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Feeding behaviour of underyearling hybrids of the grass carp, *Ctenopharyngodon idella* ♀ and the bighead, *Hypophthalmicthys nobilis* ♂ on selected species of aquatic plants

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Underyearling hybrids of the cross *Ctenopharyngodon idella* ♀ (grass carp) and *Hypophthalmichthys nobilis* ♂ (bighead), averaging 104·8 mm total length were stocked for two weeks in cement tanks holding 605 l of water with various combinations of submersed or floating aquatic plants. The submersed species most preferred were *Ceratophyllum demersum, Chara* sp. and *Najas guadalupensis. Hydrilla verticillata, Hygrophila polysperma, Myriophyllum pinnatum* and *Utricularia foliosa* were fed on from a minor to moderate extent. No feeding damage was observed on *Egeria densa* and *Potamogeton illinoensis. Azolla caroliniana, Lemna* sp. and *Wolffia columbiana* were readily consumed while *Salvinia rotundifolia* was not preferred when in combination with these floating plant species. Feeding damage to the submersed roots of *Eichhornia crassipes* and *Pistia stratiotes* was minor during a 30 day period. Hybrid fingerlings readily fed on mosquito larvae and small leeches when offered to them in an aquarium on one occasion.

I. INTRODUCTION

Introduction of the grass carp (*Ctenopharyngodon idella* Val.) into the United States as a biological control agent for aquatic weeds has produced considerable controversy. Proponents argue that the fish provides economical and environmentally safe aquatic weed control with little environmental impact, while those opposing its use suggest the possibility of escape and increased numbers through reproduction resulting in a negative impact on native biocoenoses (Cross, 1969; Stott & Robson, 1970; Michweicz *et al.*, 1972; Greenfield, 1973; Vinogradov & Zolotova, 1974; Stanley, 1976; Stanley *et al.*, 1978; von Zon, 1979). Large-scale studies of grass carp introductions in Florida show that grass carp effectively eliminate target weeds although ' over grazing ' may be of concern with respect to beneficial aquatic plants (Beach *et al.*, 1976; Miley *et al.*, 1979). The impact of grass carp on native fish populations, nutrient cycling and primary productivity are still controversial subjects (Sneed, 1971; Michewicz *et al.*, 1972; Stanley *et al.*, 1978). Grass carp are now banned from all states except Arkansas, Mississippi, Alabama and Kansas, while state officials in Florida, Iowa and Missouri allow fish purchases by permit only (Lynch, 1979).

Recently, attention in the United States has been directed toward the result of an intergeneric cross between female grass carp (*C. idella*) and male bighead carp (*Hypophthalmichthys nobilis* Rich.) as a possible alternative to the grass carp. Several European and Soviet researchers have successfully demonstrated this cross, primarily for producing a fish with better food quality characteristics

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(Makeeva & Sukhanova, 1966; Aliev, 1967; Andriyasheva, 1968, 1969; Makeeva, 1969; Andriyasheva, 1973; Bakos *et al.*, 1978; Márian & Krasznai, 1978). Karyological studies by Márian & Krasznai (1978) show that the somatic chromosome number of their F_1 hybrids to be $2n = 72$ compared to $2n = 48$ for both parent species. Aliev (1967) reported that young-of-the-year grass carp × bighead hybrids did not show any significant morphological differences as compared to similar age grass carp. Aliev (1967) also reported that these hybrids, in ponds, fed on terrestrial and aquatic vegetation and showed the greatest degree of heterosis as compared to other hybrids having the grass carp as one parent.

The potential of a sterile, phytophagous hybrid as a ' safe ' replacement for the grass carp in the United States was realized by J. M. Malone, a commercial fish farmer in Arkansas. As a result, Malone produced a spawn of grass carp × bighead hybrids in June, 1979. The U.S. Fish and Wildlife Service and physiologists at Memphis State University confirmed the triploid condition from a random sample of 100 fish from the Arkansas spawn through karyological techniques (Lynch, 1979; Malone, pers. comm.). The triploid condition was produced without outside force or manipulation of the egg stage (Malone, pers. comm.).

On 5 September, 1979, researchers at the Lee County Hyacinth Control District in Fort Myers, Florida, received approximately 2400 hybrid fingerlings from the June 1979 spawn by Malone in Arkansas. These fish were obtained for an experimental programme to evaluate the hybrid with respect to its potential for controlling aquatic weeds, primarily *Hydrilla verticillata* (L.f.) Casparay. This study was designed to demonstrate possible feeding preferences and to qualify feeding activity by underyearling grass carp × bighead hybrids when presented with a choice of several different aquatic plant species.

II. MATERIALS AND METHODS

The hybrid fingerlings were held in four earthen ponds (18·3 m long × 9·1 m wide having a maximum depth of 2·0 m, with 300–400 fingerlings per pond) and nine cement tanks (2·25 m long × 0·83 m wide × 0·55 m deep, with 100 fingerlings per tank). The cement tanks were filled with 605 l of water and maintained with a continuous flow-through or flushing rate of 37·9 l per hour and with constant aeration. Aquatic plants primarily *Najas guadalupensis* (Spreng.) Magnus, *Hydrilla* and *Chara* sp. were available to fingerlings in the ponds and *Najas* and *Hydrilla* was provided to those fish in the tanks. Floating catfish pellets were offered to fingerlings in both ponds and tanks, five days per week. The fish were maintained under these conditions for 12 weeks prior to establishing the feeding behaviour study.

Phase I of this study dealt with nine species of aquatic plants (*Ceratophyllum demersum* L., *Najas guadalupensis, Hydrilla verticillata, Hygrophila polysperma* (Roxb.) T. Anders., *Myriophyllum pinnatum* (Walt.) B.S.P., *Chara* sp., *Utricularia foliosa* L., *Egeria densa* Planch., *Potamogeton illinoensis* Morong) characterized as primarily submersed forms. The plants were presented to the fish as combinations of five or six species in a group. Three separate plant groups (six replicates per group) were presented individually to ten hybrid fingerlings per tank for two weeks. The cement tanks having the same dimensions as described were not aerated or flushed during the two-week period. The same fish were used for each plant group assessment and were chosen from fish held in both ponds and tanks prior to initiating the study. Individual plant species were represented by two or three sprigs anchored in a wide mouth glass jar with sand as a substrate, overlaid with coarse gravel to further anchor the plant. The plant species utilized were selected from local ponds and canals and represented the most typical form of the plant in this area. Epiphytic growths and gastropods, when present, were manually removed from the plants before placing them in the study tanks.

A numerical rating system was used to evaluate damage to the plant and potential feeding preferences by hybrid fingerlings after a two-week exposure. The rating system was based on points [5 (extensive), 3 (moderate) and 1 (minimal)] used to assess plant damage according to the following categories: stem fragmentation; leaf feeding; meristem feeding and plant disruption excluding consumption (uprooting). A cumulative point total for each plant species, from six replicates, was used to determine the initial rank of a plant species in each group. To reduce possible bias of the initial ranking, each plant species was assigned a rank based on the numerical rating of plant damage in each tank for all six replicates of each plant group. The cumulative total of the rank multiplied by the number of occurrences at that rank for all six replicates, where rank 1 = 6 points, rank 2 = 5 points . . . etc., is referred to as the weighted point total and was the basis for the final ranking. Points corresponding to plant damage were assigned to individual plants by the same person throughout the study.

Phase II of this study concerned four species of floating plants (*Salvinia rotundifolia*, Willd., *Wolffia columbiana* Willd., *Azolla caroliniana* Willd. and *Lemna* sp.). Ten hybrid fingerlings averaging 111·3 mm total length, were placed in each of three tanks. A rectangular Styrofoam float (55 cm long × 15 cm wide × 2 cm thick) having four circular openings (10·5 cm in diameter) was placed in each tank and anchored in place by a nylon rope to a drainspout at both ends of the tank (Fig. 1). The determination of fresh weight was based on the quantity of plant material that would completely cover the surface area of each circular opening. Excess water was allowed to drain from the plants before weighing. Due to the different plant morphologies involved, the fresh weight needed to adequately cover the surface of the circular openings, varied between plant species. Two additional tanks were set up as above without fish for controls.

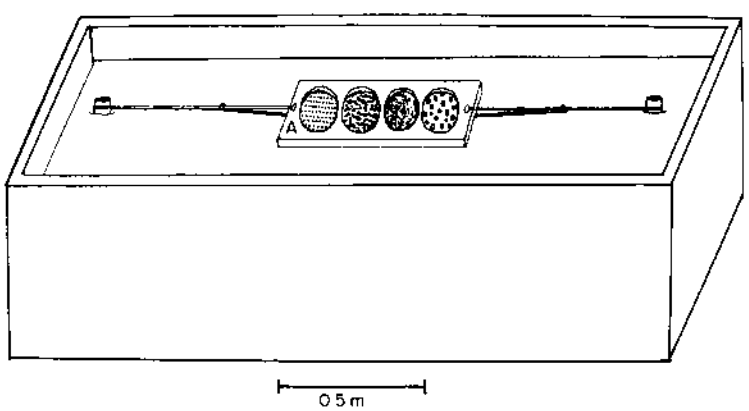

FIG. 1. Cement tank and floating apparatus used to assess consumption of floating aquatic plants by hybrid carp fingerlings. (A) Styrofoam raft used to hold floating plants in place.

The floating plants in each tank were observed at 24 h intervals and a visual estimate of the percentage of plant material consumed was determined. The mean % consumption for three replicates at each 24 h interval was calculated.

Eichhornia crassipes (Mart.) Solms. and *Pistia stratiotes* L. were also incorporated into this part of the study. Two medium size plants of each species were placed one each in the circular openings of the floating apparatus described above. The submersed roots were visually monitored every other day, five days per week for 30 days.

Mean water temperature in the tanks was determined from a maximum-minimum thermometer submerged to the mid-depth level in one tank. Maximum and minimum temperatures were recorded daily, five days per week.

III. RESULTS AND DISCUSSION

Results of the preference tests for the submersed plant species (Phase I) are presented in Table I. The use of a numerical rating system designed to assess

plant damage, as described, corresponded well with general observations of plant damage by hybrid fingerlings. An assessment of one plant group by another individual, using the same method, resulted in the same results as compared to the original assessment. The weighted point total reduced the bias of the initial ranking when plant damage did not occur consistently to a plant species in all replicates, as was the case with *Najas* in the last plant group where it had a higher weighted point total but a lesser cumulative total than *Chara* (Table I).

Of the nine submersed plant species utilized, *Ceratophyllum*, *Chara* and *Najas* were consistently favoured when in combination with other plant species (Table I). When in combination, preference among these three species was not consistent as exemplified by their respective ranks (Table I). *Ceratophyllum* was generally fed on first, beginning with the leaves on the lower, more succulent whorls and extending upward. The apical region where the whorls are bunched and unfolding were not fed on. Stem fragmentation to *Ceratophyllum* by hybrid carp ranged from moderate to extensive.

TABLE I. Ranking of submersed plant species according to feeding damage or preference by ten 0- to 1 year-old (avg. 98·1 mm total length) hybrid carp per replicate of each plant group. A higher point total indicates greater feeding damage

Submersed plant species by group	Combined* point total	Mean point total	Weighted† point total	Mean water temperature (° C)
Ceratophyllum demersum	57	9·5	35	21·3
Najas guadalupensis	36	6·0	30	
Hydrilla verticillata	19	3·2	26	
Hygrophila polysperma	8	1·3	20	
Myriophyllum pinnatum	2	0·3	15	
Chara sp.	78	13·0	36	20·6
Ceratophyllum demersum	64	10·7	32	
Najas guadalupensis	19	3·2	17	
Hydrilla verticillata	4	0·7	9	
Myriophyllum pinnatum	1	0·2	4	
Hygrophila polysperma	0	—	—	
Ceratophyllum demersum	54	9·0	31	17·0
Najas guadalupensis	43	7·2	29	
Chara sp.	54	9·0	27	
Utricularia foliosa	27	4·5	18	
Egeria densa	0	—	—	
Potamogeton illinoensis	0	—	—	

* Cumulative point total based on numerical rating assessment of plant damage with six replicates of each plant group. Points (5, extensive; 3, moderate; 1, minimal) were assigned to plant damage with respect to stem fragmentation, leaf feeding, meristem feeding and plant disruption excluding consumption (uprooting) by hybrid carp.

† $\sum_{i=1}^{6} Y_i$ where Y_i = Rank × no. of occurrences (0–6) at that rank: Rank 1 = 6 points, Rank 2 = 5 points . . . etc. Where no feeding occurred, 0 points were assessed.

Chara did not thrive very well in the controls although extensive feeding damage to the leaves was evident in the majority of replicates when compared to the controls. In most of the tanks, sprigs were uprooted. Stem fragmentation was minimal but the leaves were effectively nibbled back, almost to the stem including the apical region in a majority of the replicates.

Feeding activity with respect to *Najas* could generally be characterized by stem fragmentation. Leaf feeding was moderate to minimal. The succulent stem was probably more desirable to the fish than the leaf tissue, resulting in extensive stem fragmentation. Feeding damage to *Hydrilla* was minor in all replicates, characterized by occasional stem fragmentation and minor leaf feeding usually at the apical meristem. Damgage to *Utricularia* was moderate but sporadic in occurrence. The majority of feeding occurred at the lower leaves on the stem. Very slight leaf feeding was observed on *Myriophyllum* and *Hygrophila* and no feeding damage was evident to *Egeria* or *Potamogeton*.

In addition to the tank studies, the feeding activity of 300 hybrid fingerlings in an earthen pond (18·3 m long × 8·3 m wide, with a maximum depth of 2·0 m) having a large infestation of *Hydrilla verticillata* and a lesser growth of *Najas guadalupensis* was observed. Over a period of 12 weeks hybrid carp selectively fed on the *Najas* growing in the centre and around the periphery of the *Hydrilla*. Damage to *Hydrilla* was minimal during this time and after 20 weeks no noticeable reduction in *Hydrilla* was readily evident, nor did it increase noticeably.

Of the four floating plant species tested together, three (*Azolla, Wolffia* and *Lemna*) were completely consumed after 96 h (Table II). *Salvinia* was least preferred and after 30 days approximately 5% (mostly leaf tissue) still remained in all three replicates. *Azolla* was the most preferred, with total consumption occurring in all three replicates after 72 h.

Feeding damage to the root hairs of *Eichhornia* and *Pistia* tested together in separate tanks was minimal. After 30 days no signficant portion of the roots of either species was consumed nor could any preference be detected. Mean water temperature during this 30 day period was 17° C.

The feeding behaviour of underyearling grass carp × bighead hybrids, reported here is similar in some respects to the grass carp parent. *Ceratophyllum, Chara, Najas, Lemna, Myriophyllum, Wolffia* and *Azolla* were readily eaten by grass carp of similar size to the hybrid fish used in this study (Willey *et al.*, 1974). Mehta *et al.* (1976) reported that small grass carp prefer *Najas foveolata, Chara* and

TABLE II. Mean percent floating plant material consumed by 10 0- to 1 year-old hybrid carp per tank (avg. 111·3 mm total length). Mean water temperature was 20·0° C.

Plant	Fresh weight (g)	Hours	Mean % Consumed* 24	48	72	96
Azolla caroliniana	8		35·0	70·0	100	100
Wolffia columbiana	16		38·3	68·0	71·6	100
Lemna sp.	16		36·6	38·3	58·3	100
Salvinia rotundifolia	15		0	0	0	0†

* Determined by visual estimates of three replicates.
† Minor root (submerged leaf) feeding.

Potamogeton pectinatus as compared to *P. perfoliatus* and *Hydrilla verticillata*. Chaudhuri *et al.* (1976) determined that fingerling grass carp readily utilize duck weeds but may take considerable time in tackling infestations of larger plants like *Hydrilla, Nechamandra* and *Salvinia. Ceratophyllum, Chara, Myriophyllum, Najas, Potamogeton, Hydrilla* and *Lemna* are preferred or readily eaten plants of older grass carp as well (Penzes & Tolg, 1966; Singh *et al.*, 1967; Blackburn & Sutton, 1971; Sneed, 1971; Michewicz *et al.*, 1972; Opuszynski, 1972; Sutton, 1974; Mehta *et al.*, 1976).

Fingerling hybrids of the cross *Ctenopharyngodon idella* ♂ and *Cyprinus carpio* L. ♀ show a similar preference to the plants preferred by grass carp × bighead fingerlings reported here with the exception that *Ceratophyllum* was poorly utilized by *C. idella* × *C. carpio* fingerlings (Duthu & Kilgen, 1975; Theriot & Sanders, 1975). Theriot & Sanders (1975) also reported that *C. idella* × *C. carpio* fingerlings utilized *Hydrilla* and *Myriophyllum* only sparingly as did grass carp × bighead hybrids in this study.

Grass carp × bighead fingerlings were also observed feeding on invertebrates. Mosquito larvae (*Culex quinquefasciatus* Say) and small leeches (Hirudinea) offered to several fingerlings in a 143 l aquarium were readily consumed. It is probable that these hybrid fingerlings utilize invertebrates when in natural situations, although any preference between invertebrates and macrophytes is yet unknown.

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