132

89858

132

MANAGEMENT OF WEEDY LAKES AND PONDS WITH GRASS CARP

Roger Rottmann

The biological control of excess aquatic vegetation with grass carp (*Ctenopharyngodon idella*) is a controversial issue. Grass carp are frequently the topic of magazine and newspaper articles, radio and T.V. programs, and local and state government meetings. There is agreement in the literature that grass carp can effectively control aquatic vegetation. The widespread use of grass carp for aquatic weed control in the United States, however, has been delayed because little information exists concerning their food habits and effect on water quality and native fish populations. The purpose of this paper is to provide information concerning the grass carp and to discuss their possible use for management of aquatic vegetation in ponds and lakes.

Roger Rottmann

AQUATIC HABITAT

When present in moderate quantities, rooted macrophytes increase the stability of aquatic ecosystems and are beneficial to fishery interests (Boyd 1971). In addition to their role in primary production, aquatic vegetation provides support, shelter, and oxygen to fish and fish food organisms. Aquatic plants prevent erosion of pond banks by inhibiting wave action and provide habitat for birds and wildlife. Submerged plants however are not grazed extensively by herbivores, and when they die, their standing crop is added to the organic detritus pool so important in aquatic food webs (Odum 1959). The objective of aquatic vegetation management should be directed toward maintaining an optimum quantity and diversity of flora rather than eliminating all vascular plants.

Because of introduced exotic plants, nutrient enrichment, or undetermined factors, aquatic plant production often increases to a level that alters aquatic productivity and reduces the recreational and economic value of lakes and ponds. Oxygen depletion or supersaturation and high pH have been associated with dense submerged vegetation. Severe conditions may cause fish mortality, while marginal conditions may reduce fish production by adversely affecting feeding, growth, or reproduction. Excess cover provided by dense submerged vegetation may hinder predation (Swingle and Smith 1942; Bennett 1962) resulting in imbalanced fish populations which severely limit fishing quality. It appears unwise to manage fish populations in the presence of overabundant submerged vegetation. Water weeds can develop to such extent that recreational activities such as fishing, boating, waterskiing, and swimming are aesthetically unappealing or physically impossible, which reduces the value of the surrounding property and developments. Fish culture ponds choked with vegetation are difficult to seine and require more labor to recover fish when drained. Dense aquatic weeds also hinder agricultural, municipal, industrial, and hydroelectric water use.

The four basic alternatives in use for aquatic vegetation management are mechanical control, chemical control, habitat manipulative control, and biological control. All of these methods have application in certain situations but no single type of control is the best for all conditions. A combination of two or more types of management practices may be the best alternative. In lakes and ponds where certain submerged and floating plants are excessively abundant and where escape potential of the fish is minimized, grass carp can be an effective, relatively long-term, economical management tool for habitat improvement by macrophyte reduction.

THE AUTHOR: **Roger Rottmann** received a B.S. and an M.S. in Fishery Biology from the University of Missouri in Columbia. He is presently a Fishery Biologist for the School of Forest Resources and Conservation, University of Florida. He is studying the culture techniques, spawning, feeding, growth, and survival of grass carp.

GRASS CARP FEEDING

The grass carp, also known as the white amur or Waan Ue, is one of the largest members of the minnow family (Cyprinidae) reaching 50 kg in weight (Nikol'skii 1956). Grass carp require flowing water to spawn and apparently do not reproduce in lakes and ponds. In Asian and European countries this species is incorporated in polyculture systems to take advantage of their utilization of macrophytes.

Grass carp fry less than approximately 30 mm total length feed primarily on phytoplankton and invertebrates (Konradt 1968; Stott 1967). Preliminary results indicate that young grass carp may need diets high in animal protein until approximately 150 mm total length (Shireman et al. in press a); larger fish however are definitely herbivorous (Kilgen 1974; Terrell and Fox 1975).

Grass carp exhibit a definite preference for some species of plants over others. Verigin et al. (1963), Alabaster and Stott (1967), and Cross (1969) present tables listing various plants eaten by grass carp in their approximate order of preference.

In general, submerged and some types of floating vegetation are preferred over emergent and terrestrial types. The plants preferred are typically young and succulent, with negligible fiber; fibrous and woody plants are least preferred (Prowse 1971). *Hydrilla verticillata* was determined to be an excellent food for grass carp (Tan 1970). *Hydrilla's* superiority as a food was attributed to the soft nature of the plant and high ash content. Preferred food plants are easiest to control, but other plants can be controlled as well (Bailey 1973).

Food preference is also influenced by age, size, physiological state, and the environment of the fish (Stroganov 1963). Smaller fish beyond the plankton feeding stage select soft weeds such as filamentous algae, duckweeds, and the softer pond weeds. As the fish grow, they become less selective; algae become less preferred, duckweed and pond weeds are still preferred, and fibrous weeds are accepted more readily (Bailey 1973). Grass carp feed less selectively at higher temperatures (Stroganov 1963). Feeding preference may also be influenced by past feeding history.

Under aquarium conditions, young grass carp will eat many species of small animals. However, under natural conditions, organisms could be expected to have lower vulnerability. Edwards (1973) demonstrated that when stones were provided as a substrate and cover in aquaria, grass carp consumed few invertebrates. Grass carp are predominately surface and mid-water feeders, and may take worms and other baits suspended in the water column when weeds are absent (Terrell and Fox 1975). In a 3.6 ha lake with no macrophytes, no artificial feed, abundant benthic organisms, and an established fish population, animal remains made up no more than 0.2% of the total stomach contents of grass carp (286–588 mm total length) in any month (Terrell and Fox 1975). Terrestrial plants were the most abundant food item; no fish or fish eggs were observed in grass carp stomachs. Terrell and Fox (1975) concluded that in the absence of aquatic vegetation, grass carp did not utilize benthic organisms or become piscivorous even though they were losing weight. Kilgen (1974) also reported little use of crustaceans and insect larvae by grass carp (<1%) in a vegetated pond containing a supplementally fed largemouth bass/bluegill/redear sunfish population. The author concluded that grass carp rarely ate anything except plant material and the small number of invertebrates found in grass carp stomachs was probably inadvertently ingested with the vegetation. Similar feeding habits were reported by Mitzner (1976) for grass carp in Red Haw Lake, Iowa.

Under favorable conditions, grass carp will eat more than their own weight of plants in a day. Verigin et al. (1963) and Stott (1967) present tables of daily consumption rates of various plants by grass carp; values range from 11.5% to 135%. When fed duckweed (*Lemna minima*) small grass carp (61–190 mm total length) consumed approximately 150% of their body weight of fresh vegetation daily (Shireman et al. in press a). Duckweed and most submerged vegetation is about 95% water. These fish were consuming 7.2% to 7.4% dry matter daily (Shireman et al. in press a). Opuszynski (1972) determined that intensive feeding does not occur until temperature reaches 20 C. At this temperature, consumption was 50% of body weight, whereas consumption was 100% to 120% of body weight at 22 C. Dissolved oxygen levels below 4 mg/l reduces grass carp consumption by 40% (Stanley 1973; Shireman et al. in press a). Little is known of the daily consumption of large sexually mature grass carp; additional research is needed to determine their consumption rates.

GRASS CARP GROWTH

Growth of grass carp is quite rapid. Small fish grown in tanks doubled in weight approximately five times in three months: 2.7 to 72.7 g in 88 days (Shireman et al. in press a). Similar growth rates were observed by Stevenson (1965). Grass carp grow faster than catfish when fish within the same weight range are compared. In weedy ponds, grass carp grew from 0.6 kg in May 1973 to 3.8 kg in October, 1973 (Rottmann and Anderson in press). Grass carp in Red Haw Lake, Iowa, grew from 0.38 kg to 5.81 kg in three years (Mitzner 1976). The growth potential of the fish is an important factor in stocking strategies.

When plants are not available in ponds for food, grass carp growth, condition, and survival are reduced (Terrell and Fox 1975; Rottmann and Anderson in press). Grass carp are especially vulnerable to angling at this time: 61% were caught in only 8 days of public fishing (Terrell and Fox 1975). Commercial fishing methods may also be employed to remove excess grass carp due to overstocking.

Contrary to popular opinion, grass carp efficiently convert aquatic vegetation to fish flesh. Overall feed conversion (dry wt consumption/live wt gain) of fish fed duckweed varied from 1.72 to 1.97 (Shireman et al. in press a). Similar results were observed by Van Dyke (1973). These values compare quite favorably to those of intensively cultured channel catfish fed nutritionally complete diets (Andrews et al. 1971). Van Dyke (1973) determined that 67% of the dry weight of duckweed was digested by grass carp. Similar digestibility values (60% to 70%) were reported by Stroganov (1963). Because grass carp cannot digest cellulose (Hickling 1966; Fischer 1972), vegetation with high fiber content, such as ryegrass, is utilized less efficiently (Shireman et al. in press b). Submerged vegetation however contains less fiber than terrestrial or emergent vegetation.

[illegible] AND SURVIVAL

Preliminary studies indicated that small grass carp are vulnerable to predation by fish and other animals (Shireman unpublished data[1]). In August, 5000 grass carp fry (48.2 mm T.L.) were stocked in each of two 0.81 ha vegetated Florida ponds. One pond had an established largemouth bass/bluegill/redear sunfish population; the other pond was rotenoned prior to initial stocking of grass carp to remove fish. When the ponds were renovated the following February only 1 grass carp was recovered from the pond with the established fish population; 259 grass carp were recovered from the other pond (mortality = 94.8%). Hatton (1977) studied the predatory behavior of largemouth bass under laboratory conditions. He concluded that bass were more effective at capturing grass carp than the other prey species tested (golden shiners *Notemigonus crysoleucas* and bluegills *Lepomis macrochirus*). Shireman (1976) estimated the theoretical size of grass carp that largemouth bass could ingest. To eliminate predation by largemouth bass, grass carp should be larger than approximately 450 mm (17 inches) when stocked. If small grass carp (<200 mm) are used, they should be stocked when water temperature exceeds 20 C. Grass carp are hardy fish, withstanding water temperatures from 1 to over 32 C, and dissolved oxygen concentrations as low as 0.5 ppm. According to Cross (1969), grass carp mature in 5 to 9 years. Additional research is needed to determine the natural mortality of grass carp in ponds and lakes.

[1] J. V. Shireman, Associate Professor, School of Forest Resources and Conservation, University of Florida, Gainesville, Florida.

LIMNOLOGICAL RESPONSES

Questions have been raised as to limnological and aquatic organism responses to vegetation management with grass carp. It is feared that the release of nutrients previously tied up in submerged vegetation would result in "pea-soup" phytoplankton blooms. But apparently, conditions in ponds and lakes conducive to the luxurious growth of submerged plants may not necessarily favor the growth of noxious plankton blooms when weeds are controlled by grass carp. Phytoplankton, as measured by total photosynthetic pigment, was not excessively abundant in ponds stocked with grass carp (Rottmann and Anderson in press). Terrell (1975) and Mitzner (1976) also observed little change in phytoplankton with vegetation control by grass carp.

Phosphorus is regarded as being of great importance in the determination of primary production in many ponds and lakes. Boyd (1967) reported phosphorus concentration and solubility are much greater in the anaerobic mud than in aerobic lake water. This condition results from the low solubility of iron and aluminum phosphates in the presence of dissolved oxygen (Mortimer 1941). Phosphorus can also precipitate on the bottom as insoluble calcium phosphate (Matida 1956; Hepher 1958). Rooted aquatic plants unlike phytoplankton, periphyton, or floating plants can absorb nutrients directly from the mud (Martin et al. 1969; McRoy and Barsdate 1970). In shallow, macrophyte infested reservoirs, a considerable proportion of the phosphorus is cycled through pathways in which vascular plants are involved (Boyd 1971).

Much of the readily available nutrients in the cell contents of aquatic plants consumed by grass carp are assimilated (Van Dyke 1973); the less soluble portion of the plant sinks to the bottom in fecal pellets. The phosphorus in grass carp feces may be incorporated in detritus food chains or tied up by the sediments and is not released directly to the water column where it would be available for phytoplankton (Terrell 1975).

Daniel (1972) observed that chemical control of aquatic weeds, however, resulted in a 20-fold increase in total phosphorus in the water and over 30-fold increase in available phosphorus 8 days after treatment because of the rupture of the cell walls and the subsequent release of the highly soluble cell contents. Phosphorus values did not return to pretreatment levels until several months later when plant regrowth absorbed some of the excess nutrients.

In pond fertilization programs, phytoplankton blooms are encouraged and sustained by periodic addition of nutrients before rooted plants become established (Swingle 1965). The amount of phytoplankton in lakes has been correlated with the rate of phosphorus input (Bachman and Jones 1974). Noxious algae blooms in lakes may be supported by the addition of allochthonous nutrients rather than the cycling of nutrients within the ecosystem by grass carp. Impoundments or lakes receiving large quantities of nutrients in runoff would be expected to develop phytoplankton blooms regardless of the presence of grass carp.

If grass carp stocking rates are too high, all submerged vegetation may be eliminated. Rottmann and Anderson (in press) observed complete elimination of submerged plants in ponds in one summer at stocking densities ranging from 70 to 233 carp/ha (length 330–409 mm). The removal of submerged vegetation would reduce their contribution to primary production. Since this loss would not be compensated for by phytoplankton, an overall decrease in primary production would be anticipated. In shallow ponds where the nutrient rich mud is in the photic zone, periphyton on the bottom may partially compensate for the reduction of submerged plants; in a deeper lake, however, overall primary production was reduced (Mitzner 1976). If emergent plants, which are not controlled by grass carp, are established and encouraged, primary productivity should not decline to a level that is detrimental to the resource.

Because of the high rate of photosynthesis in weedy ponds and lakes, and the concurrent utilization of free CO_2 and HCO_3 in the photic zone, pH increases and $CaCO_3$ may be precipitated (Sreenivasan 1967). In densely vegetated ponds pH may rise to near toxic levels for fish (Buck and Thoit 1970; Rottmann and Anderson in press). When grass carp control excess submerged vegetation, the pH of the pond water is lowered and total alkalinity values are higher than when weeds are abundant (Rottmann and Anderson in press). Similar responses were noted by Buck et al. (1975) in small pools when vegetation was controlled by either grass carp or an herbicide.

Because surface mats of submerged vegetation shade lower strata, dissolved oxygen is often reduced or absent near the substrate and fluctuates widely near the surface. Dissolved oxygen may be completely consumed during the night in shallow weedy ponds (Welch 1952). Improvements of the oxygen regime by mixing of surface water with lower portions of the epilimnion by wind action is also impaired by submerged vegetation. Grass carp feeding activity opens areas in the vegetation. This improves mixing and allows light to penetrate to a greater depth. Rottmann and Anderson (in press) observed increased mean dissolved oxygen at the 0.5-m and 1.0-m depth in 1.5-m deep ponds when surface mats of vegetation were controlled by grass carp.

The control of luxurious growth of submerged vegetation by grass carp does not appear to result in deleterious limnological responses; some water quality parameters may be improved. Compared to chemical control, the release of nutrients by grass carp is much more gradual, allowing natural systems time to adjust to the changes with less dramatic responses.

EFFECTS ON FISH AND FISH FOOD ORGANISMS

Since grass carp in ponds and lakes consume insignificant quantities of benthic invertebrates and no small fish or fish eggs (Terrell and Fox 1975), changes in the abundance of these organisms are in response to aquatic vegetation reduction. The biomass of benthic organisms (g/m^2) was slightly lower in ponds where grass carp controlled submerged vegetation as compared to weedy ponds, but the difference was not statistically significant (Rottmann and Anderson in press). The density of glass shrimp (*Palaemonetes kadiakensis*) in these ponds was not affected by grass carp, but bluegills did significantly lower the abundance of these macroinvertebrates. A shift from plant-associated benthic organisms to more open bottom-dwelling types would be expected with vegetation reduction. Additional studies are needed to better determine the response of benthic organisms to various types of vegetation management.

The great benefit in fish production obtained from the introduction of grass carp in polyculture pond fish farming is well documented. In Russia, the use of plant-eating fishes resulted in an increase in the average production of ponds from 480 kg to 900 kg (Studeneskiy 1973). Nikol'skii and Verigin (1968) reported increased fish production in ponds of 50% to 100%. Although grass carp may feed on pelleted fish food, the production of channel catfish in weed-free ponds was not affected by the presence of grass carp (Forester 1975). In small pools with dense vegetation, control by either grass carp or herbicide resulted in increased bluegill and golden shiner production (Buck et al. 1975). When grass carp were stocked in weedy ponds, the resultant decrease in submerged vegetation had a positive effect on the reproductive success of bluegills and fathead minnows (Rottmann and Anderson in press). Production and condition of these species were not significantly different in ponds with and without grass carp. Because of the rapid growth of grass carp, the addition of this species increased the total fish production of these ponds by 270%. This supports the statement by Cure (1970) that grass carp makes profitable a trophic level little or even non-utilized by the native species, changing it into useful production (fish meat) of good quality and increasing the fish crop per hectare.

The dense cover provided by submerged vegetation communities can reduce the vulnerability of young bluegills and other prey species to largemouth bass predation. Increasing amounts of vegetation in a Missouri reservoir resulted in reduced feeding activity (as determined by stomach contents) and reduced growth of bass (Heman et al. 1969). Bass in lakes with excessive submerged vegetation grew rapidly during the insect feeding stage (< 200 mm; ~7 -8 inches), but grew slower at greater lengths when fish are needed as forage (Hickman and Congdon 1972). Forage-size fish inhabit dense submerged vegetation; piscivorous bass however are rarely abundant in submerged plant beds, but are frequently observed at the periphery (Barnett and Schneider 1974). Michaelson (1970) concluded that bass are inefficient predators in dense submerged vegetation, and bluegill populations in weedy Missouri ponds were non-vulnerable and crowded and produced few harvestable size fish. Similar conditions were reported by Thomaston (1962) in Georgia ponds with excess submerged vegetation. Reduction of submerged vegetation by grass carp would logically increase the vulnerability of prey, improve the growth of bass, and the quality of fish populations.

[illegible]

When managing aquatic vegetation with grass carp, the objective should be to stock only enough fish to control the excess or nuisance growth of submerged plants. Grass carp should not be stocked in bodies of water with only marginal vegetation. The density stocked should be related to the species, abundance and area of littoral plants, the degree of control desired, and the climatic conditions of the area. Since two large fish (10/ha) controlled most submerged weeds in the 0.2-ha ponds studied by Weithman (1975) one fish per pond may be the appropriate number of grass carp to stock in small weedy farm ponds in the Midwest.

There should be a great economic advantage in the utilization of grass carp for the regulation of excessive plant growth. Treatments with herbicides may cost from $35 to more than $1000 per acre per year. Preliminary results indicate that grass carp fingerlings in tanks fed nutritionally complete pelleted catfish rations may grow as efficiently as channel catfish (Shireman et al. in press b). Compared to the cost of herbicide treatment, the production cost of sufficient numbers of stocking size grass carp would be relatively low. Because of the longevity and hardiness of the fish, the benefits of one introduction may persist for at least 5 years.

A satisfactory balance between a changing grass carp biomass and the growth of submerged vegetation may be difficult to maintain over the long term. The growth of submerged plants is hard to predict; their abundance fluctuates widely from season to season and year to year. Because of this variability, identical grass carp stocking rates may not produce the same degree of control in ponds of similar morphometry and limnology (Rottmann and Anderson in press).

Fibrous emergent and semi-floating plants, as discussed above, are not consumed as readily by grass carp and therefore may not be controlled as effectively as submerged vegetation. Emergent vegetation however is limited by water depth and does not usually develop to nuisance proportions. Stocking density of grass carp would not need to be as precise to maintain a moderate abundance of these plants necessary for aquatic productivity. If excessive emergent vegetation does become a problem, spot chemical and mechanical control methods to open up boating and fishing lanes and swimming areas in the littoral fringe are effective.

Emergent vegetation may serve those functions necessary to maintain aquatic productivity. It protects the pond and lake banks from erosion by wave action and contributes its production to the detrital food chain. Beds of emergent vegetation would provide spawning sites for some fishes, offer limited cover for small fish, and habitat for birds and wildlife. Submerged vegetation, which usually dies back during the winter and does not reappear until summer, is not a good source of invertebrate production for nesting female and young wood ducks or fingerling fish since it does not supply food organisms in the spring when needed (Arner et al. 1974). When compared to *Vallisneria, Eleocharis, Potamogeton* and *Nymphaea*, bulrush (*Scirpus*), an emergent type community, was found to harbor the best and largest sport fish populations in Lake Okeechobee, Florida (Alger et al. 1974). In Orange Lake, Florida, *Cabomba-Ceratophyllum-Najas* beds had the fewest harvestable size fish; emergent beds of maidencane (*Panicum*) had the largest number of catchable-size bass and bluegills (Vaughn 1975).

By reducing the nuisance or excess submerged vegetation with grass carp and simultaneously establishing and encouraging a diversity of native emergent and semi-floating flora, the aquatic manager could increase the aesthetic beauty and recreational value of the body of water and improve aquatic productivity.

In summary, grass carp can be an effective, low-cost tool for managing nuisance plant abundance without drastically altering water quality of ponds and lakes. But as with any tool, it must be used properly to achieve the desired results. Emphasis in any weed control program should be placed on maintaining an optimum quantity and diversity of aquatic plants rather than total eradication. As submerged plants are controlled by grass carp, beds of emergent vegetation should be encouraged to maintain aquatic productivity. By skillful management of aquatic vegetation, the economic and recreational value of the body of water could be enhanced, without reducing the ecological value of the resource.

Even though vegetation control with grass carp will improve environmental conditions in small impoundments overgrown with submerged aquatic plants, their introduction should be controlled in public and private waters. Their impact on stream systems is difficult to predict. Stocking in the near future might best be allowed by permit and only in drainage basins of rivers where grass carp are already present.

Ager, L. A., and K. E. Kerce. 1974. Completion report for aquatic plant communities-associated fauna investigation. Fla. Game and Fresh Water Fish Comm., Tallahassee.

Alabaster, J. S., and B. Stott. 1967. Grass carp (*Ctenopharyngodon idella*, Val.) for aquatic weed control. European Weed Research Council Symposium. August, 1967.

Andrews, J. W., L. H. Knight, J. W. Page, Y. Matsuda, and E. E. Brown. 1971. Interactions of stocking density and water turnover on growth and food conversion on channel catfish reared in intensively stocked tanks. Prog. Fish Cult. 33:197–203.

Arner, D. H., E. Norwood, and B. Teels. 1974. A study of the aquatic ecosystems in two national wildlife refuges in Mississippi. Proc. 28th Ann. Conf. Southeastern Assoc. Game and Fish Comm. 456–467.

Bachmann, R. W., and J. R. Jones. 1974. Phosphorus inputs and algal blooms in lakes. Iowa State J. Res. 49(2):155–160.

Bailey, W. M. 1973. Arkansas' evaluation of the desirability of introducing the white amur (*Ctenopharyngodon idella*, Val.) for control of aquatic weeds. Presented at 102nd Annual Meeting of the Am. Fish. Soc. and Intern. Assoc. of Game and Fish Comm. Hot Springs, AR.

Barnett, B. S. and R. W. Schneider. 1974. Fish populations on dense submersed plant communities. Hyacinth Control J. 12:12–14.

Bennett, G. W. 1962. Management of artificial lakes and ponds. Rheinhold Publ. Corp., New York. 283 pp.

Boyd, C. E. 1967. Some aspects of aquatic plant ecology. Pages 114–129 *in* Reservoir Fishery Resources Symposium. Univ. of Georgia Press. Athens, Ga.

Boyd, C. E. 1971. The limnological role of aquatic macrophytes and their relationship to reservoir management. G. F. Hall (ed.). Reservoir Fisheries and Limnology. Am. Fish. Soc. Spec. Pub. 8:153–166.

Buck, D. H., R. J. Baur, and C. R. Rose. 1975. Comparison of the effects of grass carp and the herbicide Diuron in densely vegetated pools containing golden shiners and bluegills. Prog. Fish Cult. 37(4):185–190.

Buck, D. H., and C. F. Thoit, III. 1970. Dynamics of one-species populations of fishes in ponds subjected to cropping and additional stocking. Dept. of Registration and Education, Ill. Nat. Hist. Surv. Bulletin 30(2):165 pp.

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

Cure, V. 1970. The development of grass carp (*Ctenopharyngodon idella*, Val.) in Frasinet Pond. Bul. Cercet. Pisci. Anul 29. 4 pp.

Daniel, T. C. 1972. Evaluation of diquat and endothall for the control of water milfoil (*Myriophyllum exalbescens*) and the effect of weedkill on the nitrogen and phosphorus status of a waterbody. II. Design and construction of a shallow water sediment core sampler. Ph.D. Dissertation, Univ. of Wisconsin. 121 pp.

Edwards, D. J. 1973. Aquarium studies on the consumption of small animals by O-group grass carp. *Ctenopharyngodon idella* (Val.). J. Fish. Biol. 5(5):599–605.

Fisher, Z. 1972. The elements of energy balance in grass carp (*Ctenopharyngodon idella* Val.) Part III. Assimilability of proteins, carbohydrates, and lipids by fish fed with plant and animal food. Pol. Arch. Hydrobiol. 19:83–95.

Forester, T. S. 1975. Effects of white amur, *Ctenopharyngodon idellus* (Valenciennes), and common carp, *Cyprinus carpio* (Linnaeus), on populations of pond fishes. M. S. Thesis, Auburn Univ. 49 pp.

Hatton, D. C. 1977. Predatory behavior of largemouth bass on soft and spiny-rayed forage species. Ph.D. Dissertation. Univ. Florida. 73 pp.

Heman, M. L., R. S. Campbell, and L. C. Redmond. 1969. Manipulation of fish populations through reservoir drawdown. Trans. Amer. Fish. Soc. 98(2):293–304.

Hepher, B. 1958. On the dynamics of phosphorus added to fish ponds in Israel. Limnol. Oceanogr. 3(1):84–100.

Hickling, C. F. 1966. On the feeding process of the white amur, *Ctenopharyngodon idellus*. J. Zool. 148:408–419.

Hickman, G. D., and J. C. Congdon. 1972. Effects of length limits on the fish population of five north Missouri lakes. Symp. Overharvest and Management of Largemouth Bass in Small Impoundments. N. Central Div., Am. Fish. Soc. Spec. Pub. 3:84–94.

Kilgen, R. H. 1974. Food habits of white amur, largemouth bass, bluegill, and redear sunfish receiving supplemental feed. Proc. Southeastern Assoc. Game and Fish Comm. 27(1973):620–624.

Konradt, A. G. 1964. Methods of breeding the grass carp *Ctenopharyngodon idella*, and the silver carp, *Hypophthalmichthys molitrix*. FAO World Symposium on Warm-Water Pond Fish Culture 44(4):195–203.

Martin, J. B., Jr., B. N. Bradford, and H. B. Kennedy. 1969. Factors affecting the growth of *Najas* in Pickwick Reservoir. National Fertilizer Development Center, Tenn. Valley Auth., Muscle Shoals, Ala. 47 pp.

Matida, Y. 1956. Study of farm fish culture. 3. Fates of fertilizer elements and the relationship between the efficiency of fertilizer and biochemical environment in the pond. Bull. Freshw. Fish Res. Lab., Tokyo, 6(1):27–39.

McRoy, C. P., and R. J. Barsdate. 1970. Phosphate absorption in eelgrass. Limnol. Oceanogr. 15:6–13.

Michaelson, S. M. 1970. Dynamics of balanced and unbalanced bass-bluegill populations in ponds in Boone County, Missouri. M.S. Thesis, Univ. of Missouri. 67 pp.

Mitzner, L. 1976. Evaluation of biological control of nuisance aquatic vegetation by white amur. Federal Aid to Fish Restoration Annual Performance Report, Iowa Conservation Commission. 48–63.

Mortimer, C. H. 1941. The exchange of dissolved substances between mud and water in lakes. J. Ecol. 29:280–329.

Nikol'skii, G. V. 1956. Fishes of the Amur basin. Itog Amurskoi Ikhtiologicheskoi Ekspeditsii 1945–1959. Moscow. Akademia Nauk SSSR. 551 pp. (in Russian, English Summary).

Nikol'skii, G. V., and B. V. Verigin. 1968. Results of research with herbivorous fish. Basic Objectives and Directions of Future Investigations. New Investigations in the Ecology and Breeding of Herbivorous Fish. Nov. Issled. Ekol. Razved. Rast. -yadn. Ryb. Nauka, Moskva, 1968, 12–19.

Odum, E. P. 1959. Fundamentals of ecology. W. G. Saunders Co., Philadelphia. 546 pp.

Opuszynski, K. 1972. Use of phytophagous fish to control aquatic plants. Aquaculture, Netherlands. 1(1):61–74.

Prowse, G. A. 1971. Experimental criteria for the study of grass carp feeding in relation to weed control. Prog. Fish Cult. 33(3):128–131.

Rottmann, R. W. and R. O. Anderson. In Press. Limnological and ecological effects of grass carp in ponds. Proc. S. E. Assoc. Game and Fish Comm. 30.

Shireman, J. V. 1976. Predation, spawning, and culture of grass carp (*Ctenopharyngodon idella*). Annual Report to the Florida Department of Natural Resources—1976. 48 pp. (mimeograph report).

Shireman, J. V., D. E. Colle, and R. W. Rottmann. In press a. Intensive culture of grass carp, *Ctenopharyngodon idella*, in circular tanks. J. Fish Biol.

Shireman, J. V., D. E. Colle, and R. W. Rottmann. In press b. Growth of grass carp fed natural and prepared diets under intensive culture situations. Proc. Icth. Symp. Munich, Germany.

Sreenivasan, A. 1967. Application of limnological and primary productivity studies in fish culture. FAO Fisheries Report 44(3):101–109.

Stanley, J. G. 1973. 1972 Annual Report to U.S. Army Corps of Engineers. 11 pp (mimeograph report).

Stevenson, J. H. 1965. Observations on grass carp in Arkansas. Prog. Fish Cult. 24(4):203–206.

Stott, B. 1967. Aquatic weed control by grass carp (*Ctenopharyngodon idella*, Val.). Proc. of the Third British Coarse Fish Conf. Liverpool. 62–65.

Stroganov, N. S. 1963. The food selectivity of the Amur fishes. Problems of the Fisheries Exploitation of Plant Eating Fishes in the Water Bodies of the USSR, Ashkhabad. 181–191.

Studenetskiy, S. A. 1973. Location and development of pond fish farming in the USSR. Izv. Akad. Nauk SSSR, Ser. Geogr., No. 6.

Swingle, H. S. 1965. Fertilizing farm fish ponds. Agr. Exp. Sta. Auburn Univ., Highlights of Agr. Res. 12(1):11.

Swingle, H. S. and E. V. Smith. 1942. The management of ponds with stunted fish populations. Trans. Am. Fish. Soc. 71:102–105.

Tan, Y. T. 1970. Composition and nutritive value of some grasses, plants, and aquatic weeds tested as diets. J. Fish Biol. 2:253–257.

Terrell, J. W. and A. C. Fox. 1975. Food habits, growth, and catchability of grass carp in the absence of aquatic vegetation. Proc. Southeastern Assoc. Game and Fish Comm. 18(1974):251–259.

Terrell, T. T. 1975. The impact of macrophyte control by the white amur. Verh. Internat. Verein. Limnol. 19(3):2510–2514.

Thomaston, W. W. 1962. The results of population alteration and factors affecting balance in farm ponds in Georgia. Proc. 16th Cons. S. E. Assoc. Game and Fish Comm. 361–369.

Van Dyke, J. M. 1973. A nutritional study of the white amur (*Ctenopharyngodon idella*, Val.) fed duckweed. M.S. Thesis, Univ. of Florida. 35 pp.

Vaughn, T. L. 1975. 1974 fish management report, northeast region. Fla. Game and Fresh Water Fish Comm., Tallahassee.

Verigin, B. V., N. Viet, and N. Dong. 1963. Data on the food selectivity and daily ration of white amur. Problems of the Fisheries Exploitations of Plant-Eating Fishes in the Water Bodies of the USSR, Ashkhabad. 192–195.

Welch, P. S. 1952. Limnology. McGraw-Hill Book Co., New York. 538 pp.

Weithman, S. 1975. Survival, growth, efficiency, preference, and vulnerability of angling of Esocidae. M.S. Thesis, Univ. Missouri, 71 pp.