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Hybrid grass carp resulting from the cross of a female grass carp, *Ctenopharyngodon idella* (Val.), and a male bighead carp, *Hypophthalmichthys* (*Aristichthys*) *nobilis* Rich., 12–18 months old (*c.* 300 mm T.L.) were studied in a two-part experiment to determine feeding preference and total daily consumption fish^{-1} on selected species of aquatic plants. Fish were maintained in circular pools with 6840·8 l of water inside a temperature-controlled greenhouse. Preference tests were conducted at three temperature ranges; 25–28° C, 17–20° C and 12–15° C. Based on the time to complete consumption or the relative quantity consumed, the most preferred plant was *Lemna gibba* when in combination with six other species. *Chara* sp., *Najas guadalupensis* and *Potamogeton pectinatus* were readily consumed and considered to be of about equal preference. *Ceratophyllum demersum* and *Myriophyllum brasiliense* were least preferred. Hybrid grass carp generally consumed as much plant material species^{-1} and in the same order of preference at the 12–15° C range as they did at 25–28° C. In the second part, mean daily consumption (g) fish^{-1} at 25·7–31·0° C for five plant species tested separately was as follows: *Chara* sp. 369·8; *Lemna gibba* 178·2; *Najas guadalupensis* 172·6; *Hydrilla verticillata* 106·4 and *Ceratophyllum demersum* 8·8.

I. INTRODUCTION

The utilization of grass carp, *Ctenopharyngodon idella* (Val.) for biological control of aquatic weeds in the United States is still a controversial subject (Greenfield, 1973; Stanley *et al.*, 1978; von Zon, 1979). Natural reproduction has occurred in Mexico and is suspected in the Mississippi River system (Sutton, 1977). Most states still prohibit grass carp introductions despite its great potential for controlling aquatic weeds (Sutton, 1977).

Production of a grass carp hybrid, resulting from the cross of a female grass carp and a male bighead carp, *Hypophthalmichthys* (*Aristichthys*) *nobilis* Rich., began in the United States on a commercial basis in 1979. The hybrid has been reported to be triploid and theoretically sterile (Marian & Kraznai, 1978; Beck *et al.*, 1980). However, we have found through karyological techniques that the majority of fish received by us from the 1979 and 1980 broods were diploid with the opposite result for hybrid grass carp received in 1981. Literature concerning results with the grass carp × bighead cross by European researchers is reviewed by Sutton *et al.* (1981).

Hybrid grass carp are being produced in the United States as a potential substitute for the grass carp. This transition has already taken place in Florida whereby a permit system has been established allowing the hybrid grass carp to be used by the general public for aquatic weed management purposes. Fingerling hybrid grass carp are omnivorous, feeding readily on aquatic invertebrates and several

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duckweed species (Cassani, 1981; Sutton *et al.*, 1981). *Chara* sp., *Najas guadalupensis* (Spreng.) Magnus and *Ceratophyllum demersum* L. are reported as preferred species of submersed aquatic plants by fingerling hybrid grass carp in artificial enclosures (Cassani, 1981).

The purpose of this study is to determine the feeding behaviour of yearling and older hybrid grass carp for several weed species on a selective and quantitative basis.

II. MATERIALS AND METHODS

This study was conducted in two parts, the first dealing with aquatic plant selectivity and the second part with total daily consumption for individual plant species. The fish utilized in the first part were purchased as fingerlings. At 18 months of age, 10 of the largest fish were selected from the rearing ponds and placed in an indoor pool. The average T.L. and weight of the fish was 296·7 mm ± 29·6 and 272·2 g ± 92·8 respectively. The pool was cylindrical with a diameter of 3·66 m and filled to an average depth of 0·65 m (6840·8 l) and was covered with semitransparent sheets of fibre-glass.

The following aquatic plant species were used in the first part concerning fish preference: *Lemna gibba* L., *C. demersum*, *N. guadalupensis*, *Hydrilla verticillata* (L.f.) Caspary, *Chara* sp., *Potamogeton pectinatus* L., *Myriophyllum brasiliense* Camb. Enough terminal sprigs to equal 30 g (fresh weight) for each species were potted individually in sand in glass jars overlaid with coarse gravel to prohibit scattering of the sprigs. The *Lemna* (150 g fresh weight) was placed in a styrofoam float with a square opening since it is a surface inhabiting plant. All seven plant species were presented to the fish simultaneously for a 6-day period. The plants were arranged in a row, 60–70 cm apart, toward one side of the pool. A second set of plants, arranged in the same manner, were placed into a small screened enclosure in the same pool as a control. The fish were allowed to acclimate to the pools for a period of 7 days prior to initiating each part of the study. Plant material remaining was noted each morning and afternoon and the time required for complete consumption was recorded. Plant material remaining after 6 days was removed and weighed to the nearest gram on a Mettler E20 electronic balance. Prior to introduction and removal, the plant material was placed in a fine mesh net bag and spun for 5 min at approximately 500 rpm in a washing machine to eliminate excess water. The resultant weight is referred to as the fresh weight.

Each treatment was repeated three times at 25–28° C and 17–20° C, and once at 12–15° C. The first three replicates were begun at the 25–28° C range and followed by the 17–20° C and 12–15° C ranges respectively. The water temperature was decreased from the initial range by manipulating the air temperature with evaporative coolers and in the 12–15° C range by repeatedly adding blocks of ice when needed. The water temperature was reduced slowly over a period of 48 h. The fish were allowed to acclimate for an additional 24 h before introducing the next set of plants. The pool water was aerated by pumping air through two 15-cm long airstones. Water temperature and dissolved oxygen measurements were recorded twice daily with a Y.S.I. Model 57 Dissolved Oxygen Meter.

In the second part of this study five aquatic plant species were evaluated for total daily consumption by yearling (12–14-months-old) hybrid grass carp. The fish used in the second part were also purchased from the same source as fingerlings from a brood produced during 1980. Five fish were placed into each of two pools of the same dimensions and volume as described. The average T.L. and weight of the fish used was 319·8 mm ± 9·9 and 381·2 g ± 34·2 respectively. These fish represented the fastest growing individuals from the 1980 brood received by us.

The five plant species used in this segment of the study were *C. demersum*, *L. gibba*, *Chara* sp., *H. verticillata* and *N. guadalupensis*. A predetermined fresh weight for each plant species was offered to the fish individually in each pool daily for 7 consecutive days.

The fish were offered at least 10% more plant material than could be consumed in a 24-h period as determined in several pre-test trials. The plant material was introduced in a bunch with the terminal sprigs outward in one direction. Each bunch was tied at one end with a rope attached to an overhanging support allowing the bunch to hang completely submersed but off the bottom. The *Lemna* was allowed to float freely but confined within a floating rectangular raft (84 × 107 cm). Each day uneaten plant material was removed and spun as described prior to weighing. A control bunch for each species was set up as described for the first part. Control bunches were introduced and weighed daily in the same manner as the treatment bunches.

In this segment of the study the pools were aerated as described for the first part. Water temperature for each pool was kept in the range of 25–31° C by manipulating the air temperature with thermostatically controlled evaporative coolers. About 70% of the water in each pool was drained and replaced by fresh water from a well after each set of replicates for each plant species.

Plant material used in both parts of the study was collected from ponds and canals in the vicinity of Fort Myers, Florida. The plant material collected for each species was fresh with little or no periphyton and showed no signs of senescence.

III. RESULTS AND DISCUSSION

All of the plant species used cause variable aquatic weed problems in the southeastern United States. *Hydrilla verticillata* presents the most severe problem (Haller, 1979).

The fish chosen for this study were typically intermediate in most morphological characters between the parent species and were unlikely gynogenetic specimens. Our hybrid grass carp differed most noticeably from grass carp in that it has smaller scales and a longer pectoral fin. Kilambi & Zdinak (1981) found that adult hybrid grass carp showed significant differences in five of eight proportional morphometric measurements as compared to grass carp but no mention was made as to whether the specimens were triploid or diploid.

The normal range of dissolved oxygen in the pools for the duration of the study was 6·0–8·0 ppm and was never below 5·0 ppm. Variation in dissolved oxygen between pools was rarely more than 1·0 ppm.

Of the seven plant species used in the first part of this study, involving selectivity, *L. gibba* was consistently the first plant species consumed regardless of temperature. *Chara, N. guadalupensis* and *P. pectinatus* were readily consumed at all three temperature regimens usually within 48 h after introduction but in no discernable order of preference (Table I). Consumption of *H. verticillata* was complete in all but one replicate at the 25–28° C range. *Hydrilla verticillata* was not usually completely consumed until the four previously mentioned species had been consumed. Water temperature below 20° C did not cause a feeding reduction on this plant. The remaining two plant species in the test group, *C. demersum* and *M. brasiliense* were never completely consumed and were usually the last plant species to show initial feeding damage.

These results are similar to those reported by Cassani (1981) with respect to *L. gibba, Chara, N. guadalupensis, H. verticillata* and a *Myriophyllum* sp. for fingerling hybrid grass carp with the exception that *C. demersum* was preferred by fingerling fish. Grass carp have been reported to feed on all of the aquatic plant species used in this study although the order of preference as reported by several authors, varies. Generally *Chara, N. guadalupensis, H. verticillata, Lemna* spp.

TABLE I. Mean consumption by hybrid grass carp (average 296·7 mm T.L.) for seven aquatic plant species when offered together at three temperature ranges

Plant	Initial weight (g)	25–28° C		17–20° C		12–15° C†	
		Mean consumption (g)*	Control	Mean consumption (g)*	Control	Consumption (g)	Control
Lemna gibba	150	150·0	150·5±2·1	150·0	128·4±26·9	150	145·9
Ceratophyllum demersum	30	13·3±13·5	34·7±9·9	27·5±2·8	29·1±1·9	23·3	32·0
Myriophyllum brasiliense	30	9·3±16·2	32·0±7·0	24·7±4·6	29·8±1·0	19·6	29·9
Hydrilla verticillata	30	25·6±7·5	32·0±5·3	30·0	30·6±2·0	30	27·5
Chara sp.	30	30·0	34·3±7·6	30·0	26·8±3·8	30	34·7
Najas guadalupensis	30	30·0	32·7±5·5	30·0	29·0±1·7	30	33·7
Potamogeton pectinatus	30	30·0	32·3±7·5	30·0	30·1±0·6	28	31·0

*Mean of three replicates (6 days exposure pre replicate).
†One treatment only.

and several *Potamogeton* spp. are readily consumed or 'controlled' by grass carp (Michewicz *et al.*, 1972; Sutton, 1974; Willey *et al.*, 1974; Chaudhuri *et al.*, 1976; Fowler & Robson, 1978). Grass carp have been particularly effective in eliminating *H. verticillata* in several large lake systems in Florida (Beach *et al.*, 1976; Miley *et al.*, 1979). Edwards (1974) reported that grass carp did not consume *C. demersum* until they had reached a T.L. of 350 mm. Also, Cole *et al.* (1978) found that *C. demersum* in a vegetated pond was discriminated against by grass carp that were 63–220 mm T.L.

Uninhibited feeding at temperatures below 20° C was not expected. Cassani *et al.* (1982) reported a decrease in feeding on duckweed by hybrid grass carp fingerlings as the water temperature dropped consistently below 24° C. The effect of increasing or decreasing photoperiod may have caused a more pronounced effect on feeding activity than previously thought. During the majority of the first part of this experiment the photoperiod was increasing daily while the results reported by Cassani *et al.* (1982) were based on a decreasing photoperiod. The fish used here represented the fastest growing, most vigorous individuals which may have been more tolerant to cooler temperatures with regard to feeding activity than the majority of slower growing individuals. Grass carp begin to consume aquatic plants at 12° C and begin intensive feeding at 22–33° C (Opuszynski, 1972).

Weight changes for the control plants are thought to be due to errors in handling the plants (lost fragments, etc.) prior to weighing. In most replicates, the weight changes were minor (Table I).

The results of the second part of this study, dealing with maximum consumption of individual plant species are listed in Table II. The water temperature during this part of the study was maintained in the range of 25·7–31·0° C. The feeding preference of hybrid grass carp for *Lemna, N. guadalupensis* and *Chara* as demonstrated in the first part of this study (Table I), is reflected in the results for total consumption (Table II). If maximum consumption accurately reflects maximum preference then *Chara* was highly preferred, followed by *L. gibba, N. guadalupensis, H. verticillata* and *C. demersum* in decreasing order of preference. Comparing the results on consumption to findings for grass carp by other authors indicates that grass carp consume greater quantities of the plants in question than

TABLE II. Daily consumption by hybrid grass carp (average 319·8 mm T.L.) during feeding trials (7 days per trial) with five aquatic plant species tested separately at a temperature range of 25·7–31·0° C

Plant	Mean amount fed daily (g)	Mean daily consumption (g)	Mean daily consumption fish^{-1} (g)	Mean control
Najas guadalupensis	1503·2 ± 4·1	863·4 ± 162·0	172·6	1475·6 ± 37·5
Hydrilla verticillata	1002·6 ± 2·8	532·1 ± 144·5	106·4	992·0 ± 19·4
Chara sp.	2002·6 ± 3·1	1849·2 ± 284·7	369·8	1964·0 ± 20·3
Lemna gibba	1500·0 ± 0	891·2 ± 180·4	178·2	1070·9 ± 36·6*
Ceratophyllum demersum	400·4 ± 1·1	44·1 ± 25·9	8·8	378·9 ± 6·9

*Only 1000 g were used for the control.

hybrid grass carp. Sutton (1974) reports that at 23·3–28·9° C, grass carp of 153 g initially consumed an average of 145 g (fresh weight) of *H. verticillata* day^{-1} fish^{-1} which was approximately 40 g more fish^{-1} than did hybrid grass carp used in this study weighing an average of 381·2 g. Considering the lesser weight of grass carp used by Mehta *et al.* (1976), grass carp consumed greater quantities of *H. verticillata* and *Chara* g^{-1} body weight than did larger hybrid grass carp in this study. Sutton (1976) reported that grass carp weighing 35 g consumed their body weight in *Lemna* day^{-1}. Hybrid grass carp weighing an average of 381·2 g consumed only 47% of their body weight in *Lemna* day^{-1} as reported here.

In summary, hybrid grass carp of a size that would normally be stocked for aquatic weed control ($\geqslant$ 300 mm T.L.) demonstrated an intermediate preference for *H. verticillata* when in combination with several other minor aquatic weed species. With respect to both preference and total consumption, the most preferred aquatic plants were *L. gibba, Chara* sp., *N. guadalupensis* and *P. pectinatus.* Least preferred were *C. demersum* and *M. brasiliense.* In the preference trials, hybrid grass carp generally consumed as much plant material species^{-1} and in the same order of preference at the 12–15° C temperature range as they did at 25–28° C. On a total consumption basis, hybrid grass carp consumed relatively less than grass carp for the same or closely related plant species reported by other authors. As a result, stocking rates for hybrid grass carp will have to be increased to necessitate the equivalent control achieved by grass carp, especially for *H. verticillata.*

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