North American Journal of Fisheries Management 13:757–765, 1993

Effect of Triploid Grass Carp on the Aquatic Macrophyte Community of Devils Lake, Oregon

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Abstract.—Two years after stocking 274-hectare Devils Lake, Oregon, with 27,090 triploid grass carp *Ctenopharyngodon idella* (180 fish/vegetated hectare, 6.1 fish/tonne wet vegetation), the total volume of vegetation declined by 30%, whereas the total vegetation biomass increased, primarily from the expansion of short, compact communities of Brazilian waterweed *Egeria densa*. Comparison of the open lake with areas protected by net barriers, and the results of grass carp 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 slow the invasion of *E. densa* and to help maintain species diversity in the plant community. Feeding experiments suggested that food preference was related to grass carp size, which should be considered when evaluating control of target plant species. Grass carp can provide economical and effective control of plants in cool northern waters, although stocking rates will have to be higher than those used in warm waters of the southern United States.

Devils Lake is one of the most popular recreation sites on the central Oregon coast and an important habitat for a variety of fish and wildlife species (Johnson et al. 1985). For many years, the lake supported large populations of aquatic macrophytes that interfered with boating, water skiing, and fishing (McHugh 1972, 1979; Liao and Grant 1983; Johnson et al. 1985). To control these macrophytes, the lake was stocked with triploid grass carp *Ctenopharyngodon idella* in September 1986 and again in March 1987. This stocking represented the first legal release of grass carp in the Pacific Northwest region of the United States.

Few studies have investigated the effect of grass carp on large northern lakes and reservoirs. Grass carp stocked at 7.7 fish (4.5 kg) per tonne of vegetation eradicated almost all aquatic plants in 94.5-hectare Lake Dgal Wielki, Poland (Krzywosz et al. 1980). Aquatic plant biomass declined from 2,438 g/m^2 to 211 g/m^2 in 3 years following the release of grass carp in a 29-hectare lake in Iowa (Mitzner 1978). Most treatments in northern waters have been applied in small ponds and canals (Mugridge et al. 1982; Wiley and Gorden 1984a, 1984b; Fowler 1985; Swanson 1986; Woltmann and Goetke 1989). The treatment of Devils Lake with triploid grass carp provided a unique opportunity to study the effect of the fish in a large northern body of water.

The objectives of our study were to document the response of the plant community in Devils Lake to grass carp and to ascertain whether the control of macrophytes with grass carp is economically feasible in large, northern water bodies.

Study Site

Devils Lake (44.56°N, 124.00°W) is a 274-hectare, polymictic lake in Lincoln County, Oregon. The lake has an average depth of 3 m and a maximum depth of 6.7 m (Johnson et al. 1985). It is about 4.8 km long from north to south and averages about 0.6 km in width. Two small streams, Thompson and Rock creeks, feed into the lake. The southern portion of the lake drains into the

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Pacific Ocean by the 300-m long D River. The lake is influenced by the Pacific maritime climate and rarely freezes. Surface water temperature in the winter of 1986 dropped to a low of 7°C, and daytime monthly surface temperature averaged between 17 and 21°C from May through September.

In May 1986 plant community biomass (wet weight) was dominated by Brazilian waterweed *Egeria densa* (33%), Eurasian watermilfoil *Myriophyllum spicatum* (19%), and coontail *Ceratophyllum demersum* (23%). Other submergent species included flat-stemmed pondweed *Potamogeton zosteriformis* (3%), Canadian waterweed *Elodea canadensis* (6%), and wild celery *Vallisneria americana* (1%). The remaining 15% of plant community biomass consisted of filamentous algae, detritus, and miscellaneous leaf litter. Large plant mats, consisting of a mixture of the dominant plant species, were present in 1986, primarily in the southern end of the lake.

Methods

Stocking rates.—Ten thousand triploid grass carp were stocked in September 1986 (mean weight approximately 270 g), and 17,090 fish (mean weight 215 g) in March 1987. Based on mean wet plant biomass, this stocking represented 6.1 fish (1.4 kg) per tonne of vegetation (180 fish/vegetated hectare). Stocking rates were based on an average of rates that studies in Europe and Colorado (Fowler 1985; Swanson 1986; Bonar et al. 1987) indicated controlled, but did not eradicate, all plants. A fish screen was installed at the mouth of the D River to prevent the grass carp from leaving the lake.

Monitoring the plant community.—We determined the biomass (g/m^2, wet weight) and volume (m^3) of the Devils Lake plant community before stocking (1986) and for 3 years after stocking (1987–1989). We also monitored the plant biomass from 1987 to 1989 in four 58-m^2 exclosures (reference areas) designed to exclude grass carp. Oblique photography from fixed-wing aircraft and shore observations were used to qualitatively assess changes in plant surface coverage.

Volume of submergent plant beds was estimated by hydroacoustical procedures described by Thomas et al. (1990). We used either a Simrad EY-M scientific echosounder or a Sitex HE-203 commercial echosounder to survey vegetation along 14 transects in July 1986–1989. The vertical cross-sectional area occupied by plants on each echogram was calculated by subtracting the open-water area from the area of the entire water column. Vertical cross-sectional area was calibrated to square meters by comparing the transect length, measured from a map of the lake, with the scale of the echogram. The cross-sectional area occupied by aquatic plants on each transect was used to calculate the average height of the aquatic plants; these averages were then used to calculate the volume of water occupied by aquatic plants in the lake through simple multiplication.

Plant biomass was sampled directly in May, July, and September during the 1986–1989 growing seasons. In 1988, additional sampling was conducted in the early spring to provide information on plant biomass after winter senescence. Macrophytes were collected by scuba divers using a 0.25-m^2 quadrat sampler patterned after Purkerson and Davis (1975). Sampling sites were chosen on the basis of simple random sampling from a numbered grid superimposed over a map of the lake. At each sampling site, the sampler was lowered to the lake bottom and all plant material (including roots) was removed from the quadrat and transferred to a mesh onion bag attached to the side of the sampler. Samples were stored in airtight plastic bags at 6°C until processed. Samples were rinsed, sorted to species, spun in a washing machine for 1 min (Wiley and Gorden 1984b), and then weighed on a spring balance to the nearest gram (spun wet weight). Ninety samples were collected on each sampling date to estimate mean plant biomass within 15% of the true mean, an accepted amount of error for measuring aquatic macrophyte biomass (Nichols 1984).

Sites for the four 58-m^2 exclosures were also selected at random. Four 6-m poles were driven into the lake bottom at the corners of the site, and the area was cordoned off with 2.5-cm stretch mesh net, elevated 1 m above the water surface to prevent grass carp from jumping into the exclosure. The bottom of the net was weighted to the sediment with 1.3-cm-diameter anchor chain, and floats were attached at the top of the net to prevent it from submerging. We checked exclosures every sampling period for damage and entry of grass carp. Three plant biomass samples were collected randomly from each exclosure each time the lake was sampled.

A two-factor extension of the nonparametric Kruskal–Wallis procedure (Zar 1984) was used to test for annual and seasonal changes in macrophyte biomass. A nonparametric multiple comparison procedure for unequal sample sizes (Dunn 1964; Zar 1984) was used to determine where significant differences occurred.

Two-tailed t-tests were used to determine if differences between treatment and exclosure area plant biomass in 1987 were equal to differences in 1988 and 1989 (Stewart-Oaten et al. 1986). If the differences in plant biomass between the two areas changed over time, one-tailed tests were used to test if there was significant change in one direction. Shannon's index of diversity (Zar 1984) was calculated each sampling period for the plant community in the open lake and in the exclosures. Regression was used to compare changes in the index over time for the lake versus the exclosures, and to evaluate the effect of grass carp on plant species diversity. A significance level $\alpha = 0.05$ was used for all tests.

Feeding preference experiments.—Experiments were conducted in six 4,270-L recirculating-water tanks to relate feeding preferences of grass carp to observed shifts in the relative abundance of plant species in the lake. Temperatures in the tanks during the experiment ranged from 18 to 23°C. Each of three tanks was stocked with 11–16 small grass carp (mean ± 95% confidence intervals: 269 ± 18 g; 264 ± 18 mm total length), and each of three other tanks was stocked with four large fish (927 ± 148 g; 414 ± 22 mm) to determine whether fish size affected plant preference. Three of the plants tested were predominant species in Devils Lake: *E. densa*, *M. spicatum*, and *C. demersum*. The other plant tested, *V. americana*, was in several of the lake's shallow coves, where grass carp were observed grazing.

The experiment was conducted for 3 d, during which the plants were offered to the fish six times (two 3-h periods each day). At the start of the experiment, 150 g (spun wet weight) of each of the four plant species were tied to weighed trays in a manner that closely resembled their natural growth form. The trays were randomly placed on the bottom of each tank. Remaining plants were removed from the tanks after each 3-h period, spun, and weighed to the nearest gram. At the end of each day, remaining plants were stored overnight in wading pools adjacent to the tanks. Plant species eaten by the grass carp were not replaced under the assumption that the fish would remove the most preferred species first and switch to others when those preferred were no longer available. One-way analysis of variance was used to compare the biomass of all plants remaining at the end of each feeding period, and a Student–Newman–Keuls' test was used to separate means. Preference was evaluated by determining which plant species disappeared first.

Results

Plant Community Changes

Aerial photography and observations from shore revealed that macrophyte surface coverage declined after the lake was stocked with grass carp. Particularly conspicuous after stocking was the absence of a large surface mat of mixed macrophyte species that had covered the southern third of the lake during the 1986 growing season.

The volume of aquatic plants did not change from 1986 to 1987 but declined by 30% in 1988 and then remained constant in 1989 (Figure 1). Peak plant volume changed primarily because of a reduction in the average height of the aquatic plants in the water column.

In contrast, total macrophyte biomass in the open lake increased after stocking with grass carp (Figure 1). In the exclosures, total biomass increased from 1987 to 1989. Annual changes in the biomass of several dominant plant species were also significant. In both the open lake and the exclosures (Figure 2), *E. densa* increased and became the dominant macrophyte species, whereas *M. spicatum* biomass declined. Annual biomass of *C. demersum* declined in the exclosures but did not change in the open lake.

Two less abundant species, *Elodea canadensis* and *P. zosteriformis*, and miscellaneous algae and leaf litter declined in the lake and the exclosures. The biomass of *V. americana* did not change in the lake or in the exclosures.

Grass Carp Impact

The magnitude of change in the plant biomass of several species was not the same in the exclosures and the lake. The increase in *E. densa*, the dominant macrophyte in Devils Lake, was greater in the exclosures than in the lake at large (Figure 2). *Myriophyllum spicatum* almost disappeared from the exclosures, whereas it declined but was still common in the lake (Figure 2). The biomass of *C. demersum* in the exclosures declined but remained at a constant level in the lake (Figure 2). Changes in total biomass between the exclosures and the lake were not significantly different. Changes in less common species such as *Elodea canadensis*, *P. zosteriformis*, and *V. americana* and in miscellaneous algae and leaf litter were not different between the exclosures and the lake.

Diversity decreased in the lake and the exclosures, but the decline in the exclosures was greater (Figure 3). Species diversity leveled off in the open lake in 1989, whereas in the exclosures it continued to decline.

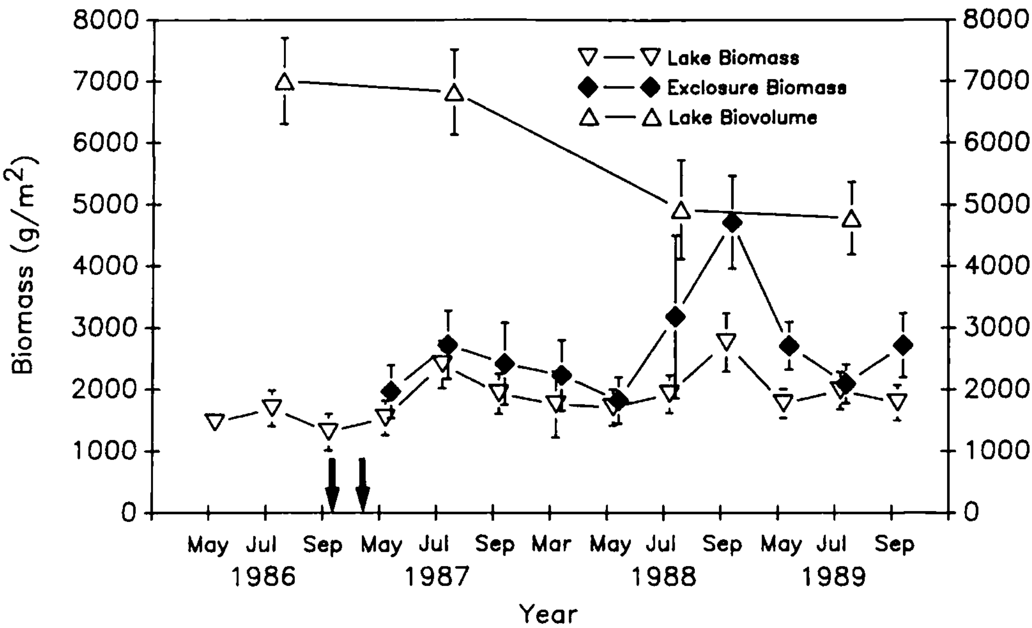

FIGURE 1.—Total aquatic plant biomass (spun wet weight) and plant biovolume, with associated 95% confidence intervals, in Devils Lake, 1986–1989. Arrows indicate time of grass carp stockings.

Feeding Experiments

The feeding experiments showed that *E. densa* was a preferred food of large grass carp but was not eaten readily by small grass carp. Ranking plants in the middle of the feeding experiment, when separation of the means was the greatest, resulted in the following hierarchy of preferences.

Small grass carp:
V. americana(x) > *M. spicatum*(y)
> *C. demersum*(yz) > *E. densa*(z).
Large grass carp:
E. densa(x) > *V. americana*(xy)
> *M. spicatum*(xy) > *C. demersum*(y).

Plants were not removed at significantly different rates if their names are followed by a common parenthetic letter.

Discussion

Following stocking with grass carp, aquatic plant surface cover and volume declined whereas total biomass increased. This change may have been due to the expansion of *E. densa* into areas that contained other macrophytes, and its subsequent cropping by grass carp. This plant formed denser beds than other Devils Lake macrophytes, which either declined in biomass or did not change significantly.

The feeding experiment, historical records of *E. densa* expansion in Devils Lake, and a comparison of plant communities between exclosures and the open lake suggested that the shift to an increased dominance of *E. densa* was not due to grass carp grazing on other more preferred plants, except during the first few months after the grass carp were released. Results from our feeding preference experiment and Bowers et al. (1987) showed that, of the Devils Lake macrophytes, *E. densa* was the least preferred by small (200–300 g) grass carp. Because released fish were within that size range, they may have initially removed more preferred plants, such as *M. spicatum* and *C. demersum*, and thereby facilitated an expansion of *E. densa*. Because less common plants, such as *Elodea canadensis* and *P. zosteriformis*, were rarely found in the lake in the latter years of the study and were found to be highly preferred in previous feeding experiments (Bowers et al. 1987), they were probably also removed by the small grass carp. However, the statistical analysis was not able to detect any change in these species. Shifts in the plant community to less preferred species are well documented in grass carp treatments (Fowler and Robson 1978; Leslie et al. 1987). By grazing on the most preferred species, grass carp give the less preferred plants a competitive advantage to col-

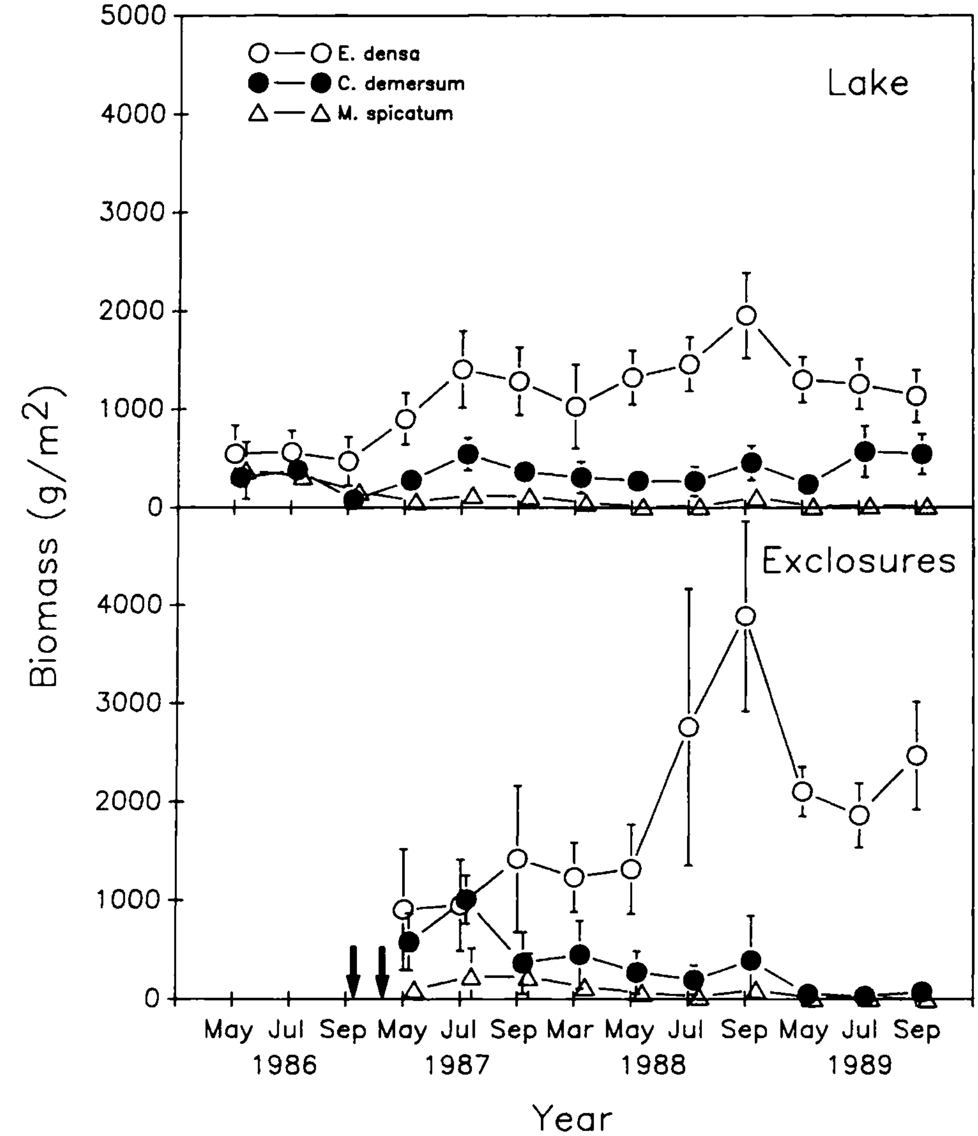

FIGURE 2.—Mean biomass (spun wet weight) and 95% confidence intervals of the dominant aquatic macrophytes in the open lake and in exclosures in Devils Lake, 1986–1989. Arrows indicate time of grass carp stockings.

onize areas previously occupied by more favored species.

The feeding experiments showed that as fish grew (up to 927 g) their preference for *E. densa* shifted from least preferred to most preferred. Because grass carp reached 927 g in the summer of 1987, they may have begun to graze on *E. densa* then and subsequently limited some of the plant's expansion. Other researchers have reported that large fish can consume large, fibrous, or bushy plants that are difficult for small fish to consume (Hickling 1966; Prowse 1971; Edwards 1974).

Historical accounts show that *E. densa* communities were expanding in Devils Lake before the lake was stocked with grass carp. The plant was first found in the lake in 1967 (Stewart 1985) and increased in abundance throughout the 1970s (McHugh 1972, 1979; Meyerhoff 1977). *Egeria densa* was not mentioned in the first quantitative survey of the lake's plants in 1981 (Liao and Grant 1983), but it was probably misidentified, given the results of previous studies (Meyerhoff 1977; McHugh 1979). Possibly, it was misclassified as *Elodea canadensis*, a common mistake according

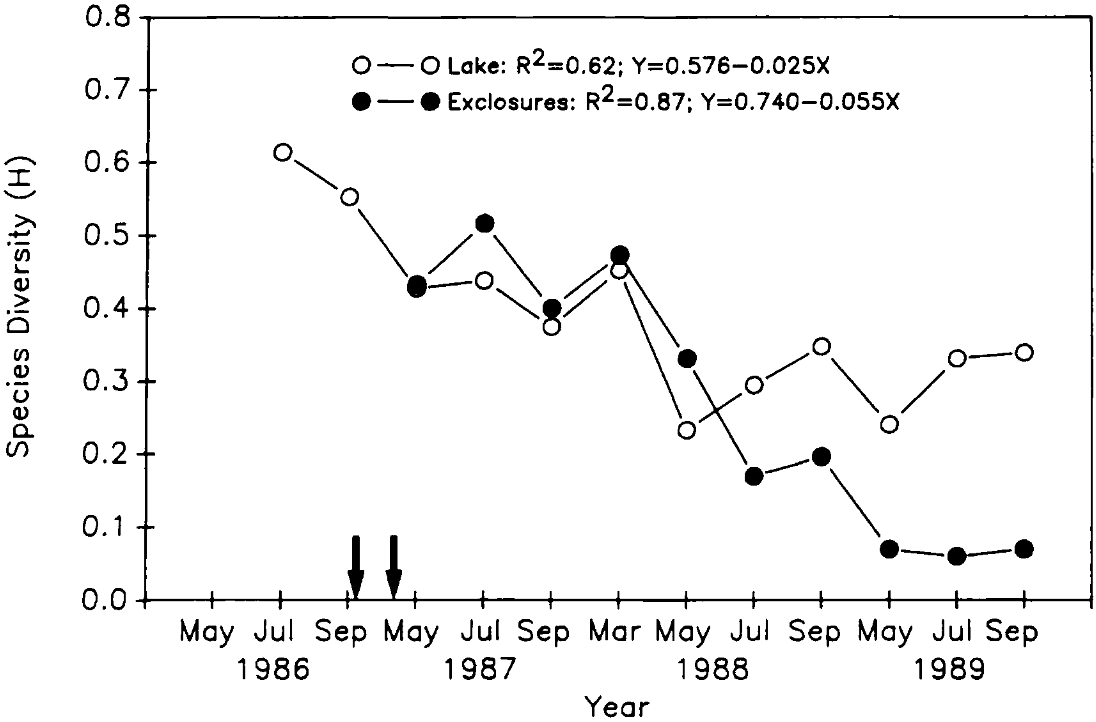

FIGURE 3.—Aquatic macrophyte diversity (*H*) in Devils Lake, 1986–1989. Arrows indicate time of grass carp stockings.

to Cook and Urmi-Koenig (1984). Even if misidentification occurred, only 14–16% of the mean submerged plant biomass from the 1981 surveys could have been either *Egeria* or *Elodea*, in contrast to our 1986 surveys, when *Egeria* was 39% of the biomass.

A comparison of the biomass of *E. densa* in the open lake and in the exclosures indicated that the natural expansion of *E. densa* continued after grass carp were stocked. However, after 1987, the increase in *E. densa* biomass was greater in the exclosures than in the lake. Given the greater preference for *E. densa* by adult grass carp, historical data, and the exclosure–lake comparisons, grazing adult grass carp may have slowed the expansion of this plant in the lake. By slowing the expansion of *E. densa*, the grass carp may have helped to maintain diversity in the plant community (Figure 3). Because our data suggest that grass carp were not causing the increase in the spread of *E. densa*, environmental factors must have been responsible. Rapid natural changes in the biomass of *E. densa* are not unusual and have been documented in several studies (Sculthorpe 1967; Getsinger and Dillon 1984; Welch and Kelly 1990).

Differences in total biomass between the exclosures and the lake were not statistically significant, and differences in exclosure versus lake biovolume were not measured. However, there still was considerable evidence that grass carp helped increase the amount of open water area. Following the release of grass carp, the large mixed-species mats of plants that covered the southern end of Devils Lake disappeared and fishing, boating, and waterskiing increased (Isham 1988). Two of the lake's predominant species, *E. densa* and *M. spicatum*, usually form canopies (Aiken et al. 1979; Getsinger and Dillon 1984; Coffey and Clayton 1987); however, surface grazing by grass carp may have prevented this formation in Devils Lake, as was indicated by reduced plant volume. Grass carp prevented the formation of mats in Lake Conroe, Texas, by cropping surface growth of *Hydrilla verticillata* and other plant species (Martyn et al. 1986). Our observations from boats and with scuba indicated that plants grew closer to the surface in the control exclosure sites, whereas plants in the open lake seemed to be cropped. Grass carp were also seen feeding in shallow water near the surface in beds of *E. densa*.

The growth of grass carp in Devils Lake indicated that they removed large quantities of aquatic plants. Grass carp of about 270 g at release weighed an average of 1,250 g in August and September of 1987 and 3,250 g during the same months in 1988 (Thomas et al. 1989). Grass carp measurements were not available for 1989. These data indicate that grass carp grew an average of 980 g in 1987 and 2,000 g in 1988.

In a bioenergetics study of triploid grass carp, Wiley and Wike (1986) found that an average 12% of the total energy consumed by the fish was allocated to growth. Using data in Wiley and Wike (1986), we estimated that the energy content of plant tissue in Devils Lake was 1,647 J/g and that of grass carp tissue was 6,715 J/g in 1987 and 7,791 J/g in 1988. From these estimates of energy content and energy allocated to growth we predicted that each grass carp would have had to consume an average of 33.13 kg of plant biomass in 1987 and 78.84 kg of plant biomass in 1988 to achieve the recorded size. Assuming a survival rate of 99.67% (Miller and Decell 1984), grass carp could have removed 879,210 kg of plants in 1987 and 2,011,130 kg in 1988.

The calculated rate of feeding (320 g/m^2 in 1987; 733 g/m^2 in 1988) approximates the difference in maximum total biomass between the lake and exclosures in 1987 (312 g/m^2), but was less than the difference present in 1988 (1,952 g/m^2). Although feeding rates of grass carp from growth information did not explain the entire difference in plant production between exclosures and the open lake, feeding rates demonstrate that the grass carp were removing large amounts of plant material.

The Devils Lake grass carp treatment provided the first opportunity to evaluate stocking rates for control of plants in the Pacific Northwest. Presently, recommended stocking rates in the United States range from 10 to 120 fish/vegetated hectare (Bonar 1990). The rate used in Devils Lake (180 fish/vegetated acre) is much higher than rates used in most other regions of the United States for control (not eradication) of aquatic plants, and are closer to those that have been successful in Europe (Table 1). Even though this rate was high, the volume of aquatic plants was reduced by only 30%. Stocking rates in cool northern climates might have to be even higher than 180 fish/vegetated hectare to achieve complete success. Subsequent to the Devils Lake stocking, several lakes in Washington State were stocked with grass carp (Table 1) and also demonstrated the need for high stocking rates in cool climates (Bonar 1990).

Even though the treatment of Devils Lake demonstrates that high stocking rates are required for plant control in northern temperate waters in the United States, the grass carp may still be an economical means of control of aquatic macrophytes. Liao and Grant (1983) estimated that the cost of controlling macrophytes in Devils Lake by dredging would be US$11,000,000 (one time cost) and by harvesting $117,500 (annual cost). The grass carp stocked in Devils Lake cost $102,000. Assuming the effective life of the grass carp is roughly 10 years (Swanson 1986), the annual cost would be $10,200, considerably less than dredging or harvesting. Even if stocking rates were increased slightly, grass carp would still be less costly than the other techniques.

Grass carp are a long-term control agent, and more pronounced changes in the plant community in subsequent years may occur. However, the changes in the plant community 3 years post-stocking were modest, despite the high stocking rate. Selective feeding by grass carp may over time encourage the expansion of *C. demersum*, a plant that may be suppressed by *E. densa*. By selectively grazing on *E. densa*, the grass carp may have prevented or slowed a natural decrease in plant species diversity that was occurring in Devils Lake. This result contradicts results from study sites in Washington where grazing grass carp decreased plant species diversity (Bonar 1990). These differences in seemingly similar geographic regions suggest that knowledge of the grass carp's plant preferences is important if one is to accurately predict changes in a plant community due to grass carp grazing.

TABLE 1.—Grass carp stocking rates used for aquatic plant control in various regions of the United States and in the United Kingdom.

Site	Stocking rate (fish/vegetated hectare)	Source
Devils Lake, Oregon	180	Present study
Lake Conway, Florida	15–25	Miller (1982)
Missouri (recommended)	25–50	Belusz (1986)
Town Creek embayment, Gunthersville Reservoir, Alabama	~54	Webb et al. (1987)
Lake Conroe, Texas	74	Martyn et al. (1986)
Illinois (recommended for preferred and intermediately preferred plant species)	40–119	Wiley et al. (1987)
Washington	113–550	Bonar (1990)
United Kingdom (recommended)	1,000–2,000	Seagrave (1988)

Acknowledgments

We thank Sally Marquis of the U.S. Environmental Protection Agency, Krystyna Wolnialowski of the Oregon Department of Environmental Quality, and Harold Frederick, Del Isham, Al Rice, and others from the Devils Lake Water Improvement District for their help and guidance throughout this research. Christian Grue, Robert Stickney, Gordon Swartzman, and Eugene Welch at the University of Washington provided constructive comments on this manuscript and advice during our project. Many students assisted with collection of samples and data analysis, especially Karen Bowers, Dave Beauchamp, Jon Frodge, Hanh Nguyen, Huey Nguyen, Tho Nguyen, Hong That Ton, Thurman Wheeler, and Sharon Vecht. The Devils Lake Water Improvement District and the U.S. Environmental Protection Agency funded this research.

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