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An Assessment of Triploid Grass Carp Stocking Rates in Small Warmwater Impoundments

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Abstract.—Various stocking rates for triploid grass carp *Ctenopharyngodon idella* were evaluated to identify a threshold rate at which macrophytes were suppressed but not eliminated. Eight southwest Florida urban impoundments (0.8–45.3 ha) containing macrophyte species preferred by grass carp were monitored to document changes in macrophyte biomass, chlorophyll *a*, and total phosphorus after stocking. Stocking rates were determined from empirical estimates of the macrophyte biomass of the entire lake and ranged from 3 to 10 grass carp/metric ton of vegetation (wet weight). Stocking rates of 4–8.4 grass carp/metric ton resulted in gradual reductions to zero macrophyte biomass in 8–17 months. Macrophyte biomass at two sites stocked with 3 grass carp/metric ton decreased significantly but did not decline to zero during the 4 or 5 years they were monitored after stocking. Annual mean chlorophyll-*a* and total phosphorus concentrations remained stable at sites where macrophytes were suppressed but varied greatly at some sites where they were eliminated. Shifts in macrophyte species composition did occur at sites where macrophytes were suppressed or began to regrow after a period of zero macrophyte biomass. However, the number of species present and composing at least 4% by weight of the total macrophyte biomass did not decline.

Since the early 1970s grass carp *Ctenopharyngodon idella* have been stocked in lakes in the United States to control aquatic macrophytes. However, this practice has sometimes been questioned, often when overstocking and the rapid elimination of submersed macrophytes occurred. The predictability of attaining specific plant management scenarios (i.e., maintenance control or suppression) with grass carp is often low, frequently because there is a lack of quantitative information on the stocking rates needed to achieve the management objective. Important information on macrophyte abundance, seasonality, and nutrient dynamics is often difficult to obtain and is frequently overlooked by resource managers who contemplate the use of grass carp. Managing aquatic vegetation with grass carp has generally resulted in one of two outcomes: complete macrophyte removal or inadequate control (Lembi et al. 1978; Shireman and Maceina 1981; Leslie et al. 1983; Martyn et al. 1986; Leslie et al. 1987; Kirk 1992). Because neither outcome is usually the management objective, a closer evaluation is needed of how these fish are used, especially in multiuse systems where macrophyte elimination is undesirable. The use of grass carp for suppression rather than elimination of submersed macrophytes is a concept that is receiving more attention. Maintaining intermediate levels of submersed macrophytes is generally more desirable than eradication because many forms of aquatic biota depend on some level of macrophyte abundance (e.g., phytophilic fish and invertebrates, waterfowl). Maintenance of intermediate macrophyte levels has rarely been achieved because adequate stocking rates for macrophyte suppression have not been developed and because it is labor and cost intensive to calculate stocking rates based on an estimate of macrophyte biomass.

Stocking rates are usually estimated from the surface area of macrophyte coverage and not from multidimensional estimates of macrophyte abundance, such as whole-lake biomass or volume of lake infested. The use of grass carp stocking rates estimated from macrophyte area coverage reduces the predictability of the outcome because this approach does not account for plant biomass, which can vary with water depth and the plant species in question (Killgore and Payne 1984). Few authors have reported stocking rates determined from actual estimates of whole-lake macrophyte biomass. Osborne et al. (1982) reported that 14–20 grass carp/metric ton (wet weight) of plants would always eliminate hydrilla *Hydrilla verticillata* and, at 20 fish/metric ton, in as little as 4 months. Bonar (1990) estimated grass carp stocking rates of 4.7–15.1 fish/metric ton in lakes in the Pacific Northwest, but because climate differences affect the rate of plant consumption by grass carp, his results are not applicable to lakes in the southeastern U.S., where similar results can be achieved with lower stocking rates.

References herein to studies involving grass carp have not been segregated according to the

TABLE 1.—Physical characteristics of eight small impoundments in South Florida (A–H) used for grass carp stocking rate assessment, together with data on macrophyte sampling and stocking rate.

Site	Surface area (ha)	Approximate lake volume (1,000 m^3)	Number of plant biomass samples[a]	Sampling interval (months)	Dominant plant genus	Stocking rate[b]	Month and year stocked	Months to zero macrophyte biomass
A	0.8	12.2	20	2	*Najas*	10.0	Dec 1985	4
B	1.4	34.1	25	2	*Hydrilla*	8.4	Oct 1985	13
C	2.5	53.5	25	2	*Chara, Ruppia*	8.0	Jul 1986	12
D	5.2	63.4	30	2	*Najas*	5.6	Nov 1985	8
E	1.0	18.3	20	2	*Chara*	4.0	Nov 1988	10
F	22.4	273.1	25	2[c]	*Najas*	4.0	Oct 1985	17
G	45.3	579.9	100	2	*Chara, Utricularia*	3.0	Jul 1986	[d]
H	19.5	237.7	60	3	*Najas, Utricularia*	3.0	Jan 1989	[d]

[a] Numbers of samples per sampling interval (before and after stocking).

[b] Number of triploid grass carp (254–305 mm total length) per metric ton of vegetation.

[c] Sampling interval was 2 months between 1985 and 1989 and 4 months after 1989.

[d] Macrophytes were not completely suppressed during the study.

ploidy of the fish (i.e., diploid versus triploid). Wiley et al. (1986) found that "the triploid grass carp was an extremely close energetic match to the normal diploid grass carp," but in the laboratory triploid grass carp exhibited a slight reduction (10%) in ingestion rate. This reduction has yet to be documented in a comparative field study.

We examined the effects of various stocking rates on macrophyte decline. Our objectives were to identify a stocking rate that would result in macrophyte suppression without elimination, to describe and compare water quality changes at sites having rapid macrophyte decline versus a gradual reduction, and to describe changes in macrophyte species composition after prolonged exposure to grass carp grazing.

Methods

Eight impoundments, primarily in urban areas of Lee County, Florida (26°N latitude, 81°W longitude), were established as study sites for monitoring changes in macrophyte abundance after triploid grass carp were stocked at rates of 3–10/metric tons of vegetation (Table 1). All grass carp stocked were 25.4–30.5 cm total length. Stocking rates were determined from an estimate of macrophyte biomass, and stocking occurred within 30 d of the estimate. Macrophyte abundance was estimated by random sampling with a biomass sampler of the drop-and-cut type with a cutting area of 0.1 m^2. Macrophyte sample locations were determined by random selection of quadrats from a grid overlay of the site, in which each quadrat had a previously assigned number. Field location of a specific quadrat was done by visual approximation to landmarks and the occasional use of a range finder. Equal number of samples were used to estimate macrophyte biomass before and after stocking (Table 1). Macrophyte samples were separated by species in the laboratory, spun in a garment washer to remove excess water, and then weighed to the nearest 0.1 g. Mean plant density expressed as wet weight was used to extrapolate whole-lake macrophyte biomass.

Two water quality variables used to index lake trophic state, total phosphorus and chlorophyll *a*, were monitored for up to 5 years after triploid grass carp were stocked. Water samples were collected at each site and analyzed according to the methods outlined in APHA et al. (1980). Sites F and G (Table 1) were sampled at two stations, and results were averaged; the remaining sites were sampled at one station. The entire water column profile (sampled at 0.5-m intervals) was represented in a sample by combining subsamples taken with a Kemmerer sampler. Sampling started 1 or 2 months before stocking, and sampling frequency was the same as for macrophyte biomass determinations (Table 1).

The SPSS statistical methods (Norusis 1986) were used to calculate 95% confidence intervals for mean macrophyte biomass estimates and to statistically ($P < 0.05$) separate annual water quality means (Duncan's multiple-range test preceded by a one-way analysis of variance). Water quality data were log-transformed to gain approximate normality and homogeneity of variance before statistical analyses.

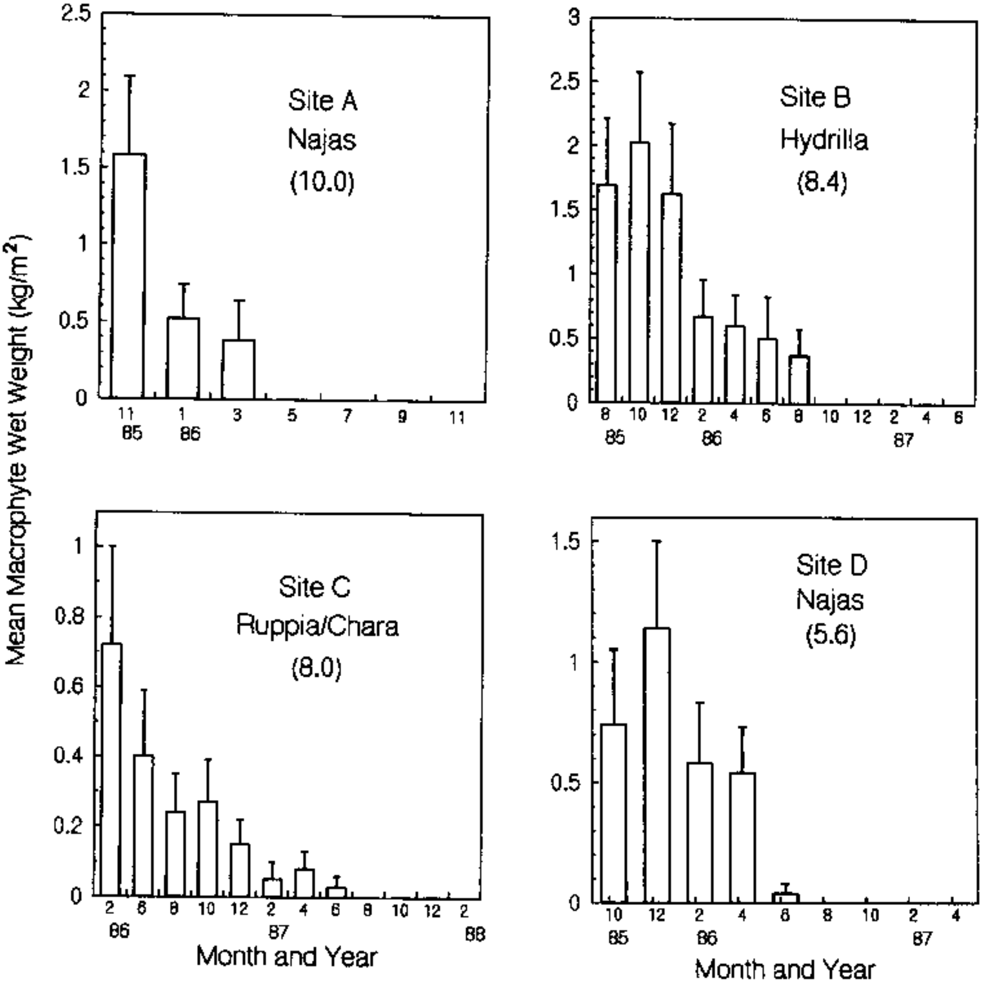

FIGURE 1.—Mean macrophyte density in impoundments stocked with 5.6–10.0 grass carp/metric ton of vegetation (wet weight) at sites A–D. Error bars show half the 95% confidence intervals. The macrophyte taxa listed were the dominant genera present when grass carp were stocked.

Results

Macrophyte biomass at four sites (A–D) stocked with triploid grass carp at relatively high rates, (5.6–10.0 fish/metric ton) declined to zero within 13 months (Figure 1). At a stocking rate of 4.0 triploid grass carp/metric ton (sites E and F), macrophyte decline to zero biomass took 10–17 months, and some macrophyte recovery occurred at site F (Figure 2). Macrophyte biomass at sites G and H (Figure 2), stocked at 3.0 triploid grass carp/metric ton, never declined to zero, but a distinct suppression was evident. Macrophyte biomass samples were not collected during the sixth year after stocking at site G (1991), but periodic visual inspections indicated that macrophytes were still present during this period. Macrophyte decline was more rapid at site G and biomass remained relatively low through the fifth year after stocking. At site H macrophyte suppression was less evident, perhaps because of grass carp mortality.

Plant species compositions at sites F, G, and H shifted following the stocking of triploid grass carp (Figure 3). The comparison at site F represents plant species composition before stocking and after macrophytes began to regrow after a period of zero biomass. Before stocking, macrophyte composition at site F was a monoculture of *Najas guadalupensis*, but *Nitella* sp. became codominant after the period of zero macrophyte biomass. The shifts in plant composition at sites G and H took place without a period of zero macrophyte bio-

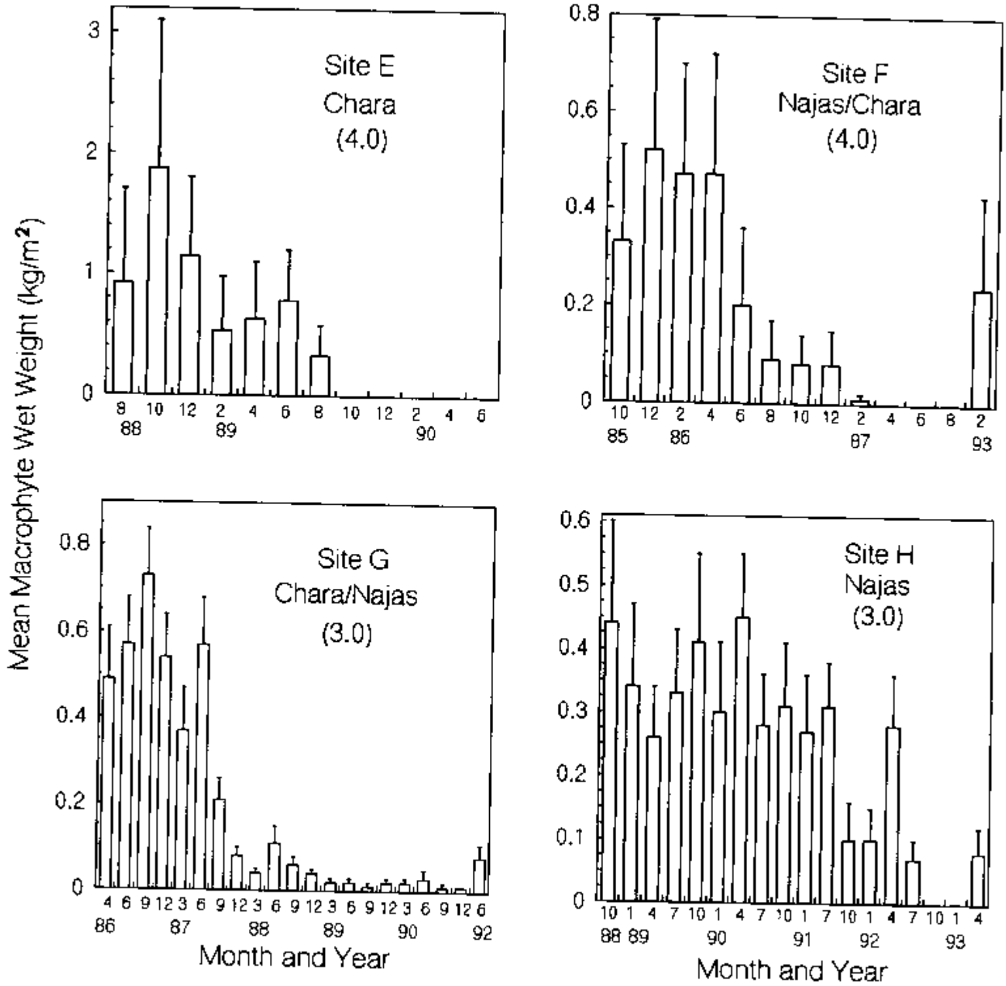

FIGURE 2.—Mean macrophyte density in impoundments stocked with 3.0–4.0 grass carp/metric ton of vegetation (wet weight) at sites E–H. Error bars show half the 95% confidence intervals. The macrophyte taxa listed were the dominant genera present when grass carp were stocked. No samples were taken during 1991 at site G and during January 1993 at site H.

mass. At site G, *Chara* sp., which was the dominant macrophyte (81% by weight) before grass carp were stocked, was almost entirely replaced by *Nitella* sp. 6 years later. Macrophytes at site H were suppressed the least and the species composition showed only minor changes 4.5 years after stocking, with *Najas* constituting at least 75% of the samples. Presumably other factors (e.g., water quality changes) may affect plant species composition over time as well. It is apparent that major shifts in plant species composition may occur (e.g., site G), but macrophyte communities were no less diverse (total species present) after a long exposure to triploid grass carp compared with conditions before stocking.

At sites G and H, where macrophytes were not eliminated, chlorophyll-*a* and total phosphorus concentrations remained relatively stable for the duration of the poststocking period (Table 2). Between-year differences in mean chlorophyll *a* and total phosphorus at sites A–F, where macrophytes were eliminated, were quite variable but few of the differences were statistically significant, possibly due to seasonal influences (Table 2).

Discussion

Variability in macrophyte decline within certain stocking rate ranges (i.e., 4.0–10.0 triploid grass carp/metric ton) was likely due to several factors. Variations between sites in target plant

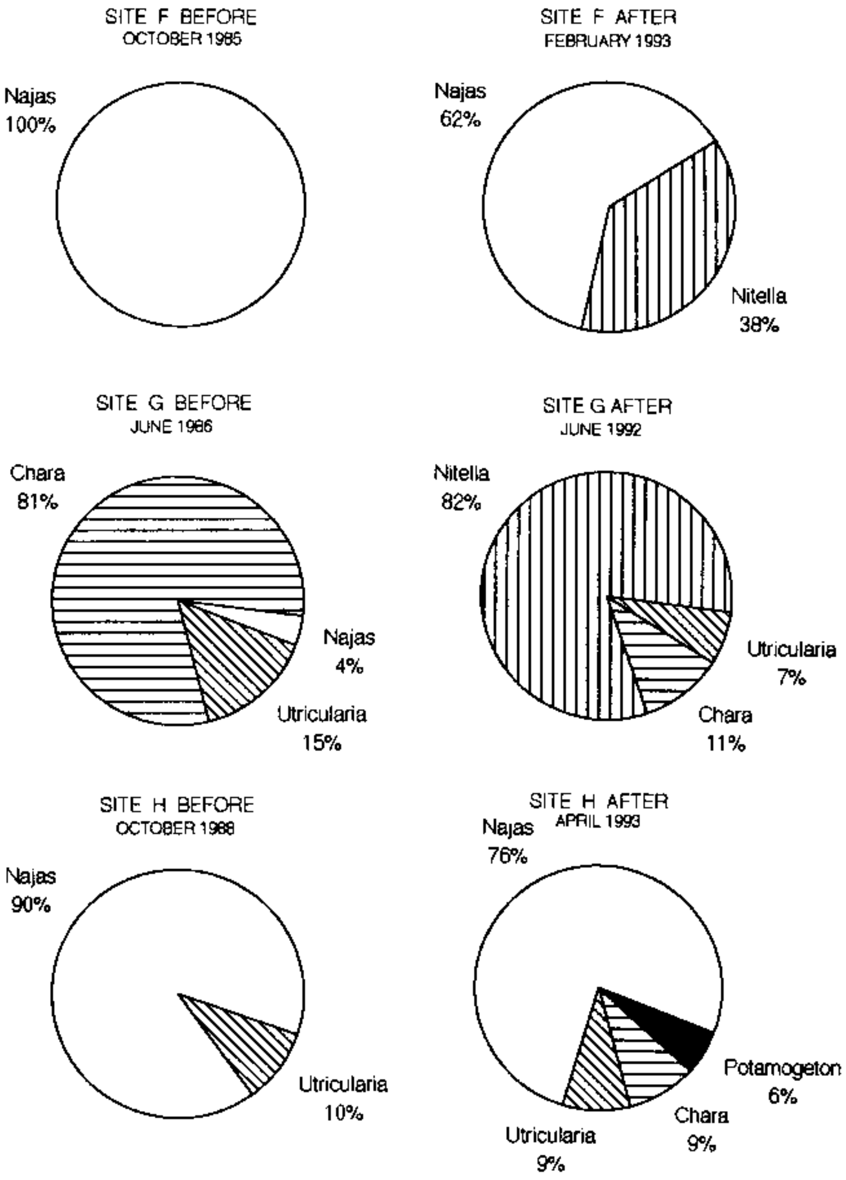

FIGURE 3.—Macrophyte species composition before and after triploid grass carp were stocked at sites F–H.

species may affect triploid grass carp feeding preference and, therefore, their rate of consumption. All dominant plant species in the test impoundments (*Chara* sp., *Hydrilla verticillata*, *Najas guadalupensis*, and *Ruppia* sp.) have been reported as plants readily consumed or preferred by grass carp (Sutton and Vandiver 1986; Wiley et al. 1986; Leslie et al. 1987), but slight differences in chemical composition of different populations of the same plant species can potentially affect preference and consequently consumption rates. According to Bonar et al. (1990) grass carp consumption was positively correlated with the concentrations of calcium and lignin and negatively correlated with the concentrations of iron and cellulose. Variability in grass carp survival may also reduce the predictability of macrophyte decline. Predation from birds and piscivorous fish may have been lower at sites where macrophyte decline was more rapid than expected (i.e., site D, Figure 1). Kirk (1992) found that survival (1 month after stocking) for relatively small triploid

TABLE 2.—Annual mean chlorophyll *a* (*Ca*, mg/m^3) and total phosphorus (TP, mg/L) for sites A–H after grass carp were stocked. Values in parentheses are SD. Means followed by the same letter in each row are not significantly different ($P > 0.05$).

Site	Variable	Years after stocking: 1	2	3	4	5	6
A	*Ca*	38.3 z (30.6)	213.1 z (126.5)				
	TP	0.095 y (0.068)	0.205 z (0.045)				
B	*Ca*	5.3 z (6.3)	6.7 z (3.9)	6.6 z (5.8)	6.4 z (4.6)		
	TP	0.012 y (0.005)	0.021 z (0.007)	0.018 yz (0.007)	0.020 z (0.008)		
C	*Ca*	8.2 z (1.1)	5.5 zy (5.9)	0.8 y (0.2)			
	TP	0.020 z (0.005)	0.008 z (0.002)	0.007 z (0.004)			
D	*Ca*	11.8 z (8.4)	52.8 z (47.8)	42.5 z (42.1)	20.0 z (16.6)		
	TP	0.050 y (0.018)	0.105 z (0.070)	0.271 z (0.147)	0.116 z (0.051)		
E	*Ca*	7.7 z (8.5)	22.3 z (8.1)	22.5 z (12.5)			
	TP	0.024 y (0.014)	0.038 z (0.008)	0.036 yz (0.009)			
F	*Ca*	2.9 z (1.1)	4.9 z (2.1)	4.3 z (1.3)	4.8 z (0.9)		4.3 z (1.4)
	TP	0.011 yz (0.004)	0.013 z (0.005)	0.008 y (0.007)	0.015 z (0.005)		0.013 z (0.005)
G	*Ca*	4.5 z (3.0)	5.6 z (2.5)	7.1 z (3.2)	6.2 z (2.7)	7.0 z (2.8)	
	TP	0.020 z (0.013)	0.015 z (0.007)	0.022 z (0.007)	0.018 z (0.007)	0.020 z (0.007)	
H	*Ca*	2.5 z (2.0)	2.4 z (0.8)	3.3 z (1.6)	7.9 z (6.1)		
	TP	0.011 z (0.002)	0.011 z (0.006)	0.014 z (0.010)	0.013 z (0.008)		

grass carp (20–28 cm total length) ranged from 57 to 72% in South Carolina farm ponds, which contributed to the variable efficacy of the use of triploid grass carp as the only method of macrophyte control. If a stocking rate of 3 triploid grass carp/metric ton is a realistic threshold for macrophyte suppression in the southeastern United States, then low survival and a relatively low stocking rate may explain the general lack of control reported by Kirk (1992), whose highest stocking rate was equivalent to only 3.6 triploid grass carp/metric ton (wet weight).

Evaluating whole-lake macrophyte biomass estimates (after stocking) should be done with a consideration for variable macrophyte distribution. This type of estimate is subject to error especially when macrophytes are unevenly distributed or during periods of relatively low overall abundance, such as in site G, December 1988–June 1992. During this period, *Nitella* sp. and *Chara* sp. were locally abundant, perhaps because triploid grass carp avoided relatively shallow or confining areas (Cassani and Maloney 1991). However, heterogeneous distribution of macrophytes may provide a preferred habitat for sport fish compared with a uniform plant distribution (Engel 1984; Killgore et al. 1987; Morrow et al. 1991).

Water quality variables, such as those compared here, are generally of limited value because it is impossible to isolate the effects of decreasing or absent macrophyte populations from other lake processes, such as the rate of allochthonous nutrient loading or watershed disturbances, without a control reference (Carpenter and Lodge 1986). Our water quality information, however, demonstrates that algal biomass does not necessarily increase when macrophytes are reduced or eliminated. The rate of macrophyte reduction and the level of nutrient loading are probably the key factors regulating shifts in primary productivity dominance from macrophytes to algae. Site A is a good example of a rapid shift, whereas sites F, G, and H are examples of a gradual macrophyte reduction that resulted in little or no overall change in algal abundance. Canfield and Hoyer (1992) found that lakes in Florida where macrophytes were eliminated by grass carp functioned like other Florida lakes and were at trophic levels expected for their aquatic ecoregions.

The basic premises of this study are that triploid grass carp are the only macrophyte controls used and that stocking rates are calculated for a single stocking. This approach is still appropriate for those situations in which other control methods are impractical or inappropriate due to economic considerations or restrictions on herbicide use. However, since this study was initiated in 1985, two other macrophyte control strategies have come to be more widely used. The first is an integrated approach, in which grass carp are stocked at a very low rate, usually after macrophytes have been reduced by chemical treatment. Sutton and Vandiver

(1986) suggested, as an optimal approach, stocking 3–8 triploid grass carp/ha in small ponds after hydrilla was reduced with a herbicide. In the second strategy, a relatively low rate is used for an initial stocking, and, after the effectiveness of control is assessed, the rate is increased if necessary (Wiley et al. 1986). This method attempts to avoid stocking too many grass carp and permits responses to potentially unknown variables, such as predation pressure and water quality changes.

Our methodology and results should provide a basis for calculating grass carp stocking rates in small warmwater impoundments that contain macrophyte species preferred by the fish and where macrophyte suppression or gradual reduction is the management goal. The predictability of achieving similar results depends on several complex variables that are often difficult to measure. Thus we suggest further research with stocking rates of 2.0–4.0 triploid grass carp/metric ton, with fish larger than 25 cm in total length.

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