J. Aquat. Plant Manage. 36: 79-83

Preferences of Grass Carp for Macrophytes in Iberian Drainage Channels

L. F. CATARINO[1], M. T. FERREIRA[2] AND I. S. MOREIRA[2]

ABSTRACT

Grass carp, *Ctenopharyngodon idella*, feeding preferences were studied from the age of 0+ to the age of 2+, in tank and pond conditions, by using combinations of macrophytes occurring as typical weed assemblages in Iberian drainage channels. The exotic species waterhyacinth and parrotfeather are the most common and troublesome. Ivlev's index showed that two flotant soft-tissue species, *Azolla filiculoides* and *Lemna* sp., were clearly preferred by grass carp, whilst other species such as *Potamogeton pectinatus* and *Myriophyllum spicatum* were moderately eaten; and parrotfeather and waterhyacinth were avoided up to the age of 2+, and then only moderately eaten, as long as no preferred species were present. Selectivity decreased with carp age. Daily consumption rates of the two exotics were low, up to 25% of body weight. Preference indexes were found to be a useful tool to assess resource preference and make a preliminary evaluation of the efficacy and environmental impact of grass carp introduction on a new habitat/region.

Key words: preference indexes, *Ctenopharyngodon idella*, *Eichhornia crassipes*, *Myriophyllum aquaticum*, Portugal.

INTRODUCTION

In Mediterranean areas, drainage channels are a common landscape feature throughout the lowland parts of river basins. In Portugal, there are presently about 10^6 ha of irrigated farmland of which 12% are included in national irrigation programs having extensive drainage systems.

Drainage channels are dominated by macrophytic assemblages that tend to occupy the water column and surface, as well as the banks, with a remarkable cover and persistence. Heavy plant infestations are common, preventing the establishment of phytoplankton and periphyton, while anoxia is established a few centimetres from the surface, and zooplankton, benthos and fish practically disappear (Moreira et al. 1989). From the farmers view point, the plants obstruct the channels and decrease their recreational value and drainage performance.

The macrophyte cover of Portuguese drainage channels is generally dominated by two south-American species, waterhyacinth *Eichhornia crassipes* (Mart.) Solms. and parrotfeather *Myriophyllum aquaticum* (Vell.) Verd., though other species can also proliferate, such as *Potamogeton pectinatus* L., eurasian watermilfoil *Myriophyllum spicatum* L. and *Lemna gibba* L. (Ferreira and Moreira 1990). These plants and filamentous algae were indicated as the most troublesome weeds in a recent national inquiry to water managers and administrators (Aguiar 1996).

Mechanical removal of plants, the only weed control method extensively used in Portugal, is expensive and generally ineffective, because fragments of all major weeds form new shoots and roots, and reinfestation rapidly occurs (Ferreira and Moreira 1990). Chemical control is rarely employed, though good experimental results were obtained against waterhyacinth and common reed *Phragmites australis* (Cav.) Trin. with glyphosate (Fernandes et al. 1978). However parrotfeather, the species presenting the largest weed problem, showed weak responses to several active ingredients such as diquat, glyphosate and glyphosinate-ammonium, and was only moderately sensitive to 2,4-D amine, an herbicide presenting environmental constraints (Monteiro and Moreira 1990). Some experimental results of plant control by grass carp in canals and ditches are available from New Zealand (Edwards and More 1975), Egypt (Gharably et al. 1982), England (Mugridge et al. 1982), Sudan (George 1983) and California (Stocker et al. 1990), but its effective use in the European Union has been restricted to dutch canals (Zweerde 1990).

Iberian drainage channels have favourable water temperatures (14C) for grass carp suitable for the maintenance of regular feeding throughout most of the year. Water velocity can reach 0.50 $cm.s^{-1}$ but is generally lower or non-detectable. Also, grass carp are highly tolerant to adverse limnetic conditions such as low oxygen, high salinity and chemical hazards (Opuczynski 1972, Zweerde 1990, Chilton and Muoneke 1992) common to agricultural canals (Schramm and Jirka 1986). There is in Portugal, however, a large controversy concerning the environmental non-target effects of grass carp introduction, namely the possibility of overgrazing of desirable native plant species.

The composition and relative abundance of the existing plant assemblages are important in determining the control efficacy, the most favourable stocking rates and potential changes in local vegetation. Prior to the field introduction of grass carp as a management tool for weed control in drainage channels, information was needed on its dietary selection for the commonly therein occurring weeds, especially the target plants waterhyacinth and parrotfeather, as well as to the extent these preferences change with fish age. In this study, we present the feeding preferences of grass carp over an assemblage of plants from Portuguese drainage channels and discuss the practicability of this type of weed control.

[1]Research Assistant, Instituto de Investigação Científica Tropical, Rua da Junqueira 86. 1300 Lisboa, Portugal.

[2]Professors, Instituto Superior de Agronomia, Tapada da Ajuda, 1399 Lisboa codex, Portugal. Received for publication March 1, 1997 and in revised form June 4, 1997.

MATERIALS AND METHODS

We examine the preference of grass carp for aquatic weeds found in the drainage channels of one of the largest Portuguese irrigation systems, located in the Tagus basin, central Portugal. The system occupies an area of 13000 ha, with a NNE-SSW orientation, a total channel network of about 470 km, and a channel density of 1.3 km/km^2. A previous limnological survey of 100 channel reaches showed a significant difference between Northern canals, deeper, less transparent and with smaller conductivity and Southern canals, which were shallower, less turbid and with higher conductivity, thus providing habitat for different plant assemblages and dominant aquatic weeds (Catarino 1995).

A hundred and twelve young-of-the-year diploid grass carp were imported into Portugal in the summer of 1994 from the Organization for the Improvement of Inland Fisheries, Netherlands. At arrival, the grass carp were placed in tanks for a 3 month quarantine period. Unless in the trials, grass carp were fed *ad libitum* from a pool of several macrophytes. This diet was supplemented twice a week with frozen crustacean *Artemia salina* (0.125 kg per tank in the first year, and 0.25 kg in the following years). Grass carp were regularly fed and instantaneous growth was estimated as g/100g.

Six 660 l plastic tanks (145 cm long, 70 cm wide, 80 cm total depth, 65 cm water depth), placed outdoors and covered with shadecloth, were used in the study of feeding preferences. The tanks were aerated by a Hiblow SPP-40GJ-L air pump and had an open circuit water exchange system that completely replaced the water volume every 12 hours. Preference trials were conducted in September 1994 (age 0+), June 1995 (age 1+) and September 1996 (age 2+) using carp with an average weight (g) of 9.8 (SD,1.6), 37.8 (SD, 5.9) and 304.7 grams (SD, 38.2), respectively. Five tanks were used as replicates. In each trial (duration of two days each) a distinct group of four plants, previously weighed, with total biomass (fresh weight) of the same order of magnitude of the fish biomass per tank were presented to the fish. By the end of the first day, a visual inspection was made and, if any plant was nearly or totally consumed, additional plants were added. The remaining plant biomass was weighed by species at the end of each trial.

Two sets of five macrophytes were used in the experiments, corresponding to the two described field situations: 1) a Northern set, including *Azolla filiculoides* Lam., *Ceratophyllum demersum* L., *Eichhornia crassipes*, *Lemna* spp. (*L. minor* L. and *L. gibba* L.) and *Myriophyllum aquaticum*; and 2) a Southern set, including *Azolla filiculoides*, *Eichhornia crassipes*, *Myriophyllum aquaticum*, *M. spicatum* L. and *Potamogeton pectinatus* L. Mature plants for experiments and maintenance were collected weekly from drainage canals where they occurred naturally. The plants were placed in the fish tanks respecting their life forms and when plants could be mixed (e.g. *Lemna* spp and *Azolla filiculoides*), a 15 cm high plastic net was used, placed at the water surface, and fixed to the edges of tanks with clamps.

We assumed that there was no plant growth in the test tanks during the 48 hours of each experiment. No grass carp mortality occurred during the trials. Water pH, conductivity, and dissolved oxygen were measured twice a week and max-min thermometers were placed in two randomly sorted tanks.

The assessment of grass carp feeding preferences was conducted by comparing data on food usage and availability (Johnson 1980). We used the preference index developed by Ivlev (1961) which permits comparison of two or more food items at a time, although the maximum and minimum values attainable depend upon the relative food item densities or quantities (Chesson 1983). In our case this problem was avoided since we always provided equal quantities of different plant species in each trial. This index ranges from -1 (plant/item not consumed at all) to +1 (the only plant/item consumed). Zero corresponds to a non selected plant/item. To assess the statistical significance of the differences we used the Duncan's Multiple Range test ($p>0.05$).

An additional trial was conducted to assess the potential of grass carp to consume the exotic target weeds parrotfeather and waterhyacinth. After the end of age 1+ trials, grass carp were transferred to two small ponds (17m length, 9m width, 1m water depth). Each pond, containing 48 carp, was divided in two parts by a plastic net, providing four replicates, and preventing the passage of plants but not carp. A third pond, with the same treatment except without carp, acted as control, with two replicates. All ponds were previously dried and cleaned of natural vegetation. Nearly 8 kg of each plant were placed in each half pond, waterhyacinth on the water surface and parrotfeather rooted in boxes with soil on the bottom. Both species were allowed to acclimatize to experimental conditions for one week. This experiment took place in the summer of 1995 for two months. At the end of the experiment, total plant cover in each half-pond was evaluated, by visual inspection. Carp and plants were weighed at the beginning and at the end of the experiment. To assess the statistical significance of the differences found, we used a Mann-Whitney U test ($p>0.05$).

In August 1996, we transferred 4 age 2+ carp to the plastic tanks, and both parrotfeather and waterhyacinth, previously weighed, were presented to the fish. After two days, the remaining plant biomass was weighed. Between these two trials, carp were kept in the ponds and fed with grass, mainly *Paspalum paspaloides* (Michx) Scribner, and periodically weighed.

RESULTS AND DISCUSSION

The water quality parameters in the tank and pond studies presented variations, with mean water temperature (22.8C, min 13C, max 34C), pH (8.4, min 8.2, max 8.6), dissolved oxygen (9.6 mg.l^{-1}, min 8.7 mg.l^{-1}, max 15.0 mg.l^{-1}) and conductivity (420µS.cm^{-1}, min 290µS.cm^{-1}, max 630µS.cm$^{-1)}$. These values are within ranges which have been reported to not limit feeding or growth of the grass carp (Shireman and Smith 1983, Chilton and Muoneke 1992).

During the three years of the experiments, grass carp showed generally small instantaneous growth rates (average 0.53 g/100g, range 0.19-2.17), though an increase occurred after pond release of the age of 1+, with values generally above 0.5% per day. Other authors reported similar small values, such as Blackburn and Sutton (1971) with small age 1+ carp fed exclusively with waterhyacinth, and Cai and Curtis (1989) with 0+ carps fed with *Ceratophyllum demersum*. Instantaneous growth values, revised by Cai and Curtis 1989, p.57, are generally higher, up to 3.1% per day. Grass carp growth rates are known to vary widely because they are related to several factors such as the type, quantity and nutritional value of plant food, the salinity, temperature and oxygen content of the water, and the age and density of the carp population (Shireman and Smith 1983, Zweerde 1990). The high carp densities used in this study and the type of food offered were likely responsible for the reduced growth rates observed, in fact, the release of four grass carp in a near-by pond infested with *Chara vulgaris* L. resulted on a six-fold weight increase when comparison was made at the age of 2+ (data not shown).

In the age 0+ trials, from the Northern set, two soft-tissue species (*A. filiculoides* and *Lemna* spp.) were preferred (PI 0.44 and 0.40) and one, coontail *C.demersum*, was avoided, with a PI of -0.43. Waterhyacinth and parrotfeather were virtually not consumed. In the age 1+ trials with the same plants, *A.filiculoides*, *Lemna* spp. and coontail had positive PI with similar values. Waterhyacinth was consumed, although selected against, with a PI of -0.26; parrotfeather was not eaten (Table 1).

In the age 0+ trials with the Southern set, two plants had positive mean PI: *A. filiculoides,* 0.44 and *P. pectinatus,* 0.14. Eurasian watermilfoil and waterhyacinth were eaten but had negative mean PI of -0.46 and -0.72, respectively. Parrotfeather was not eaten at all. In the age 1+ trials, parrotfeather was undoubtedly eaten in one trial, but not in the others. Waterhyacinth remained with negative mean PI but raised from -0.72 to -0.27, that is, the avoidance decreased. *A. filiculoides* and *P. pectinatus* maintained their positive mean PI and Eurasian watermilfoil increased to a mean PI of 0.16 (Table 1).

The variation of plant biomass and cover in the ponds are presented in Table 2. During this two month trial, the ponds developed a set of natural plants, of which the most noticeable was common reed *Phragmites australis* (Cav.) Trin. At the end of the experiment, the total vegetation cover was significantly higher in the control pond (p>0.05). However, parrotfeather cover and weight in the test ponds was no different from the control, suggesting that grass carp with age of 1+ did not eat this species. The final biomass of waterhyacinth showed a great difference between test and control ponds (p>0.05), namely a 14 percent increase in the test ponds against a 496 percent increase in the control one.

At the age of 2+, when presented exclusively with the two exotic weeds in tank conditions, grass carp fed on both, eating the roots, petioles and the outer parts of the waterhyacinth and nearly all parrotfeather tissues. The preference trial at this age, however, using the two exotics and the natives *Lemna* spp. and *P. pectinatus*, showed the maintenance of a distinct preference for native plants (Table 2).

Several authors have listed the types of plants consumed or/and preferred by grass carp, whether diploid, triploid or hybrids (e.g. Cross 1969, Duthu and Kilgen 1975, Gharably et al. 1982, Chilton and Muoneke 1992). However, feeding preferences using specific combinations of plants were less commonly evaluated (e.g. Cassani and Caton 1983, Wiley et al. 1986), while observations showed that, when pond or field conditions are used, with particular plant assemblages, large variations of food preference can occur (e.g. Kilgen and Smitherman 1971, Fowler and Robson 1978, Mitchell 1980, Harberg and Modde 1985, Leslie et al. 1987, Pine and Anderson 1991).

In this study, selectivity of grass carp decreased with age. The mean PI for the preferred plants decreased from age 0+ to 2+, though the exotic weeds were never preferred. The smaller fish had a marked preference for the smaller and tender plants (e.g. *Lemna* spp and *A. filiculoides).* The larger fish exhibited a less evident plant preference and ate a wider variety of plants. Wateryacinth in the Southern set was eaten only in the second year trials and several others had similar, positive, preference indexes (*A. filiculoides,* coontail and *Lemna* spp. from the Northern set and *A. filiculoides,* Eurasian watermilfoil and *P. pectinatus* from the Southern set).

Younger fish have long been reported to select softer plant tissues and youngest plants while older fish eat a wider variety of plants, some tougher and more fibrous (Opuczynski 1972). *Lemna* spp. and *P. pectinatus* have been reported as preferred whilst coontail, Eurasian watermilfoil, parrotfeather and waterhyacinth are generally avoided (e.g. Cassani and Caton 1983, Pine and Anderson 1991). Blackburn and Sutton (1971) and Riechert and Trede (1977) verified that grass carp ingested roots and leaves of waterhyacinth, but was very reluctant to eat the petioles and older leaves. Results in this study showed the potential of medium to large

TABLE 1. PREFERENCE INDEXES (WITH SD VALUES BETWEEN BRACKETS) FOR AGE 0+ AND 1+ GRASS CARPS (NORTHERN AND SOUTHERN SETS OF PLANTS) AND FOR AGE 2+ GRASS CARPS (EXOTIC VERSUS NATIVE PLANTS). LINES ARE REFERRED TO THE DUNCAN'S MULTIPLE RANGE TEST RESULTS (α=.05).

Age 0+ Grass Carp - Northern Set				
M. aquaticum	*E. crassipes*	*C. demersum*	*Lemna* sp.	*A. filiculoides*
-1.00 (0.00)	-0.97 (0.05)	-0.43 (0.20)	0.40 (0.12)	0.44 (0.15)
Age 1+ Grass Carp - Northern Set				
M. aquaticum	*E. crassipes*	*A. filiculoides*	*C. demersum*	*Lemna* sp.
-0.98 (0.02)	-0.26 (0.13)	0.17 (0.07)	0.17 (0.07)	0.18 (0.08)
Age 0+ Grass Carp - Southern Set				
M. aquaticum	*E. crassipes*	*M. spicatum*	*P. pectinatus*	*A. filiculoides*
-1.00 (0.00)	-0.72 (0.34)	-0.46 (0.11)	0.14 (0.37)	0.57 (0.06)
Age 1+ Grass Carp - Southern Set				
M. aquaticum	*E. crassipes*	*M. spicatum*	*P. pectinatus*	*A. filiculoides*
-0.91 (0.13)	-0.27 (0.06)	0.16 (0.10)	0.17 (0.08)	0.19 (0.10)
Age 2+ Grass Carp - Exotic vs Native plants				
M. aquaticum	*E. crassipes*	*Lemna sp.*	*P. pectinatus*	
-0.91 (0.09)	-0.87 (0.19)	0.18 (0.11)	0.25 (0.05)	

TABLE 2. MEAN BIOMASS (KG/M²) AND COVER (%) OF PLANTS AT THE BEGINNING AND THE END OF POND EXPERIMENTS WITH GRASS CARP (RANGE OF VALUES BETWEEN BRACKETS). COMMON REED ESTABLISHED SPONTANEOUSLY IN THE PONDS.

			Final	
		Beginning	Control (range)	Test (range)
Biomass (kg/m²)	waterhyacinth	0.11	0.64 (0.60-0.68)	0.12 (0.11-0.14)
	parrotfeather	0.11	0.09 (0.08-0.10)	0.09 (0.08-0.10)
Cover (%)	waterhyacinth	10	20 (15-25)	5 (4-6)
	parrotfeather	5	5 (4-6)	5 (4-6)
	Common reed	0	80 (70-85)	7.5 (5-10)

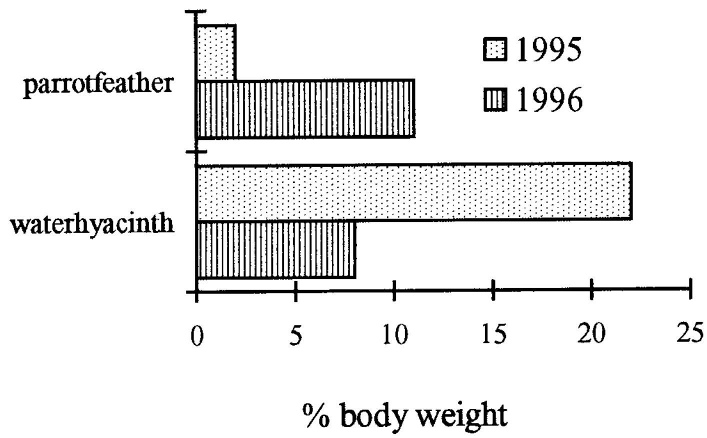

Figure 1. Daily consumption rates for grass carps of age 1+ (1995) and 2+ (1996) fed with waterhyacinth and parrotfeather in tank environment

sized grass carp (1+ and plus) to control waterhyacinth by eating its root system and outer parts of leaves, and also most parrotfeather tissues, as long as no preferred species are present.

Daily consumption rates for the two exotics were relatively low (Figure 1) though published values show a large variation, from 100 percent body weight and more to as low as 1% (Shireman and Smith 1983, Shireman et al. 1983, Cai and Curtis 1989). Some studies seem to indicate that the type and rate of fish consumption, and its growth, are related to the chemical content or nutritive value of the plants, such as the gross energy content of the diet and the dietary protein (Shireman et al. 1983, Jobling 1987). Plant chemistry will also likely affect palatability and plant selection, and Bonar et al. (1990) found that calcium and celulose were the best predictors of consumption rates.

Alternatively, Wiley et al. (1986) found no correlation between preference and plant characteristics, as protein, caloric content and crude fiber, and they suggested fish eat first those plants that they can consume more easily. The lack of feeding preference has often been related to plant accessibility and fibrous nature, and the increase in handling time due to the above-water inacessibility of some plant canopies, causing their consumption to be energetically unattractive (Prowse 1971, Wiley et al. 1986, Pine and Anderson 1988). Grass carp behaviour of feeding top downwards (George 1983) will require more manipulation for large floating plants such as waterhyacinth, and the half-emergent branching canopies of parrotfeather.

The use of grass carp is frequently a controversial subject, and in many cases has resulted in negative environmental effects, such as eutrophication, decrease in fish production and major community changes (Chilton and Muoneke 1992). Assessment of control efficacy and feeding preferences for target species should then proceed prior to its introduction. The preference index we used seemed to be useful for assessing the resource preference between a set of feeding alternatives. This method help simplify the preliminary evaluation of grass carp introduction in a new habitat/region.

Results obtained indicate that grass carp can effectively control the aquatic weeds of Portuguese drainage channels, but will preferably consume other more easily handled (and frequently native) plants. Should water managers and farmers choose this type of weed control, caution must be practised to avoid the escape of carp to feed on indigenous plants in non-target areas, which may favour the spread of undesirable species. In many Portuguese lowland water courses, the original plant community, mainly composed of species such as *Zanichellia palustris* L., *Potamogeton crispus* L. and *P. fluitans* Roth., is already being substituted by exotic plants such as *P. paspaloides* and parrotfeather, which can locally represent more that 50% cover (Ferreira and Moreira 1994). Grass carp feeding, if selective for the indigenous plants, might further enhance this situation, decreasing the plant diversity of these ecosystems. Grass carp stocking for weed control in drainage channels should then proceed only with 2+ aged (or more) grass carps, under confined situations, with non-fertile triploid specimens and under the supervision and frequent inspection of the local Agricultural and Forestry Services.

ACKNOWLEDGMENTS

This study was supported by Junta Nacional de Investigação Científica, Contract Project STRD/AGR/0047/93. We are deeply grateful to Dr. Bill Haller and to Dr. Scott Bonar for the revision of the manuscript and the many helpful suggestions to improved it.

LITERATURE CITED

Aguiar, M. F. 1996. A percepção da vegetação infestante em ecossistemas dulciaquícolas pelas entidades gestoras de recursos hídricos. MSc Thesis. Technical Univ. Lisbon. Lisbon. 231 pages.

Blackburn, R. D. and D. L. Sutton. 1971. Growth of the white amur (*Ctenopharyngodon idella* Val.) on selected species of aquatic plants. Proc 3rd EWRS Symp. Aquatic Weeds. Oxford. pp. 87-93.

Bonar, S. A., S. H. Sehgal, G. B. Pauley, and G. L. Thomas. 1990. Relationship between the chemical composition of aquatic macrophytes and their consumption by grass carp, *Ctenopharyngodon idella*. J. Fish Biol. 36: 149-157.

Cai, Z. and L. R. Curtis. 1989. Effects of diet on consumption, growth and fatty acid composition in young grass carp. Aquaculture 81: 47-60.

Cassani, J. R. and W. E. Caton. 1983. Feeding behaviour of yearling and older hybrid grass carp. J. Fish Biol. 22: 35-41.

Catarino, L. F. 1995. Utilização da Carpa Herbívora em Protecção Integrada. MSc Thesis. Technical Univ. Lisbon. Lisbon. 128 pages.

Chesson, J. 1983. The estimation and analysis of preference and its relationship to foraging models. Ecology, 64 (5): 1297-1304.

Chilton, E. W. and M. I. Muoneke. 1992. Biology and management of grass carp (*Ctenopharyngodon idella*, Cyprinidae) for vegetation control: a North American perspective. Reviews in Fish Biology and Fisheries 2: 283-320.

Cross, D. G. 1969. Aquatic weed control using grass carp. J. Fish Biol., 1: 27-30.

Duthu, G. S. and R. H. Kilgen. 1975. Aquarium studies on the selectivity of 16 aquatic plants as food by fingerling hybrids of the cross between *Ctenopharyngodon idella* and *Cyprinus carpio*. J. Fish Biol. 7: 203-208.

Edwards, D. J. and E. More. (1975) Control of water weeds by grass carp in a drainage ditch in New Zealand. N. Z. J. Marine and Freshwater Research 9: 283-292

Fernandes, J. D., A. R. Guerreiro, T. M. Vasconcelos, and I. S. Moreira. 1978. Essais de lutte contre les plantes aquatiques au Portugal. Proc. 5th EWRS Symposium on Aquatic Weeds. Amsterdam. pp. 189-194.

Ferreira, M. T. and I. S. Moreira. 1990. Weed evolution and ecology in drainage canals of central Portugal. Proc. 8th EWRS Symposium on Aquatic Weeds. Uppsalla. pp. 97-102.

Ferreira, M. T. and I. S. Moreira. 1995. The invasive component of the macroflora from river systems within agricultural mediterranean areas. *in* Plant Invasions - General Aspects and Special Problems. Edited by P.

Pysek, K. Prach, M. Rejmanek and P. M. Wade. SPB Academic Publishing. Amsterdam. pp. 117-127.

Fowler, M. C. and T. O. Robson. 1978. The effects of the food preferences and stocking rates of grass carp (*Ctenopharyngodon idella* Val.) on mixed plant communities. Aquatic Botany 5: 261-276.

George, T. T. 1983. The chinese grass carp, *Ctenopharyngodon idella*, its biology, introduction, control of aquatic macrophytes and breeding in the Sudan. Aquaculture 27: 317-327.

Gharably, Z., A. F. Khattab, and F. A. Dubbers. 1982. Experience with grass carp for the control of aquatic weeds in irrigation canals and drains in Egypt. Proc. 2nd EWRS Symposium on Herbivorous Fish. Novi Sad. pp. 17-26.

Harberg, M. C. and T. Modde. 1985. Feeding behaviour, food consumption, growth and survival of hybrid grass carp in two South Dakota ponds. N.-A. J. Fish. Mgmt. 5: 457-464.

Ivlev, V. S. 1961. Experimental Ecology of the Feeding of Fishes. Yale University Press, New Haven.

Jobling, M. 1987. Influences of food particle size and dietary energy content on patterns of gastric evacuation in fish: test of a physiological model of gastric emptying. J. Fish Biol. 19: 245-257.

Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61: 65-71.

Kilgen, R. H. and R. O. Smitherman. 1971. Food habits of the white Amur stocked in ponds alone and in combination with other species. Prog. Fish Cult. 33: 123-127.

Leslie, A. J., J. M. Van Dyke, R. S. Hestand, and B. Z. Thompson. 1987. Management of aquatic plants in multi-use lakes with grass carp (*Ctenopharyngodon idella*). Lake Reserv. Mgmt. 3: 266-276.

Mitchell, C. P. 1980. Control of water weeds by grass carps in two small takes. N.Z.J. Marine and Freshwater Research 14: 381-390.

Monteiro, A. and I. S. Moreira. 1990. Chemical control of parrotfeather (*Myriophyllum aquaticum*). Proc. 8th EWRS Symposium on Aquatic Weeds. Uppsalla. pp. 163-164.

Moreira, I. S., M. T. Ferreira, and A. Monteiro. 1989. Aquatic weed bioecology and control in Portugal: a review. *in* Portuguese German Cooperation in Applied Agricultural Results. A.Bianchi (ed.). Universidade de Vila Real. Vila Real, pp. 71-106.

Mugridge, R. E., B. R. Buckley, M. C. Fowler, and H. G. Stallybrass. 1982. An evaluation of the use of grass carp for controlling aquatic plant growth in a canal in Southern England. Proc. 2nd EWRS Symposium on Herbivorous Fish. Novi Sad. pp. 8-16.

Opuszynski, K. 1972. Use of phytophagous fish to control aquatic plants. Aquaculture 1: 61-74.

Pine, R. T. and L. W. J. Anderson. 1988. Potential for use of triploid grass carp in northern California: feeding preference and nutritional studies. Proc. 4th Annual California Weed Conference, Sacramento, California. pp. 194-200.

Pine, R. T. and L. W. J. Anderson. 1991. Plant preferences of triploid grass carp. J. Aquat. Plant Manage. 29:80-82.

Prowse, G. A. 1971. Experimental criteria for studying grass carp feeding in relation to weed control. Progve Fish Cult. 33: 128-131.

Riechert, C. and R. Trede. 1977. Preliminary experiments on utilization of waterhyacinth by grass carp. Weed Research 17: 357-360.

Schramm, H. L. and K. J. Jirka. 1986. Evaluation of methods for capturing grass carp in agricultural canals. J. Aquat. Plant Manage. 24: 57-59

Shireman, J. V. and C. R. Smith. 1983. Synopsis of biological data on the grass carp *Ctenopharyngodon idella* (Cuvier and Val., 1844). FAO Fisheries Synopsis, N135. FAO Rome. 86 pages.

Shireman, J. V., R. W. Rottman, and F. J. Aldridge. 1983. Consumption and growth of hybrid grass carp fed four vegetation diets and trout chow in circular tanks. J. Fish Biol. 22: 685-693.

Stocker, R. K., M. R. Mizumoto, N. T. Hagstrom, and M. D. Remington. 1990. Impacts of triploid grass carp introduction on the recreational fishery in Imperial Valley, CA irrigation canals. Final Report. California Fish and Game Commission. California Department of Fish and Game. 30 pages.

Wiley, M. J., S. M. Pesticelli, and L. D Wike. 1986. The relationship between feeding preferences and consumption rates in grass carp and grass carp × bighead carp hybrids. J. Fish Biol. 29: 507-514.

Zweerde, W. van. 1990. Biological control of aquatic weeds by means of phytophagous fish. *in* Aquatic Weeds. Edited by A. H. Pieterse and K. J. Murphy. Oxford Science Publications. Oxford. pp. 201-221.