|---|---|---|---|
| | STATIC | FLOWING | STATIC | FLOWING | STATIC | FLOWING |
| Plant Analysis | | | | | | |
| Winter | | | | | | |
| Nitrogen | 2.3 ± 0.1 | 2.7 ± 0.1 | 2.1 ± 0.1 | 2.3 ± 0.1 | 3.4 ± 0.1 | 2.9 ± 0.0 |
| Ash | 53.8 ± 2.7 | 49.8 ± 0.9 | 60.2 ± 1.8 | 58.4 ± 3.3 | 34.6 ± 3.3 | 43.5 ± 8.5 |
| Fat | 0.5 ± 0.1 | 2.0 ± 0.2 | 0.4 ± 0.4 | 2.6 ± 1.2 | 0.5 ± 0.1 | 1.8 ± 0.2 |
| ADF | 46.3 ± 1.6 | 44.2 ± 0.6 | 45.3 ± 2.4 | 46.4 ± 1.6 | 50.1 ± 0.3 | 53.8 ± 0.8 |
| Summer | | | | | | |
| Nitrogen | 2.0 ± 0.2 | 2.7 ± 0.4 | 1.8 ± 0.2 | 2.8 ± 0.5 | 2.2 ± 0.1 | 2.6 ± 0.2 |
| Ash | 50.1 ± 0.2 | 42.9 ± 0.4 | 51.4 ± 0.6 | 56.1 ± 0.5 | 30.2 ± 1.2 | 34.5 ± 1.2 |
| Fat | 1.1 ± 0.2 | 1.6 ± 0.2 | 1.4 ± 0.3 | 1.2 ± 0.2 | 0.9 ± 0.3 | 1.2 ± 0.2 |
| ADF | 41.2 ± 1.6 | 49.0 ± 1.1 | 40.2 ± 0.5 | 43.5 ± 1.3 | 44.9 ± 1.2 | 45.8 ± 1.2 |
| Fall | | | | | | |
| Nitrogen | 2.8 ± 0.2 | 2.1 ± 0.3 | 2.0 ± 0.2 | 2.1 ± 0.0 | 3.1 ± 0.2 | 2.6 ± 0.5 |
| Ash | 51.6 ± 0.3 | 51.1 ± 1.5 | 38.1 ± 1.0 | 54.1 ± 0.5 | 41.2 ± 2.4 | 38.6 ± 0.5 |
| Fat | —[1] | —[1] | 0.3 ± 0.2 | 0.9 ± 0.1 | 0.6 ± 0.1 | 1.5 ± 0.6 |
| ADF | —[1] | —[1] | 34.5 ± 0.8 | 39.0 ± 1.0 | 41.9 ± 0.7 | 52.6 ± 1.5 |

[1]Samples contaminated with sediment and could not be run.

plant fresh weight in static water than in flowing water in winter and fall trials ($P \leq 0.05$). Also, plants in static canals did not grow as long as those in flowing canals (data not shown). This difference in plant stature may have affected accessibility of plants to the fish. These results were similar to our earlier studies (Pine et al., 1989a). In these studies, we suggested that flow rate in a canal might influence the physical presentation of a plant and thus effect consumption rate by triploid grass carp. High flow rates might pull partially emerged plants under water thus making them more available to fish. Thus, by increasing flow rates within canals, consumption of certain aquatic plants may be increased.

Levels of plant control in the present study were best in summer due to higher temperatures (Figure 1), which suggests that the triploid grass carp should be introduced in spring in order to match fish consumption with increases in plant production in canals. A spring stocking would also work well with the normal time for re-watering canals in northern California, and in many other western states.

The smaller fish used in this study did not show the high levels of control exhibited by the larger fish used in our previous study. This points to the need of adequate grow-out facilities to allow for sufficient size increase of fish before stocking. Triploid grass carp weighing less than about 250 g if stocked in static or flowing water might increase problems associated with aquatic plant infestations due to plants "over-compensating" in response to grazing. In our study, no reduction of elodea by these small fish was observed at any of the three seasons stocked in canals with flowing water.

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