THE USE OF GRASS CARP IN COMPARISON WITH OTHER AQUATIC WEED CONTROL METHODS

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INTRODUCTION

Control of nuisance aquatic weeds can be achieved by a number of methods based on the following principles:

1. Growth Prevention. This can be done by measures that prevent waterbodies from becoming eutrophicated or removing growth factors for noxious vegetation. Examples are the use of harmless competitive plants (Yeo 1976), stimulation of phytoplankton that fixes light and nutrients (Bungenberd de Jong 1967) or continuous shading by trees or shrubs (Krause 1977, Lohmeyer and Krause 1975), black plastic (Mayhew and Runkel 1962) or cardboard screens (Bernatowicz 1966). The use of preemergence herbicides is also regarded as preventive control, but its duration is usually much shorter than the other methods.

2. Growth Retardation. Not many methods have been studied, however, one biological example is the use of shade caused by aquatic plants with big floating leaves (von Zon 1976, 1977). Also growth-retardants have been tried, but have not been very successful.

3. Growth Cessation. This principle is most commonly used for aquatic weed control, and can be divided into two catagories: one without harvest, including all chemical and some mechanical methods, and one involving harvest as with some mechanical methods. The latter method is preferred in many situations because at least part of the weed problem is removed, reducing nutrient release in the water.

   The use of grass carp (*Ctenopharyngodon idella*) is intermediate: there is progressive retardation of weed growth, so that growth stops at a certain moment, while some of the plants are harvested.

AQUATIC WEED MANAGEMENT

There are not only different methods for aquatic weed control, but also various types of aquatic weed problems. The control method should be adjusted to the problem, and therefore it is necessary to know the water demands by user groups, and under which conditions the control methods are efficient.

The latter can easily be answered by empirical studies such as herbicide concentrations, grass carp stocking densities, solidity of paths for mechanical devices, in relation to water depth and width. Demands are more difficult to quantify because for most uses the criteria are not well known. Of course, all plant material is in principle unwanted in a waterway used exclusively for water transport. This means that the most effective method is best as long as it is not dangerous to crops or the receiving water at the end of the irrigation system. The other extreme can be found when a water is in a nature-reserve, where as much species diversity as possible is wanted. Here only the aging process (becoming land) must be retarded.

Most waterways have more than one function. In many developing countries fish production and navigation may be as important as water transport, while in heavily populated parts of the western world often recreation becomes more important than the original agricultural function. In the Netherlands, where 14 million people live on only 4 million ha, the thousands of kilometers of ditches constructed for irrigation and drainage also provide recreation for a million sport fishermen. In consequence, these waters should contain a diverse and sound fish population with good opportunities for breeding and growth. In addition, they play an important landscape role, connect many relatively small nature reserves in the Rhone and Meuse Delta, and have educative value in biology teaching. Also important is their function of providing drinking water for cattle and even humans. It is practically impossible to judge the relative importance of such functions for every ditch, canal, brook, pond or lake and even then, it would be nearly impossible to prescribe maintenance programs for each one. For example, the critical amount of emergent vegetation needed for breeding of pike (Esox lucius), the quantitative relation between weeds and other organisms and the resistance created by various aquatic plant species for water transport are essentially unknown. It is also not possible to predict the amount of transport needed in a certain year, since the weather is not predictable.

In these uncertain situations weed control must be carried out in such a way that everyone is satisfied. This is not possible via the use of rigorous control methods, but only via the way of careful weed management. This means that the following demands must be fulfilled.

1. A set of minimum standards for water transport should be formulated, including a realistic small risk. In the Netherlands it seems possible to predict the percentage of the waterway capacity that may be blocked by aquatic weeds in some periods of the year.

2. Aquatic weed management should be directed as much as possible to the most vulnerable function of the waterway. In the Dutch situation this is often providing a biotone for many aquatic organisms. Most of these inland waters become a refugium for eutrophic freshwater organisms that originally found their habitat in old river areas which no longer exist. In considering the use of weed control methods, species diversity (especially its constancy and composition in a certain waterbody during the year) plays an important role.

3. Broad scale weed control methods must be developed. Making allowance for 1 and 2 above often leads to compromises, however, it will become increasingly possible to adjust weed control systems to local situations especially as more data are collected concerning the positive and negative effects of various control methods, waterway usage and plant biology. This means, that in the course of time aquatic weed management can be adapted to fit common types of natural management which create high local diversity, with high temporal constancy. This type of management is not as futuristic as it may seem. In Dutch road verges, a similar system was introduced with success during the past years: every verge unit has its own prescribed maintenance scheme which takes into account both traffic safety and vegetation type in the surrounding lanscape. As an example, mowing time is adjusted to the time of seedfall of the most important plant species.

With these demands in mind, existing aquatic weed control methods can be compared in a general way, but the emphasis will be placed on the use of grass carp.

EFFECTIVITY OF METHODS

There are various parameters to evaluate the effectiveness of a control method. Generally, only short-term effects are evaluated and rated either "good" (no plants) or "bad" (plants still present). "Moderate" may turn into "bad" very soon. A comparison of the effects of a method with the wanted level of control does not seem practical at the moment, since clear definitions of water levels cannot be given. Still another criteria for judging methods is the duration of the effect. Longer durations are usually considered better, but correlations with the period of the year that control is wanted is usually not made, nor is an adjustment of the method to the growth cycle of the species made. Sometimes species are removed mechanically during the steep part of their growing cycle, so that the effect lasts only a few days, or they are killed or removed only a few weeks before their natural die-off.

When grass carp are applied, criteria for effectiveness must be judged more subtly and more knowledge is necessary of the desired level of control throughout the growing season. Rapid effects cannot be expected, since every plant species that is not consumed in the beginning continues to grow. Rapid effects require mechanical or chemical methods or a very high stocking of grass carp, followed by removal of individuals after a few weeks. With grass carp weed control progresses relatively slow so that stocking should be realized in such a way that good control is achieved in the most critical periods for water transport. In doing so, the duration of the effect in the first year is not important. In temperate regions such a stocking routine is relatively easy, since most aquatic weed problems are present in autumn when rainwater must be drained. Grass carp control vegetation during the summer causing a more acceptable level during the time of critical water transport. A big part of spring and summer weed control with mechanical or chemical methods was considered necessary to prevent weed growth from becoming too dense for efficient control in the autumn.

When method effectiveness is considered over a period of years another criterium other than the rapidity and duration of control is more important, namely the consistance of the weed problem.

In the past, aquatic plants were harvested every year and in succeeding years the same species appeared again, which, as stated before, is a demand for good management. Presently this is still the case where some types of mechanical control are used, at least as long as cut material is harvested in some way. The use of herbicides causes some form of selectivity. The most common example is that control of emergent or floating vegetation with phenoxy-herbicides, nearly always gives rise to a submerged weed problem, which is often worse for some water or waterway functions than the original problem.

The results of years of submerged vegetation control with chemicals can be seen in parts of the Netherlands. In relatively stagnant water, bound nutrients from plants were released after every treatment resulting in hypertrophic conditions. These waters now support only filamentous green or blue-green algae. Even these algae could be controlled chemically with herbicides, like diuron, but these compounds were not controlling all algal species. The results were very unattractive canals (both from an aesthetic point of view and biological) unusable for nearly every function and with a practically unsolvable algal problem. For various reasons the use of these algicides is now forbidden in the Netherlands (Zonderwijk and von Zon 1974, von Zon and Zonderwijk 1976) and means that users of allowed herbicides must be aware that they can create algal problems that overshadow the original problem.

Grass carp are sometimes reported to be selective in their food choice, although this decreases with age (Cagni, Sutton and Blackburn 1971). Vegetation shifts are, however, in quite another direction and not as detrimental as those seen with herbicides. The reasons are:

1. Not all nutrients of consumed plant material flow back into the water; about 50% of the ingested phosphorus and nitrogen is retained in the fish (Nikolskii 1956, Hickling 1966, Mickewicz, Sutton and Blackburn 1972, Fischer and Lyakhnovich 1973, van Rijn, Werumeus Buning and van der Zweerde 1975). As long as the grass carp does not die, these nutrients are withdrawn from the system. The other 50% is only partially available for plant growth, so that severe eutrophication effects do not become visible within the system.

2. Shifts towards filamentous algae are not possible, since those plants are consumed with eagerness.

3. Plant species that are commonly rejected, even by a mixed population of grass carp, are generally of not much importance, with the exception of water hyacinth. Strongly rejected species are those of the genus Batrachium (Ranunculus), of which many are toxic or raise blisters. Experiments in containers showed that they are consumed to a certain extent after starvation (van Rijn, Werumeus Buning and van der Zweerde 1975); in practice many species of this genus have ended their yearly cycle before they can cause difficulties for water transport (von Zon and Zonderwijk 1975). Another group of unedible species are the Nymphoids (Nymphaea, Nymphoides, Nuphar, Lotus and

others). These plants are consumed when no other species are left, so that selectivity is probably not a matter of unpalatability, but of difficulties in attaining them.

In the Netherlands, an object of study at the moment is whether these Nymphoids, with big floating leaves, can be used in an integrated approach with the grass carp: the big leaves shade submerged species to some extent, probably without interfering with water transport. The fish consumed the remaining submerged material and prevents the floating mat from becoming too dense. In a temperate climate such integration is useful, because summer temperatures can be very different from one year to another. If grass carp are stocked in densities to be effective in a rather cold year, this could lead to starvation in warm summers. The combination of grass carp with floating plants might allow reduction in the initial grass carp stocking density. In cold summers, the mat of floating leaves will increase and in warm summers this mat will serve as a reserve food source for the fish.

The physical and chemical quality of the water is one important factor that can interfere with the success of weed control operations. In general, mechanical control is independent of these factors; however, the effect of herbicides can sometimes be influenced by it. A well-known example is, that herbicides such as paraquat and diquat lose their activity immediately when there is a high content of floating organic matter, which can be increased suddenly by rainfall or improper application techniques. It is clear that biological weed control methods are susceptible to changes in environmental quality. The water must be suitable for fish, which means that the oxygen content should not change very much, and there should be open areas. This may sound very clear, but in practice grass carp are often used by purely technical people for whom this is not the first thought. It is often written that grass carp are not very effective in shallow waters or in often disturbed waters. In experiments where grass carp could not avoid shallow water and disturbances they acclimated to these conditions rather fast (van Starkenburg and van der Zweerde 1976). In practice shallow water areas should be fenced to acheive good effects. In the same experiments no habitation occurred in brackish water (over 500 ppm Cl^-) and food intake was lower than in controls, which means that higher stocking densities were needed to achieve the same effects.

It is difficult to compare the economics of grass carp usage with those of common mechanical and chemical methods. Grass carp are stocked for several years, which means a loss of interest in invested capital, but inflation does not occur. Fences must be constructed and maintained, especially in shallow water where fish kills might occur. Literature data and Dutch experiences indicate that in countries where the fish can be bred the total weed control price will be half of that of chemicals and a quarter of that of mechanical control (Hone 1973, Janichen 1974, von Zon, van der Zweerde and Hoogers 1976).

The different aspects of the effectiveness of various aquatic weed control methods are summarized in Table 1. I concluded that grass carp are an effective, relatively cheap, and lasting weed control agent, provided that the environment is suited for their survival and rapid effects are not wanted.

SIDE EFFECTS

Another reason to use grass carp is that herbicides can be directly or indirectly toxic to various aquatic organisms. Another is the high cost of the mechanical alternative. Grass carp, however, have other side effects that should be studied before their utilization, such as chemical, physical and biological changes of the aquatic environment and the consequences of these changes upon other organisms. During the last few years an enormous amount of data has been collected, but the interpretation of this data is difficult for various reasons.

1. In nearly all studies grass carp are compared to an undisturbed control situation. Shifts in biological parameters that are found in such studies have scientific value, but in practice, grass carp will only be introduced where the weed problem cannot be left undisturbed. It is necessary to make comparisons between the side effects of commonly used mechanical and chemical methods and grass carp. One of the rare documented studies, in this respect, is that of Buck, Baur and Rose (1975). They did not find clear biological differences during one year after application of grass carp and diuron in preplanted swimming pools. Some differences in water quality (e.g. higher orthophosphate levels after diuron) indicate that shifts to other problems were less in the pools stocked with grass carp.

2. Most studies concerning side effects have been conducted in aquaria and data from such studies cannot be translated directly to field situations (von Zon 1977). Generally the stocking density in laboratory situations is so high that changes are exaggerated (Michewicz, Sutton and Blackburn 1972 and von Zon, van der Zweerde and Hoogers 1976). Furthermore, aquaria do not simulate a total ecosystem with its compensating and buffering capacities. There are indications that changes, which are often based on laboratory studies, are not found in the field. This is true for food selectivity since in an aquarium the supply of plants is not natural and the grass carp are usually very small. It is often observed that macroinvertebrates are consumed in aquaria, which probably results because they are easily caught and are needed for essential amino acids which are lacking in their food supply. The small fish used in these studies might need more animal food (Bailey 1972, Opuszynski 1972). Differences are found between field and aquarium studies as pertains to plankton, which is related to increased nutrients. In laboratory studies with grass carp, the orthophosphate content of the water increases, which leads to blooms of phytoplankton. In the field this is generally not the case (Johnson and Laurence 1973, Rottmann and Anderson 1977) because released nutrients are probably bound in bottom-sediments (Terrell 1975) or in parts of the living aquatic ecosystem, especially fish. Recent reviews on the side-effects of grass carp can be found in von Zon, van der Zweerde and Hoogers 1976, and von Zon 1977.

3. The results of grass carp research are interpreted to a great extent by investigators and agencies that are not involved in herbicides and mechanical control and they tend to ask more questions. In fact,

work on the side effects of mechanical control is nearly not carried out, except as pertains to dredging. Chemical control side effects are partly studied by industrial weed specialists (often in the framework of what governments ask for allowance) and partly by biologists. Fishery people have cared little about herbicides and held the view that their side effects were well studied. They generally have not asked for special studies for herbicide allowances. But when grass carp came into reality, fishery people felt capable of judging and asked for more research than has ever been required for other types of aquatic weed control. The usual argument that grass carp are persistent, whereas herbicides are temporary is unrealistic, since curtailment of a herbicide or mechanical treatment program immediately brings back the weed problem.

4. Field methods currently in use do not allow for valid conclusions. Original fish populations are often estimated by rotenone samples, but the impact of these samples on the remaining fish populations is unknown. The influence of grass carp on fish populations is in a few years measured with a new sample. Although drawn from a same area, the situation may be completely different; for example, it may be different to catch fish in a weedy or clean situation (Newton, Merkowsky, Martin, Ellis and Stanley 1976). Moreover, cleaning often stimulates sportfishing, and this may alter the fish population. The same type of difficulties are encountered in sampling macroinvertebrates and plankton.

Summarizing these points, it seems evident that the only way to establish the relative importance of grass carp side effects is a field study in which during a number of years, various commonly used control methods are computed. However, such a study would require so much work that international cooperation is needed. At the moment, policy-people often will not accept data from other countries, since they are not familiar with the names of organisms. However, the structure of aquatic ecosystems with weed problems will be so similar, that the different species occupying niches is not relevant. Therefore, it should be possible to design experiments to answer questions of general importance in order that the results will be applicable to many world situations.

In Table 2 a rough estimation is given of the side effects of various weed control methods in the Netherlands. In this connection, it should be noted that a very clear yearly cycle occurs for most organisms in temperate regions. For many of them, a very important part of the cycle, breeding, is in spring or early summer. The role that aquatic weeds play in the production of these organisms will not be greatly affected by grass carp since the quantitative effects on aquatic vegetation is not important before midsummer if overstocking is prevented (von Zon 1974). The other methods, especially chemical, are often carried out as early in the season as possible, both for maintenance work and for prevention of heavy weed growth. Dense stands of vegetation when treated could cause serious problems (e.g. oxygen depletion by killing all vegetation). In tropical countries, the influence could be more severe because of constant grass carp pressure, although there, a lower stocking density must be compared with a higher herbicide input.

The impact of grass carp on the quantity of other biota in an aquatic ecosystem is mainly temporary (only in the first one or two years) and the diversity is at most only slightly influenced. Therefore, its use for weed control in waters or waterways with different functions is very attractive. The old situation can be restored easily by removing the fish, as has been shown in Dutch experiments. On the other hand, chemical control influences the structure of the living community much more and leads to impoverishment so that a very long restoration time is needed. The effects of persistent herbicides are more severe since they also affect small, nontreated side-waters that otherwise could act as a biological buffer. The influence of mechanical control is hardly known. If mechanical control is merely an imitation of clearing with handpower it can be expected that the influence on the biota will be small.

SUMMARY

As far as possible from the scarce field experiments comparing the effects of various methods to control aquatic weeds, the following two conclusions can be made.

1. The use of grass carp is generally as reliable as mechanical and chemical methods, relatively cheap and lasting, but not fast-working.

2. The side effects of this use are at least less severe and anyway less irreversible than those of chemical control.

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