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High-density grass carp stocking effects on a reservoir invasive plant and water quality

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ABSTRACT

Stocking grass carp [*Ctenopharyngodon idella* (Valenciennes)] is a commonly applied technique to control nuisance aquatic vegetation in reservoirs. Factors that influence the degree of aquatic vegetation control are fish stocking density, regional climate, abundance and species composition of the aquatic plant community, and relative grass carp feeding preferences for plant species. We evaluated high-density grass carp stocking in a southeastern U.S. reservoir for control of parrot-feather [*Myriophyllum aquaticum* (Vell) Verdc.], an invasive aquatic plant that is not preferentially consumed by grass carp and the associated effects on water quality. Lookout Shoals Lake, a 528-ha piedmont North Carolina reservoir, was stocked with triploid grass carp at a density of 100 fish per vegetated hectare. Parrot-feather biomass in the lake was significantly reduced three months after grass carp stocking, compared to biomass in in-situ exclosures. During the second year after grass carp stocking, parrot-feather biomass in the lake compared to biomass in in-situ exclosures indicated continued control, but unexplained lack of growth within most experimental exclosures precluded biomass analyses. Increases in ambient water chlorophyll *a*, reactive phosphorus, and nitrate-nitrite concentrations were measured after grass carp stocking. The biological significance of observed changes in water chemistry and long-term effects on lake biota remain undetermined. Our results demonstrate that intensive grass carp stocking can control an invasive aquatic plant that is not preferentially consumed by grass carp and reveal associated changes in water quality.

Key words: biological control, *Ctenopharyngodon idella*, exclosure, *Myriophyllum aquaticum*, parrot-feather.

INTRODUCTION

Stocking grass carp [*Ctenopharyngodon idella* (Valenciennes)] is an increasingly employed control technique for the management of nuisance aquatic vegetation, but control has not been achieved in all grass carp applications (Allen and Wattendorf 1987, Li and Moyle 1999). Factors that influence the degree of vegetation control with grass carp are fish stocking density (Fowler and Robson 1978), regional climate (Van Dyke et al. 1984, Bonar et al. 1993), abundance and species composition of the aquatic plant community (Prowse 1971, Opuszynski 1972, Van Dyke et al. 1984), and relative grass carp feeding preferences for the plant species (Fowler and Robson 1978). Application of this technique typically involves varying grass carp stocking densities in an effort to achieve the desired amount of vegetation control. High-density grass carp stocking (i.e., densities greater than regional guidelines) to control persistent nuisance aquatic vegetation is receiving increased attention as an application, but scientific evaluation has been limited.

Aquatic plants perform important ecological functions and benefits to humans, including provision of food and cover for fish and wildlife, as well as aesthetic appeal (Hall and Werner 1977, Savino and Stein 1982, Schramm and Jirka 1989). Conversely, invasive plant infestations may suppress native aquatic plants (Aiken et al. 1979, Madsen et al. 1991, Boylen et al. 1999), clog water intake facilities (Holm et al. 1969, Vinogradov and Zolotova 1974), degrade water quality (Roach and Wickliff 1934, Wickliff and Roach 1937, Boyd and Tucker 1998), hinder recreation, and provide habitat for nuisance insects (Aliyev and Bessmertnaya 1968, Orr and Resh 1992). Management of nuisance aquatic plants is a frequent problem for reservoir managers, and stocking grass carp is commonly applied.

Grass carp exhibit selective herbivory in aquatic systems with diverse macrophyte community structures. Field and laboratory studies indicate a preference for succulent plant species and an aversion to fibrous plant species (Avault 1965, Prowse 1971, Fowler and Robson 1978, Pine and Anderson 1991, Catarino et al. 1997). Grass carp feeding preference for a particular plant species may also vary by region, as soil and water quality characteristics affect plant texture or taste (Chapman and Coffey 1971, Leslie et al. 1987). Feeding preference is of particular concern if the preferred vegetation is native or endemic to the system (Allen and Wattendorf 1987), and grass carp could adversely affect the species composition of the plant community (Vinogradov and Zolotova 1974, Fowler and Robson 1978). Thus, feeding preference for the target plant relative to other aquatic vegetation is an important consideration for determining stocking densities for aquatic plant control (Fowler and Robson 1978).

High-density grass carp stocking is a potential management technique for controlling target plants that are not preferred by grass carp as a food source (Fowler and Robson 1978, Pine and Anderson 1991, Catarino et al. 1997).

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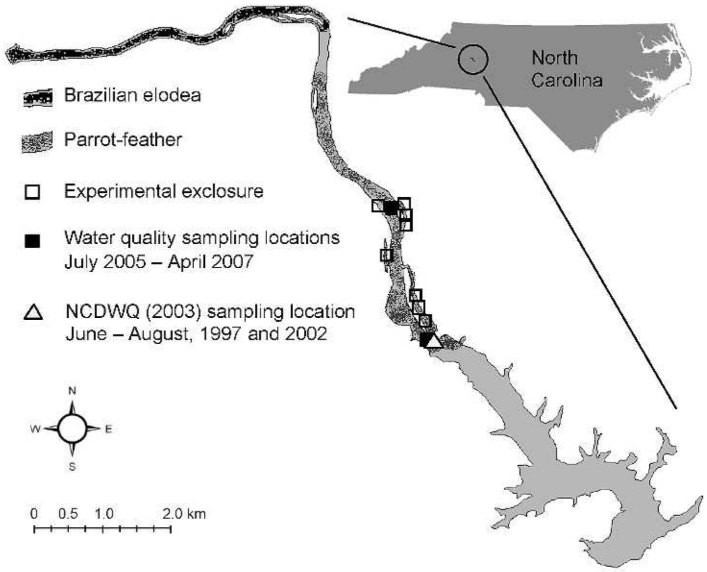

Figure 1. Location of study site, Lookout Shoals Lake, parrot-feather and Brazilian elodea approximate coverage, and experimental exclosure and water quality sampling locations on Lookout Shoals Lake, North Carolina.

However, achieving control of aquatic vegetation not preferentially consumed by grass carp with intensive stocking could result in elimination of all aquatic vegetation in the system, including native species (Shireman et al. 1985, Kohler and Courtenay 1986, Allen and Wattendorf 1987). High-density grass carp stocking and the associated effects to the aquatic plant community may also impact water quality. Excessive turbidity and accelerated eutrophication are two issues of concern that may result from plant removal, destabilized sediment, and the release of nutrients via grass carp excreta (James and Barko 1994, Cassani 1996, Bachmann et al. 2004).

Field investigations in reservoirs where grass carp have controlled nuisance aquatic vegetation detected some moderate changes in water quality. In general, aqueous nutrient concentrations decrease, and water clarity increases following aquatic plant infestations (Canfield et al. 1983). Aquatic vegetation control using grass carp may result in nutrient increases and decreased water clarity (Canfield et al. 1983, Leslie et al. 1983). Conversely, decreases in nutrient concentrations and increased water clarity have also followed aquatic vegetation control with grass carp (Mitzner 1978). Water depth, retention time, nutrient loading, relative abundance of vegetation to lake volume, and rate of vegetation removal influence the impact grass carp may have on lake and reservoir water quality (Mitzner 1978, Leslie et al. 1983, Shireman et al. 1985, Cassani 1996). The mechanisms producing such conflicting results remain unclear and demonstrate the need for additional research.

Controlling aquatic plant species that are food sources not preferred by grass carp with stocking densities of grass carp that are higher than typically recommended is an unproven practice, and the effects of such a practice on reservoir aquatic plant communities and water quality remain largely unknown. Greater insight into the efficacy and the indirect effects of this practice would enhance the aquatic plant management knowledge base and inform risk analysis to guide nuisance plant control strategies (e.g., Zajicek et al. 2009). Thus, the objectives of our study were to evaluate the efficacy of a high-density triploid grass carp stocking to control nuisance levels of parrot-feather, a non-native nuisance aquatic plant that is not a food source preferred by grass carp and to detect associated changes in the water quality in a piedmont North Carolina reservoir.

MATERIALS AND METHODS

Study area

Lookout Shoals Lake is a 528-ha reservoir located between Lake Hickory and Lake Norman on the Catawba River in the western piedmont of North Carolina (Figure 1). The lake is jointly managed by Duke Energy and the North Carolina Wildlife Resources Commission. It was impounded in 1915 by the construction of the Lookout Shoals Dam and Hydroelectric Station for power production, which is the primary use of the reservoir; municipal water source and recreation are secondary uses (Duke Power 1999, NCDWQ 2003). Parrot-feather and Brazilian elodea [*Egeria densa* (Planch.) Casp.] are two invasive aquatic plant species that dominate the submersed aquatic plant community of Lookout Shoals Lake (Figure 1). Both are introduced from South America that often form large, extensive mats on the water surface that interfere with ecological processes and human uses of the reservoir (Weatherby 1932, Blackburn et al. 1969, Sutton 1985).

Water-level management and aquatic herbicides have been utilized to control parrot-feather and Brazilian elodea abundances and distributions. Brazilian elodea has been successfully controlled with winter drawdowns of Lookout Shoals Lake that have restricted the infestation to the upstream riverine section of the impoundment. Visual aerial surveys conducted during September 2004 estimated that parrot-feather had infested 90 to 95 ha of the littoral zone of the upper reservoir (17 to 18% of the entire reservoir). Winter drawdowns were not effective at controlling its spread, and it had been selectively controlled with aquatic herbicides. However, recent installation of a municipal water facility resulted in increased restrictions on the use of aquatic herbicides, and other control options were sought for the management of this invasive aquatic plant. Parrot-feather is not considered to be a food source preferred by grass carp (Avault 1965, Pine and Anderson 1991, Catarino et al. 1997); thus, control of this nuisance aquatic plant with grass carp was questionable. This presented an opportunity to experimentally evaluate a high-density grass carp stocking management technique in an attempt to control a nuisance aquatic plant species that was not a food source preferred by grass carp.

In May 2005, Lookout Shoals Lake was stocked with approximately 9,200 grass carp (100 fish per vegetated ha). This stocking rate is twice that recommended for North Carolina public waters (Rice et al. 1999), and is higher than those applied in previous studies (Bailey 1978, Fowler and Robson 1978, Leslie et al. 1983, de Kozlowski 1994, Hanlon et al. 2000). Stocked fish were approximately 350 mm in total length and 525 g in weight. Additional detail on the study reservoir and its management may be found in Garner (2008).

Experimental exclosure and vegetation sampling

To determine grass carp efficacy as a control agent of parrot-feather, eight 6-m square exclosures approximately 2 m high were installed prior to grass carp stocking to allow vegetation growth within the exclosures without grass carp influence (Figure 2). They were constructed in shallow water, less than 2 m deep, in areas of known parrot-feather occurrence. Galvanized pipe was driven into the substrate at the exclosure corners, and plastic 1.3-cm square mesh fencing was stretched around and held in place by vinyl-coated galvanized cable at the top and reinforcement bar weights at the bottom. An area of equal size and morphology adjacent to each exclosure was delineated to sample for comparison of parrot-feather biomass within the corresponding exclosure.

Harvested plant biomass sampling was conducted for sensitivity in detecting changes in parrot-feather abundance to evaluate the degree of control (Madsen and Bloomfield 1993). Throughout the growing season, vegetation was harvested from six rectangular quadrats within each exclosure and the area adjacent to the exclosure. The quadrats were 1 m wide by 6 m long and extended the length of the exclosure perpendicular to the reservoir shoreline. One quadrat from inside each exclosure and one quadrat from outside each exclosure were sampled monthly from July through September of 2005 and 2006 after grass carp stocking. Rooted vegetation was completely harvested by hand and by the same observer. The vegetation from each quadrat was then spun in a mesh bag to remove excess water, and fresh weight was measured (± 1 g). This process was repeated until the weight stabilized. The first vegetation samples (July 2005) from inside the exclosures were used to verify an adequate sample size using the equation suggested by Madsen (1993) for estimating adequate sample sizes required for aquatic vegetation biomass sampling. Evidence of non-normality was detected in the parrot-feather biomass samples, which was not remedied by data transformation. Thus, a Wilcoxon signed rank test was used to detect differences in parrot-feather biomass between inner and outer quadrats. All statistical comparisons were considered significant at a probability of less than 0.05 (alpha).

Water quality sampling

Lookout Shoals water quality was monitored monthly from July 2005 through April 2007. Surface samples and measurements were collected from two main lake locations in the middle and upper lake areas and from inside and outside each of the eight experimental exclosures (Figure 1). Measurements of temperature, dissolved oxygen, and pH were made using a Hydrolab® model MS5 multi-probe datasonde and Surveyor 4a display unit. Surface samples for ammonia, nitrate, nitrite, and reactive phosphorus were filtered immediately under low pressure through a 0.45-μ glass fiber filter to remove suspended solids. Surface samples were placed on ice immediately following collection or collection and filtration and maintained at less than 4 C until analyzed. Samples were analyzed within 24 h of collection for total alkalinity (phenolphthalein and total method) and total hardness (ethylenediaminetetraacetic acid titration), and within 48 h of collection for ammonia (salicylate method), nitrate (calcium reduction method), nitrite (diazotization method), reactive phosphorus (PhosVer 3 method), using a Hach® CEL/850 test kit. Chlorophyll *a* samples were delivered to the Center for Applied Aquatic Ecology, North Carolina State University, within 24 h of collection, where they were analyzed using the EPA 445.0 (revision 1.2) method (EPA 1997).

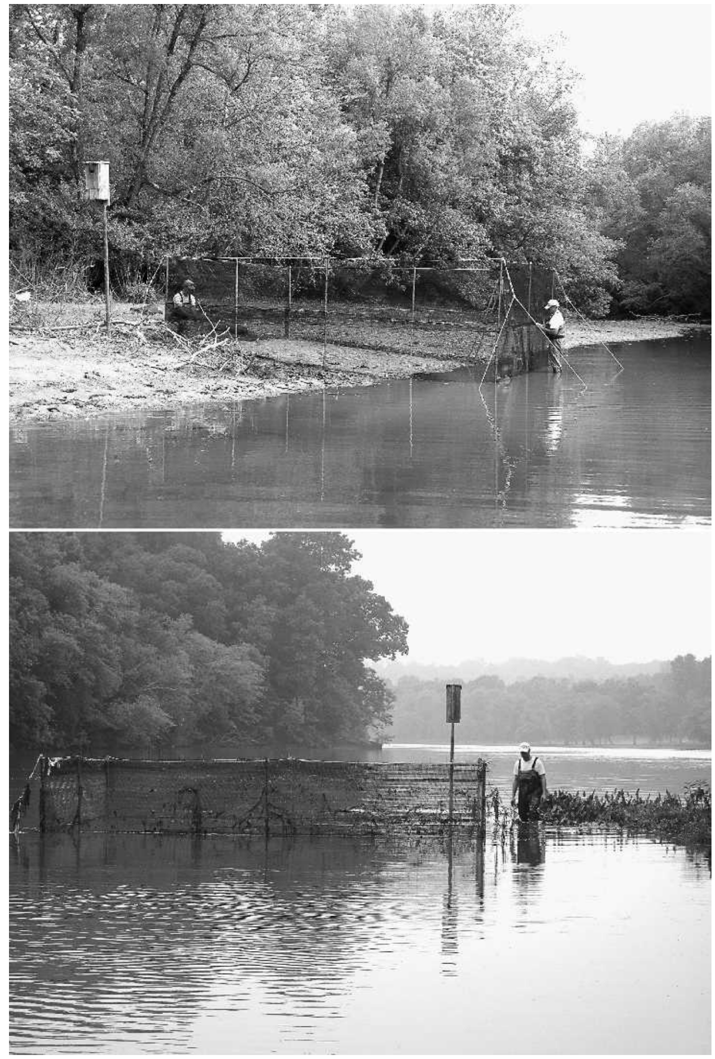

Figure 2. Exclosures (6 m × 6 m × 2 m, 1.3-cm plastic mesh) used as experimental controls to detect grass carp herbivory effects. The upper photograph was taken during exclosure construction with a 1-m water-level drawdown of Lookout Shoals Lake. Lower photograph depicts normal lake level.

Lookout Shoals Lake water quality was also monitored during the months of June, July, and August of 1997 and 2002 by the North Carolina Division of Water Quality (NCDWQ 2003). One of these locations corresponds to one

Table 1. Total submersed vegetation biomass (g/m²) from inside and outside eight experimental exclosures during July, August, and September of 2005 and 2006, following the May 2005 stocking of grass carp.

	2005			2006		
Species	July	August	September	July	August	September
Inside						
Chara spp.	223	142	45	140	0	0
Brazilian elodea	1	0	0	0	0	0
Parrot-feather	416	4,784	4,349	462	1,459	1,330
Outside						
Parrot-feather	180	26	12	0	0	0

(midlake) of the two main lake locations monitored for our research. This location provides a comparison of water quality parameters before (1997, 2002) and after (2005 to 2007) grass carp stocking. One-way analysis of variance (ANOVA; JMP 7, Statistical Analysis Software, Cary, North Carolina) was performed to detect differences among years for water quality determinations available from the NCDWQ (NCDWQ 2003) and those conducted for our study. A one-way ANOVA was also used to detect differences among seasons and years between the inner and outer exclosure water quality determinations with blocking by exclosure.

RESULTS AND DISCUSSION

Vegetation

Only three submersed aquatic plant taxa were encountered in the sampling for this research; they were Chara (*Chara* spp.), Brazilian elodea, and parrot-feather (Table 1). Chara and Brazilian elodea were only encountered in quadrats inside the exclosures, while parrot-feather was encountered inside and outside the exclosures. Parrot-feather biomass was highly variable among exclosures and sampling occasions (Table 2). Analysis of July 2005 parrot-feather biomass indicated no significant difference in the mean parrot-feather biomass from the quadrats available to the grass carp (0.02 kg/m²) and the quadrats from inside the exclosures (0.05 kg/m²) two months after grass carp were stocked and one month into the parrot-feather growing season (Figure 3). A significant reduction in parrot-feather biomass was observed outside the exclosures, relative to that inside, three and four months after grass carp were stocked. Mean parrot-feather biomass from the quadrats available to the grass carp was less than 0.01 kg/m² in both August and September, whereas mean parrot-feather biomass from the quadrats in the exclosures was 0.60 kg/m² and 0.54 kg/m² in August and September, respectively. These results demonstrate an average difference in parrot-feather biomass inside and outside of exclosures over 50-fold.

In the 2006 sampling season, no vegetation was encountered in any quadrat available to grass carp (Table 2). One exclosure (number 7) contained more parrot-feather biomass during all three months than in the corresponding months of 2005. Among all exclosures, no growth was observed in five of the eight quadrats in July, four of the eight quadrats in August, and seven of the eight quadrats in September. This absence of parrot-feather precluded statistical analyses of abundance in 2006. However, on average, parrot-feather biomass inside the exclosures was 0.06 kg/m² during July, 0.18 kg/m² during August, and 0.17 kg/m² during September, relative to no plant biomass outside of the exclosures.

Our analysis of parrot-feather biomass indicated that control was achieved shortly after grass carp stocking. One factor that may have influenced the degree of control is the timing of the stocking. Grass carp were stocked in May, one month prior to the initiation of the parrot-feather growing season and two months prior to its peak growth period in Lookout Shoals Lake. In this case, the plant biomass of a major infestation did not require depletion to achieve reasonable control; rather, grass carp could consume less abundant vegetation as it grew. Grass carp presence at the initiation of the parrot-feather growing season may be a key factor contributing to the level of control observed. Also, parrot-feather new growth may be more palatable to grass

Table 2. Parrot-feather biomass (g/m²) from inside (In) and outside (Out) eight experimental exclosures during July, August, and September of 2005 and 2006.

	2005						2006					
	July		August		September		July		August		September	
Exclosure	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
1	27	2	1,643	0	385	0	0	0	0	0	0	0
2	2	2	3	0	8	0	0	0	0	0	0	0
3	37	2	178	2	197	0	13	0	2	0	0	0
4	0	0	23	0	48	0	117	0	2	0	0	0
5	245	33	1,660	0	2,025	0	0	0	0	0	0	0
6	38	113	580	2	447	0	0	0	2	0	0	0
7	65	28	687	22	1,177	12	332	0	1,453	0	1,330	0
8	2	0	10	0	62	0	0	0	0	0	0	0

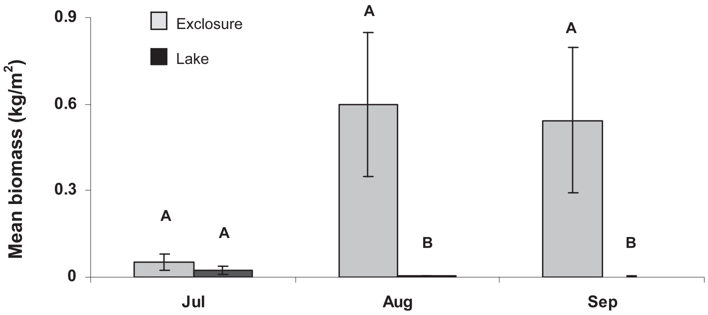

Figure 3. Mean biomass (kg/m^2) of parrot-feather within eight exclosures and corresponding quadrats outside exclosures during July, August, and September 2005. Different letters indicate significant differences ($P < 0.05$) between inside and outside quadrats within months.

carp facilitating early and continued control as the growing season progressed (Prowse 1971, Leslie et al. 1994). This factor (i.e., timing) may be of equal importance as density of grass carp for controlling parrot-feather.

Lake wide visual estimation and quantitative quadrat sampling indicated a lack of plant biomass and continued vegetation control in 2006 and 2007. Visual field surveys during all post-stocking years (2005–2012) detected no occurrence of parrot-feather or Brazilian elodea in the reservoir. The finding of little to no vegetation growth inside the exclosures during 2006 was unexpected and may be due to herbivore intrusion, sedimentation effects, or annual variation in plant growth. Water-level fluctuations in the reservoir are not a likely cause of the annual differences in vegetation growth inside the exclosures, as parrot-feather is generally tolerant and resilient to flooding and drawdown events (Maltchik et al. 2007, Wersal and Madsen 2011). Doyle et al. (1997) reported herbivory and sedimentation as deterrents to the establishment of aquatic plants in exclosures in two Texas reservoirs. Evidence of sedimentation and intrusion by painted turtles [*Chrysemys picta* (Schneider)] was observed among all exclosures during our study. Painted turtles are known to be omnivorous (Martof et al. 1980) and may have sought the vegetation food source within the exclosures as the vegetation outside the exclosures was depleted. Further, other vertebrate or invertebrate organisms may have been attracted to the vegetation in the exclosures, as similar physical structure became scarce throughout the lake. No clear explanation for the interannual differences in results were revealed even after careful field observation. Thus, we conclude that the evidence we collected during the first plant-growing season after high-density grass carp stocking clearly demonstrates parrot-feather control by grass carp, but our findings of the second post-stocking growing season are more equivocal, yet parrot-feather remained at low densities within the reservoir.

Water quality

No significant differences were detected before and after grass carp stocking for temperature, pH, and secchi depth, or dissolved oxygen, ammonia, and nitrate-nitrite concentrations from existing data and our sampling (Table 3). There was a significant increase in chlorophyll *a* concentrations from 2002 and 2005 to 2006, but this change did not coincide temporally with grass carp stocking.

Additional supporting water quality findings were reported by Garner (2008). In general, water quality measurements were similar between the two years following grass carp stocking, but differences were found among seasons and locations. No consistent water quality differences were detected between the inside and outside of the experimental exclosures.

Of the significant changes detected in the water quality parameters in Lookout Shoals Lake after grass carp stocking, only those for nutrient and chlorophyll *a* concentrations pose ecological significance. The elevation in chorophyll *a* during the second year after grass carp were stocked could be indicative of a shift in nutrient availability to the phytoplankton community resulting from grass carp excreta or resuspension of sediments (Boyd 1971, Shireman et al. 1985). The elevated nitrogen and phosphorus levels observed beginning in the summer of 2005 and through the spring of 2006 were followed by a four-fold increase in chlorophyll *a* concentrations during the summer of 2006. Chlorophyll *a* serves as an index of primary production (Brylinsky and Mann 1971). In lakes with extensive littoral areas, aquatic macrophytes can comprise a significant portion of the primary production as they sequester nutrients and alter photic conditions early in the growing season in competition with phytoplankton communities (Boyd 1971). Aquatic macrophytes also have added competitive advantages over phytoplankton by accessing nutrients in the substrate as well as stabilizing those substrates preventing nutrient recycling to the water (Bachmann et al. 2004). However, attributing this increase in phytoplankton production to the loss of littoral vegetation is not clear. Lookout Shoals Lake water quality is influenced by watershed inputs and releases from upstream impoundments (NCDWQ 2003), and our ability to detect any grass carp influence on the water quality of Lookout Shoals is confounded by these factors and a low water retention time.

Conclusions

Invasive aquatic vegetation is a persistent problem for water resource managers. The triploid grass carp is an increasingly useful biological control agent of aquatic vegetation that can decrease cost and risk to public health (Bailey 1978, Li and Moyle 1999), and our results demonstrate that high-density grass carp stocking can be considered among management options for controlling aquatic plant species considered to be food sources not preferred by grass carp. We observed control of an invasive aquatic plant previously considered difficult to control with grass carp, presumably due to the high-density component of the stocking. The changes observed in reservoir water quality following vegetation control were not ecologically detrimental and likely of minimal concern for management and water use.

In addition to stocking density, timing of grass carp stocking may influence the degree of vegetation control. Stocking soon after infestation or early in the season before

Table 3. Mean, standard error (in parentheses), and range of water quality measurements from Lookout Shoals Lake monthly (June to August) in 1997 and 2002 (NCDWQ 2003) prior to grass carp stocking, and in 2005 to 2006 after grass carp stocking. Within each parameter, different superscript letters indicate significant differences ($P < 0.05$).

Parameter	Year			
	1997	2002	2005	2006
Temperature (°C)	25.3^{a} (3.2)	26.0^{a} (1.9)	24.7^{a} (< 0.1)	27.8^{a} (1.2)
	19.7–30.9	22.3–28.1	24.7–24.8	26.0–30.0
pH	6.5^{a} (0.3)	6.9^{a} (0.2)	6.7^{a} (0.2)	7.4^{a} (0.3)
	6.1–7.2	6.6–7.2	6.5–6.8	7.1–7.9
Dissolved oxygen (mg/L)	7.0^{a} (0.8)	6.3^{a} (0.9)	5.5^{a} (1.0)	7.0^{a} (0.5)
	5.6–8.3	4.6–7.3	4.5–6.5	6.1–7.6
Secchi depth (m)	1.5^{a} (0.3)	1.5^{a} (0.5)	1.2^{a} (0.6)	1.4^{a} (0.1)
	1.0–2.0	1.0–2.4	0.6–1.8	1.3–1.5
Chlorophyll *a* (µg/L)	—	3.5^{a} (1.5)	2.1^{a} (0.4)	8.7^{b} (0.6)
	—	0.4–5.0	1.7–2.5	8.0–9.9
Ammonia (mg/L NH_3-N)	0.05^{a} (0.02)	0.03^{a} (0.01)	0.07^{a} (0.02)	0.02^{a} (0.01)
	0.01–0.07	0.02–0.04	0.05–0.08	< 0.01–0.03
Nitrate-nitrite (mg/L NO_3^--N, NO_2^--N)	0.25^{a} (0.03)	0.07^{a} (0.04)	0.31^{a} (0.20)	0.27^{a} (0.15)
	0.22–0.30	0.02–0.15	0.11–0.52	0.06–0.56

vegetation biomass reaches peak levels should enhance successful control. This consideration may be critical for control of invasive aquatic vegetation that is not preferred by grass carp.

When developing a management strategy for the control of invasive aquatic plants, one must consider the ecological and economic impacts of control techniques versus the cost of no control (Pimentel et al. 2005, Zajicek et al. 2009). The array of benefits provided by native aquatic plants should be included in such analyses. Our study did not address possible impacts to native or endemic vegetation because the aquatic plant community of the study reservoir was dominated by invasive plant species, but we found evidence of an impact to the macroalgae following grass carp stocking (Table 1).

Our results confirm research on grass carp effects in other water bodies that indicate full control of aquatic plants is likely to result with high-density grass carp stocking (Bailey and Boyd 1972, Martyn et al. 1986, Hanlon et al. 2000), and managers should expect full control and depletion of aquatic vegetation with this strategy. Current knowledge is not sufficient to understand and predict long-term ecological effects of stocked grass carp (Dibble and Kovalenko 2009). The changes that we observed in the aquatic plant community and water quality of Lookout Shoals Lake raise additional questions regarding the long-term effects on littoral and shoreline aquatic plant and fish species. Future research may address those issues, as well as broader ecosystem-level effects. Our results and those of other studies addressing the effectiveness and ecological impacts of utilizing grass carp for aquatic plant control will aid managers in developing aquatic plant management plans. Relating the effectiveness and potential ecological impacts of various control techniques is crucial in this process.

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