ENVIRONMENTAL EFFECTS OF AQUATIC HERBICIDES

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Summary The environmental effects of aquatic herbicides are related to the expected effects from more traditional methods. The time of treatment the frequency of treatment, and the area treated are factors which can determine the effect of both methods on the aquatic flora and fauna. These effects can be deleterious or beneficial to the nature conservation interests of an area and this is discussed. Fundamental differences do exist however between mechanical methods and herbicide treatment. These differences could relate to oxygen balance, the problem of resistant species, and long term ecological change. The efficiency of herbicides and their method of use is questioned. A relationship is given between algae and macrophytes which indicates that the production lost from the removal of macrophytes is compensated for by the regrowth of the non-susceptible algae and a method is suggested which could make the herbicide efficient for the drainage engineer whilst still maintaining a biological interest.

INTRODUCTION

The Nature Conservancy Council in this International Wetland Year, organised by the Council of Europe, are faced with the loss of many interesting plants in wetland areas, partially because of adverse management techniques whether mechanical or chemical. Not only is the Nature Conservancy concerned over the decline of many rare or attractive plants in our dyke systems which now represent relict sites of former wetlands, but we are also concerned with the quality of the environment. Quality is difficult to define and is often subjective but is connected with a high diversity in both flora and fauna.

The management of dyke systems determines the quality of the fauna and flora present in them. Correct management is essential if the nature conservation interest of a dyke is to be maintained: George (1976) has established that some traditional methods of management are not as destructive to nature conservation interests as imagined, but only if the interval between clearance is long enough. Such methods can even maintain the nature conservation value of a site by limiting the cycle of hydro seral development to those stages having the highest diversity of plant and animal life.

Why then is the Nature Conservancy Council concerned about the alternative method, the use of aquatic herbicides when the chemicals in use have been approved by the Ministry of Agriculture Pesticide Safety Precautions Scheme and the principles of management namely plant removal are essentially the same?

This paper will attempt to assess the differences between the traditional methods of management and herbicide use on the ecology of aquatic systems.

MECHANICAL METHODS

Weed clearance can be achieved by hand, weeding cutting rakes, weed cutting buckets, weed cutting boats with U and V shaped reciprocating blades, mechanical dredgers and drag lines. The last two methods are also used to maintain the profile and batter of a channel.

HERBICIDES IN USE

At present only nine chemicals have been cleared by the Pesticide Safety Precautions Scheme for use in or near water. Those used for controlling bankside and emergent vegetation are 2, 4-D (amine salt) maleic hydrazide and dalapon with or without paraquat. Aquatic vegetation is treated by diquat chlorthiamid, dichlobenil, terbutryne and cyanatryn. Algae are controlled by treating with terbutryne and cyanatryn. Only one chemical has been designed for use in rivers, this is cyanatryn.

TYPE OF HERBICIDE

Robson (1973) identified two types of herbicide, the selective and total herbicide. The selective herbicide, namely 2, 4-D and dalapon has a limited spectrum of susceptible aquatic plants leaving the non-susceptible species to take its place. They can be a valuable tool in removing problem weeds and can be used with advantage for nature conservation purposes, e.g. Dalapon has been used by the Royal Society for the Protection of Birds (RSPB) to remove dominant stands of Phragmites communis, the common reed, in some areas of their reserves creating open water lagoons. One other herbicide, diquat, a quick acting contact herbicide has also been used by local naturalist trusts following the advice of the Nature Conservancy Council.

Diquat represents the other type of herbicide which is the total herbicide and this includes dichlobenil, terbutryne and cyanatryn. None are truly total in effect. There are always some resistant species but from the evidence available these 'total' herbicides have been listed in ascending order of totality. For example, dichlobenil can remove some but not all aquatic macrophytes and most of their root biomass but be generally ineffective in removing algae, whereas cyanatryn at the highest treatment level can remove most floating and submergent aquatic macrophytes and most species of algae.

WETLANDS AS AREAS OF HIGH NATURE CONSERVATION INTEREST

Robson (1973) identifies three levels of management:-

"Complete eradication. Where drainage is paramount the need is sometimes for the permanent eradication of all plant growth. This is only likely where there is a very high flood risk such as might occur in urban areas. Usually in these situations the channels would be lined and little weed control would be needed.

Controlled growth. Excessive weed growth is removed, at least for part of the year, without seriously reducing the density of plant cover at the soil surface. This is the commonest objective and applies to both banks and channels of almost all unlined watercourses where the improvement of surface drainage is the main reason for weed control but where fishing is also of importance.

Occasional control. Periodic treatment is normally necessary for the management of fish and other wildlife habitats. It is usually applicable to many lakes and ponds and to wildlife sanctuaries on watercourses."

Unfortunately those areas requiring an "improvement in surface drainage" are those areas such as the East Anglian fens, Thorne Moors, Romney Marsh, the Pevensey Levels, the Somerset Levels, and the grazing marsh dykes of Norfolk. These areas were once extensive wetlands and they have all been drained for agricultural purposes. The resulting drainage channels were in many cases the only available refuge for the survival of the original flora which must have been present in much greater numbers on the now drained wetland. Some species may not have been able to adapt to the change and Perring (1970) has attributed, on a national basis the extinction of four plant species to the effects of drainage. Five others have become very rare and seven are in a state of decline.

The manipulation of water levels particularly in arable areas where a low water table is required poses one threat to the survival of the flora but the additional threat of management techniques which could adversely affect the survival of aquatic flora and fauna might give rise to extinctions on a large scale.

The conflict of interest between the nature conservationist and the drainage engineer arises from both the intensive use of some mechanical methods (George 1976) and the general use of non-selective or total herbicides on a wetland site. Even sites which have been identified as sites of special scientific interest (SSSI) have been sprayed by Internal Drainage Boards, and the code of practice as laid down by the Ministry of Agriculture Fisheries and Food recommends that such sites are left untreated.

TRADITIONAL METHODS OF MANAGEMENT AND HERBICIDE USE AND THEIR ENVIRONMENTAL EFFECTS

Handcutting, weed cutting boats, and buckets are the traditional and preferred methods of management for nature conservation purposes. The indications are that these methods are not detrimental in the long term to the biological interest of an area, but more scientific data is required. Mechanical dredgers if used intensively on a three year cycle of management can give rise to a reduction in plant diversity but an interval of five to seven years between management may not be detrimental and could be beneficial in the long term to the flora (George 1976).

Selective herbicides and those total herbicides killing a small spectrum of species, e.g. diquat, if used with caution and for spot treatment only may also be beneficial to nature conservation interests and a long term ecological change which is of benefit to the nature conservationist could occur, (Brooker 1975).

Total herbicides which either destroy the root tissue or have a large spectrum of susceptible species, could give rise to a long term ecological change which could be detrimental to the nature conservation interest of an area (Newbold 1975 b).

Both mechanical methods and herbicide usage will however give rise to short term ecological effects and these are well documented for the herbicides paraquat, diquat and dichlobenil (Brooker and Edwards 1974) (Newbold 1975 a). Some fundamental differences do exist however between herbicide management and traditional methods which should give rise to ecological differences in response.

Short Term Ecological Effects

All mechanical methods remove the plants from the channel, with aquatic herbicides plant decay takes place in situ. This has important short term ecological effects on the system (Fig.1) which are additional to the expected effects from mechanical methods, namely (i) a more severe depletion of oxygen: this is caused primarily by the oxygen demand placed on the system by the fauna, but particularly the bacteria which are the agents of plant decay (Jewell 1970). Oxygen depletion is

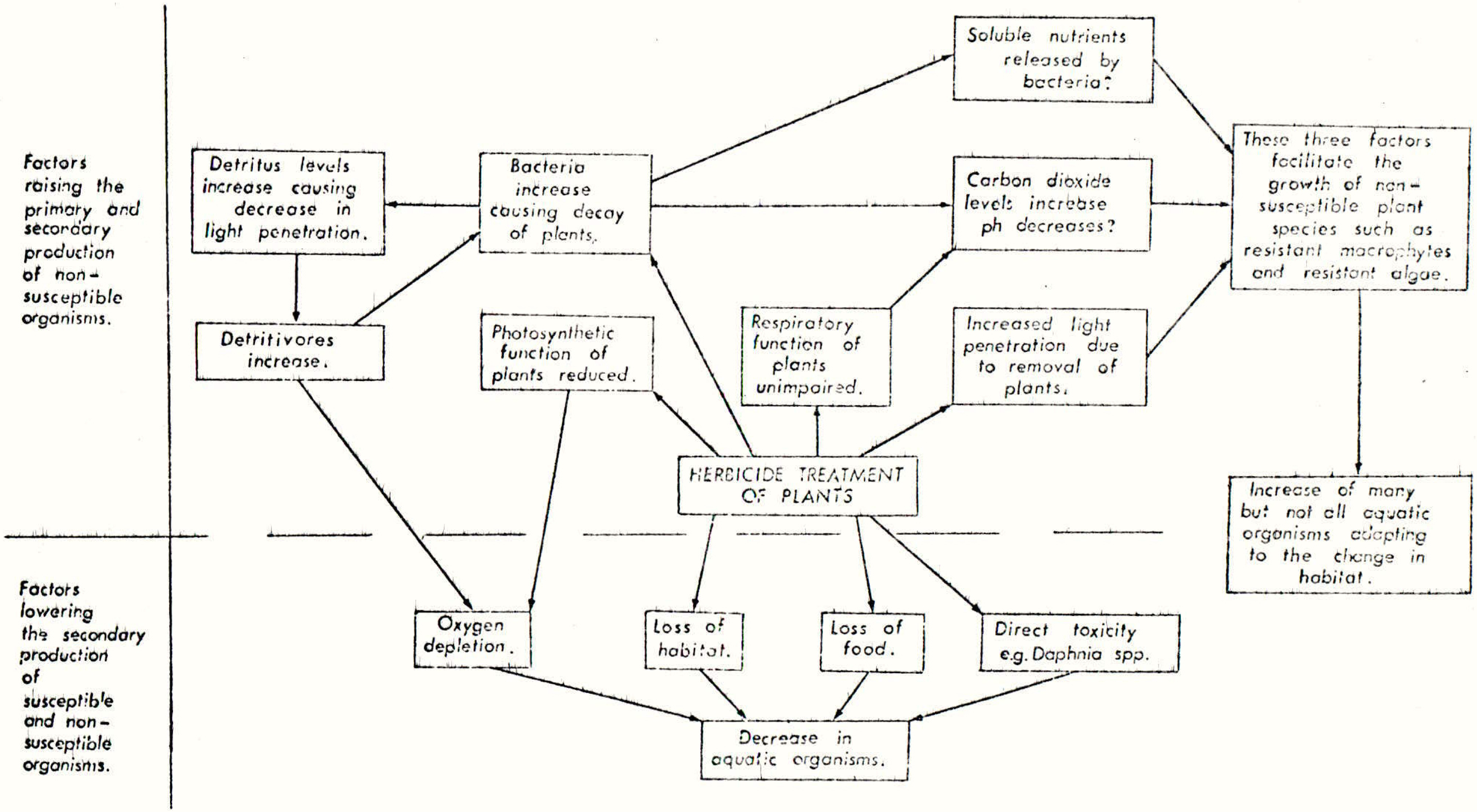

Figure 1. Possible short-term ecological effects of herbicides in aquatic systems.

primarily biomass related (Brooker 1974). However, some herbicides can, by their mode of action, lower oxygen levels even further. Diquat affects the photosynthetic function of plants (Krieger et al 1973) which prevents oxygen production, but the respiratory phase is unaffected for up to four days after treatment (Newbold 1973). Oxygen is therefore taken from the water to produce carbon dioxide. The same effect seems to occur with cyanatryn (Crossland 1975) and serious oxygen depletion apparently unrelated to plant biomass has occurred with terbutryne (Tooby T. E. pers comm). More research is required to confirm whether or not these observations have parallels with the effects recorded for diquat.

Time of Treatment

Herbicides are generally applied in the Spring when plant biomass is low. This avoids excessive oxygen depletion, but the aquatic fauna is not soley dependant on oxygen for its survival. In fact the equilibrium of the system is disturbed at a critical time, i.e. when the fauna is dependant on an increased plant production for its cycle of growth and reproduction. Food production is therefore suddenly cut off and the ability of an aquatic animal to survive depends on switching food preferences or migration. Some invertebrate species are plant specific (Mellanby 1963) and Brooker and Edwards (1974) attributed the loss of *Acentropus niveus* a lepidopterous larva to the host plant being killed by paraquat.

Plants also provide a refuge against excessive predation for both fish and invertebrates alike; and fish spawning sites may be lost. The change in the system may last only a few weeks before a new balance is achieved and the effects on the fauna can be slight e.g. paraquat treatment (Brooker & Edwards 1974) and diquat treatment (Newbold 1975 b) or even beneficial when removing emergent vegetation (Brooker 1975). This so far is only true of the one selective herbicide dalapon. Severe effects on the fauna were however recorded when pond ecosystems were treated with a total herbicide 7.5% dichlobenil (Newbold 1975 a). The effect was correlated with total plant destruction, and the replacement species, algae, were a poor substitute habitat.

Herbicide treatment therefore occurs at the worst possible time for the fauna. Predictably mechanical methods would have the same effect if used during early spring but they are not tied to one specific season.

Ease of Application

One of the greatest threats from herbicide use to the quality of the environment arises from the ease of application of any herbicide whether it is selective or total Areas which may take one season to clear by traditional methods could be treated by herbicides in a matter of days. Both types of herbicides whether selective or total are therefore capable of destroying or changing the dyke flora of whole catchment areas if applied on a very large scale. This habitat destruction could impoverish the wildlife interest of whole regions, e.g. Brooker (1975) found that invertebrate diversity increased following the removal of *Phragmite communis* with dalapon. Complete removal of the reed however, could impoverish Reed Warbler (*Acrocephalus scirpaceous*) populations and the attendant invertebrate life of the reed. Clearly if large areas have to be treated with any herbicide some areas ought to be left untreated. This is the recommended method as set out in the code of practice for the use of aquatic herbicides. This code recommends that four hundred metre lengths in a channel should be alternatively treated and untreated. Many of the Internal Drainage Boards are not following this code. However, the Wessex Water Authority has produced its own code suggesting that the treated and untreated lengths in their region are reduced, because of the generally short dyke lengths in their area, to two hundred metres (Toms R. G. pers comm). This is to be commended.

Problems of Resistant Species

Mechanical methods can remove plant stem, root and some mud but this form of management imposes no constraints on renewed plant growth. Herbicides impose a constraint on the regrowth of the susceptible species for as long as the phytotoxic period lasts. The selective herbicide , dalapon and the total herbicide, diquat persist in the water for 3 to 12 days (Chancellor and Ripper 1960) (Calderbank 1972) and appear to be phytotoxic for that period (Brooker 1975) (Newbold 1975 b). The "total" herbicides have longer phytotoxic effects, 7.5% dichlobenil is phytotoxic for approximately 20 days (Newbold 1975 b) but the 22.5% dichlobenil is designed to maintain a phytotoxic period for a longer period of time (Spencer Jones 1974).

Terbutryne has a half life of 25 days (Tyson 1974) but the period of phytotoxicity can depend on many unknown factors since 0.08 ppm. was still detected 42 days after the original treatment level of 0.10 ppm. Many plant species are still killed at the 0.05 ppm level (Robson 1974).

Cyanatryn has a very short phytotoxic period but its slow release properties and method of application effectively maintain a phytotoxic period for approximately ten days (Payne 1974).

Although the phytotoxic period effectively prevents the regrowth of the susceptible species, resistant species can grow in their place. The longer the phytotoxic period the greater is the chance that the resistant species will firmly establish themselves preventing regrowth of the original flora. By definition a resistant species is not susceptible either to that treatment level or to that herbicide. Re-treatment or re-spraying with another herbicide may have to be considered. A long phytotoxic period is to many land drainage engineers considered to be a desirable property in a herbicide, but it could be a distinct disadvantage, and could also cause problems with irrigation and livestock watering.

Resistant species have been observed following:-

i) Paraquat treatment where Chara globularis invaded and became dominant (Brooker and Edwards 1973).

ii) Diquat treatment where Chara contraria and Vaucheria dichotoma invaded becoming co-dominant (Newbold 1975 b)

iii) Dichlobenil treatment (7.5%) where Ranunculus trichophyllus became dominant (Newbold 1975 a).

iv) Dichlobenil treatment (7.5%) where algae became dominant (Robinson G. W. pers comm; Spencer Jones D. H., and Newbold 1975 a).

v) Terbutryne treatment where diatoms became dominant (Robson 1974).

The problem of resistant species particularly algae to herbicide management has long been a problem which has affected the efficiency of herbicide treatment. To this end the development of terbutryne and more recently cyanatryn both algicides, could overcome this problem. In any event herbicide treatment with the more total herbicides and even with the selective herbicides if used widely, could give rise to resistant species dominating which would induce a long term ecological change in the system.

Long Term Ecological Change

Most mechanical methods produce a short term ecological change, some can produce a cycle of ecological change lasting over five years which is of benefit to nature conservation. Spot treatment with dalapon and diquat can also produce an ecological change of benefit to nature conservation. In all of these examples the management objective has achieved the desired result. The management objective of most land drainage engineers is to totally eradicate plant growth, which is against the code of practice. The total treatment of a dyke system with any herbicide would in the past hardly ever achieve this objective because of the problem of resistant species. The ecological change which follows herbicide treatment could be cyclical even with dichlobenil if the dyke system were allowed to recover, e.g. pond ecosystems were treated with 7.5% dichlobenil during May 1972 at the recommended treatment level of 1.0 mg/l. The initial flora of two similar ponds with a mean number of five macrophytes but dominated by Chara delicatula Ag. and Typha latifolia L. changed to: one pond totally dominated by Ranunculus trichophyllus L. and the other dominated by algae (Newbold 1975 a). The ponds are only now reverting to the pre-treatment stage three years after the original application.

Many engineers found however that the resistant species which dominated after treatment often at the original biomass level were not acceptable so they re-treated the area with another herbicide in an attempt to achieve their management objective, clear water.

In those areas I have studied the eventual problem species became the floating and rooted filamentous algae. These plants could either resist most herbicides or they were only partially susceptible. Now however, with the development of the algicides, terbutryne and cyanatryn, these species can be partially or totally eliminated.

Technology may have overcome the problem of the resistant species but once the constraints of these two herbicides i.e. phytotoxicity, are lifted, algae the most able of colonisers will again dominate. The hydrosere is essentially being pushed right back to its first and second phases. These are i) nudation which is the initiation of the succession by a major disturbance and ii) the migration of available species (migrules) to fill the vacant ecological niches (Clements 1916). Diversity in both fauna and flora will fall but the most detrimental effect will be that seasonal growths of algae can be expected which will require seasonal treatment: macrophytes will not be able to re-establish themselves. The engineer who mis-uses herbicides in this way has gained very little in terms of both cost effectiveness and efficiency of treatment and he may have induced a "permanent" long term ecological change. The great danger therefore is that the system becomes herbicide dependent because i) there are no suitable mechanical methods available for removing algae and ii) the seasonal treatment of the system to prevent or remove algal growth also prevents macrophyte growth.

Cost Effectiveness of Herbicides

It is extremely difficult to give accurate comparative costs between mechanical methods and herbicide treatment. The Middle Level Commissioners in the East Anglian fens have stated that a channel 5 metres wide costs £37.50/km to treat with the herbicide terbutryne at 0.05 ppm and £63/km if treated at 0.1 ppm. A hydraulic excavator costs £75/km and a dragline costs £125/km. (Cave T. G. pers comm.). A blanket treatment with terbutryne over this area could mean an annual re-treatment to control algae in an effective manner. George (1976) has indicated that a five year cycle of weed clearance by a hydraulic excavator is adequate for the grazing marsh dykes of Norfolk. The comparative costs on a five year cycle would therefore be £187.50 for terbutryne at 0.05 ppm and £75 for the hydraulic excavator.

Efficiency of Herbicides

Efficiency is defined here from the standpoint of the drainage engineer in that the herbicide effectively lowers the biomass of the plants to a level which would not impede the flow of water or raise the water level by excessive displacememt.

Efficiency need not be biomass related because the coefficient or friction of aquatic plants could vary according to the species and growth form. As comparative coefficients of friction have not been studied, efficiency in this paper is synonymous with biomass.

The only available evidence on efficiencies is related to the herbicides, diquat and dichlobenil (Newbold 1975 b). Studies have not concentrated on this problem because accurate assessments are required on the comparative levels of macrophyte and algal production.

Both herbicides were only marginally effective in the first year although they both eliminated the macrophytes. In the second year regrowth of the macrophytes gave an increased efficiency or lower overall biomass in both diquat replicates and in one dichlobenil replicate only. In the second dichlobenil replicate, algae dominated and reached overall biomass levels comparable with the control ponds (Table 1).

It was also found that the algae were a very poor habitat for invertebrates (Newbold 1975 a) and so this pond suffered a loss in diversity in both fauna and flora.

Superficial assessments of dichlobenil treatment have suggested that the herbicide is effective for the first season with a very little algal growth but that algae in the second year reached bloom conditions (Robinson G. W. pers comm.) (Spencer Jones D. H. pers comm.). This pattern of events was followed in the ponds studied but the following example will illustrate how dangerous it is to make assumptions on superficial or qualitative assessments. The algae bloomed in both my dichlobenil replicates 64 days after treatment but superficially the blooms were not serious with a lot of clear water. The standing crop was therefore low but the production was very high and the difference was accounted for by a very high sedimentation rate. During 1973 one year after treatment the algae in one replicate dominated, the production was high but the sedimentation rate was low giving a high standing crop or bloom of algae. Superficially therefore there was a lot of difference between 1972 and 1973 but quantitatively there was very little difference in the production of these ponds over the two years. It is possible that the high sedimentation rate of algae is an obscure sub lethal effect of dichlobenil since Spencer Jones (pers comm) observed that Lemna triscula sank following dichlobenil treatment.

Qualitative assessment on the regrowth of algae following or during any herbicide treatment are not adequate in determining the efficiency of a herbicide. Quantitative assessments with adequate controls must be made before it is established whether a herbicide is efficient or not. This is particularly pertinent to the two new herbicides terbutryne and cyanatryn. It is possible that even as algicides they are simply replacing macrophytes or algae with similar production estimates for algae after the phytotoxic period has elapsed.

RELATIONSHIP BETWEEN MACROPHYTES, ALGAE AND ZOOPLANKTON FOLLOWING HERBICIDE TREATMENT

In a previous paper (Newbold 1974) it was established that algal production was lowered by grazing from zooplankton in the presence of macrophytes. It has been possible to quantify this relationship (Fig. 2). The lower line has the relationship $y = 2.134 - 0.454x$ ($0.001 < P > 0.0001$) where y is the logarithm of macrophyte production and x is the logarithm of the recorded algal production. The upper line has the relationship where $y = 2.360 - 0.523x$ ($0.01 < P > 0.001$) where x is the logarithm of the true algal production.

TABLE 1 Observed standing crop of algae (St), sedimentation (Se) net production estimates (NP), and macrophyte production (MP) expressed as g Org C/mean m^2.

27 April - 28 October 1972

		St	Se	NP	MP	Total (NP+MP)
Control	replicate 1	4.60	3.05	11.12	70.94	82.06
	replicate 2	1.25	0.25	6.91	72.65	79.56
Dichlobenil	replicate 1	10.26	10.48	51.63	24.15	79.78
	replicate 2	2.95	30.74	37.99	26.14	64.13
Diquat	replicate 1	17.93	8.55	57.87	29.46	87.33
	replicate 2	0.67	1.21	15.02	29.83	44.85

Ponds treated on 22 May 1972

26 April - 4 October 1973

		St	Se	NP	MP	Total (NP+MP)
Control	replicate 1	6.96	3.12	14.09	63.03	77.12
	replicate 2	1.97	0.31	4.91	71.39	76.30
Dichlobenil	replicate 1	8.48	0.39	15.36	23.85	39.21
	replicate 2	38.40	10.10	59.64	14.73	74.37
Diquat	replicate 1	2.89	0.26	7.21	50.35	57.56
	replicate 2	0.76	0.05	4.76	47.85	52.61

The graph illustrates the following points:-

i) A high macrophyte biomass gives low algal production

ii) A low macrophyte biomass is replaced by a high algal production

iii) The grazing pressure on algae by zooplankton decreases at a high macrophyte biomass and a low macrophyte biomass.

iv) The optimum grazing pressure occurs at a reduced biomass level approximately 40-45% of the original biomass

v) The zooplankton graze the algae such that the reduction in macrophyte biomass is not compensated for by an equal production in algae.

The graph therefore suggests that macrophyte biomass can be reduced to approximately 40-45% of the original level without an equal increase in algal production. This gives a very effective reduction in overall biomass whilst still preserving a suitable habitat for the fauna and maintaining the floral diversity.

The value of the macrophytes in controlling algal production is two fold. They control algae through competition and they provide a suitable refuge for the algal grazers, prdventing over-predation from other secondary producers (Newbold 1975 b).

The biomass reduction could be achieved by simply treating half the width of a dyke leaving half as the controlling agent. Not only would this achieve a real reduction in biomass but it would reduce the cost of treatment to a level proportional to the cost of the herbicide.

This suggestion is counter to the code of practice of treating 400 metre lengths with equal lengths left untreated. It also raises the problem of herbicides which "creep" laterally from the treated area. This is true of terbutryne (Robson 1974) and from my own observations also true of cyanatryn. These suggestions may therefore be only applicable to dichlobenil and diquat, but they could prove to be an effective means of lowering biomass and not simply exchanging macrophyte production for algal production. This method would also maintain a high level of diversity in both flora and fauna, maintaining a biological and fisheries interest within the area.

CONCLUSIONS

Generally herbicides must not be regarded as a panacea to end all management problems in wetland areas and if used contrary to the Pesticide Safety Precautions Scheme Code of Practice they can be i) uneconomic compared with mechanical methods because of the danger of creating a herbicide dependent system which requires annual treatment ii) create habitat destruction on a wide scale.

It is stated that some herbicides are an effective tool in the management of dyke systems but only if used as an integrated method of control with the controlling influence of macrophytes.

Two herbicides, diquat and dichlobenil were only effective in my ponds in reducing total plant biomass when macrophyte biomass was re-establishing itself following herbicide treatment. It is possible that this situation could apply to the dyke systems in lowland areas where such systems are still dominated by macrophytes.

It is logical to suggest that the macrophytes are not totally eliminated by the initial herbicide treatment: It is not known whether these observations will apply to the more recent herbicides terbutryne and cyanatryn.

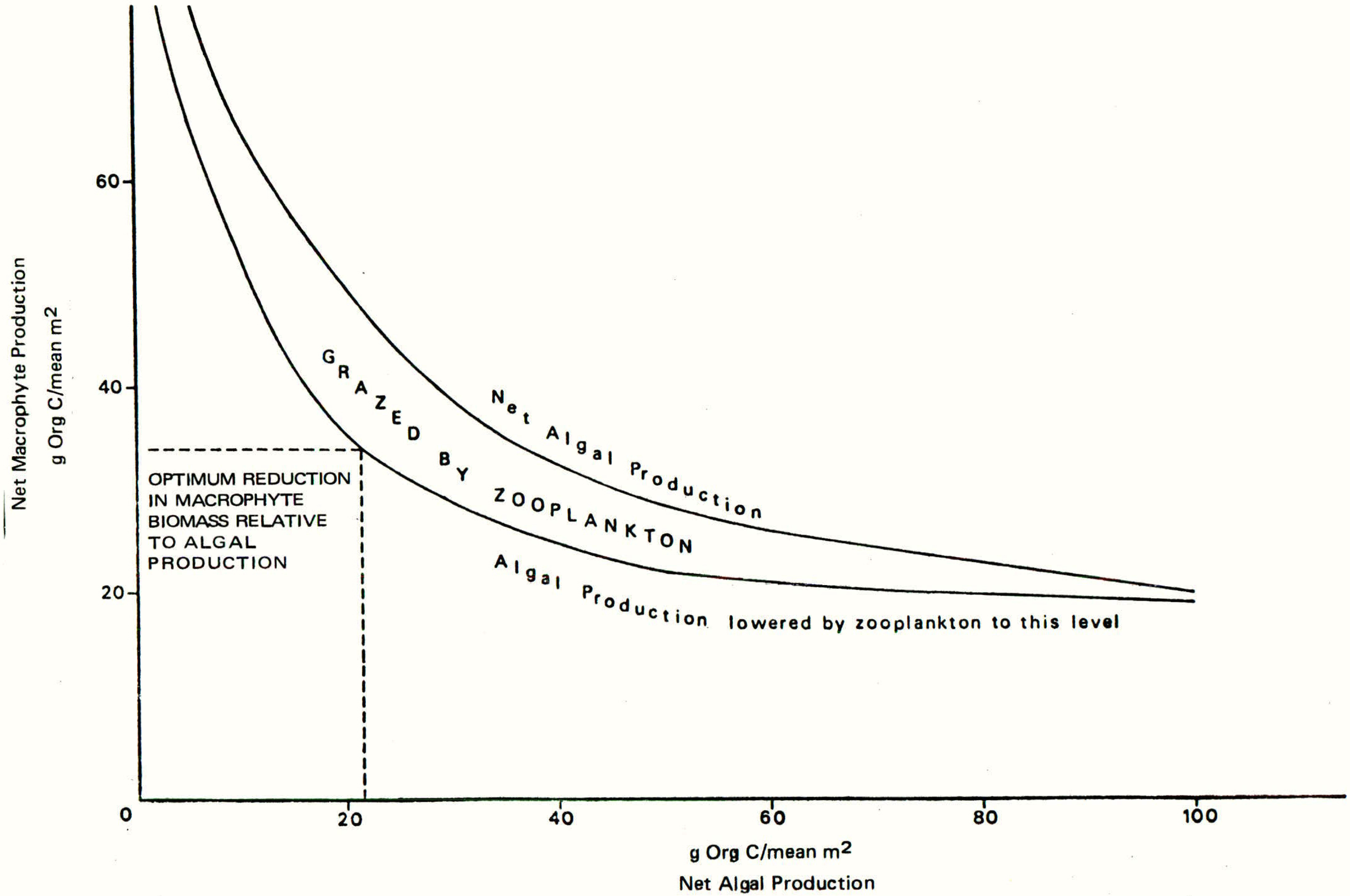

FIG 2 A possible relationship between Net Algal Production in the presence and absence of zooplankton and macrophytes

Macrophytes are a favourable habitat for a greater diversity of invertebrates, algae are not, so these suggestions whilst being practical to the drainage engineer have a nature conservation value in maintaining the biological interest and possibly the fisheries interest of the general environment.

It is suggested that the code of practice should endorse the view that it would be far better to treat half the width of a channel rather than spraying alternate 400 metre lengths.

The nature conservation interests of our sites of special scientific interest (SSSI) are best maintained by regular cutting. In exceptional circumstances selective herbicides have been used on nature conservation areas owned by the local naturalist trusts and the R.S.P.B. and their value as management tools is recognised. However, prior consultation with the Nature Conservancy Council is asked for if a Water Authority or Internal Drainage Board wishes to carry out any management programme, whether cutting, spraying or dredging which could either directly or indirectly affect an SSSI.

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