# Simulation Model Evaluation of Sources of Variability in Grass Carp Stocking Requirements

*by*

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## Introduction

Grass carp have proven an effective control of nuisance aquatic plant growth since their introduction into the United States in 1963 (Guillory and Gassaway 1978). Grass carp were initially banned from many States because of the potential ecological risk associated with releasing reproductively viable diploid variants (Stanley, Miley, and Sutton 1978). Though the advent of reliable triploid inducement techniques (Cassani and Caton 1986) has lessened the ecological threat stemming from releases of reproductively viable diploids, grass carp use is still restricted in large open waterways by some States and prohibited altogether by others (Allen and Wattendorf 1987).

Part of the reason for continued restrictions on grass carp use is concerned with the uncertainty in determining stocking strategies that provide desired control levels without risking unwanted impacts (Noble, Bertolli, and Bestill 1986; Leslie et al. 1987). Table 1 illustrates the extreme variability in stocking rates that have been used under different conditions.

**Table 1**
**Stocking Rate Requirements for Case Studies**

| Source | State | Stocking Rate, fish/vegetated ha |
|---|---|---|
| Sutton and Van Diver (1986) | Florida | 3 to 638 |
| Leslie et al. (1987) | Florida | 9 to 440 |
| TVA (1990) | Alabama | 17 |
| Klussman et al. (1988) | Texas | 74 |
| Santha et al. (1991) | Texas | 79 to 130 |
| Wiley et al. (1984) | Illinois | 47 to 370 |
| Bonar et al. (1993) | Oregon | 180 |
| Stocker and Hagstrom (1985) | California | 6,323 |

Factors accounting for variability in reported stocking rates include control objectives, water body characteristics (e.g., size, temperature regime, and geographic region), plant infestation characteristics (e.g., plant species, overwintering level, regrowth rate, and peak density), and grass carp stocking size, mortality, and feeding and dispersal behavior.

Because of the multiple issues involved, determination of proper stocking rates must be based on individual site conditions and objectives. Further, because grass carp are long-lived and difficult to remove after stocking, overstocking can create long-term undesirable impacts (Leslie et al. 1987; Klussman et al. 1988). In efforts to aid determination of proper stocking rates, several computer models have been developed by various State and Federal agencies in the past (Miller and Decell 1984; Swanson and Bergersen 1988; Wiley et al. 1984; Boyd and Stewart 1990; Santha et al. 1991). In general, each of these models represents a simplified account of the overall processes that interact within this complex biocontrol system. They by no means have been designed to consider all of the biological or environmental variability encountered under real conditions. Instead, these models provide a desktop tool for examining the effects of user defined variability in one or more of the identified system drivers. Through exercise of these tools, aquatic plant control decision makers are provided the opportunity to ask "What if" type questions regarding grass carp use under environmental and biotic conditions representative of their water body.

The objectives of this paper are to illustrate use of the White Amur Stocking Rate Model

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developed by the U.S. Army Engineer Waterways Experiment Station (WES) for evaluating effects of selected site conditions on stocking rate requirements.

## Model Description

The current version of the WES White Amur Stocking Rate Model (AMUR/STOCK) is based in part on an earlier model developed by WES (Miller and Decell 1984) and on the grass carp bioenergetics module included in the Illinois Herbivorous Fish Simulation System (Wiley et. al 1985). Along the lines of these two earlier simulations, the current WES model has separate routines for generating daily estimates of plant biomass and for estimating the size and remaining number of grass carp.

The plant growth simulation routine considers the effects of plant species, season, temperature, current plant biomass, and previous herbivory level on daily plant growth and mortality rates. Daily net growth is calculated by subtracting mortality losses (leaf sloughing) from the daily growth increment. Daily net growth, which is also corrected for a fish herbivory estimate generated by the fish routine, can therefore be negative in value. A daily update of total plant biomass is calculated by adding the daily growth increment to the total plant biomass estimate for the previous day.

Daily plant consumption by grass carp is determined by the number of grass carp remaining and relationships that consider the average size of fish, temperature, and plant species. Daily fish growth is calculated from the daily consumption amount, which is adjusted to account for assimilation efficiency of consumed plant material. Assimilation efficiency is also a function of fish size, temperature, and plant species. Finally, fish metabolic costs are subtracted from the assimilated amount. All calculations in the fish bioenergetics module are based on caloric values, which are estimated for each plant species. Final conversion of net caloric gain into fish biomass is a function of previous fish size and temperature. Reductions to the number of fish are made at the end of each year of the simulation period. Yearly mortality estimates can be input by the user, or the model can be run using a default mortality setting of 10 percent per year.

## Model Application Procedures

The first step in applying the model is calibration of the plant growth module for the plant infestation in question. This is a two-step process that involves initializing the module for the plant species, the overwintering plant biomass level, and the peak plant biomass level. These biomass estimates should be provided from field measurements. Next, the user must make adjustments to the calibration datasets for the effects of season and temperature on daily plant growth and mortality rates. These calibration datasets must be corrected in order that calculated plant growth rates generate a seasonal plant growth curve that represents field conditions. This process should include input of a water temperature dataset for the water body to be evaluated. If temperature datasets are not available to the user, the model can be initialized with one of several default datasets included with the model software package.

Initialization of the grass carp module includes inputs for the number of grass carp to be stocked and the average size of individual fish. Finally, the user inputs the duration of the simulation period and a fish mortality estimate for each year of the simulation period.

After first generating an estimate of the number of hectares of control for each year of the simulation period that the stocked fish will exert on the target plant infestation, the model next calculates the initial stocking rate requirement (fish per vegetated hectare) for obtaining control during each subsequent year. For example, consider a simulation under which 1,000 grass carp were estimated to control 10 ha of vegetation at the end of Year 1, 50 ha by Year 2, 200 ha by Year 3, 500 ha by Year 4, and 1,000 ha by Year 5. Final model calculations would estimate that initial stocking rates of 100 fish per vegetated acre would provide control by the end of Year 1. If control objectives were to obtain control within the first year, a stocking rate near this level would be considered appropriate for the simulation conditions. However, if control objectives provided that control was not necessary until the third year after stocking, then initial stocking rates could be reduced to five fish per vegetated hectare (i.e., 1,000 fish stocked at 200 ha controlled by Year 3).

## Demonstration of Model Use

### General initializations

As stated above, the objectives of this paper are to demonstrate use of the WES White Amur Stocking Rate Model for evaluating effects of selected site conditions on stocking rate requirements. For these comparisons, certain initialization conditions were constant for all simulation runs. The water temperature dataset illustrated in Figure 1 was taken from average median monthly water temperatures from Guntersville Reservoir, Alabama, for the 4-year period, 1984-1987. Note shading in Figure 1 that highlights those times of the year when water temperatures are below 12 °C, the lower threshold temperature for grass carp feeding. Average size of stocked fish was initialized at 0.34 kg, an approximation of the average weight of a 30-cm fish (Kirk, Morrow, and Killgore 1994). All simulations additionally considered that the target plant was *Hydrilla verticillata*, a plant that ranks highly on most feeding preference lists of grass carp (Sutton and Van Diver 1986; Leslie et al. 1987). Finally, grass carp mortality rates were set to zero for simulations generated to evaluate the effects of different levels of peak and overwintering plant biomass.

### Levels of peak biomass

Peak biomass levels evaluated for their effects on grass carp stocking requirements were 110, 220, and 440 g/m$^2$. These values equate on a fresh weight basis to approximately 11, 22, and 45 metric tons per hectare, respectively. In field situations, these differences in peak biomass levels could occur because of different plant species or for a given

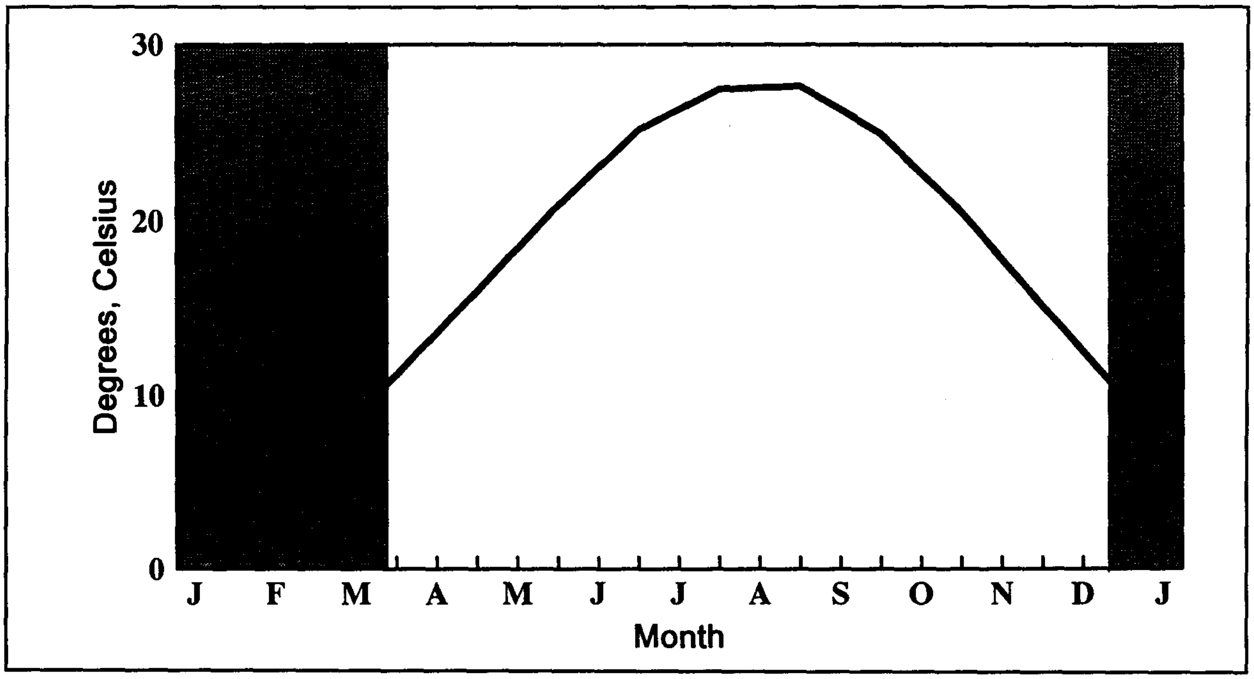

*Figure 1. Water temperature file derived from average median monthly water temperatures for Nickajack Dam tailrace, Guntersville Reservoir, Alabama, during 1984-1987. Shading indicates periods when temperatures were below 12 °C, the lower threshold temperature for grass carp feeding in the model*

plant species because of differences in colony age, prior treatment history, or for a list of environmental factors, including water depth, light availability, and sediment nutrient levels.

For each of these three peak biomass levels, plant growth was initiated with an overwintering biomass level of 11 $g/m^2$, or approximately 1 metric ton per hectare. The resulting plant growth curves, generated using different calibration datasets for the effects of season and temperature on growth rates, are shown in Figure 2. Note that the spring regrowth rate for the high peak biomass growth curve is the highest, as illustrated by this growth curve having a greater slope during the spring period.

## Levels of overwintering biomass

Overwintering biomass levels can also vary among plant species, geographic region, water body type, and location within a water body. Overwintering biomass levels considered herein were 11, 44, and 110 $g/m^2$. The lower level represents plant colonies that overwinter as root crowns, specialized overwintering structures (e.g., tubers) or nonintact stem fragments. In these plant colonies, the majority of shoot material generated during the growing season is lost through senescence or by other processes (e.g., displacement because of hydrological breakage and transport). The highest overwintering level represents plant colonies that overwinter intact. As stated above, these differences in overwintering levels can be due to differences in either plant species or site conditions.

Peak plant biomass for the simulations representing the three overwintering biomass levels was initialized at 440 $g/m^2$. Resulting plant growth curves are illustrated in Figure 3. In comparison, note that although regrowth rates were similar for the three simulations, attainment of peak biomass was delayed by approximately 2 months in the simulation for the lowest overwintering biomass level.

## Levels of grass carp mortality

Differential mortality levels in stocked grass carp are a major source of variability in stocking effectiveness. Numerous factors account for mortality variability, including differences

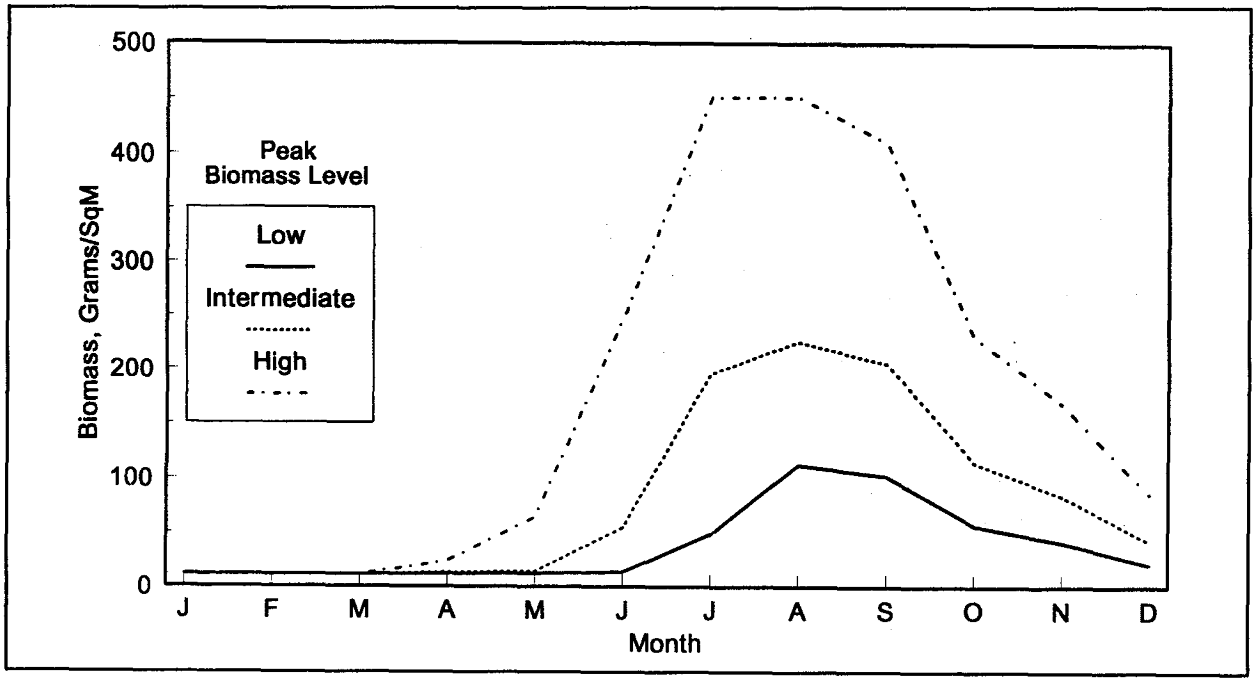

*Figure 2. Seasonal plant biomass curves generated by the AMUR/STOCK model for considering the effects of three different peak biomass levels on grass carp stocking rate requirements. Refer to text for initialization conditions*

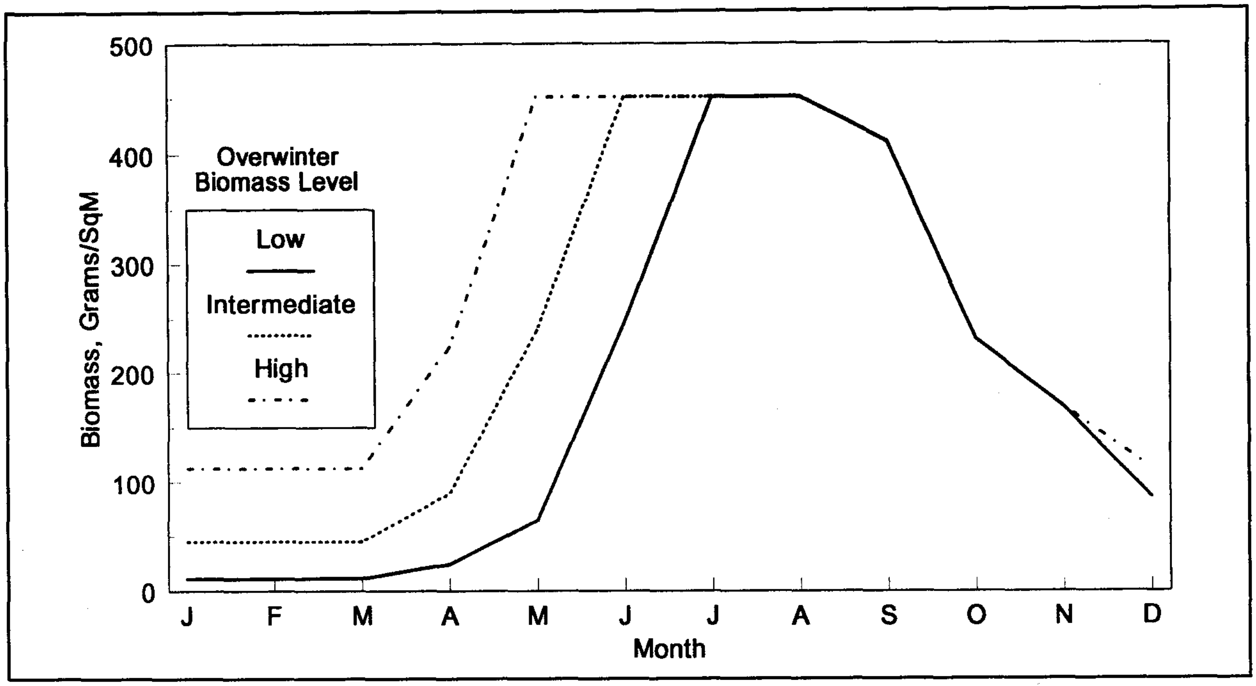

*Figure 3. Seasonal plant biomass curves generated by the AMUR/STOCK model for considering the effects of three different overwintering biomass levels on grass carp stocking rate requirements. Refer to text for initialization conditions*

in stocking size, predator populations, and commercial fishing pressure. In addition, movement of stocked fish results in variable losses from the target treatment area over time. To illustrate the significance of fish losses, simulations for a 10-year period representing three levels of grass carp mortality were generated. As a baseline for comparison, one set of simulations considered a zero-mortality level for each year of the 10-year period. The second set of simulations used the model default setting of 10-percent mortality per year. The highest mortality settings for these comparisons considered 50-percent mortality in Year 1, 25 percent in Years 2 and 3, and 10 percent in Years 4 through 10.

## Simulation Outputs

For the three sets of conditions described above, simulation outputs were generated to provide estimates of the stocking rates (April of Year 1) required to provide control by late summer of poststocking Years 1 through 10. Stocking rate requirement estimates generated for the effects of peak plant biomass are provided in Table 2. As was expected, stocking rate requirements were sensitive to peak biomass level as well as to poststocking time. Stocking requirements ranged from 167 fish/ha for control of high peak biomass plant growth by Year 1 to 4 fish/ha for control of low peak plant biomass growth by Years 6 through 10. Stocking requirements for the high peak biomass plant growth simulations were consistently highest for each poststocking year. For control in the first poststocking year, rates

**Table 2**
**Stocking Rate Requirements for Different Peak Biomass Levels**

| Poststocking Year | High | Peak Biomass Level Intermediate | Low |
|---|---|---|---|
| 1 | 167 | 71 | 32 |
| 2 | 31 | 22 | 12 |
| 3 | 16 | 13 | 7 |
| 4 | 12 | 9 | 6 |
| 5 | 10 | 8 | 5 |
| 6 | 9 | 7 | 4 |
| 7 | 9 | 7 | 4 |
| 8 | 9 | 7 | 4 |
| 9 | 8 | 7 | 4 |
| 10 | 8 | 7 | 4 |

estimated for high peak biomass plant growth were five times higher than for low peak biomass plant growth. This difference had decreased to a two-fold higher rate by the fifth poststocking year. Differences in stocking rates remained approximately two-fold for the remainder of the 10-year period.

Stocking rate requirements for the three overwintering plant biomass levels are given in Table 3. Increases in overwintering biomass resulted in significant increases in stocking rate requirements. Stocking requirements in the simulations ranged from 526 fish/ha to 8 fish/ha, depending on overwintering biomass levels and poststocking year. The stocking rate requirement for the high overwintering biomass level was approximately three times higher than the low level in each poststocking year. These simulation outputs are of further significance when compared with simulation outputs for low peak biomass described above. Under these comparisons, stocking requirements for Years 7 through 10 for the high overwintering biomass plants, which were initialized with the highest peak biomass level, are approximately 6 to 7 times higher than requirements for low peak biomass plants, which were initialized with the lowest overwintering biomass level.

**Table 3**
**Stocking Rate Requirements for Different Overwintering Biomass Levels**

| | | Overwintering Biomass Level | |
|---|---|---|---|
| Poststocking Year | High | Intermediate | Low |
| 1 | 526 | 222 | 167 |
| 2 | 95 | 42 | 31 |
| 3 | 50 | 22 | 16 |
| 4 | 37 | 16 | 12 |
| 5 | 31 | 14 | 10 |
| 6 | 29 | 13 | 9 |
| 7 | 27 | 12 | 9 |
| 8 | 26 | 12 | 9 |
| 9 | 26 | 11 | 8 |
| 10 | 25 | 11 | 8 |

Simulation outputs of stocking rate requirements for the three grass carp mortality levels are given in Table 4. Outputs for "zero mortality" simulations indicate that stocking rate requirements will decrease annually over the first 4 years and then stabilize for the remainder of the 10-year simulation period. Increases in grass carp mortality rates resulted in increased stocking rate requirements for each poststocking year. For example, in order to maintain control into the tenth poststocking year, Year 1 stocking rates would have needed to have been approximately seven times higher under the high mortality conditions (58 fish/ha) than under the zero-mortality conditions (8 fish/ha). It is further noteworthy that peak effectiveness (i.e., minimum stocking requirements) for simulations that experienced grass carp mortality losses occurred in poststocking Years 5 to 6, after which time stocking rate requirements gradually increased.

**Table 4**
**Stocking Rate Requirements for Different Grass Carp Mortality Levels**

| | | Grass Carp Mortality Level | |
|---|---|---|---|
| Poststocking Year | Zero | Intermediate | High |
| 1 | 167 | 169 | 175 |
| 2 | 31 | 36 | 68 |
| 3 | 16 | 21 | 48 |
| 4 | 12 | 17 | 45 |
| 5 | 10 | 16 | 42 |
| 6 | 9 | 16 | 43 |
| 7 | 9 | 17 | 45 |
| 8 | 9 | 19 | 48 |
| 9 | 8 | 20 | 53 |
| 10 | 8 | 22 | 58 |

## Management Considerations

Numerous interacting factors account for variability associated with grass carp effectiveness following release. The effects of these factors therefore must be considered in order to determine proper stocking rates for the desired level of aquatic plant control. The WES Stocking Rate Model was designed to help aquatic plant managers consider the effects of some of these factors. Examples presented herein illustrate the significance of poststocking time coupled with two characteristics of plant growth (i.e., overwintering and peak biomass levels) and with grass carp mortality rates.

Poststocking time was the single most important factor affecting stocking rate requirements in these simulations. For the different sets of simulation conditions considered, stocking rate requirements were as much as 20 times higher for control by the end of the first year than by the end of the sixth and subsequent years. These differences stem from the fact that as fish grow in size, they eat more, and therefore fewer are required to provide the same level of control. Leslie et al. (1987) advised caution in selecting stocking rates that would provide control of hydrilla in the first couple of years in multiuse lakes. As peak effectiveness of stocked fish is often delayed until the fifth or sixth year following stocking, stocking rates aimed at providing control of all target areas within the first few years following stocking will probably be too high. Results of such improper stocking would include both unnecessary costs for purchase of fish and possible detrimental ecological impacts to nontarget areas.

Generally speaking, grass carp are effective only when they can consume more plant biomass than is produced by plant growth in the target area. Because plant growth varies among different plant species and site conditions, researchers often recommend that stocking rates be based on numbers of fish per metric ton of vegetation (Leslie et al. 1987). Though this method is more advantageous than stocking rates based solely on area of infestation, simulation outputs herein indicate that overwintering biomass levels and regrowth rates should also be considered in addition to peak biomass levels.

In addition to plant growth characteristics, grass carp losses also affect stocking results. Variability in loss rates are known to occur because of differences in grass carp health condition or size at stocking or to differences in predator populations. Additionally, similar losses could result from nonmortality-based factors, such as off-target movement within the stocked water body or escape from the water body. No matter what the cause in grass carp losses, the net result is decreases in plant consumption and control effectiveness. In situations where actual losses are high and cannot be reduced by stocking technique, higher stocking rates will be required.

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