WEED CONTROL AND FISH PRODUCTION

Karol Opuszyński

Inland Fisheries Institute, Department of Fish Culture
Zabieniec near Warsaw, 05-500 Piaseczno, Poland

INTRODUCTION

The control of undesirable aquatic vegetation by means of herbivorous fish species appears to be a promising possibility. A desirable effect from the point of view of human interests could possibly be achieved without the danger of chemical methods, and furthermore avoiding labor outlay and the costs of mechanical vegetation control. An additional advantage of a biological method is that useless plant matter is transformed into fish meat utilized directly as a food product, for sport fishing or as feed for other animals of economic importance.

In introducing new fish species it is necessary to analyze their food habits and efficiency of food utilization, as also the food relationship with indigenous species on order to foresee, as far as possible, the effect of these new species on the aquatic vegetation and on fishery production.

Another problem is that of dewatering the influence of the introduced fish species on the water ecosystem as a whole. The immediate advantages gained in bringing in such species to remove undesirable plant groups might well result in more serious, natural and economic consequences.

PHYTOPHAGOUS FISH SPECIES DISCUSSED IN THE PAPER

Since both in Poland as well as in Europe there is a lack of indigenous phytophagous fish species of economic importance, the following Asiatic species were imported from the Soviet Union in 1964: grass carp, Ctenopharyngodon idella (Val.), silver carp, Hypophthalmichthys molitrix (Val.), and bighead carp, Aristichthys nobilis (Rich.). More intensive studies were hitherto carried out on the first two species mentioned, with more intensive studies on the third species planned for the future. The present paper presents the results of studies conducted in Poland on the background of available world literature.

FOOD HABITS AND FOOD UTILIZATION

Grass carp fry initially feed exclusively on animal feed consisting chiefly of plankton crustaceans and Chironomidae larvae. Transition from animal to plant food takes place at a weight of 1.1-1.8 g and body length (longitudo corporis) of 36-43 mm (Opuszyński 1969) or total length (longitudo totalis) of 49 mm (Ciborowska 1972). Some data indicate that this transition depends, apart from the size of fish, also upon water temperature. Scheer et al. (1967) consider that the grass carp feeds on zooplankton up to a water temperature of 15°C, and on plants above this temperature. The
proportion of macrophytes ingested increase with growth, the larger individuals living mainly on macroflora. In two-year old fish reared in ponds, the animal food represented less than 1% of all the diet (Figure 1). It was also reported by Boruckij (1952), who studied the food of grass carp 33–58 cm long in the Amur River, that their alimentary tracts were filled with macroflora. The author states that since grass carp feeds on macroflora together with leaves and plant stems, all living organisms such as algae, Rotatoria, Chironomidae larvae, Oligochaetes and other aquatic organisms pass to the alimentary tract. Their number and biomass was, however, negligible in comparison with those of the macroflora.

The type of plant eaten changes with the development of grass carp. Initially its food consists of phytoplankton, filamentous algae, Fontinalis sp., Charales and small species of flower-bearing plants such as Lemna sp., Potamogeton pectinatus L., Elodea canadensis Rich. Larger fish weighing more than 250 g also eat emergent plants.

Food selection of grass carp with respect to aquatic plants was studied under experimental aquarium conditions as well as in the natural environment (Stroganov 1963, Verigin et al. 1963, Penzes and Tolg 1966, Drupauer 1967, Fischer 1968). The results of these experiments are not, however, unequivocal which is probably the result of widely varying experimental conditions. Different sizes of fish and various water temperatures during the experiments made these results difficult to compare. Further, different types of plants were used for food selection.

In general, the foods most desired by grass carp are soft submerged plants. The aquatic plants which are readily consumed include Elodea canadensis Rich., Ceratophyllum demersum L., Potamogeton pectinatus L. and Myriophyllum spicatum L. The suitability of other plant species for grass carp is still under discussion. This concerns emergent plants and filamentous algae, which frequently occur in great abundance and create considerable difficulty in the management of fisheries and proper use of water bodies for other purposes.

According to Stroganov (1963) Typha sp. and Phragmites communis Trin., at a height above one meter are not consumed by the grass carp. On the other hand, Aliey (1963) and Verigin et al. (1963) are of the opinion that these two plants are readily eaten. Grass carp first breaks a tall Phragmites communis by catching its leaves and then consumes them together with the soft upper part of the stem. Typha is broken at the base of the shoot and then eaten in toto. Similarities in reed breaking and Typha consumption of Schoenoplectus lacustris L. by grass carp over one kg in weight were observed in our ponds. This does not mean, however, that these plant species are always readily eaten by the fish.

Filamentous algae are most frequently mentioned as the most attractive food for grass carp (Avault 1965, Přihodk and Nosal 1966, Penzes and Tolg 1966). It has been reported by other authors that filamentous algae and Hydrodictyon reticulatum (L.) are not eaten willingly (Stroganov 1963, Tsharyiev and Aliey 1966) or are completely neglected (Ilin and Solovleva 1965). Reluctant consumption of filamentous algae by grass carp has been confirmed in our studies (Opuszyński 1969). In 1965, in ponds, a massive
development of filamentous algae appeared. Quantities of algae were so great that they represented a considerable obstacle while fishing with nets. Despite this fact the amount of algae in grass carp food was small. During the whole season the algae accounted for, on the average, 9% of the total food intake, whereas the consumption of macroflora amounted to 72% of total food intake. When given a choice, grass carp clearly prefer macroflora to algae.

From the point of view of utilizing the grass carp for controlling aquatic vegetation of ponds, an important problem is that of its consumption of feed designed for other fish species. Stevenson (1965) suggests that grass carp may prefer pellets over aquatic plants. This is not supported in our studies, in which the fish were fed on sorghum, the fodder generally used in fisheries in Poland. Analysis of alimentary tracts of grass carp revealed that the share of plants ingested was greater than the fodder. Similar studies were done for fry. The proportion of these plants ingested since fodder for fish was first added, amounted to 86 and 81% of the total food intake of fry in 1965 and 1966, respectively. In one-year old fish macroflora and filamentous algae represent 81% of the food intake during the whole season. Two-year old fish consume an even greater proportion of macroflora amounting to 91% of their diet. In experiments with two-year old fish the distribution of fodder and plants was similar. There were no aquatic plants in the ponds and these two types of food were introduced at two sites in the pond. During the whole period of investigation fodder was found to dominate in the food of fish only on July 29, 1965 (Figure 1). These results may indicate that under conditions of intensive culture and feeding of fish, grass carp can be used also for controlling aquatic plants.

**QUANTITY OF FOOD CONSUMED**

Food intake is often given as a percentage of body calorific content, or as a ratio of wet weight of food eaten to wet weight of fish, or simply as wet weight of food consumed. Lukarin (1959) reports that grass carp weighing about 2000 g consume 500–2300 g of fresh vegetation. Verigin (1963) ascertained that daily intake varied from 115 to 1350 g fresh weight per kilogram of fish, depending on the species of plant eaten. Cure (1970) maintains that the grass carp eats its own weight of plants a day at a temperature of 20–28 C. Zolotova (1971) states that the average daily intake of grass carp on a plant diet is 30% of fish body weight.

Fischer (1968) investigated the daily ration of one-year old grass carp kept under laboratory conditions and fed various plants normally eaten by it. The values obtained varied from 660 to 9786 calories per individual, depending on the species composition of the diet. The daily intake of grass carp weighing 20–50 g was 3000–56,000 calories, when fed on a pure plant diet of one species, while that of 86–107 g fish on a pure animal diet was 3000–10,000 calories. However, a mixed animal-plant diet gave astonishing results (Fischer 1973), the intake being higher than for animal food alone (Figure 2). Food intake increased uniformly with fish body weight when a mixed animal-plant diet was fed to excess. However, when plants only were supplied food intake increased considerably with change of fish weight from about 240 to 300 g. Within this relatively narrow weight range daily intake increased threefold from 16 to 45 Kcal. In a 10 day experiment the fish fed on animal food gained about 4% in weight and the fish fed on plant food lost about 2%.
According to Fischer's and Lyakuovich's (1973) considerations it is possible that after reaching a weight of about 300 g there is an increased demand for some "minimum factor" (a vitamin or an aminoacid) which results in increased food intake and retarded growth.

There are interesting results of experiments in which grass carp were fed different quantities of animal and plant food (Fischer 1973). The fish faced with an excess of animal food (Figure 3) did not consume it in a constant rate. In the first two series when the food supply seemed to be sufficient, since the fish does not consume it wholly, the amounts of Tubificinae eaten were similar. When the availability of plants was diminished the fish consumed fewer animals. In the reverse situation, however, when animal food was limited and plant food was in excess, the consumption of food did not decrease. The plant food (given in excess) was consumed in greater quantities when the supply of animal food was diminishing. However, when converted to calories (Figure 4) the amount of plant food eaten remained practically unaffected (differences range from 4 to 4.5 Kcal.). From these data (Fischer and Lyakuovich 1973) concluded that the grass carp needs a certain minimum of plant food, which facilitates the ingestion and probably digestion of animal food.

Water temperature exerts an important influence on the amount of food consumed. In feeding fry with Chara sp. and Fontinalis antipyretica L. Opuszyński (1967a) found that the diurnal amount of plant matter consumed at temperatures from 16 to 28 C increased more than twofold and was from 0.5 to 1.03 g/gram of fish body weight. At temperatures from 22 to 28 C the diurnal increase in food consumed was similar for fry and two-year old fish, and reached 29 and 30%, respectively. The significant correlation \( r = 0.79 \) between the amount of hydrilla (Hydrilla verticillata Royle) consumed by the grass carp and water temperature was estimated by Sutton (1974).

**Food Conversion and Efficiency**

The food conversion ratio, that is the ratio between food intake and growth of fish, was determined for three year old grass carp (Opuszyński 1969). Since vegetation did not develop in the ponds, practically the whole amount of plant food consumed was supplied from outside. The initial stock of grass carp weighing 116 kg/ha consumed from 6652 to 7406 kg/ha of wet plant weight. Consumption of green plant matter per 1 kg of initial stock ranged from 57 to 64 kg at food conversion coefficients of from 25 to 35.

Higher ratios were obtained in feeding grass carp fry weighing 8-10 g and two year old fish weighing 91-109 g with water plants under aquarium conditions (Opuszyński 1967a). Food conversion coefficients in this case depended upon the water temperature and ranged from 78 to 92 (Figure 5). These high food conversion coefficients appear to indicate that the fry had not yet changed from feeding on zooplankton to plant food, and probably still required considerable additions of animal protein in their diet for rapid growth.

Food coefficients for two year olds were more than twofold lower, and were from 36 to 35 at a temperature range of 22-28 C. They were likewise less variable within this range than fry. A considerable increase in the
food conversion coefficient was observed at a temperature of 35 C. This temperature was very close to the lethal temperature of 36.6 C (Opuszyński 1967b). Poor growth was not the result of lower food rations. No studies were carried out to determine if the increased food conversion coefficient was caused by poor digestion and food assimilation or by increased maintenance requirements (standard metabolism) of the fish at this high temperature.

Food conversion coefficients averaging 30 were obtained by Verigin et al. (1963). The fish used in his experiment weighed 170 - 260 g, and the water temperature ranged from 30 to 34 C. Stroganov (1963) in his experiments with fish ponds having a water temperature of not more than 24 C, obtained coefficients ranging from 14 to 21, with an average of 18. These results, similarly as those cited previously for experiments in ponds (Opuszyński 1969), are probably lower because invertebrate fauna consumed by the grass carp in ponds was not taken into consideration.

Fish food conversion coefficients might likewise result from the high water content in the tissues of aquatic plants. Sutton (1974) called attention to this fact when feeding hydrilla to grass carp. The food conversion coefficient calculated for the wet mass of hydrilla was 62. Samples taken for dry weight determinations indicated that the hydrilla contained 91.8% moisture. In other words, 23.2 g of dry hydrilla produced 4.6 g of fish weight. The conversion relationship showing the amount of hydrilla consumed divided by fish growth, indicated that 5.04 g of dry hydrilla were required for each 1.0 g increase in growth of these fish.

Fischer (1972) calculated a food assimilation and energy budget for grass carp fed on animal and plant food under aquarium conditions. As animal food tubificids (Tubifex tubifex) were used and as plant food lettuce (Lactuca sativa). Fish fed exclusively with plants had a gross production efficiency index $K_1 = 2.2\%$ (this is the proportion of food intake used for fish growth) whereas those 2.2% fed with animals $K_1 = 12.5\%$. The assimilability of plants was also very low and amounted to about 20%.

Fischer and Lyakuovich (1973) assumed that under natural conditions, where fish consume both plant and animals, growth was caused mainly by animal proteins and by lipids of both animal and plant origin. It is more likely that carbohydrates (mostly in plants) and proteins of plant origin are used chiefly for energy metabolism. Glycogenesis probably occurs to a marked extent.

Fischer's values produced under laboratory conditions with excess food and a strict monospecific diet are probably lower than those for natural conditions. Nevertheless, it can be concluded from these data of the importance played by addition of animal feed to the diet of grass carp, and of the probable drop in food utilization for growth as the share of the animal food component is decreased.

SILVER CARP

Food Quality

The silver carp is also a phytophagous fish which filters its food
from the water by means of gill rakers embedded in the gill arches. The space between gill rakers in adult fish is 20 to 25 microns (Voropajev 1968). This species also feeds on zooplankton during its initial period of life (Opuszynski 1969, Ciborowska 1972). It was found that phytoplankton became the essential food component when fry reach a body length (longitudo corporis) of over 32 mm and a weight of 0.7–0.8 g (Figure 6). In contrast to the grass carp, vegetation does not always constitute the main food component of older silver carp. As can be seen from Figure 1, zooplankton was the predominant food of two year old silver carp in ponds.

The food composition of the silver carp is very variable. Detritus makes up 90–99% of the food in spring in the Amur River, whereas in summer during the peak period of blooms it drops to 5–15% with zooplankton constituting 1% and phytoplankton the remaining part (Boruckij 1950, Verigin 1950). Depending upon the type of natural waters and fishery ponds, some authors found chiefly phytoplankton in the digestive tracts of silver carp, while others, detritus (Boruckij 1973). Opuszynski (In Press) found that the percent share of phytoplankton and zooplankton drops while detritus increases in the food as density of the fish in ponds grows from 1.5 to 12 thousand individuals per ha. The percent share of phytoplankton and zooplankton in consecutive densities of silver carp was 10.1, 4.3, 3.9, 1.6, 1.4.

Food selectivity of the silver carp is a controversial question. Some authors (Salar 1967, Lupaceva 1969, Tarasova 1970, 1971) are of the opinion that phytoplankton dominant in the environment constitutes the basic food of fish. These authors compare the activity of silver carp to a "natural plankton net". On the other hand other authors found distinct selectivity of the fish with respect to specific groups and species of algae (Savin 1965a and b, Kajak 1977, Opuszynski In Press). These authors are of the opinion that the silver carp cannot be compared to a plankton net filtering mechanical particles of a given size. There is no universal opinion as concerns consumption of blue-green algae. These algae are considered as being both willingly consumed (Muchamedova 1974), and as avoided by the fish (Omarov and Lazareva 1974, Kajak 1977).

Quantity of Food Consumed

A number of authors when investigating the nutrition of silver carp determined the amount of food found in the digestive tracts. This amount is in general expressed in 0/000 as the index of filling, or the amount of feed multiplied 10 thousand times per unit of body weight of the fish under study. The index of filling for the silver carp from the Amur River was found to be 57–582 0/000 (Boruckij 1973), and from ponds as follows: 502–547 (Savin 1965b), 142–143 (Omarov 1970), 80–570 0/000 (Tarasova 1970). Similar values were obtained in our investigations (Table 1).

In order to determine the actual amount of food consumed by silver carp it is necessary to know the rapidity with which food passes through the digestive tract. Omarov (1970) found that at a water temperature of 23 C filling and emptying of the digestive tract takes place 6 times diurnally. By multiplying the amount of food found in the digestive tract of silver carp by 6, the diurnal food ration of this species ranges from 17 to 20% of the body weight.
Food Conversion and Efficiency

Opuszyński (In Press) found that the index of food conversion efficiency for the silver carp was 2.6%. Without doubt this index is low. Attention is likewise called to the fact that the value of this index drops as density of fish increases. There are not data in the literature with which the values obtained could be compared.

BIGHEAD CARP

I have little to say as concerns the bighead carp. As shown by Opuszyński (In Preparation) zooplankton is of greater significance as food than for silver carp (Figure 7). This might possibly be due to the sparser spacing of filtering rakers than in silver carp. The spacing of filtering rakers in the bighead carp ranges from 20 to 60 microns (Vovopaje 1968).

FOOD RELATIONSHIPS WITH INDIGENOUS FISH

In view of the fact that in reality there is a lack of herbivorous fishes in the European ichthyofauna, food competition between indigenous fish species and introduced Asiatic ones can be limited by comparing the amount and type of animal food consumed by these species. Comparisons were made on the animal food composition of carp, grass carp and silver carp raised jointly in ponds (Opuszyński 1968, 1969). The carp seemed to be the most typical representative of indigenous ichthyofauna, as this is a species basically consuming all species of invertebrates on which other autochthonic fish feed.

Animal food was characterized by means of the index of filling/quotient of animal food weight and fish weight in the 0/000/- and also by the index of food convergence after Shorogin. The latter is the sum of lower percent shares of food constituents appearing in the food of two fish species under comparison. The index varies within the limits from 0—when the food composition in the species compared is entirely at variance—to 100 when it is exactly the same.

The index of filling for animal food in grass carp fry in the respective years under consideration was only 2.6 to 4.7 times less than that for carp fry (Table 3). At the same time the convergence of food composition in the two species was high and ranged from 33.2 to 51.8. The index of filling in older grass carp individuals showed a downward trend. In the stocks of two-year old fish, it was 11.4 times less than that in carp. A high convergence of animal food composition in carp and grass carp was due chiefly to the fact that both fish species fed on the same groups of Chironomidae larvae. Larger species of Cladocera and Copepods were also important (mainly Daphnia longipes Mull) although in grass carp food it tended to decrease with fish growth.

With regard to silver carp, the index of filling varied considerably as compared with carp. It was 1.7 (fry during the cold season of 1965) to 12.1 times less than that of carp and grass carp in individual experiments. The convergence of food composition in carp and silver carp was less marked than that in carp and grass carp. This convergence in individual years under observation ranges from 3.7 to 25.4 (Table 3). Crustacean plankton invariably
represented the basic animal food constituent in silver carp. The amount of crustacean plankton tended to increase as fish aged. It accounted for 98% of the animal food of two-year old silver carp, and 93% of all the crustacean plankton weight was attributed to *Bosmina longirostris* Mull.

The development of *B. longirostris* on a mass scale should be looked upon as a harmful side effect of intensified carp production. These crustaceans which are consumed by carp only to a very small extent, feed on phytoplankton which serves for a staple food of other animal organisms significant in the carp diet. Therefore, the fact that the silver carp feeds on *B. longirostris* seems to be of double advantage. In addition to a better utilization of food resources for production, it may have a restrictive effect on the numerical increase of this crustacean.

**INFLUENCE ON THE ECOSYSTEM**

**Control of Aquatic Plants**

The effectiveness of grass carp in controlling plant overgrowth in bodies of water depends on a number of factors, the most important probably being water temperature, composition of plant species and individual weight of fish and stock density. Elevated water temperature and stock density augment the effectiveness of grass carp in controlling aquatic plants. Man's contribution to the solution of this problem is limited to controlling stock density.

According to investigations carried out under the moderate climatic conditions of Poland there is a general opinion that the grass carp can hamper the development of macrophytes to a great extent, but it cannot completely solve the problem of overgrowth of inland water (*Opuszyński* 1969, 1972, Bernatowicz and Wolny 1969). Two factors limiting grass carp utilization for aquatic weed control are food selectivity and the relatively high temperature needed for active feeding. Effective control could be obtained using a very high stocking density with a high initial weight of individual fish. This, however, due to slow growth of fish under such conditions, would not be economically justified in countries where grass carp is a marketable fish.

It should be stated that partially positive results were obtained even in a relatively cold climate in England (*Stott and Robson* 1970). The mean daily water temperature was 15.8 C with a range of 8.5 - 21.5 C. A stock density giving a mid-season biomass of approximately 300 kg of two-year old fish reduced plant growth to about 50% of its potential. Fish growth was not satisfactory (the mean weight increment was 37.8 g), and the mean survival was only 61%. In the moderate climate of the Moscow area, ponds did not show excessive overgrowth during the entire season with a stock of 200 - 600 grass carp/ha (500 - 700 kg/ha). The initial mean weight of individual fish was over 1 kg. After exhaustion of the preferred plants, grass carp ate the "compulsory plants" (plant species which are not consumed in the presence of other food). The growth rate of fish was slow.

The optimistic evaluation of the effectiveness of grass carp in the control of aquatic plants in the German Democratic Republic is given by *Janichchen* (1976). According to this author the following premises must exist for the successful
application of grass carp: (1) sufficient water quality; (2) water temperatures higher than 15-16 C; (3) water depths of at least 0.3 m with areas of 1 m and deeper; (4) exclusion of waters with single-species-colonization, for instance by Stratiotes aloides, Ranunculus sp. or with an abundant development of Nymphaeaceae; (5) objects suitable to prevent any migration of fishes; (6) fishes with a minimum age of two years; and (7) mean stocking rate of 200 kg/ha, which is to be reduced or raised due to the extent of plant density.

The effectiveness of grass carp for plant control increases with an increase in temperature. A good example is represented by the results obtained in the moderate climatic zone in water heated by effluents from a thermal power station. Attempts to use grass carp for this purpose were carried out in a heated lake in Poland. About 5000 grass carp of individual weight 250-1000 g were introduced to this lake of 154 ha. The fish considerably reduced the plants in the lake. The only plant that remained was Nuphar luteum Sm., which is reluctantly eaten by grass carp. In order to learn if these plants disappeared as a result of the introduction of phytophagous fish, a portion of the littoral zone was separated by means of a wire net 25 x 10 m in size. Plants grew in abundance only in this zone, where no fish could enter. In the middle of July the water level in the lake was increased and the edge of the net was about 30 cm above the water surface. As a result, several grass carp of about 6 kg jumped over the net. Three days later no plants except Najas sp., which is reluctantly eaten by these fish, were seen in the isolated area (Horoszewicz, personal communication).

Stocking grass carp into water bodies heated by thermal power stations in a moderate climate as well as water bodies in a hot and tropical climate may solve the problem of overgrowth in these waters without the use of the traditional methods. The only condition is that the vital requirements of the fish must be met.

Phytoplankton

Massive algae blooms are the most visible and troublesome symptoms of rapidly progressing eutrophication of surface waters resulting from human activities. The problem of controlling communities of plankton algae is one of highest priority.

Silver carp, because of food habits, may be a way to control phytoplankton by direct consumption by a suitably large population of fish (Prowse 1969, Vovk 1974). Other authors (Opusynski 1972, Grygierek 1973, Barthelmes 1975a), although optimistic as to the role of the silver carp in this respect, call attention to the possibility of more complicated effects due to this species on the biocenosis beyond the direct relationship of silver carp and phytoplankton. Experimental studies allowing for an evaluation of the role of the silver carp in counteracting eutrophication processes are, however, few in number, and their results discrepant (Januszko 1972, 1974; Kajak et al. 1975).

Recent studies by Januszko (In Press) showed increases in phytoplankton biomass in ponds stocked with carp and silver carp as compared to ponds treated as controls and stocked with carp only. The stocking density with silver carp was 4, 8 and 12 thousand fish per ha. The control group of ponds showed an average seasonal phytoplankton biomass of 16 g/m³ whereas ponds with
successive silver carp densities showed 21, 18 and 22 g/m³. The dynamics of seasonal changes in phytoplankton biomass are shown in Figure 8.

Changes occurred within the plankton algae community as silver carp stocking densities were increased. The percental share of diatoms increased and Chlorophyceae decreased. In consecutive groups of ponds the biomass of diatoms increased 32, 42 and 66% as compared to the control ponds. The decline in the biomass of Chlorophyceae of 18, 35 and 37% in consecutive groups of ponds as compared to the control ponds was due chiefly to the three to fivefold drop in the biomass of the dominant species, Chlorella minutissima Pott, which is a small algae (3 microns). It passes easily through the gill filtration apparatus. The average weight of plankton algae was higher in ponds with silver carp than in the controls.

Other experiments differ in their results from those under discussion herein. The influence of silver carp on plankton and benthos was investigated in enclosures of plastic foil (2.5 x 2.5 and 1.5 m in depth) in a eutrophic lake. A fourfold drop in the phytoplankton biomass and twofold growth of the benthos biomass was found in the enclosures with silver carp, as compared to non-stocked control enclosures (Kajak et al. 1975).

Januszko (1974) found considerable effect of bighead carp on the biomass and composition of algal communities. In the ponds stocked with 1500 bighead carp/ha and 2000 common carp/ha there was more than a twofold increase in algal biomass in comparison with control ponds stocked with carp alone. The mean seasonal biomass value in the control group was 32 g/m³ and in the group with bighead carp 67 g/m³. In control ponds blue-green algae biomass (Cyanophyta), mainly Anabaena flos aquae, increased innumerably (Figure 9).

Influence on Fish Production

Studies on the effect of phytophagous fish on pond production have been carried out in various European countries. In general, all investigators emphasized the possibility of obtaining additional yield without a diminution in production of carp. Little is known, however, as to the validity of the data describing the magnitude of this additional production, since only in a few studies have control ponds been used.

Experiments conducted to determine the effect of additional stocks of fry and one- and two-year old phytophagous fish on carp production were conducted in Poland (Opuszynski 1969). The results of these experiments are presented in Figure 10. Each column represents the mean from three experimental ponds similar in area and depth. The ratio of carp to phytophagous fish was 1:1. The stocks of phytophagous fish were composed of 50 percent grass carp and 50 percent silver carp. It is seen from Figure 10 that in both years the additional stock of phytophagous fish caused a decrease in production of carp fry, although in 1966 the total polyculture production was 338 kg/ha higher than in monoculture. Considerable differences between the results of both years can be explained in terms of different thermal conditions as 1965 was an exceptionally cool year.

Carp production was not decreased when older phytophagous fish were stocked. These fish gave an additional yield of 330–370 kg/ha, representing
an increase of 20–25 percent. It should be emphasized, that in the fish farm, in which the experiments were conducted with one- and two-year old fish, the growth of the silver carp was much slower than in other farms in Poland. This was probably due to exceptionally high percentages of blue-green algae in the phytoplankton.

The main reason for reduced carp fry production in polyculture situations seems to have been food competition between carp and grass carp. This was evident when we analyzed the index of filling for animal food and the convergence of food composition.

Stocking silver carp within the range of 4 to 12 thousand two-year old fish per hectare resulted in a decline in carp production. This decline occurred at the lower silver carp stocking rates, whereas density increases of from 8 to 12 thousand individuals per hectare did not cause a further drop in carp production (Figure 11). Lowered carp production was caused by poor fish growth rather than increased mortality. Increased silver carp densities resulted in reduced individual weight increments as silver carp production increased. The highest silver carp stocking density increased total production of ponds by almost 800 kg/ha in high density carp ponds.

Causes for the decrease in carp production cannot be attributed only to direct food interrelations between the two fish species. Although the silver carp caused a decrease in the numbers of zooplankton (Grygierek, In Print), the numbers and biomass of Chironomidae larvae (Wasilewska, In Print) increased. In all probability, complex ecological mechanisms might have caused changes in behavior as a result of fish density. Similar results have been described previously (Ivlev 1955, Nelsson 1967).

Influence on Some Elements of the Environment and the Biocenosis

Grass carp

In addition to reduction of aquatic weeds, grass carp may induce considerable changes in biocenosis. This process has not been subjected to detailed study until recently.

Taking into consideration the previously cited data on food consumption and assimilation, I assume that an initial stock of grass carp weighing 100 kg/ha discharges approximately 5000 kg/ha of excrements into the environment during one growing season under temperate climatic conditions (May to September). Grass carp possess strong pharyngeal teeth with sharp masticating surfaces. As a result the food becomes highly disintegrated. According to Hickling (1966) the plant particles after passing through the alimentary tract are smaller than 3 sq. mm. Thus, the feeding activity of grass carp releases into the environment large quantities of highly disintegrated and only partly digested plant parts. This process may cause intensive fertilization of water bodies, as grass carp excrements are easily decomposed by micro-organisms. As a result the released nutrients may cause development of phytoplankton. Cure (1971) reported increased eutrophication of a pond following introduction of grass carp at a stocking rate of about 70 two-year old fish/ha. From year to year the pond became more and more eutrophic. Primary plankton production
increased gradually, as macrophytes diminished. Before stocking, in 1967, the pond was unproductive with a primary plankton production in the range of 6.7 and +1.0 g O₂/m²/day, in 1968, after stocking and until 1970, the pond was considered as mesotrophic-eutrophic (+2.6 to 7.1 g O₂/m²/day and even highly eutrophic +11.1 g O₂/m²/day). Cure (1971) maintains that in ponds strongly overgrown with macrophytes, non-drainable and with a thick mud bottom, grass carp at a moderate rate are able to substitute for organic and mineral fertilization.

Removal of vascular plants can result in disruption of the ecological equilibrium in a water body since these plants can effectively assimilate biogenic compounds of autochthonic and allochthonic origin. In consequence, reduction of macroflora by grass carp may indirectly contribute to the development of other groups of aquatic plants, thus leading to undesirable phenomena such as water blooms.

Stocking of water bodies with grass carp may directly cause alterations in species composition and fish abundance. This was observed in a heated lake in Poland as the spawning grounds of fish laying their eggs on the aquatic plants was destroyed (Backiel, personal communication).

Silver Carp

The importance of biological methods in countering eutrophication processes led to the decision to undertake investigations pertaining to these methods by a group of workers of the Inland Fisheries Institute in Poland. It was decided to increases stocking densities with silver carp to very high levels in a number of ponds (Figure 11), and to investigate the influence of such densities on selected elements of the environment and the biocenosis. These investigations were carried out on physico-chemical conditions (Piotrowska, In Press), bacteria (Kruger, In Press), phytoplankton (Januszko, In Press), zooplankton (Grygierek, In Press), benthos (Wasilewska, In Press), fish health (Peitrzak, In Press), and food relationships and fishery production (Opuszynski, In Press).

The presence of silver carp in the ponds resulted in a number of environmental and biocenosis changes. Changes in particular factors varied with respect to their course, magnitude and frequency but were not directly correlated with silver carp stocking density, since consecutive densities of stocking did not always result in a gradual intensification of change (Figure 12).

When compared to the control group the greatest effect of the silver carp was noted with respect to the chlorophyll content of the water, primary production and the number of bacteria. As concerns the groups of bacteria under study, proteolytic and ammonification bacteria in the water, and total numbers of bacteria and denitrification bacteria in sediments showed the strongest reaction to environmental changes. Smaller changes of a positive character were found with respect to oxygen content, biochemical oxygen demand (BOD₅), pH values (an average 8.1 in control ponds and 8.3 in ponds with silver carp), organic phosphorus content, total number of bacteria, phytoplankton biomass and benthos number and biomass.

As to negative changes due to the influence of silver carp the following
should be mentioned: lower levels of nitrogen, phosphorus, and dissolved carbonates; lower levels of accumulation of organic carbon, nitrogen and total phosphorus in the sediments. The only, but very strong negative change in the biocenosis, consisted of a drop in the numbers and biomass of zooplankton.

According to our investigations the role played by the silver carp in the circulation of matter appears to consist of ingesting dead and living organisms, decomposing them and rapidly transporting them to the bottom in the form of excrements. Fish excrements are, then, acknowledged to be a good medium for bacteria, undergoing rapid mineralization in the water. It can be concluded from these deliberations that as silver carp stocking rates are increased, the inflow of partially decomposed plant matter should likewise increase. Simultaneously, an increasingly smaller part of the algal biomass (per biomass unit of fish) would be incorporated into fish flesh and removed from the ecosystem (Table 2). Hence, a basic effect of introducing very high stocking densities of silver carp would consist of a considerable acceleration of circulation of matter in the water. Mosevic and Rodhe (Wrobel 1965) are of the opinion that the rapidity with which circulation of matter takes place is of greater importance than the direct supply of mineral nutrients.

Results of our investigations carried out in carp ponds do not indicate any possibility of controlling algal blooms by means of large stocks of silver carp. The reasons for this are as follows: (a) low effectiveness of feeding on algae due to detrital feeding; (b) elimination of zooplankton, which in turn feeds on phytoplankton; (c) more rapid circulation of biogens; and (d) reduced weight increments of fish as stocking densities are increased.

As mentioned above, Kajak et al. (1975) found in a eutrophic lake a significant drop in the phytoplankton biomass due to silver carp; however, in their experiment the factors causing rapid circulation of matter and biogens to the water depths were lacking when compared to our experiments. Circulation of water and the presence of a large stock of benthic fish constitute the factors in question. The diurnal stratification cycle in ponds corresponds to an annual cycle in lakes, and the carp is a fish known for its intensive mixing of sediments. In all probability, the lack of detritus in the water was the reason that silver carp in plastic foil enclosures did not cause a plankton bloom. Finally, our ponds were intensively fertilized with mineral fertilizers which constituted a basic difference between the two experiments.

Kajak (1976) suggests that the very heavy pressure of silver carp on phytoplankton can, in certain circumstances, efficiently improve the water purity in lakes, at least for some period of time. The feces of silver carp sink rather rapidly (1–3 m/sec) (Barthelmes 1975b), thus they leave the epilimnion before significant decomposition and nutrient release takes place. In comparatively stagnant environments, the nutrients were thus removed from circulation for months. In the water bodies with a definite thermocline, the nutrients would not recycle during the stagnation period.

CONCLUSIONS

Efforts were made in this paper to present an overall picture of the effects of phytophagous fish on the environment and biocenosis of water bodies, and not limiting it only to the influence of these species to selected plants.
The grass carp under north, central and east European climatic conditions can contribute to the control of plants in inland waters. The grass carp can in many cases effectively substitute present mechanical and chemical methods of control in warm and tropical climatic conditions, and also in water bodies heated by effluents from thermal power plants.

Considerable eutrophication can be one of the consequences of introducing the grass carp. Removal of vascular plants, high food rations connected with low food assimilation, and rapid decomposition of excrements might possibly accelerate circulation of biogenic substances in the water body. As a result of these processes considerable bloomings of algae can be expected.

In order to counteract the above mentioned phenomena it appears sensible to introduce fish species which feed on phytoplankton. We have endeavored to show, however, that the effect of the silver carp and the bighead carp on the ecosystem is more complex than was at first assumed. At least in some cases these fish can cause further growth in the phytoplankton biomass and evoke unfavorable changes in its species composition.

Counteracting eutrophication processes by means of phytophagous fish is of great scientific and practical importance, and for this reason requires further intensive investigations. As concerns the influence of herbivorous fish on fishery production, favorable results can be expected at least in such simple and controlled human ecosystems as warm-water fish ponds.
REFERENCES


Table 1. Average amount of food found in the digestive tract of Silver Carp.

<table>
<thead>
<tr>
<th>Food</th>
<th>Stock Density of Silver Carp (thous. indiv./ha)</th>
<th>1968</th>
<th>1974</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wet weight</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Index</td>
<td>%/ooo</td>
<td>180</td>
<td>202</td>
</tr>
<tr>
<td>Average per fish</td>
<td>mg</td>
<td>1291</td>
<td>1707</td>
</tr>
<tr>
<td>Biomass of zooplankton and phytoplankton</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Index</td>
<td>%/ooo</td>
<td>17</td>
<td>10</td>
</tr>
<tr>
<td>Average per fish</td>
<td>mg</td>
<td>131</td>
<td>73</td>
</tr>
<tr>
<td>Biomass of Phytoplankton</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Index</td>
<td>%/ooo</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Average per fish</td>
<td>mg</td>
<td>26</td>
<td>49</td>
</tr>
</tbody>
</table>

122
Table 2. Index of food conversion efficiency ($K_{fc}$) for Silver Carp in different stock densities.

<table>
<thead>
<tr>
<th>Stock Density of Silver Carp (Thous. indiv./ha)</th>
<th>4</th>
<th>8</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Fish Increment in g/day (A)</td>
<td>1</td>
<td>0.7</td>
<td>0.5</td>
</tr>
<tr>
<td>Food Ration in g/day (B)</td>
<td>16</td>
<td>22</td>
<td>23</td>
</tr>
<tr>
<td>$K_{fc}$ (A) (B) in %</td>
<td>6</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>
Table 3. Comparison of indices of filling for animal food and animal food convergence in Carp, Grass Carp and Silver Carp. (C = carp, Gc = Grass carp, Sc = Silver carp.)

<table>
<thead>
<tr>
<th>Index</th>
<th>Fish Species</th>
<th>Fry</th>
<th>2-year old fish</th>
<th>3-year old fish</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1964</td>
<td>1965</td>
<td>1966</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>103,2</td>
<td>43,2</td>
<td>20,6</td>
</tr>
<tr>
<td></td>
<td>Gc</td>
<td>38,8</td>
<td>9,2</td>
<td>5,5</td>
</tr>
<tr>
<td></td>
<td>Sc</td>
<td>13,5</td>
<td>24,8</td>
<td>1,7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gc</td>
<td>2,6</td>
<td>4,7</td>
<td>3,7</td>
</tr>
<tr>
<td></td>
<td>Sc</td>
<td>7,6</td>
<td>1,7</td>
<td>12,1</td>
</tr>
<tr>
<td></td>
<td>C and Gc</td>
<td>33,2</td>
<td>39,5</td>
<td>51,8</td>
</tr>
<tr>
<td></td>
<td>C and Sc</td>
<td>3,7</td>
<td>23,2</td>
<td>25,4</td>
</tr>
<tr>
<td>Date</td>
<td>Phytoplankton</td>
<td>Filamentous Algae</td>
<td>Rooted Plants</td>
<td>Sorghum</td>
</tr>
<tr>
<td>------------------</td>
<td>---------------</td>
<td>-------------------</td>
<td>---------------</td>
<td>---------</td>
</tr>
<tr>
<td>July 8, 1965</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>July 29, 1965</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aug. 30, 1965</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sept. 3, 1965</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average for All Season</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- carp
- grass carp
- silver carp

Figure 1. The percent food composition of two-year old carp, grass carp and silver carp.
Figure 2. Dependence of consumption rate on the type of food supplied. I - excess of plant food, II - excess of animal food, III - excess of animal food (Pfeifer and Lakhtinovich, 1973).

Fish body weight (g)
Figure 3. Dependence of consumption rate on quantity and quality of food supplied. 1 - food consumed, 2 - food remained, A - excess of animal food, B - excess of plant food (Fischer 1973).
Figure 4. Dependence of consumption rate on quantity and quality of food supplied. I - Food remained. 2 - Food consumed. A - Excess of animal food + demonstrative ration of plant food, b - Excess of plant food + demonstrative ration of animal food.
Figure 5. Food coefficients for one- and two-year-old fishes, Cyprinodon varericulatus, in various water temperatures: 1—one-year-old fish, 2—two-year-old fish, a—food coefficients.
Figure 6. Percent composition of fry food in 1966: a - carp, b - grass carp, c - silver carp.

<table>
<thead>
<tr>
<th>Date</th>
<th>Sample</th>
<th>Food Category</th>
<th>Frequency</th>
<th>Genus</th>
<th><em>Zooplankton</em></th>
<th><em>Phytoplankton</em></th>
<th><em>Macrophytes</em></th>
<th><em>Algae</em></th>
<th><em>Shrimps</em></th>
<th><em>Fish</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>26 VIII 1966</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28 VIII 1966</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 IX 1966</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 7. Percent food composition of the silver carp (Sc) and the bighead carp (Bh). Ponds number 17, 21, 37 - Sc in monoculture, 34, 53 - Bh in monoculture; 33, 42, 56 - Sc + Bh in polyculture; 1 - zooplankton, 2 - Chlorophyta, 3 - bacillariaphycean, 4 - Cyanophyta, 5 - Euglenophyta.
Figure 8. Influence of the silver carp on algae biomass in carp ponds during the season /IV - IX 1974/. The horizontal line—average biomass of algae in control groups of ponds stocked with carp alone; from left to right—the consecutive stock density of the silver carp: 4, 8 and 12 thousand ind./ha.
Figure 9. Influence of the bighead carp on the development of Cyanophyta. Ponds number: 20, 40, 44 - carp alone; 26, 32, 48 - carp + bighead carp.
Figure 9. Continued
Figure 10. Yield per ha in mono- and polyculture. Each column represents the mean from three experimental ponds.
Figure 11. The carp production and total production under increasing stock density of the silver carp in 1974. Stock density of the silver carp/ind./ha/ stock density of the carp always the same.
Figure 12. The influence of various stocking densities with silver carp on average seasonal values of some environmental and biocenotic factors.

Logarithmic scale, 1 corresponds to the value of a given factor in the control group of ponds with carp only; the three bars correspond to the three consecutive increasing densities of silver carp; the highest bar shows the particular value at lowest density of silver carp; 1 - ammonium nitrogen in the water, 2 - phosphates in water, 3 - BOD₅, 4 - soluble oxygen, 5 - phytoplankton biomass, 6 - chlorophyll, 7 - gross primary production, 8 - destruction, 9 - net primary production, 10 - total number of bacteria in water, 11 - number of proteolytic bacteria in water, 12 - number of ammonifying bacteria in water, 13 - total number of bacteria in sediments, 14 - number of proteolytic bacteria in sediments, 15 - number of denitrifying bacteria in sediments, 16 - zooplankton numbers, 17 - zooplankton biomass, 18 - benthos numbers, 19 - benthos biomass.