Bioenergetics of Grass Carp:

Water Quality Implications

by

Zhengwei Cai

Lawrence R. Curtis

Water Resources Research Institute

Oregon State University

Corvallis, Oregon

WRRI-101

August 1988

BIOENERGETICS OF GRASS CARP:

WATER QUALITY IMPLICATIONS

by

Zhengwei Cai and Lawrence R. Curtis
Department of Fisheries and Wildlife, Oregon State University

Final Technical Completion Report
Project Number G1444-06

Submitted to

United States Department of the Interior
Geological Survey
Reston, Virginia 22092

Project Sponsored by:

Water Resources Research Institute
Oregon State University
Corvallis, Oregon 97331

The research on which this report is based was financed in part by the Department of the Interior, U.S. Geological Survey, through the Oregon Water Resources Research Institute.

WRRI-101 August 1988

ABSTRACT

Triploid grass carp (TGC) were introduced into Devils Lake (near Lincoln City, Oregon) during 1985 for aquatic weed control. Use of this species as a biological pest control agent in the Pacific Northwest raised some controversy. Most previous U.S. introductions were with diploid fish in the Southeast and Midwest. Information on comparative bioenergetics of diploid and TGC under Northwestern environmental conditions was not available. Consumption rates of problem macrophytes present in Oregon coastal lakes at temperatures found in such waters were unestablished. The proportion of ingested energy utilized by TGC (i.e. assimilation efficiency) under such conditions was also unknown. This latter point was of concern since low assimilation efficiency at high consumption rates has been associated with increased available nutrient concentrations and blooms of bacteria and algae.

Bioenergetics of diploid and TGC were not significantly different. Relative consumption rates for the problem aquatic macrophytes tested were elodea > water milfoil >> coontail at 20°C. Consumption of elodea by TGC increased 4-fold between 14 and 24°C without significant effects on assimilation efficiency, which averaged 45% on an energetic (caloric) basis and 40% on a dry weight basis. Near the annual high temperature for Devils Lake (19°C) TGC consumed 25% of their body weight per day of elodea and increased their body size 24% in 32 days. Temperatures of Northwestern lakes may protect against algal and bacterial blooms associated with over-grazing by TGC. Lower consumption rates for coontail, and to a lesser extent water milfoil, than elodea may result in a shift in abundance of aquatic weeds.

INTRODUCTION

Problem

Many of Oregon's coastal lakes, including Devils Lake (near Lincoln City, Oregon), are undergoing eutrophication linked to excess influx of nutrients from a variety of sources including pollution from septic systems and livestock. Aquatic macrophytes obstruct boating, impair fishing, and encourage siltation resulting in greatly diminished recreational potential. Control technologies for aquatic weeds have not been implemented successfully and public pressure led to experimental introduction of triploid grass carp. This action was controversial for two primary reasons. (1) Over grazing by grass carp in certain waters and subsequent increases in nutrient levels associated with incomplete digestion of ingested plants lead to blooms of bacteria and algae (Kogan 1974; Menzel 1974). These organisms can produce conditions (e.g. noxious odors and surface layers) more unpleasant than aquatic macrophytes. (2) Aquatic vascular plants provide forage for waterfowl. Heavy grazing by grass carp could substantially reduce the standing crop and thereby eliminate habitat.

Careful evaluation of grass carp as a weed control technology is essential due to the scope of Oregon's lake eutrophication problem and the scarcity of data available to evaluate potential effects of these fish on Northwestern lakes.

Research Objectives

In order to rehabilite a eutrophic lake grass carp must consume sufficient plants to reduce the standing crop, and the energy should be fixed in fish tissue to remove it as a source for growth of undesirable organisms (e.g., bluegreen algae and bacteria). The desired amount of reduction in plants will depend upon perceived value of other organisms which utilize aquatic vascular plants as a resource (e.g., waterfowl). Regardless of the desired level of weed control, estimates of grass carp consumption and growth are necessary to estimate stocking rates for a target standing crop. Consumption and assimilation rates for triploid grass carp feeding on problem macrophytes in Oregon lakes are probably impossible to define in the field. Our laboratory experiments provide an empirical basis for understanding bioenergetic relationships between these animals and Northwestern lake environments.

Related Work

Ecological research on responses of aquatic macrophyte and animal communities after stocking of triploid grass carp is ongoing in Devils Lake, Oregon. This work is directed by Dr. Gilbert Pauley of the University of Washington Cooperative Fisheries Unit.

Mitzner (1978) reported decreased mean nitrites, nitrates, BOD and turbidity and increased alkalinity after introduction of grass carp at Red Haw Lake (Iowa). He also found mean concentrations of organic and inorganic phosphate gradually increased but not to a statistically significant extent. Lembi et al. (1978) reported increased potassium levels in test ponds. Nitrogen and phosphorus levels were also higher, but the increase was not statistically significant. Increased availability of nutrients from grass carp grazing can lead to excessive phytoplankton blooms. Shireman (1984) states stocking rate is an essential variable in occurrence of such problems. No report of impact of triploid grass carp on water quality has been published. No laboratory data are available for conditions patterned to reflect the environments of Northwestern lakes.

EXPERIMENTAL DESIGN AND METHODS

Rationale

One objective of this research is increased understanding of the capacity of grass carp to fix the energy of aquatic macrophytes into their tissues. Removal of plant biomass from eutrophic aquatic systems is the goal of grass carp introduction. Energy consumed as plant biomass but not fixed in fish tissues is excreted and available for subsequent plant growth, particularly algae and bacteria. Estimation of grass carp efficiency in assimilation of ingested macrophytes can help explain impacts of their introduction into eutrophic aquatic systems. The second major objective of this research is improved understanding of food consumption and growth of triploid grass under conditions in Northwestern Lakes. Food type and temperature were the two parameters studied. Such data are necessary for estimating stocking rates required for a given level of weed control.

Methods

We fed diploid and triploid grass carp the three principal aquatic macrophytes present in Devils Lake. Fish were donated by Osage Catfisheries (Osage, MO). Additional fish were fed a commercial catfish feed to serve as a control. The rates of food consumption and efficiency of conversion of ingested material were determined at temperatures relevant to Oregon coastal lakes for triploid fish.

Water milfoil (Myriophyllum sp) coontail (Ceratophyllum demersum) and elodea (Elodea canadenis) were selected based on food preference studies with triploid grass carp conducted by the University of Washington Cooperative Fisheries Unit (personal communication). Water content, protein, fat, ash, and cellulose in each diet were measured by the AOAC methods (1975). Energy content of materials was determined by an oxygen bomb calorimeter. Before feeding, fresh aquatic plants were washed to remove adherent sediments and encrusting organisms and then blotted and weighed. Uneaten food and feces in each aquarium were collected and weighed before new food was added. The uneaten food was also washed, blotted, and weighed to calculate food consumption. The collected feces were dried and used to measure protein, fat, ash, and cellulose by the same method as used in diet measurements.

Food consumption rate (mg per gram of fish per day), growth rate (mg of weight gain per gram of fish per day), assimilation efficiency and gross growth efficiency (mg of weight gain per mg of food ingested) were calculated (Warren 1971).

Assimilation efficiency was calculated using cellulose as a reference (Buddington, 1980).

$$\text{Assimilation efficiency} = 1 - \frac{\text{percentage of cellulose in food}}{\text{percentage of cellulose in feces}}$$

$$\text{Gross growth efficiency} = \frac{\text{growth rate}}{\text{food consumption rate}}$$

Bomb calorimetry was used to quantitate the assimilation and waste of energy consumed. The basic bioenergetic model of Warren (1971) was applied.

RESULTS AND SIGNIFICANCE

Table 1 summarizes the composition and energy content of various diets used in this study. Water contents of all plants were around 90% while that for the commercial feed was about 10%. As would be expected the commercial diet contained more protein than the aquatic plants. Elodea leaf did have a rather high protein content however. Lipid contents of all plants tested were higher than the commercial diet. Elodea had about twice the lipid of water milfoil and coontail was intermediate. On a dry weight basis, energy contents of all diets tested were comparable.

The consumption, growth rates, and assimilation efficiencies of diploid and triploid grass carp fed the above diets at 20°C are in Table 2. Relative consumption rates on a wet weight basis for both diploid and triploid fish were elodea > water milfoil >> coontail >>> catfish feed. When food consumption rates were expressed on a dry weight basis absolute differences between catfish feed and plants were greatly decreased while relative rates were little changed. It is important to note that relative growth rates were elodea > water milfoil ≥ catfish feed >> coontail for both diploid and triploid fish. Assimilation efficiencies decreased in the order: catfish feed > elodea >> water milfoil ≥ coontail for both diploid and triploid fish. Taken together our data indicated no differences between bioenergetics of diploid and triploid grass carp fed different diets. This suggests literature on diploid fish may be useful in understanding bioenergetics of triploid grass carp.

We next examined the effect of environmental temperature on consumption, growth, and assimilation efficiency of triploid grass carp fed elodea (Table 3). Consumption and growth rates increased from 14.4 to 24.4°C. Analysis of variance indicated assimilation efficiency, on both a dry matter and energy basis, remained nearly constant over this range. At higher consumption rates, however, fecal energy loss increased with environmental temperature. At 18.8°C (near the annual high temperature for Devils Lake) fish consumed about 25% of their body weight in elodea per day and grew 24% in 32 days. These data suggest triploid grass carp can grow at modest rates under conditions representative of Northwestern coastal lake environments. Further, since consumption rates more than double between 14.4 and 18.8°C highest grazing rates should occur in summer.

We next evaluated the relative benefit of diet type in growth of triploid grass carp between 14.4 and 24.4°C. At all temperatures growth rates decreased with time after changing the diet from elodea to catfish feed (Table 4). This effect was more pronounced at 14.4 and 24.4°C than 18.8°C. Consumption rates for catfish feed remained constant except at 14.4°C (Table 4), however feed conversion efficiency (Fig. 1) decreased within 3 weeks after changing diet in all temperatures. Onset of this effect was most rapid at 18.8°C. These data suggested triploid grass carp will grow at higher rates over prolonged periods when consuming elodea than commercial catfish feed. It therefore seems their nutrition requirements should be met in Northwestern coastal lakes. Of the three aquatic plants tested elodea had the highest protein and lipid contests. Grass Carp fed elodea consumed more and grew faster than fish on any other diet. Simple protein and lipid content alone may explain the apparent higher quality of elodea as food for grass carp. More specific aspects of plant composition, for example amino acid consistuents of proteins or fatty acid constituents of lipids, may likely contribute also.

Conclusions

Both diploid and triploid grass carp consumed the aquatic weeds tested at the relative rates: elodea > water milfoil > coontail. On an energy basis assimilation efficiency of triploid fish at 20°C was about 40% for elodea and water milfoil, but 20% for coontail. Fecal energy loss increased exponentially with the amount of elodea consumed by grass carp. Respective consumption and growth rates for triploid fish fed elodea increased about 4 and 5-fold between 14 and 24°C. Temperature did not effect assimilation efficiency over this range.

Annual peak temperatures of 18-19°C occur in late summer in Devils Lake. Our laboratory data indicate triploid grass carp will consume about 25% of their body weight per day of their most preferred food (elodea) at 18.8°C. Consumption-related reductions in assimilation efficiency do not occur at this feeding rate. Typical Northwestern environmental water temperatures may therefore protect against algal and bacterial blooms associated with over-grazing by grass carp. Low consumption rates and assimilation efficiencies for coontail and to a much lesser extent water milfoil may result in a species abundance shift for aquatic vascular plants.

References

1. AOAC. 1975. Official Methods of Analysis of the Association of Official Analytical Chemists (William Horowitz, ed.) 112th ed. Washington, D.C. AOAC.

2. Buddington, R.K. 1980. Hydrolysis-resistant organic matter as a reference for measurement of fish digestive efficiency. Trans. Am. Fish. Soc. 109,653.

3. Kogan, S.I. 1974. Overgrowing of the Kara Kum Canal and some after effects of introducing the white amur into water bodies. Gidrobiol. Zh. 10:110-115. (In Russian).

4. Lembi, C.A. et al. 1978. The effect of vegetation removal by grass carp on water chemistry and phytoplankton in Indiana ponds. Trans. Am. Fish. Soc. 107(1):161-171.

5. Menzel, A.V. 1974. Clearing water with herbivorous fish. Proc. Eur. Wed. Res. Counc. Int. Symp. Aquat. Weeds. 4:139-141.

6. Mitzner, L. 1978. Evaluation of biological control of nuisance aquatic vegetation by grass carp. Trans. Am. Fish. Soc. 117(1):135-145.

7. Shireman, J.V. 1984. Control of aquatic weeds with exotic fishes. In "Distribution, Biology, and Management of Exotic Fishes" (ed.) by

W.R. Courtenay and J.R. Stanffer. Pp. 302-312.

8. Warren, C.E. 1971. Bioenergetics and growth. In Biology and Water Pollution Control, pp. 135-167. W.B. Saunders Co., Philadelphia

Table 1. Proximate chemical composition of the experimental diets (%).*

Diet		Percent Dry Matter	Composition of dry matter					
			Protein	Lipids	Ash	Fibre	Other[a]	Energy Kcal/g
Elodea	whole	8.80±0.29	15.80±0.35	8.43±0.95	20.09±0.75	25.45±0.75	30.23	
	leaf	10.65±0.73	22.80±0.59	7.66±0.43	18.34±0.37	23.92±0.84	27.28	3.61±0.06
Coontail	whole	7.81±0.26	12.40±2.50	5.69±0.06	14.00±0.40	26.80±2.20	41.09	
	leaf	8.06±0.43	16.70±0.50	5.67±0.43	14.07±0.36	23.98±0.50	39.58	3.56±0.12
Watermilfoil	whole	13.02±1.71	9.41±0.88	4.13±0.27	17.60±2.12	22.27±0.98	46.59	
	leaf	12.05±1.72	6.51±0.25	4.93±0.20	14.17±0.12	20.15±0.15	54.24	4.27±0.06
Catfish[c] feed		89.16±0.10	33.27±0.16	3.49±0.42	9.42±0.70	7.94±0.06	45.88	4.38±0.06

* Results are mean ± SE of duplicate samples unless indicated elsewhere. Analytical methods are described in AOAC, 1975.

a "Other" represents nitrogen-free extract and was calculated by subtraction.

b Since fish consumed only the leaves of plants provided only their caloric content was determined. Other data were provided for comparison.

c Sample size for dry matter and protein measurements was 3 and that for lipid measurement was 6. Protein was measured by the Kjedahl method by the Plant Analysis Laboratory, Department of Horticulture, Oregon State University.

Table 2. Influence of diet on food consumption, growth, and assimilation efficiency of diploid and triploid grass carp at 20°C.

Diet	Elodea		Water Milfoil		Coontail		Catfish Feed	
Food Consumption (% of initial body wt/day)	Diploid Fish	Triploid Fish	Diploid Fish	Triploid Fish	Diploid Fish	Triploid Fish	Diploid Fish	Triploid Fish
wet wt. basis	42.6	40.9	29.4	27.4	14.2	15.4	1.4	1.11
dry wt. basis	4.54	4.36	3.82	3.3	1.14	1.24	1.30	1.00
Instantaneous growth rate mg g^{-1} day^{-1}	0.65* ±0.24	0.66 ±0.06	0.27 ±0.07	0.29 ±0.04	-0.15 ±0.09	-0.17 ±0.09	0.25 ±0.05	0.23 ±0.05
Assimilation efficiency (% on dry wt basis)	34.2* ±4.3	38.5 ±2.9	17.5 ±1.7	23.3 ±1.9	18.5 ±1.6	12.7 ±2.4	66.9 ±0.1	68.3 ±0.5

Results are means ± SEM for 5 individual fish (20 - 40 g wet weight) in each group. Feeding trails were of 27 days duration. *Average of two experiments.

Table 3. Consumption and Growth Rate of Triploid Grass Carp fed Elodea at different temperatures.

Temp.	14.4°C	18.8°C	24.4°C
Final body weight (g)	86.6±6.4	96.2±4.8	116.7±8.4
Initial body weight (g)	80.6±5.2	77.3±6.6	82.3±3.4
Consumption (% of body weight per day *)	11.0±0.5	25.2±0.9	39.9±2.1
Instantaneous growth rate (% per day)	0.21±0.07	0.72±0.14	1.06±0.12
Food conversion rate			
wet food	50.6	36.9	35.4
dry food	5.39	3.93	3.77
Digestion efficiency**			
on dry matter basis	41.0±1.8%	44.2±2.6%	38.6±4.1%
on energy basis	44.6±1.7%	49.2±2.3%	48.8±3.4%

* Based on the total six fish in each aquarium. Results are expressed as the mean of relative daily consumption ± SE over 32 days.

** Based on measurements of cellulose content in three feces samples.

Table 4. Consumption and Growth Rate of Triploid Grass Carp after changing diet from Elodea to catfish food.*

Temp.		Date (days) Sept.14 to 25 (12)	Sept.26 to Oct.6 (11)	Oct.7 to 16 (10)
14.4°C	GR	0.68±0.10	0.51±0.08	-0.06±0.08
	CR	112 (2.50%)	100 (2.25%)	83 (1.94%)
18.8°C	GR	0.50±0.26	0.41±0.05	0.34±0.11
	CR	164 (3.12%)	145 (2.77%)	153 (3.13%)
24.4°C	GR	1.23±0.07	1.28±0.10	0.31±0.07
	CR	302 (4.64%)	330 (4.76%)	323 (4.45%)

* Results are means±SE for 4 fish.
GR= instantaneous growth rate, % per day;
CR= consumption rate, gram of diet consumed during that period (% of body weight per day).

Figure 1. Feed conversion efficiency of grass carp before and after diet change at various temperatures.

EL-fed fish in 32 days, before diet change;

CP-fed fish in the first 12 days, after diet change;

CP-fed fish during the 13th to 23rd day, after diet change;

CP-fed fish in the last 10 days, after diet change.