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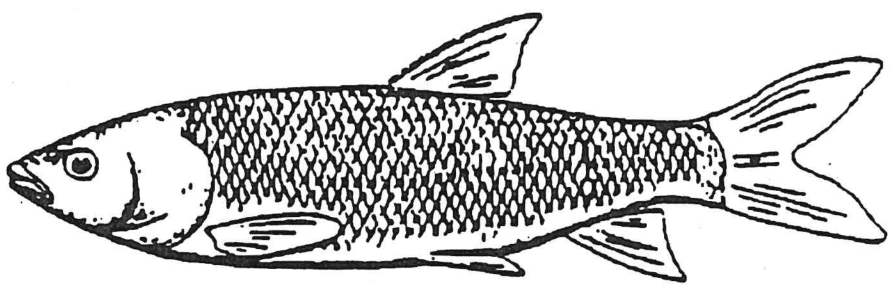

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Washington Department of Fish and Wildlife
Fish Management Program
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RESEARCH REPORT

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ABSTRACT

We investigated the effects of grass carp *Ctenopharyngodon idella* on public satisfaction, aquatic macrophyte communities and water quality of 98 Washington lakes and ponds stocked with grass carp between 1990-1995. Noticeable effects of grass carp on macrophyte communities did not take place in most waters until two years following stocking. After two years, submersed macrophytes were usually either completely eradicated (39% of the lakes) or not controlled (42% of the lakes). Control of submersed macrophytes to intermediate levels occurred in 18% of lakes at a median stocking rate of 24 fish per vegetated surface acre. Most of the landowners we interviewed (83%) were satisfied with the results of introducing grass carp. Average turbidity of sites where all submersed macrophytes were eradicated was higher (11 nephelometric turbidity units [NTU's]) than sites where macrophytes were controlled to intermediate levels (4 NTU's) or not affected by grass carp grazing (5 NTU's). Most of this turbidity was abiotic and not algal. Chlorophyll α was not significantly different between levels of macrophyte control. Grass carp are effective for controlling most submergent macrophytes in Washington State, but the effects of a particular stocking rate can vary considerably. Recommendations for updating the current management of this fish in Washington are included with this report.

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INTRODUCTION

Triploid grass carp *Ctenopharyngodon idella* were legalized for aquatic macrophyte control in Washington State in 1990. Since then, numerous lakes and ponds have been stocked with the fish to control nuisance aquatic vegetation. Although intensive studies have examined a few individual lakes and ponds (Bonar 1990, Pauley and Bonar 1995, Scherer et al. 1995), little work has been done to assess their effect statewide since their legalization.

Several questions regarding the use of grass carp for management of aquatic macrophytes in the Pacific Northwest remain unanswered. These include their ability to control, but not eliminate all submersed macrophytes when used operationally; the suitability of the current models used by the Washington Department of Fish and Wildlife (WDFW) for predicting stocking rates; effects of grass carp on general water quality paramerters statewide; and public satifaction associated with grass carp introductions.

Since many researchers have found that moderate levels of aquatic vegetation can be important for fish (Wiley et al. 1984, Durocher et al. 1984) and wildlife (Gasaway et al. 1979) populations, the goal of most grass carp users is to stock at densities which will control, but not eradicate, all submergent macrophytes. While intermediate levels of macrophytes were achieved using grass carp in some Northwest sites two to four years following stocking (Bonar 1990, Bonar et al. 1993a, Pauley and Bonar 1995), other lakes have exhibited either little control (Pauley and Bonar In prep.), or complete submersed macrophyte eradication (Scherer et al. 1995, Pauley and Bonar In prep.).

Currently, grass carp stocking rates for waters in Washington are based on two models which were developed from worldwide data. One model (COVER) predicts stocking rates based on initial macrophyte coverage, while the other (BIOMASS) predicts stocking rates based on initial macrophyte biomass (Bonar 1990, Pauley and Bonar 1995). A survey of Washington waters where grass carp have been introduced would identify how well the models worked, and suggest improvements. Additionally, such a survey would assess the feasibility of using grass carp to reduce submersed macrophytes to a predetermined level of abundance without removing all of them from the lake.

Increases in turbidity, either alga or abiotic, have been observed in some waters following the stocking of grass carp (Lembi et al. 1978, Maceina et al. 1992, Water Environmental Services 1994), and are undesirable to most Washington lake managers. It is important to determine the factors responsible for these increases and under what conditions they occur.

In Washington, grass carp have been used primarily in private lakes and ponds which receive a variety of different uses. Anglers, property owners, bird watchers, boaters, and farmers have all

applied for permits to stock grass carp in Washington. Although assessment of public satisfaction can often be overlooked, it can be important for evaluating the success of introductions.

Five years after the legalization of triploid grass carp in Washington, we evaluated the effects of these fish in 98 sites statewide. The objectives of our study were as follows: 1) determine the general effects of grass carp on macrophyte communities and water quality statewide; 2) evaluate COVER, the current stocking rate model which predicts rates based on area covered by submergent macrophytes; 3) assess public satisfaction with the results of grass carp introductions statewide; 4) compile a database of the waters in Washington stocked with grass carp between 1990 and July 1995; and 5) use these results to assist with an update of state grass carp policy.

METHODS

We contacted all WDFW regional offices throughout Washington State to obtain copies of grass carp stocking permits. These permits contained lake name, name and address of pond owner, lake area maps showing initial macrophyte surface coverage and nuisance plant species. We measured surface area of macrophyte coverage on permit maps with a planimeter to estimate the number of fish stocked per vegetated surface acre. After we had compiled permit information, we contacted landowners via a telephone survey to determine the primary use of their lakes; their overall satisfaction with the grass carp treatments; and the number of fish they actually stocked. We also noted if they saw dead grass carp following stocking; ascertained the magnitude of change in the macrophyte community; and recorded any changes they might have noted in angling quality, wildlife populations, and aesthetics of the lake. We used this information to evaluate public satisfaction, and only included lakes stocked before October 1993, so grass carp had adequate time to have an effect. We counted satisfaction by each lake separately, so the few landowners who owned more than one lake or pond had more than one vote. We also asked each landowner if we could visit their lakes to conduct a rapid assessment of current macrophyte community status and selected water quality information.

We visited 98 lakes stocked with grass carp between July 19 and August 22, 1995. At each lake, we drew maps of the current surface macrophyte coverage and used recording fathometers to assess submergent macrophyte bottom coverage and volume (Maceina and Shireman 1980, Thomas et al. 1990, Canfield and Hoyer 1992). We measured bottom coverage and macrophyte volume by moving a small boat equipped with a recording fathometer along two transects at a constant speed, one running the length of the lake, and the other perpendicular to it at the widest point.

We used the cut and weigh method (Welch 1948, Lind 1979) to determine the volume occupied by aquatic macrophytes. Chart records were photocopied twice. On one copy we cut out the cross section of the entire lake, while on the other, we cut out the same cross section of the entire lake and then removed all macrophyte tracings. We weighed each cutout on a Mettler balance with a sensitivity of 0.01 g and divided the weight of the cross section with plants removed by the weight of cross section of the entire lake, multiplied by 100, and then subtracted this figure from 100 for a measure of percent volume occupied by aquatic macrophytes (PVO).

To determine bottom coverage, we first summed the lengths of the two transects occupied by macrophytes. We then summed the total lengths of the two transects. The first quantity was divided by the second and multiplied by 100 for a measure of bottom coverage. Lakes were separated into three categories based on the degree of macrophyte control following the stocking of grass carp. Since we had little before-stocking data besides landowner-drawn surface coverage maps, we used these with a combination of qualitative data to separate lakes into the three groups. "Eradication" defined lakes where less than 5% of the lake volume was occupied by submergent vegetation at the time we conducted our survey ***and*** the waterfront property owner reported ***substantial*** declines in the submersed plants since grass carp stocking. "Control" defined lakes where the landowner noticed, or comparisons with pre-stocking surface coverage maps indicated, ***substantial*** decline in submergent vegetation ***and*** between five to 40% of the lake's volume was occupied by submergent vegetation at the time of our survey. We chose 40% as the upper limit since this was the mean volume of macrophytes in 13 lakes that the public considered overgrown and had either not stocked with grass carp yet, or had stocked the fish within the last 6 months. "No-control" defined lakes where landowners did not report ***substantial*** reductions in submergent vegetation surface coverage ***and/or*** greater than 40% of the lake's volume was occupied by submergent vegetation at the time of our survey. We defined "substantial" as large reductions in the surface coverage of the lakes, usually greater than 50% of the original. If the grass carp were seen cutting holes in the lake's macrophyte cover or removing small sections of macrophytes, we did not consider this as a "substantial" reduction. Lakes excluded from our analysis include those treated with herbicides, or drained at any time; those where no pre-grass carp stocking macrophyte information was available; or those which contained no submergent vegetation before grass carp stocking.

For analysis of stocking rate, we considered only lakes stocked before October 1993 so grass carp would have had time to have an effect. Bonar (1990) found several significant ($P < 0.05$) relationships between effective stocking rates used worldwide and accumulated air temperature units. Therefore, we regressed stocking rates against accumulated temperature units, using the procedure he reported, to determine if similar relationships existed for lakes in Washington. Accumulated temperature units were calculated using the following equation:

$$U = (T_1\text{-}55)D_1 + (T_2\text{-}55)D_2 + \ldots(T_n\text{-}55)D_n,$$

where,
T = average air temperature of month n in °F
and D = number of days in month n.

Only months where T was > 55°F were used in the calculation. A cutoff at 55°F for the calculation of temperature units was suggested by Swanson (1986) as the lower threshold of effective grass carp grazing. Average air temperatures of stocking sites were calculated by averaging weather data from the closest weather station over a 10-30 year period (National Climatic Data Center, Washington Climatological Data).

Regressions were calculated for all macrophyte communities combined, for communities containing plants less preferred by grass carp (Bowers 1987; Pauley and Bonar 1995), and for communities containing highly preferred plants. Additionally, we did each of these calculations for all lakes combined, and then for only those over one acre to reduce inaccuracies in stocking rate and macrophyte cover due to small lake size.

We measured chlorophyll α, total turbidity, secchi depth, alkalinity and water color to assess water quality. Chlorophyll α was measured to assess the degree that phytoplankton contributed to total turbidity. Alkalinity was measured to assess the potential of the different waterbodies to develop a large phytoplankton population. Water samples were composites of the top 1 m of the water column and were collected using a PVC tube. We filtered 50 ml of water for chlorophyll samples using a syringe attached to a membrane filter. Filters were stored in acetone and transported to a laboratory in the dark on ice for analysis, according to the procedures in Jefferey and Humphrey (1975) and Strickland and Parsons (1972). Total turbidity was measured on a nephelometric turbidity meter. Since we were using three different meters, all readings were calibrated to each other using regression techniques. Water color on the Forel-Ule scale and alkalinity were determined using Lamonte[1] portable water kits.

[1]Mention of a vendor does not constitute endorsement of a product.

RESULTS

WDFW approved applications to stock triploid grass carp in 184 lakes and ponds (five of these were pond complexes where the total number of ponds was unknown) in Washington during April 1990 through July 1995. Numbers of approved permits were highest immediately following legalization and have leveled off since then (Figure 1). Most stockings have occurred in the Puget Sound region (Figure 2), in lakes less than 10 acres (Figure 3).

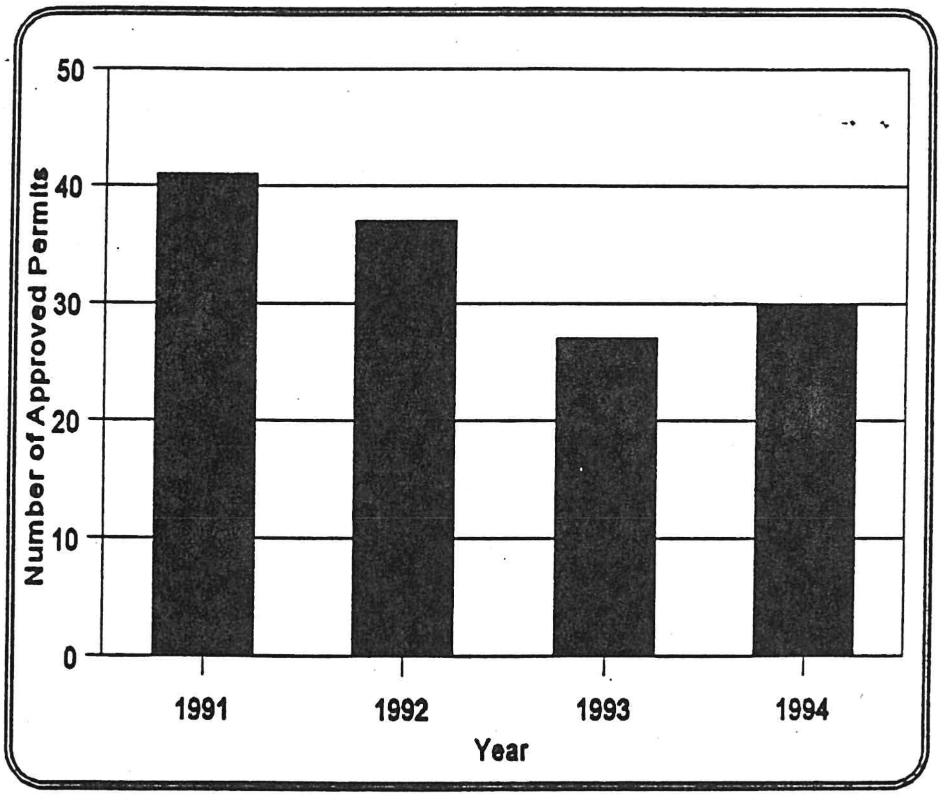

Figure 1. Number of approved grass carp permits per year in Washington State, 1991-1994.

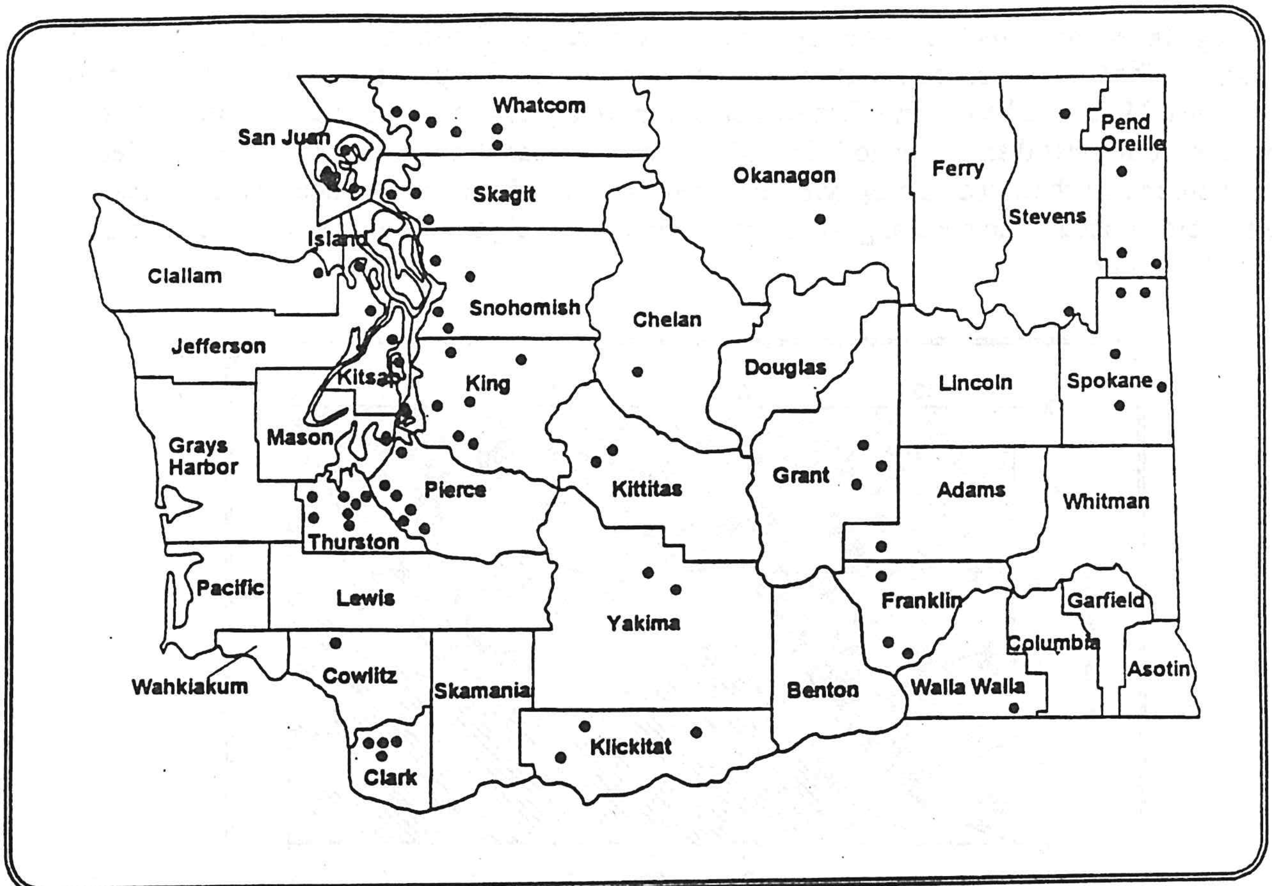

Figure 2. Locations of lakes in Washington where confirmed grass carp stockings took place, April 1990-June 1995.

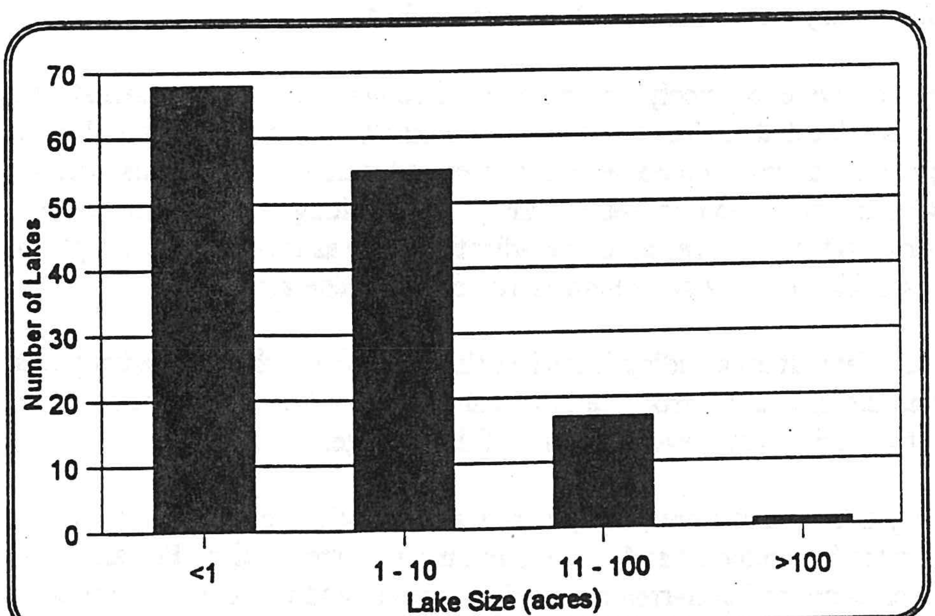

Figure 3. Size of distribution of Washington lakes stocked with grass carp.

Stocking Rates and Effects on Macrophytes - A wide range of stocking rates have been used in Washington for the control of submergent macrophytes (5-174 fish per vegetated acre). Generally it took over 24 months before an effect was observed from grass carp stocking. The majority of lakes stocked for less than this period showed little or no impact from grazing (Figure 4). After this period, most submersed macrophyte communities were either entirely eradicated or no major effects were noticed. The general goal of intermediate macrophyte control was achieved in only 18% of the waters.

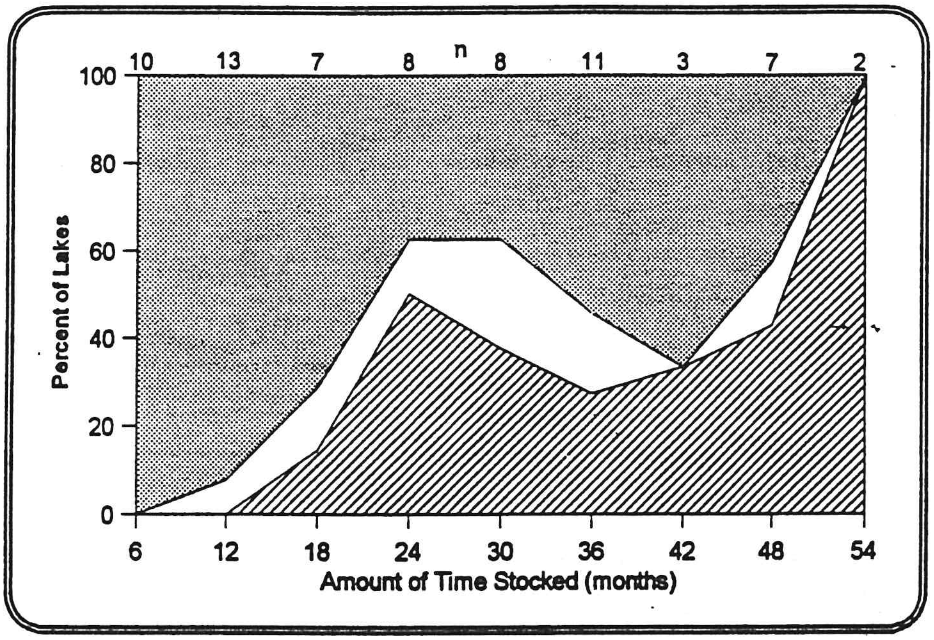

Figure 4. Percent of lakes in which submersed macrophytes were eradicated (hatched area), controlled (empty area) or not controlled (dotted area) versus number of months stocked.

Average stocking rates were extremely high because of outliers, and not representative of the group. Therefore, we decided median stocking rates would be more appropriate than means. Median stocking rate for all lakes combined which resulted in control was 24 fish per vegetated acre (Figure 5). Overlap occurred between stocking rates resulting in control, no control and eradication. Stocking rates which resulted in eradication were as low as eight fish per vegetated acre. No-control stocking rates were as high as 109 fish per vegetated acre.

When examining the data after excluding lakes less than one acre, only one eradication stocking rate was lower than the median control rate of 24 fish per vegetated acre. Stocking rates which resulted in no control varied from seven fish to 74 fish per vegetated acre.

Since "control" only occurred in a few lakes, there was insufficient information to recommend different stocking rates for preferred and unpreferred macrophyte species. For all lakes combined, the single lake which contained preferred macrophyte species and was controlled was stocked at 27 fish per vegetated acre. The five lakes which contained mixed or less preferred macrophyte

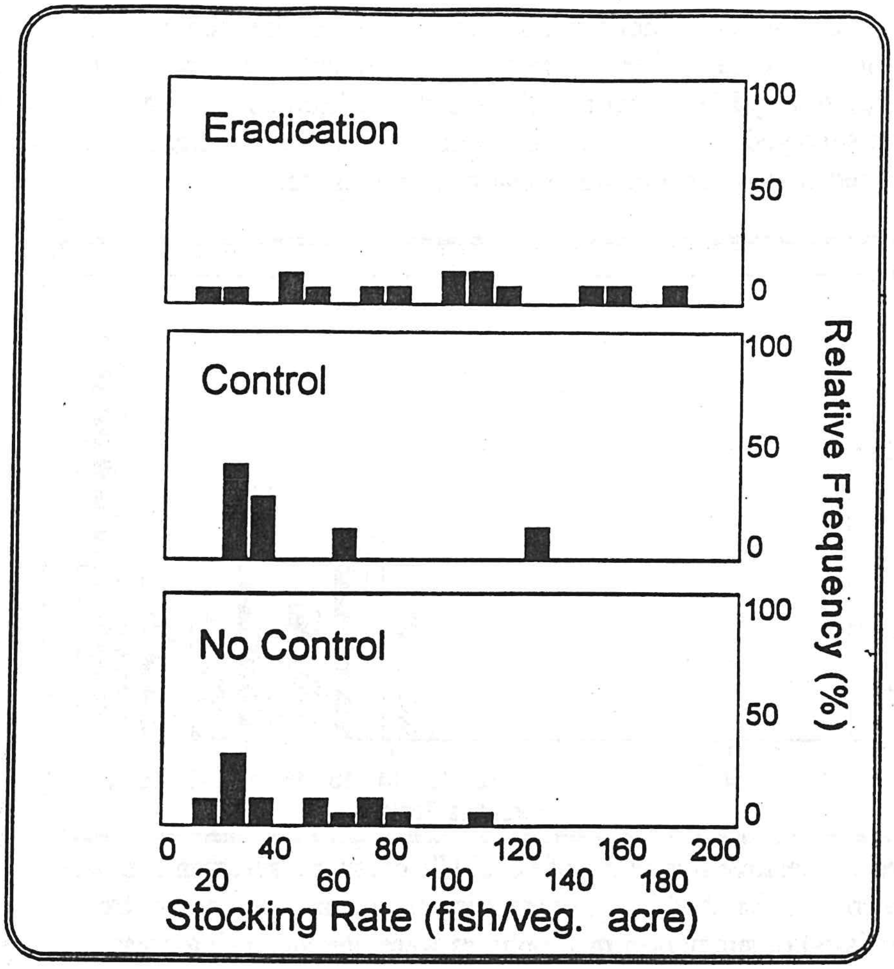

Figure 5. Relative frequency of stocking rates by level of aquatic macrophyte control.

communities were stocked at a median rate of 24 fish per vegetated acre. Additionally, we found no relationship between stocking rates that resulted in control and accumulated temperature units.

In the 23 sites where submersed macrophytes were not controlled 24 months following grass carp stocking, dominant species mentioned were broadleaved *Potamogeton* spp. (22% of the sites), thin-leaved *Potamogeton* spp. (17%), *Myriophyllum* spp. (17%), *Ceratophyllum* sp. (13%), *Utricularia* spp. (9%), *Lemna* spp. (9%), macroalgae (*Chara* sp., and *Nitella* sp.) (9%), and *Elodea canadensis* (4%). In seven sites where macrophytes were controlled but not completely eradicated, *Myriophyllum* spp. was dominant in four (57%).

Water Quality Effects - Turbidity was significantly higher ($P < 0.001$) in lakes where all submersed macrophytes were eradicated than in lakes where control or no control occurred. There was no difference in turbidity between control and no-control sites. Average turbidity was 11 nephelometric turbidity units (NTU's) in eradication sites, 5 NTU's in no control sites, and 4 NTU's in control sites. Chlorophyll α was not different between the three types of sites. Mode water color for control and eradication sites was 21 on the Forel-Ule scale, which corresponds to browns and tanins (Figure 6). For sites where no control occurred, mode Forel-Ule measurement was 14, a greenish color. We could not find a significant relationship between chlorophyll α and turbidity in lakes where grass carp effects were substantial (control and eradication). Alkalinity was sufficient (>20 ppm, Boyd 1990) for a healthy phytoplankton population in 97% of the sites. Since most lakes we surveyed were shallow, secchi depth was often greater than the lake depth, so we excluded this technique from our water clarity comparisons.

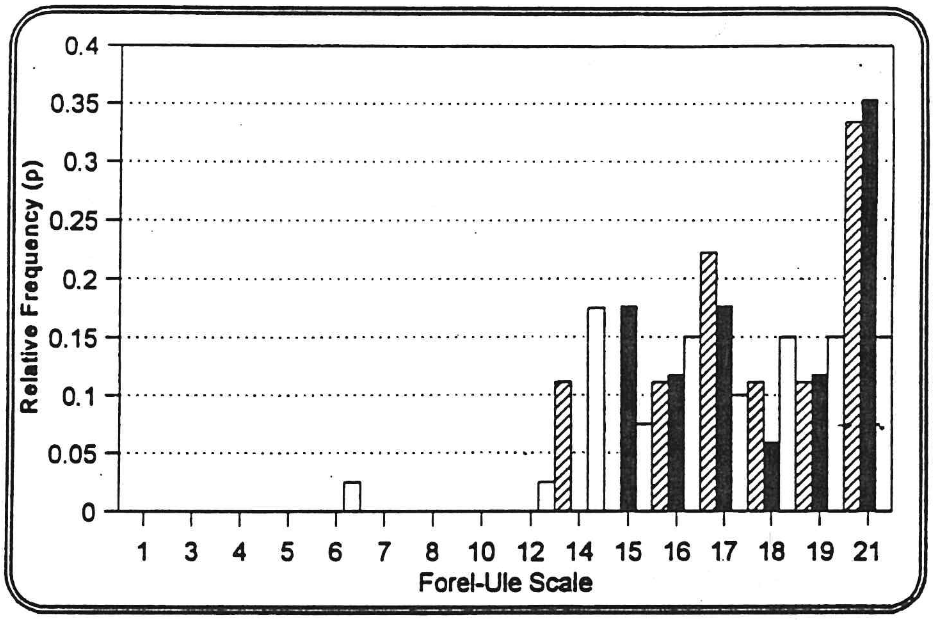

Figure 6. Relative frequency of Forel-Ule color measurements in lakes where control (hatched bars), eradication (solid bars) and no control (empty bars) of submersed macrophytes were obtained using grass carp.

Public Satisfaction Associated With Grass Carp Treatments - Stocking grass carp has been a popular method for controlling aquatic vegetation with permit holders. Property owners were highly or moderately satisfied with the results obtained in 83% of the 49 lakes stocked with grass carp prior to October 1993 (Figure 7). When subdividing satisfaction by the amount of plant control obtained, all landowners achieving control or eradication were highly or moderately satisfied. Even in 13 lakes where grass carp had little or no effect, landowners were highly or moderately satisfied with 54% of the introductions.

Grass carp grazing appeared to have little effect on perceived angling quality in lakes (Figure 8). Landowners fished in 27 of the lakes and 71% reported that angling quality had not changed substantially. Few changes in angling quality were reported for each of the three levels of plant control as well.

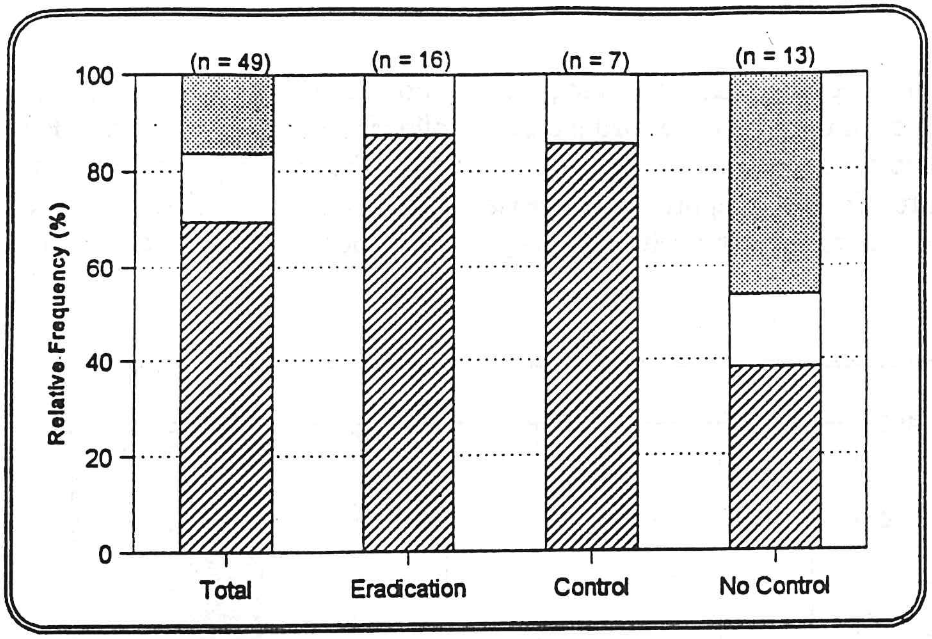

Figure 7. Percent of permit holder satisfaction associated with grass carp introductions overall, and categorized by effect on submergent macrophytes. Satisfaction recorded as high (hatched bars), moderate (empty bars) or none (dotted bars).

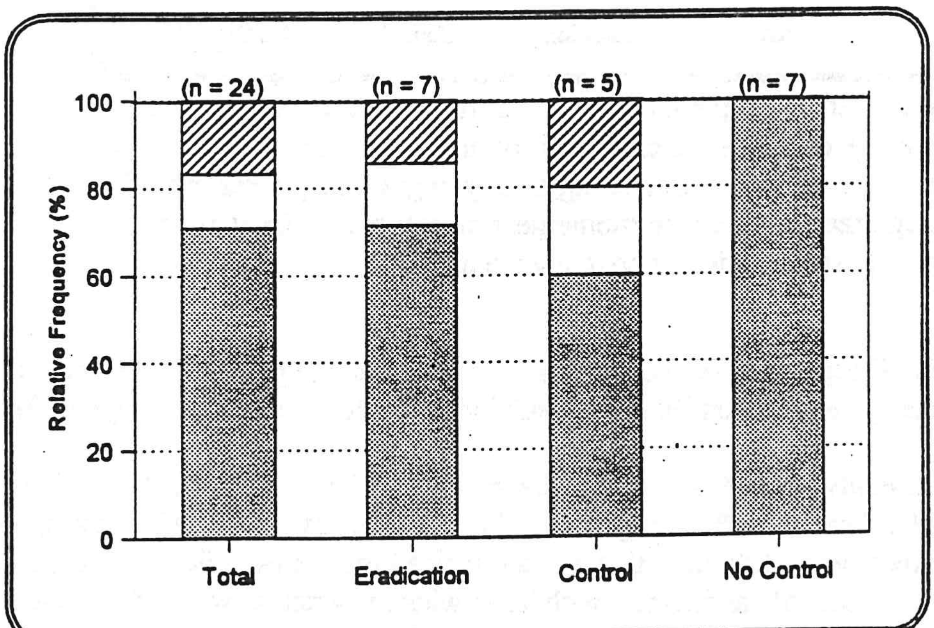

Figure 8. Percent of permit holders reporting a perceived increase (empty bars), decrease (hatched bars) or no change (dotted bars) in angling quality in grass carp lakes overall, and categorized by effect on submergent macrophytes. Only permit holders who fished were included in the survey.

Nineteen respondents reported that they swam, skied or boated at these lakes. Overall, 63% of them reported quality of these activities had increased following grass carp stocking (Figure 9). In sites where eradication occurred, all respondents reported that quality of these activities increased. In control sites 60% reported an increase, while 40% reported that quality declined or remained the same. All respondents felt swimming, skiing or boating quality had not changed in no-control sites.

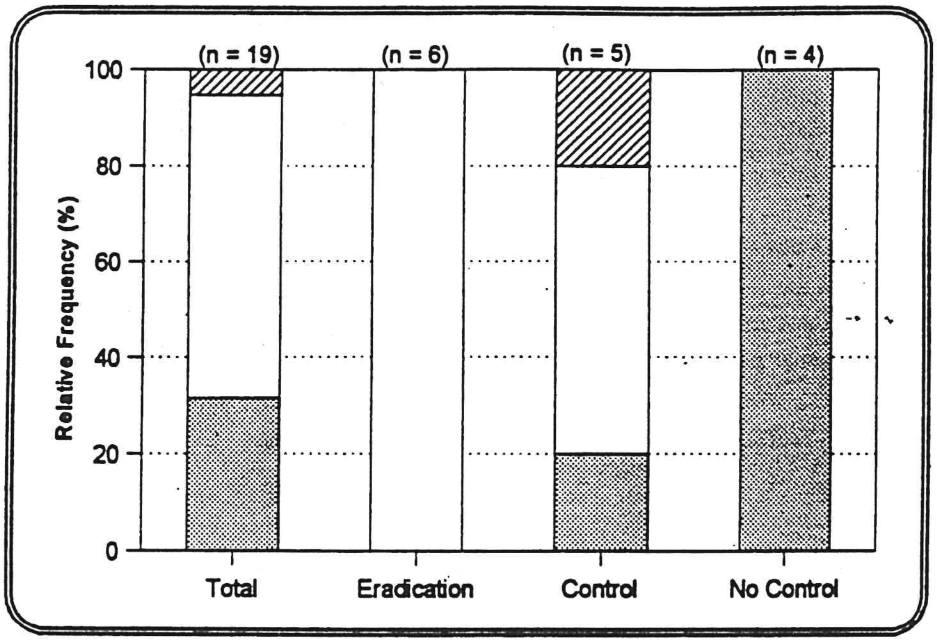

Figure 9. Percent of permit holders reporting a perceived increase (empty bars), decrease (hatched bars) or no change (dotted bars) in swimming, water skiing, or boating quality in grass carp lakes overall, and categorized by effect on submergent macrophytes. Only permit holders who swam, skied or boated were included.

Most landowners (90%) reported that they watched bird and wildlife populations at these lakes. Most reported no change, even when lakes were subdivided by level of control (Figure 10).

Landowners were generally pleased with the aesthetic value of their lakes after the stocking of grass carp (Figure 11). Overall, 83% thought that lake aesthetics had increased following grass carp stocking. Fourteen percent thought that it had remained the same, while only one (2%) felt that aesthetics had declined. All landowners with lakes where vegetation was entirely eradicated thought that aesthetics had increased, while 66% had thought it increased on control sites. Forty-five percent thought that aesthetics remained the same in no-control sites, while 55% thought that it increased.

Mortality of grass carp was reported by almost half (48%) the landowners we contacted. Most common forms of mortality were thought to be stress associated with stocking, or bird predation (Figure 12).

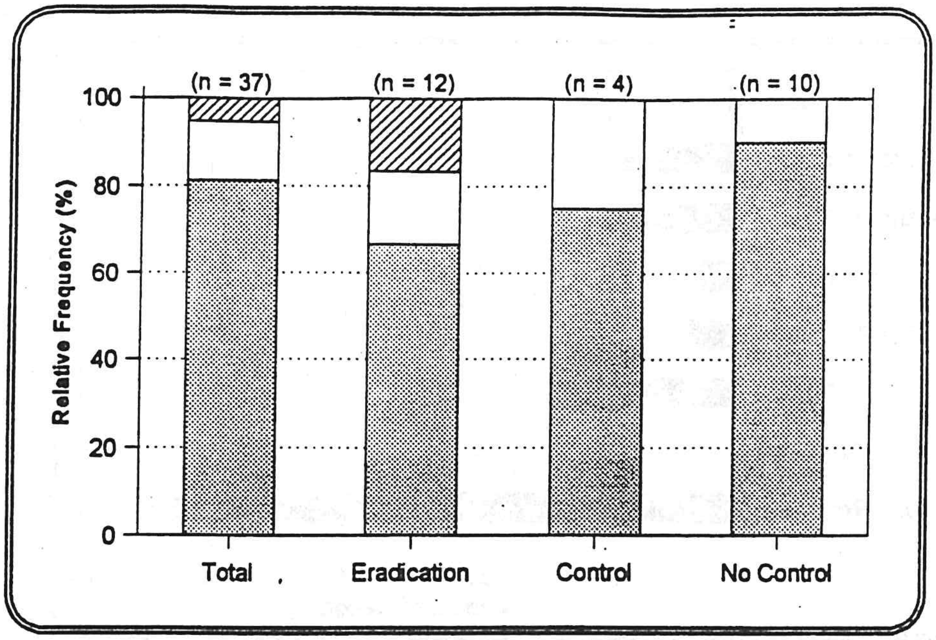

Figure 10. Percent of permit holders reporting a perceived increase (empty bars), decrease (hatched bars) or no change (dotted bars) in bird and/or other wildlife populations (not including fish) for both grass carp lakes overall, and categorized by effect on submergent macrophytes.

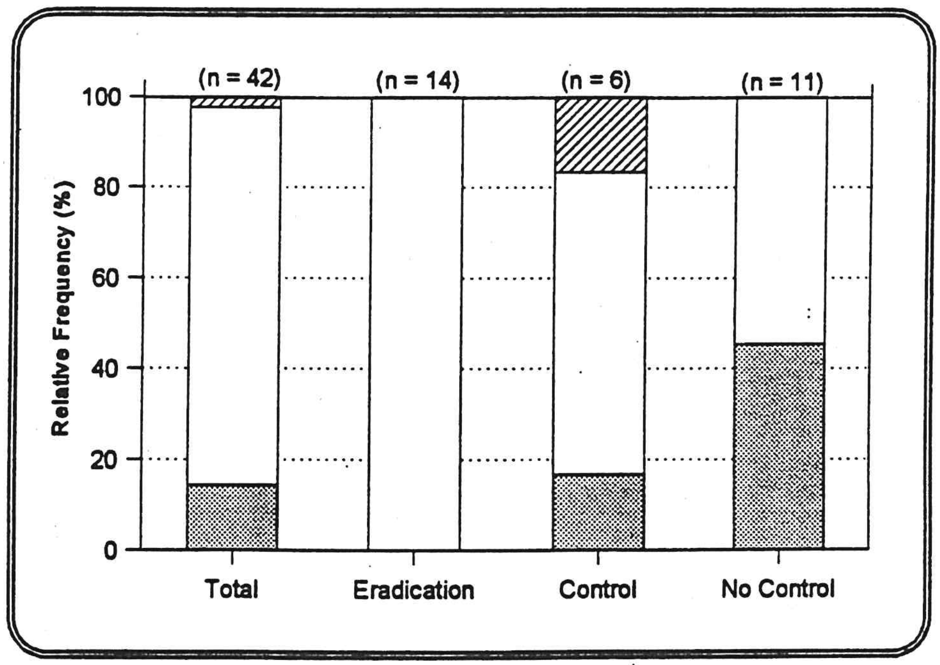

Figure 11. Percent of permit holders reporting a perceived increase (empty bars), decrease (hatched bars) or no change (dotted bars) in lake aesthetics for both grass carp lakes overall, and categorized by effect on submergent macrophytes.

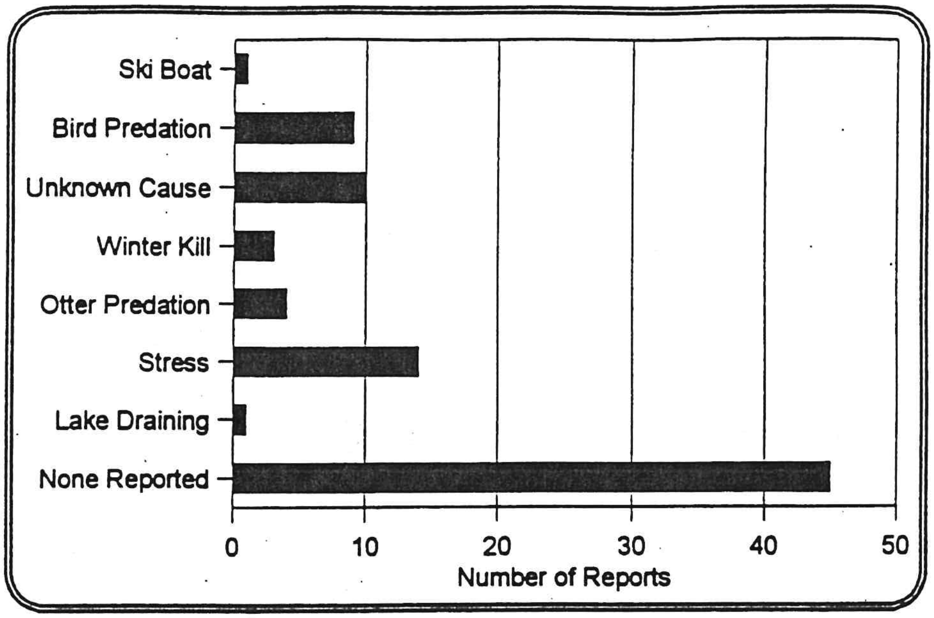

Figure 12. Reports of grass carp mortality by permit holders.

DISCUSSION

Effects of Grass Carp on Macrophytes - We found that most submersed macrophyte species in Washington were effectively grazed by grass carp, even though grass carp preference affected the order in which they were eaten. Various *Potamogeton* spp., *Myriophyllum* spp., and *Ceratophyllum* sp. were dominant macrophyte species in lakes where vegetation was not controlled. However, since these plants were effectively grazed in many other lakes, lack of control was probably not the result of grass carp being unable to effectively graze these species.

Although grass carp ate most submergent macrophytes, we did not see evidence of effective grazing of waterlillies. *Nuphar* sp. was found in several lakes where complete submergent plant eradication occurred and did not appear to be grazed in any sites. *Nymphaea* spp. showed some evidence of grazing such as cuts in the leaves, however there was no evidence of this plant being controlled in any sites. In the lakes we examined, *Brasenia schreberi* was generally not controlled, corresponding to results from an earlier study (Bonar 1990). However, this plant was grazed heavily in Silver Lake, Washington where the stocking rate was high, no submersed macrophytes were present, and grass carp were large (Scherer et al. 1995). Grazing damage was also noticed in Keevies Lake, Washington where grass carp had been present for eight years.

Grass carp generally took at least two years to have a significant effect. Information provided to landowners describing the amount of time required for macrophyte reduction would help them determine if grass carp were the best plant control option for their site and would reduce the chance of their overstocking in order to insure changes in the first year.

Controlling aquatic vegetation to intermediate levels has been the objective of many fisheries managers when stocking grass carp. While there is considerable debate whether submersed aquatic macrophytes are necessary in small lakes and ponds for optimal production of game fish, most researchers feel that when present in intermediate densities they do not harm, and in many cases can benefit lake ecosystems (Wiley et al. 1984, Durocher et al. 1984). Unfortunately, in the majority of cases, grass carp introductions in Washington resulted in either complete eradication of submersed vegetation, or no noticeable control, corresponding with results of several others who have reviewed large numbers of lake stockings (Bonar 1990, Kirk 1992, Haller 1994, Mitzner 1994). Therefore, the successful use of grass carp to reduce submersed macrophytes to a predetermined intermediate level without completely eradicating them appears to be rare at this time in Washington. Several factors may be responsible for the variation in the degree of vegetation control obtained with a given stocking rate. Unpredictable shifts in annual temperature cycles can influence macrophyte growth, grass carp feeding, and grass carp growth which in turn can affect the degree of control obtained. However, a major factor causing variability in the amount of control achieved with a given stocking rate is likely grass carp mortality. We found that many factors caused varying degrees of grass carp mortality in Washington lakes (Figure 13). Clapp et al. (1994) estimated that site-to-site mortality in Florida could range annually from 6-62%. Therefore, it is quite difficult to determine how many grass carp are present in a lake at any given time.

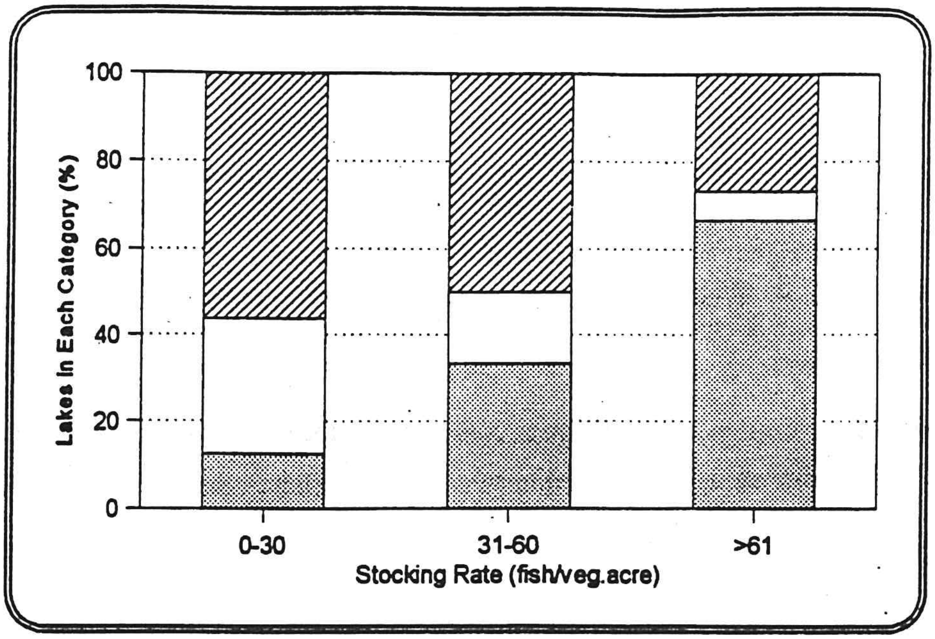

Figure 13. Percent of eradication (dotted bars), control (empty bars) and no control (hatched bars) lakes by stocking rate.

While no control or eradication is most common, several researchers have reported that macrophytes have been controlled to intermediate levels in specific lakes two to five years following stocking (Bonar 1990, Bonar et al. 1993a, Henson and Sliger 1993, Cassani et al. 1994). Therefore, while it is not impossible to achieve a control level, the chances of ***consistently*** achieving it are very low at this time in Washington lakes. Grass carp should not be used in lakes where complete eradication of submersed vegetation cannot be tolerated.

Stocking Rates - Figure 5 reveals which stocking rates may maximize the chances to achieve control in Washington lakes where only macrophyte surface coverage information is available. Stocking rates which resulted in no control varied over a wide range. This suggests that grass carp mortality was high in some sites; measurements of the vegetation coverage for the initial stocking rate calculation were in error; and/or some rates may simply have been too low for control. The few lakes where macrophytes were controlled at intermediate densities two to five years following grass carp introduction had a median stocking rate of 24 fish per vegetated acre, both for all lakes combined and those over one acre. Eradication resulted infrequently (12.5% of the lakes) where the stocking rate was less than 30 fish per vegetated acre (Figure 13). Therefore, 20 to 25 fish per vegetated acre is probably a reasonable number of fish to be stocked in small Washington lakes to control macrophytes two to five years following stocking. We could not separate the effects of different macrophyte species or temperature regimes, simply because there were so few control points. Nor could we predict the effect of these stocking rates after five years. Revisiting these control sites after several more years would assist in determining whether 20 to 25 fish per vegetated acre could provide long-term control, or would result in eventual submersed macrophyte eradication.

Bonar et al. (1995) developed a stocking rate model for the Pacific Northwest (COVER), based on data obtained worldwide and checked with results obtained in eight Washington and Oregon field trials. They recommended stocking rates for control of submersed vegetation which ranged from 20 to 150 fish per vegetated acre depending on plant species type and average accumulated air temperature units. The number of fish per vegetated acre we found most effective in this study, 20 to 25 fish per vegetated acre, was at the low end of this range, but higher than what has been recommended in the southern or the Midwestern United States (5-20 fish per surface acre depending on vegetation levels (Masser N.D., Mitzner 1994).

Curiously, 20 to 25 fish per vegetated acre is considerably lower than stocking rates which were effective earlier for Devils Lake Oregon (Bonar et al. 1993a) and seven Washington lakes (Bonar 1990, Pauley and Bonar In Prep.). These earlier stocking rates were used to help fine-tune the current Washington state stocking rate model. Temperature, plant species present, and grass carp growth was similar between studies. However, one factor which might have changed was grass carp mortality.

The shipments of grass carp in 1986 through 1990 were the first legal stockings in the Pacific Northwest. Fish for eight of the nine stockings were trucked across the country from Arkansas during late spring and early summer. After stocking, 300 to 600 fish were seen dead at some of the sites. Although stocking rates were adjusted to account for these mortalities, the actual number of fish left in the lakes may have been lower still.

Currently, sterile grass carp are sent regularly to the Pacific Northwest. Most are sent by air, arriving much more quickly than those original truck shipments. Producers, because of the larger volume of fish they send to this region, are now well acquainted with procedures needed to insure safe delivery of shipments. Possibly high stocking rates were most effective several years ago because of high mortality, but now transportation and stocking procedures have been refined, mortality has been reduced, and the results of our field study demonstrate that lower stocking rates are now appropriate.

Grass carp are hard to remove once they are stocked without killing all fish in the lake, and reaching a desired control level without eradication of plants is presently difficult. Therefore, many authors (Wiley et al. 1985, Bonar 1990, Bain 1993) recommend that a serial stocking approach should be used, where the initial stocking rates are conservative, and in subsequent years, grass carp are gradually added until a desired control level is achieved. We could find no evidence of this approach yielding consistently better results than a single stocking. It is a reasonable idea however, and should be investigated, especially in larger lake stockings.

Water Quality Effects - We found turbidity to be higher in eradication lakes than control or no control lakes, but chlorophyll α was not significantly different between the three. Also, in lakes where grass carp had an impact on the macrophyte community (control and eradication lakes) we found no relationship between turbidity and chlorophyll α. Finally, mode water color of eradication lakes was 21, which was brown or humic colored. These findings imply that the increased turbidity in eradication lakes primarily consisted of suspended sediments and not phytoplankton. Since elevated turbidity was found in a wide variety of lakes and ponds, irrespective of wind action, we hypothesize the source of this turbidity was grass carp disturbing the sediment in their search for food.

Increased turbidity following grass carp stocking has been documented frequently, but the source of this turbidity has differed. Turbidity increased in Lake Conroe following grass carp stocking from 2.4 to 3.9 NTU's, however this turbidity was attributed to higher algal biomass and not increased abiotic turbidity (Maceina et al. 1992). Lembi et al. (1978) mentioned that turbidity increased following stocking in Indiana ponds from an average of 6.7 to 9.9 NTU's, but they found no change in phytoplankton populations. In Washington, Scherer (personal communication) mentioned that abiotic turbidity increased following macrophyte removal in Silver Lake, and Frodge et al. (1995) did not measure turbidity, but showed increased conductivity following stocking in Keevies Lake.

Turbidity did not increase in lakes where submersed macrophytes were controlled to intermediate densities. In these lakes, grass carp still have submersed vegetation to graze and do not have to resort to disturbing the sediment in their search for food. Therefore, removing macrophytes to a control as opposed to an eradication level may be beneficial, not only by leaving submersed macrophyte habitat and food for fish and wildlife, but by reducing the chance that grass carp foraging in the sediments will reduce the water clarity of the lake.

While abiotic turbidity was significantly higher in eradication sites, one must question whether it poses a threat to fish and wildlife populations or perceived aesthetic value of the lake at the levels found in our study. Average turbidity of eradication lakes was 11 NTU's while control and no control lakes averaged 4.6 and 4.0 NTU's respectively. Turbidity at any of these levels are not directly harmful to adult fish. Wallen (1951) found that adult or juvenile fish of 16 different species did not show behavioral reactions to turbidities less than 20,000 ppm and most could survive turbidities of 100,000 ppm for a week or longer, turbidities much higher than those usually found in nature. Effects of elevated turbidity on reproductive behavior, egg or larval mortality may be mixed, depending on the species. Muncy (1979) reviewed several studies and concluded that there was substantial evidence that warmwater fish reproductive behavior was affected by suspended sediments. He further stated that incubation stages are particularly susceptible to suspended sediments, especially species which do not fan their nest, and larval stages are less tolerant of these sediments than eggs or adults. Conversely, Auld and Schubel (1978) found that survival of eggs and larvae of several estuarine species tested including yellow perch (*Perca flavesens*) were not affected by exposure to suspended sediments in Chesapeake Bay either at natural concentrations, or at abnormally high concentrations close to dredging and sediment disposal operations.

Abiotic turbidity at low levels can significantly affect primary productivity, and thus the food base for the aquatic community. Suspended sediments can reduce light penetration and alter habitats for primary producers (Sorensen et al. 1977). Lloyd et al. (1987) calculated that increases as little as 5 NTU's could reduce the productive euphotic volume of a clear Alaskan lake by about 80%t. Butler (1964) observed that gross primary productivity of a clear Oklahoma pond was three times that of a turbid pond. Turbidity ranging from 3.8 to 14.6 NTU's significantly affected the relationship between chlorophyll α, secchi depth, and phosphorus in Keystone Lake, Oklahoma

(Hunter and Wilhm 1984). Reduced primary production can cascade through the food chain, lowering the total production of invertebrates and fishes. Increased turbidity can further impact the food chain by resulting in significant declines in feeding efficiencies of both fish (Vinyard and O'Brien 1976) and zooplankton (McCabe and O'Brien 1983).

While chlorophyll α was not significantly higher in eradication lakes, it was also not significantly lower. Therefore we have no direct evidence that phytoplankton abundance has declined in these sites to date. However, managers should be aware that the potential for negative impacts exist with increased turbidity, and should not permit grass carp stocking in lakes where increased abiotic turbidity would be of concern.

Other changes in water quality have been associated with grass carp introductions which we did not measure in our study. Frodge et al. (1995) found that bottom dissolved oxygen increased significantly following the stocking of grass carp in Washington ponds containing thick macrophyte communities. Macrophyte canopies can prevent oxygen mixing and light penetration to lower water levels, thus decreasing the area of available fish habitat. If the majority of a lake is covered with thick macrophyte canopies, tradeoffs between the potential to increase bottom dissolved oxygen and the threat of increased abiotic turbidity must be considered.

Public Satisfaction With the Results of Grass Carp Treatments - Grass carp were a highly popular macrophyte control option with Washington landowners surveyed in this study. All were satisfied with complete eradication of submersed vegetation, and few reported any perceived changes in angling quality or wildlife populations in any sites. Therefore it seems as if most landowners feel that the aesthetic quality of their lakes and ponds are more impacted by excess macrophyte growth than higher turbidity associated with complete submersed macrophyte eradication. It is important to realize that although few perceived changes were noticed in fish and wildlife populations, this does not mean that actual changes did not occur.

Curiously, 54% of landowners with lakes showing no control were satisfied with the results. Many of these landowners considered their grass carp as pets or simply were satisfied to be trying alternative techniques to reduce nuisance aquatic plant growth in their ponds although desired results had not yet been achieved.

Management Implications and Areas for Future Research - Sterile grass carp are effective for removing submersed aquatic macrophytes from lakes and ponds in Washington, but lake managers should consider that 1) a predetermined intermediate level of vegetation control is currently difficult to achieve using grass carp, and most stockings either result in eradication or not enough control of aquatic plants and 2) if all submersed vegetation is eradicated from a lake, the potential exists for elevated abiotic turbidity.

Grass carp are long-lived, so to reduce the potential for total eradication and elevated turbidity requires the ability to manipulate the number of grass carp in a waterbody, either by stocking the "correct number" or being able to remove fish after stocking. Stocking the "correct number" is quite difficult, given in part the high variability in the mortality of grass carp after stocking. Serial stocking over a period of time may be an effective method, but as of yet is unproven. This promising technique needs further investigation before it can be recommended for general use.

Measurement of the initial macrophyte abundance could be improved and standardized to remove variability from stocking rates. Calculating stocking rates based on macrophyte biomass instead of coverage gives a much more accurate measure of fish to plants (Bonar 1990, Leslie et al. 1987) but biomass surveys are extremely labor intensive. A model, BIOMASS, is available for predicting stocking rates for Washington lakes based on the initial biomass of the submersed plant community. However, this model is based on data from other regions and early Washington and Oregon studies where grass carp may have experienced higher mortality than at present. Therefore its predictions are likely to be high and should be treated with caution until it can be refined. Assessment of the volume occupied by macrophytes is another precise technique for vegetation abundance estimation (Thomas et al. 1990) and may be promising for stocking rate calculations. Additionally, this technique is rapid, and does not require a large expenditure of effort. Predicting stocking rates in number of fish per volume of submersed vegetation may provide an attractive alternative to tedious biomass surveys or imprecise area coverage estimates.

Since uncertainty associated with grass carp might never be removed by attention to stocking rates alone, further research needs to be conducted on methods to remove the fish from overstocked waters. Rotenone is used to remove nuisance fish from lakes statewide, and it could be easily applied to lakes overstocked with grass carp. However the use of this compound in many lakes is frequently not feasible or desired, so other techniques are necessary.

Selective removal of grass carp without the use of rotenone is currently feasible in many of the small overstocked ponds in Washington. Most Washington lakes and ponds were stocked with less than 50 grass carp (Figure 14). In these sites grass carp numbers could be controlled either

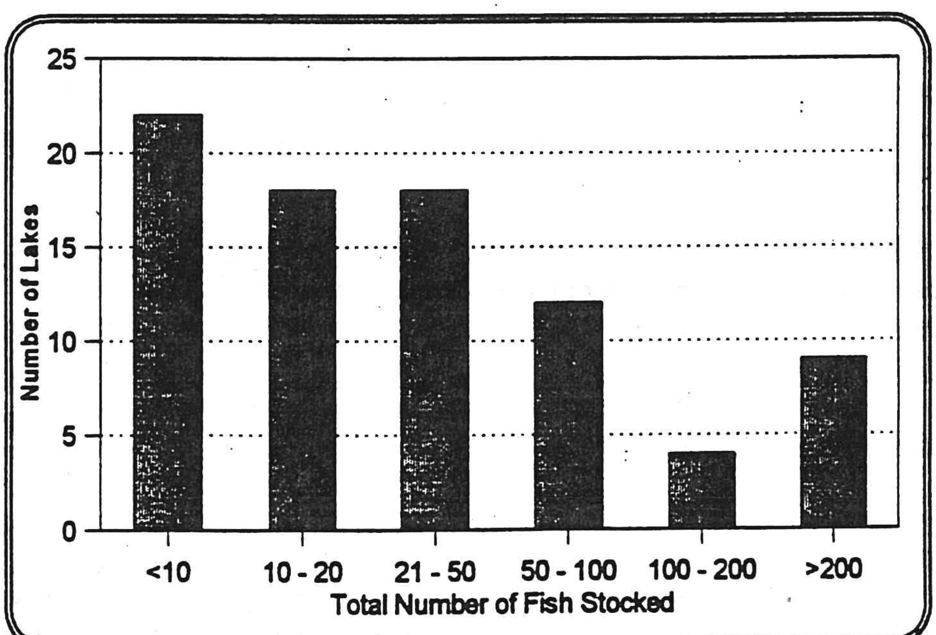

Figure 14. Total number of fish stocked per lake for Washington lakes stocked between 1990-1995.

by angling (Bonar et al. 1993b, Mallison et al. 1994a), herding (Bonar et al. 1993b) or potentially fish management bait (a bait containing rotenone tried in other areas but not the Pacific Northwest) (Mallison et al. 1994b). Grass carp are usually not attracted to baits until all submersed plants have been eradicated (Bonar et al. 1993b), so angling or use of fish management bait are options only after complete eradication has occurred. Herding is effective, but labor intensive, when submersed aquatic plants still remain in the lake (Bonar et al. 1993b).

In larger lakes where considerably more fish are stocked, selectively removing grass carp is difficult. Fish management bait, angling, and herding techniques have captured grass carp in larger sites, but we know of no studies to date where enough grass carp were selectively removed from a large system to result in macrophyte regrowth.

Since grass carp populations are much more difficult to manipulate in large lakes, and potential negative impacts are greater in these sites, grass carp are probably best suited for plant control in small lakes and ponds. Exceptions may occur where complete eradication of a submersed plant is required in a large lake, such as an invasive exotic, or when a lake can be treated with rotenone to eradicate the grass carp if too many plants are removed.

RECOMMENDATIONS FOR UPDATING CURRENT WDFW GRASS CARP MANAGEMENT

There are several areas in which we recommend current management be updated to reflect recently obtained information about grass carp in the Pacific Northwest.

1. Currently the policy sets 25% vegetated surface coverage as a minimum goal when using grass carp. The variability associated with the effects of various stocking rates suggest that controlled removal of submersed plants to a predetermined level is not currently feasible using grass carp. No control or complete eradication is much more common, even when the objective is control. Therefore we suggest grass carp should not be used in lakes where complete submersed plant eradication cannot be tolerated unless a complete rotenone treatment can be conducted on the lake if overstocked. We further suggest that all landowners and lake users considering using grass carp be informed that eradication of all submersed plants is a very real possibilty.

2. A stocking rate of 25 fish per vegetated acre should be set as the maximum with the potential of considering higher stocking rates on a case-by-case basis where rapid submersed macrophyte eradication may be desirable, such as in irrigation canals, fire control ponds, and aquaculture ponds. Although recommendation of incremental stocking of grass carp is popular, we could find no empirical evidence where this technique resulted in control in any more sites than a single stocking. However, in theory it seems reasonable and it is an approach which should be investigated.

3. Most stocking rates predicted by the University of Washington *area coverage* stocking rate model (COVER) are currently too high for the Pacific Northwest. Therefore stocking rates recommended in this report should be substituted for stocking rates recommended by the area coverage model. The *biomass* model (BIOMASS) developed by the University of Washington should be refined to reflect possible reductions in grass carp mortality. Until that time the model can be fine-tuned, it should be regarded with caution.

4. We found that almost all landowners, consultants and biologists freely shared information with us about the number of grass carp they had stocked and the results of their treatments. However, one consulting group who had stocked approximately 20 percnet of the lakes in Washington would not share basic information such as if fish were actually stocked in the lake after the permit was approved, date of stocking, number of grass carp stocked, and addresses of landowners. WDFW is charged with monitoring grass carp stockings in Washington and suggesting future improvements regarding their use. Therefore we feel that future permit approval should be contingent on providing basic post-stocking information such as if stocking actually occurred, the number of fish stocked, and landowner addresses.

5. The variability in the effects of a particular stocking rate was high partly because different non-standard methods were used to measure aquatic plant abundance to determine the

stocking rate. Measurement of vegetated area and submergent plant biomass should be standardized to remove variability in stocking rates. Since stocking rates based on plant biomass were developed using SCUBA methods outlined in Bonar (1990) these techniques should be required when stocking rate based on biomass is being calculated. Fish per vegetated area stocking rates should be based on surface area covered by submersed macrophytes. Research should be conducted to develop stocking rates based on macrophyte volume occupied. Measuring macrophyte volume is much less labor-intensive than biomass assessment, but considerably more accurate than surface coverage estimation.

6. The map of initial surface coverage of aquatic plants that landowners were required to submit with the permit was valuable for this study. We should continue to require that these maps be submitted for permit approval.

7. Currently, grass carp are illegal to capture in Washington. Provisions should be made to enable legal capture and removal of grass carp in lakes that are overstocked after contacting the WDFW. The policy should also reflect what is to be done with the captured fish.

8. Grass carp should not be stocked into lakes where increased turbidity, either algal or abiotic, cannot be tolerated unless a provision is made to allow a total lake rotenone treatment if turbidity reaches unacceptable levels. Removal of thick plant canopies which cover a majority of the lake's surface area may increase subsurface dissolved oxygen. Tradeoffs between increased subsurface dissolved oxygen and the potential for increased turbidity should be considered in these sites.

9. Because of the unpredictability of the effects of a grass carp treatment, lakes where *submersed* plant communities provide important habitat for fish and wildlife should not be stocked with grass carp.

10. Because of their difficulty in removal, submersed macrophyte eradication possibilities, and potential for damage if large numbers escape, grass carp should rarely, if ever, be used in large lakes and never in rivers.

11. To aid with quality control of grass carp shipments, the state of Washington should investigate supporting an in-state commercial vendor.

12. To improve stocking rate predictions and grass carp management, a follow-up study, similar to this, should be conducted on a regular basis.

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