MECHANICAL METHODS OF WEED CONTROL IN WATERCOURSES
AN ECOLOGIST'S VIEW

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Summary. The course of natural succession in drainage dykes in Broadland is described, and an outline given of the effects of weedcutting and dredging on plant and animal life. Because of the increasingly prevalent use of aquatic herbicides, nature reserves will have to be established by conservation organisations if species and communities are to be safeguarded. In addition Regional Water Authorities, Internal Drainage Boards and others responsible for the management of watercourses need to be informed of the location of sites of particular ecological importance so that they can take this factor into account when formulating their work programmes. Suggestions are made as to how dyke maintenance can be carried out without impoverishing the fauna and flora of drainage districts.

INTRODUCTION

One of the principal goals of nature conservation is to ensure that wildlife habitats in the countryside, be they common or rare, natural or man made, remain in a condition suitable for the long term survival of the plant and animal life which they support. Although the establishment of nature reserves forms one of the principal ways in which this objective is achieved, it has long been apparent that the limited resources available, both to the official government agency responsible for nature conservation, namely the Nature Conservancy Council and to "voluntary" bodies such as the county naturalists trusts and Royal Society for the Protection of Birds, will make it impossible for them to safeguard as reserves more than a tiny fraction of the habitats available for plant and animal life in the countryside. In the circumstances it is not surprising that conservationists have, during the past few years, strived to engender in those responsible for the management of land an awareness of the practical contributions which they can make in the sphere of nature conservation.

Insofar as rivers, streams, canals, dykes and similar water bodies are concerned, conservationists are anxious to suggest ways in which water authorities, internal drainage boards and other similar organisations, as well as individual farmers and landowners, could, without incurring unreasonable additional management costs, help to ensure the long term survival of the aquatic fauna and flora of such watercourses. This objective is very much in accord with the spirit of Section 11 of the Countryside Act 1968, and also with Section 22 of the Water Act 1973 which enjoins regional water authorities to "have regard to the desirability ..... of conserving flora, fauna and geological features of special interest".

Before one can distinguish between what is, on nature conservation grounds, theoretically desirable, and what in practice is attainable, it is necessary to monitor what actually happens to the fauna and flora when a watercourse is managed in different ways. Ideally this would involve studying under properly controlled conditions and in a variety of different types of water body, the effects of a whole range of different management techniques, including the cutting of vegetation by hand and by mechanical methods, and the employment of tractor-operated scoops, hydraulic excavators and aquatic herbicides. Although financial and other constraints have up to now made it impossible for the Nature Conservancy Council to adopt such a comprehensive approach, it has funded an investigation by a post-graduate student, Robert Driscoll, into the ecological effects of various forms of mechanical dyke clearance in Broadland.

The following paper draws heavily on a preliminary report by this worker about the effect of management on the aquatic flora of dykes. Much detailed information about the effect on invertebrates is also being obtained, but since this has not yet been written up, it is only possible to draw tentative conclusions from the work at this stage.

Driscoll is in touch with Christopher Scotter, and a number of other post-graduate students based at the University of Wales Institute of Science and Technology, Cardiff, who are working on the fauna and flora of dykes in S. Wales. It is understood that although there are some differences between the species composition of this area, compared with that in Broadland, the conclusions being reached regarding the ecological effects of management are very similar in the two areas.

Although this paper is primarily concerned with the effect of management on the flora and fauna of dykes, some of the conclusions reached are applicable to other types of watercourse, notably rivers.

NATURAL SUCCESSION IN DYKES

In a new dyke the nature of the primary plant colonisers and the subsequent succession, depends partly on its width, depth, nutrient status and salinity, and partly on the type of vegetation present in adjoining water bodies. It is from the latter that seeds and other propagules will find their way into the new dyke. The recovery of the vegetation in an existing, but freshly dredged, dyke is governed by similar factors; however, regeneration from propagules left in situ also takes place.

Although the succession is usually initiated by one or more species which happen to be grwing nearby, these are gradually replaced by a community dominated by submerged or floating-leaved aquatics together with some emergent species. Subsequently as the latter assume an increasingly important role in the community the aquatic species decline. Examples of these three stages in the succession, as observed in grazing marsh dykes in Broadland are set out below.

Stage 1: New dyke near St. Bennet's Abbey cut in July 1974 and surveyed in October 1974

Lemna trisulca)	Single specimens of
Potamogeton pectinatus)	species present in
Myriophyllum spicatum)	adjacent dykes.

Stage 2: Dyke at Upton, surveyed in July 1974

Elodea canadensis	R) *	
Hydrocharis morsus-ranae	O)	
Potamogeton lucens	O)	
P. natans	F)	
P. compressus	F)	
Ranunculus circinatus	R)	Submerged and floating
Stratiotes aloides	F)	leaved species.
Lemna minor	R)	
L. polyrrhiza	R)	
L. trisulca	R)	
Riccia fluitans	LF)	

Alisma plantago-aquatica	R)	
Apium nodiflorum	O)	
Berula erecta	O)	
Carex riparia	R)	
Equisetum fluviatile	R)	Emergent and
Myosotis scorpioides	O)	marginal species.

Phragmites communis	R)
Sagittaria sagittifolia	F)
Rorippa nasturtium-aquaticum	R)
Oenanthe fluviatilis	R)

Other species characteristic of this stage in the succession are:

Hottonia palustris
Potamogeton crispus
P. friesii
P. acutifolius
P. pusillus
Myriophyllum spp.
Ceratophyllum spp.
Nuphar lutea

Stage 3: Dyke at Hemsby, surveyed in September 1974

Potamogeton natans	R)	
P. pusillus	O)	
P. obtusifolius	LA)	Present in more open
Myriophyllum spicatum	F)	stretches, also growing
Elodea canadensis	F)	between emergent species.
Hottonia palustris	O)	
Hydrocharis morsus-ranae	O)	
Alisma plantago-aquatica	O)	
Apium nodiflorum	LF)	
Berula erecta	LF)	
Carex riparia	F)	
Equisetum fluviatile	O)	
Iris pseudacorus	R)	
Juncus effusus	O)	
J. subnodulosus	R)	
Mentha aquatica	O)	Emergent species
Oenanthe fistulosa	O)	filling most of dyke.
Phragmites communis	R)	
Sparganium emersum	R)	
S. erectum	O)	
Menyanthes trifoliata	LF)	
Rumex hydrolapathum	R)	

* A - abundant: F - frequent: O - occasional: R - rare: L - locally

The land use of the adjoining marshland constitutes a major determinant of the course of the succession. In grazing marshes the trampled margins of the dykes provide a habitat for a large number of emergent and marginal plants, such as sedges (Carex spp.), rushes (Juncus spp.), Bur-reeds (Sparganium spp.), and Water Forget-me-nots (Myosotis spp.). If poached by cattle the sides of a dyke may partially collapse to form a zone of shallow water, particularly favourable for plants such as Water Dropworts (Oenanthe spp.), Arrow-head (Sagittaria sagittifolia) and Lesser Water Plantain (Baldellia ranunculoides).

Cattle also affect the succession by grazing the marginal vegetation and thus slowing down the rate at which taller plants such as Common Reed (Phragmites communis) Reed grass (Glyceria maxima) and Great Pond Sedge (Carex riparia) can spread. This reduces shading, thus favouring the growth of smaller marginal emergent species as well as submerged aquatics.

In areas of marshland converted to arable use the dyke sides are not trampled by cattle; they therefore retain their original steep, smooth, profile for longer periods.

The absence of grazing enables Carex spp. and Phragmites to proliferate; these tend to supress other species.

If no management is carried out the smaller, shallower dykes gradually become completely choked by coarse emergent species; silt deposition in such conditions is rapid and ultimately such dykes will dry out completely. This sequence of events takes place much more slowly in larger dykes, such as the Fenland drains and in rivers, since the invasive capacity of emergent plants is limited by the depth of water. Phragmites, for example, is only able to grow if the water is less than about 1 1/4m. deep (Lambert 1951: Haslam 1970), whilst Carex riparia and other emergent species are restricted to even shallower water. It is for this reason that emergent vegetation in wider, deeper waterways is represented by bands of marginal reedswamp; the width of the latter is dependant on the underwater profile ("batter") of the dyke.

DYKE MAINTENANCE

(A) Objectives

The reasons for dyke management may be summarised as follows:

(1) To remove, or restrict the growth of, emergent aquatic weeds since these can, when growing luxuriantly:-
  (i) Obstruct the flow of water
  (ii) Increase the rate of silting

(2) To remove accumulations of mud and plant detritus, thus ensuring that the dyke remains of sufficient depth to fulfil its primary land drainage function.

(3) Grazing marsh dykes, which often have to serve as physical barriers to the movement of cattle, may have to be reprofiled to counteract the effects of trampling.

(B) The Techniques available and their effects on fauna & flora

Other papers to be presented at this conference, notably that by Newbold, will describe the effect of aquatic herbicides on aquatic plant and animal life. For this reason the following account will be concerned primarily with mechanical methods of weed control and dredging. A useful summary of the various techniques available is given by Robson (1972).

Weedcutting. In the past aquatic vegetation was raked out of dykes and rivers by hand, or cut with a scythe, or by means of a wire drawn along the bottom of the watercourse. However, apart from certain rivers in which there is an important game-fishing interest, these methods have been largely superseded during the past twenty years by mechanical techniques. These normally involve the use of a reciprocating knife mounted, in the case of rivers and wide dykes, on a specially designed boat or, for smaller watercourses, on the hydraulically-operated boom of a tractor or excavator. Exceptionally in the Upton/South Walsham area of Broadland a large rake attached to a tractor is used.

Weed cutting normally has to be carried out annually since the root systems of the plants are unaffected; it is therefore a fairly expensive management task. From the ecological point of view, however, it has several advantages. Firstly it produces a habitat particularly suitable for submerged and floating-leaved species. Secondly, since the cut material is normally removed, nutrients, as well as potential detritus, are taken out of the system. In addition there is no deoxygenation problem even if luxuriant stands of vegetation have to be cut late on in the growing season.

Dredging. Although rivers and wider dykes are still normally dredged by means of dragline excavators, JCB's, Kymac's and similar hydraulically-operated machines are normally used on most dykes; tractor-mounted mud scoops are used by some farmers, particularly on smaller watercourses. The vegetation, silt and accumulations of plant detritus removed from the sides and bottom of the dykes during dredging is generally dumped on the adjoining land and subsequently levelled.

Hydraulic excavators, with their ability to produce a steep, uniform batter on both sides of the dyke are particularly effective against marginal and emergent species. They do, however, tend to leave behind fragments of submerged and free-floating species such as Canadian Pondweed (Elodea canadensis) and Duckweeds (Lemna spp.) and these, together with plants able to propagate themselves by turions (eg. Potamogeton spp.) and from seed (eg. Sparganium spp.) normally initiate the re-generation of the dyke flora.

The rate and course of recovery of the vegetation depends on a number of factors including the adjoining land use, whether cattle have access and can graze the banks, and whether vegetation on the edges of the dyke is being managed, for instance, by mowing, spraying or burning. Regeneration is frequently a fairly slow process. Driscoll reports, for example, that whilst certain Broadland dykes dredged in 1971/72 and 72/73 had, by 1975, regained their former floristic diversity, the plants were not yet growing in sufficient quantity seriously to impede the free-flow of water.

Recolonisation, as a result of the water-borne movement of seeds and turions from adjoining water bodies also occurs if a dyke has been dredged, the relative importance of this process, as compared with regeneration, being dependent not only on how effeciently the dredging was carried out, but also on how many adjoining water bodies were cleaned out during the same period. Where a relatively small proportion of the dykes in an area of marshland are dredged at any one time, colonisation from uncleaned dykes nearby can take place fairly quickly, particularly if these contain a rich and diverse flora. Furthermore, provided each dyke is not dredged too frequently or too effeciently, regeneration can also occur. In these circumstances the overall vegetative diversity of the drainage area will not be unduly affected even though the floristic composition of individual dykes will be undergoing pronounced cyclical changes. Conversely when dredging is carried out both frequently and extensively, the dykes in whole blocks of marshland will undergo floristic impoverishment.

Periodic dredging, by preventing the spread of reedswamp and other emergent plants, favours the growth of submerged and floating-leaved plants such as those listed below; several of these are rare, or local in their distribution.

Potamogeton crispus	Butomus umbellatus
" friesii	Stratiotes aloides
" compressus	Hydrocharis morsus-ranae
" acutifolius	Groenlandia densa
" pusillus	Chara spp.
" natans	Equisetum spp.
" lucens	Veronica catenata
Ceratophyllum spp.	Phragmites communis
Myriophyllum spp.	Sagittaria sagittifolia
Lemna spp.	

All these species are able to thrive in dykes in the first growing season after dredging. In the second and subsequent seasons they are joined by:-

Rorippa nasturtium-aquaticum	Lycopus europaeus
Apium nodiflorum	Juncus spp.
Berula erecta	Carex spp.
Oenanthe spp.	Sparganium spp.

Polygonum spp.
Mentha aquatica

Scirpus spp.

In subsequent years, as the emergent and marginal species become increasingly abundant, the submerged and floating-leaved species decline, sometimes disappearing altogether eg. Elodea spp., Chara spp., and P. crispus.

Other plants which are more localised in their distribution could be eliminated altogether if dredging is carried out too often. Examples include Sium latifolium, Ranunculus lingua, Acorus calamus, P. berchtoldii and P. trichoides.

Driscoll's work on the effect of dyke management on aquatic invertebrates is still at a very early stage, but it is already clear that the diversity of the fauna is positively correlated with the diversity of the flora. Thus it is almost certain that the long term impoverishment of the flora which results from the intensification of management (cf. the Fenland dykes) is accompanied by a decline in faunistic diversity.

Dredging removes most of the invertebrates found in or on the mud of the dyke bottom, and also attached to the aquatic vegetation. Free-swimming species, such as water beetles and water bugs, are left behind, howbeit in reduced numbers. Although in theory recolonisation by flying and swimming species could take place fairly quickly provided there were undredged watercourses situated nearby, in practice this is often likely to be delayed until suitable habitat conditions have developed in the newly dredged dyke. For example oviposition in damselflies will not occur unless the required type of aquatic vegetation is available (Corbet et als 1960). Recolonisation by species with limited powers of movement, such as gastropods and lamellibranchs is a much slower process. Consequently if dredging is carried out on an extensive scale, the status of such animals will decline; ultimately certain species could be eradicated altogether from an intensively managed drainage district.

CONSERVATION IMPLICATIONS

Driscoll's investigation in Broadland shows that drainage dykes which are periodically dredged, but which are not treated with herbicides, provide a habitat for a very large number of aquatic plants and animals. Of the 157 species of flowering plants recorded by Driscoll, about one hundred occur regularly; several of the latter [eg. Sharp-leaved Pondweed (Potamogeton acutifolius) and Water Soldier (Stratiotes aloides)] are national rarities.

In the Fens, where the waterways have for many years been regularly treated with herbicides, the position is quite different. Preliminary surveys in this area suggest that few of the dykes now contain significant amounts of submerged vegetation, and that in the larger watercourses even the marginal and emergent species are much less common than in the past. Although the loss of the latter can undoubtedly be attributed to the use of herbicides, the decline in the status of submerged vegetation may have been caused by eutrophication, and in some cases increased boat traffic, as well as by the widespread use of aquatic herbicides in this district.

Can the conservationist draw any conclusions from the difference between the situation in Broadland and in the Fens, other than the obvious one that once mechanical methods of weed control give way to herbicides, a drastic impoverishment in the flora (and probably also the invertebrate fauna) will occur? Although this question has to be considered in relation to the low cost of treating a dyke system with herbicides, compared with weed cutting and dredging, it must not be overlooked that periodic dredging is required, whichever method is used to control the growth of aquatic vegetation.

The first point to be made is that it is essential for the conservationist to pinpoint by means of ecological surveys within each major drainage district, those dykes which are of particular floristic and faunistic interest. He should then endeavour to persuade the relevant drainage authority and/or individual landowners to continue to manage these dykes by mechanical means rather than switch to the use of herbicides. When a change to herbicides has already occurred and where there is evidence, as for example in the Fens, that this has caused serious floristic impoverishment, he should endeavour to persuade one or more farmers to revert to mechanical methods of dyke clearance, even if on only a few carefully selected dykes.

When making this type of approach conservationists must try and ensure that maintenance work on the dykes continues to be carried out. This is essential if their ecological interest is not to be lost as a result of natural succession.

Whilst in some cases drainage authorities and farmers may be willing to make concessions to nature conservation interests without charge to the latter, some financial recompence will often be required. This could be on the basis of a nature reserve agreement with, say, a county naturalists trust. Alternatively a management agreement negotiated with the Nature Conservancy Council under the aegis of Section 15 of the Countryside Act 1968 may be appropriate.

Similar arrangements need to be made in respect of rivers, canals and other waterways. The Nature Conservation Review, an appraisal of all the known sites of special scientific interest in Britain, which is due to be published by the Nature Conservancy Council in 1976, will list a number of flowing water sites of Grade 1 and 2 national scientific importance. The Nature Conservancy Council will shortly be having discussions with Regional Water Authorities and other interested parties, regarding ways in which such sites can be safeguarded. At regional and local level, too, it is apparent that ecological surveys aimed at identifying stretches of river of particular floristic and faunistic interest need to be carried out. In some cases such surveys have already been commissioned. For example, a party from the British Museum (Natural History) under the leadership of Mr. A. C. Jermy carried out an ecological survey of the River Wissey (Norfolk) for the Nature Conservancy Council in 1975.

In some parts of the country, flowing water sites have already been established as nature reserves. Part of the Prees branch of the Shropshire Union Canal is, for example, managed by the Shropshire Conservation Trust under a licence from the British Waterways Board.

Although the designation of nature reserves will help to prevent species becoming extinct, it is highly desirable that maintenance work carried out on watercourses should also, insofar as economic circumstances allow, take nature conservation interests into account. In this respect it was encouraging that the Anglian Water Authority should invite the Nature Conservancy Council in 1975 to identify, and make recommendations regarding the management of, ecologically important sections of the 90km. of headwater streams in Norfolk, Suffolk and Cambridgeshire which are to be used as aqueducts in connection with the Great Ouse Groundwater Scheme (George 1975).

Although co-operative ventures of this sort will undoubtedly help to ensure that Regional Water Authorities and similar bodies do not unwittingly damage wildlife interests, the acute shortage of manpower and finance available to the Nature Conservancy Council for such work, together with the considerable amount of time required to carry out the necessary ecological surveys, will undoubtedly restrict the Nature Conservancy Council's ability to respond to requests for advice of this nature for many years to come. In the circumstances it is to be hoped that Regional Water Authorities will be able to deploy their own "in-house" ecological expertise whenever possible.

Little practical experience has, as yet, been obtained as to how those responsible for the management of dykes and other watercourses can most effectively take into account the need to safeguard wildlife. Accordingly, the following suggestions are offered as a way of stimulating debate, rather than as a proven way of ensuring that the interests of nature conservation and land drainage can be successfully reconciled.

(1) Although it is often administratively easier, and marginally cheaper, to arrange for a large block of marsh dykes to be dredged more or less simultaneously, often by a contractor, this delays recolonisation by aquatic plants and animals, and if repeated several times, can seriously impoverish the fauna and flora of the whole area. It is highly desirable that some dykes within each block of marshland are dredged "out of phase" with the remainder. These will form a reservoir of wildlife from which recolonisation of the dredged dykes can take place. Ideally the dyke system of each drainage district should be dredged on a "chequer board" basis, so that dykes in all stages of the succession are present.

(2) Water movement in the smaller dykes is much more significantly impeded by coarse emergent species such as Phragmites communis and Carex riparia than by submerged aquatics. It is doubtful whether, given the efficiency of modern pumping machinery, a dyke containing a normal growth of the latter significantly increases the risk of flooding, particularly if it is situated near the distal part of the system. In these circumstances it is suggested that aquatic herbicides are not used in dykes until emergent vegetation begins to appear.

(3) Although the conservationist would wish to see some emergent vegetation growing in dykes, it is more important from an ecological point of view to have a growth of submerged aquatic species. Since the latter are supressed by emergent species, dykes should be dredged before the onset of the final stages in the succession.

(4) The frequency of dredging will vary according to local conditions: however, in Broadland many dykes need only be dredged every fourth or fifth year. All too often the frequency of dredging appears to be based on a predetermined timetable, often arbitrarily set to a three to four year rotation, rather than in response to the actual need on the ground. In parts of Broadland, the frequency of dredging appears to be increasing rather than decreasing, despite the rising cost of labour and fuel. This is certain to have damaging effects on wildlife.

(5) Dredging has to be carried out every few years to remove accumulations of silt from marsh dykes, whether or not herbicides are used to control the growth of aquatic vegetation. In the circumstances it seems reasonable to ask that herbicides should, whenever possible, be applied on a chequer board, rather than on a wholesale basis. Even though main drains may have to be treated annually, it is believed that the distal parts of the dyke system could be treated every alternate year, or in some cases even less frequently, without significantly increasing the risk of flooding. Such an arrangement would have very beneficial effects for nature conservation.

6) In rivers, streams and larger dykes, bank erosion will increase if the marginal reedswamp is destroyed by herbicides, particularly if the watercourse is being used by recreational boat traffic (George 1972), or if its margins are subject to poaching by cattle. An accelerated rate of bank erosion will make it necessary to dredge the watercourse more frequently, thus greatly increasing management costs.

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REFERENCES

CORBET, P.S., LONGFIELD, C. & MOORE N.W. (1960). Dragonflies. Collins. London. 1 - 260.

GEORGE, M. (1972). The Conservation of Aquatic Wildlife. Paper presented at the Health Congress of the Royal Society of Health. London: 138-141.

GEORGE, M. (1975). Nature Conservation and Land Drainage. Paper presented at Conference arranged by the Water Space Amenity Commission. London: 27-35.

HASLAM, S.M. (1970). The Performance of Phragmites communis in relation to Water Supply. Annals of Botany 34 (137) 867-877.

LAMBERT, J.M. (1965). Alluvial Stratigraphy & Vegetational Succession in the Region of the Bure Valley Broads. III Classification status and distribution of communities. J. Ecol. 39 (1) 149-170.

NATURE CONSERVANCY COUNCIL. The Nature Conservation Review. In press.

ROBSON, T.O. (1972). Current Developments in Weed Control in Waterways. ADAS Quarterly Review 6, 40-46.

DISCUSSION ON SESSION 3

Mr. D. Woodhead commented that the code of practice for the use of aquatic herbicides was not firm enough on the necessity for Water Authorities to be consulted before aquatic herbicides were used. The code stated that Water Authorities "should" be consulted. It was only the green recommendation sheets issued by MAFF that stated that they "must" be consulted. In many cases the Water Authorities were not consulted prior to chemical treatment. Mr. Price agreed and said there was a need for better liaison.

Dr. N.J. King was concerned that the Water Authorities should be involved before aquatic herbicides were officially cleared for use. In particular they were rightly concerned with regard to aspects of public health, but he was not certain that the Authorities would be able to interpret the toxicity data submitted under the PSPS because few of them had any experts in this field. He felt that if medical opinion was sought it would be stated that there is no health risk from the use of aquatic herbicides at the concentrations likely to be found. This opinion was more likely based on experience rather than on direct scientific evidence, but it was probably the best that could be expected without extensive epidemiological studies. Mr. Price accepted that Water Authorities did not have the necessary toxicological expertise, but thought that they must have better information than at present, e.g. the maximum concentrations that could be allowed in public water supplies without causing harm if they were to approve the use of chemicals on water supply catchments. There were no clear indications from central government of these concentrations nor for how long any given concentration could be accepted in a water supply without risk to the public. It was the Water Authorities' responsibility to provide a "wholesome" supply of water and they had to be in possession of firm facts, although they would rely on medical advisers in the interpretation of toxicological data.

Dr. Newman stated that toxicity levels were found by feeding experimental animals with a diet of the material under examination and finding the level at which no measurable effect was produced. The permissible level was thereafter taken as 1/100 of that which produced no effect and this was obviously a considerable safety margin. On this basis the caffeine present in coffee presented a greater hazard to human beings than the possible levels of aquatic herbicides in water.

Mr. P.R.Stovell referred to the comments on deoxygenation arising from the use of cyanatryn. In the particular case quoted, the treatment was made very late in the year because of difficulties in getting clearance for the use of the chemical. Before treatment it was pointed out that the amount of weed present could give rise to severe deoxygenation, but since it was stated that there was unlikely to be many fish present, agreement was given to chemical application at that time.

D.H. Spencer-Jones said that his Company had had difficulty in determining the taint threshold of dichlobenil because there was no specifically defined method of determination. The Water Research Centre had not been able to advise because industrial firms could not become members of the Centre. Following consultation with other international laboratories, a method had been devised to assess both the active ingredient and its metabolites in waters of different hardness including chlorinated and unchlorinated supplies. Mr. Spencer-Jones thought that the Water Authorities should, themselves, define a standardised test if they wishes companies to provide information on odour thresholds. The figures for dichlobenil quoted in the technical data sheets for odour thresholds, were the mean figures for all grades of water both chlorinated and unchlorinated. Mr. Price undertook to raise the matter with the National Water Council, in order that a standardised test was made available.

Mr. K.B. Elgar stated that no off-flavours had been given by cyanatryn at 0.2 and 2.0 mg/l in both distilled water and chlorinated distilled water not chlorinated tap water as stated in the technical data document. His Company had had similar problems to those of Mr. Spencer-Jones in finding a satisfactory test on which to base such figures.

Mr. A.C.R. Pratt was concerned on behalf of his Water Company about extraction from an underground source in shallow gravels where herbicides had been used on the relatively thin layer of soil at the surface. The chemicals concerned were Cambilene (containing TBA, dicamba, MCPA and mecoprop) and Supersevtox (dinoseb). Mr. Price suggested that a reply would be more appropriate from the manufacturers rather than himself.

Mr. J.A.R. Bates mentioned the experimental work which had been carried out some years ago by Dr. Key's Committee from the Department of the Environment. It was found that six inches of soil was quite adequate to absorb all herbicides added to it and that there was no chemical detected in the leachates from this amount of soil.

Mr. D.J. Eagle agreed that most herbicides broke down rapidly in soils or were strongly adsorbed so that there would be no problem in water leaching out from treatment of fields, etc. One exception to the rapid breakdown of such chemicals was 2,3,6-TBA where there was the possibility of small amounts of the chemical reaching water supplies extracted from shallow gravels.

The Chairman, Dr. N.W. Moore wondered whether there was a need for further co-ordination of research into pesticides similar to that which was carried out by the Fraser Committee some years previously. It seemed that there might be a need for co-ordination on the methodology associated with research work on the herbicides. Mr. Price said he appreciated that the manufacturers were carrying a substantial research workload, central government concerned itself with more general areas of research and it did seem there could be advantages in a Committee which could take a very broad view and provide closer co-ordination of the relevant work being undertaken by various central government research association.

Mr. D.B. James was concerned that copper sulphate was still being used in some areas regardless of the fact that it was not on the approved list of chemicals to be used on aquatic weeds. In fact it was still used within the water industry itself as an algicide and he wondered whether it had been considered under the PSPS and whether there was any better algicide which could be used in a public water supply reservoir without taking it out of use.

In reply Mr. J.A.R. Bates stated that copper sulphate had not been considered under the PSPS because of the very limited safety margin which it allowed for fish toxicity, when used at its normally recommended rates as an algicide. He doubted whether it would in fact ever be cleared under the scheme.

Mr. J.D. Fryer considered that as far as research into aquatic herbicides was concerned, there was a need for government support for it to be encouraged and co-ordinated. It fell within the responsibility of several government departments and as such could be considered at risk both in respect of the overall level of support and the development of an integrated programme of adequate stature such as to meet the needs of rapidly expanding herbicide usage. He had been assured that the aquatic weed research interests of the Ministry of Agriculture, Fisheries and Food, the Department of Agriculture and Fisheries for Scotland and the Agricultural Research Council would be reviewed by the Joint Consultative Organization sponsored

by these three organizations, but this was unlikely to take place for at least another year and the outcome in terms of commissioned R & D unknown. It was to be hoped that a reasonable input of government finance would become available for aquatic weed research. It did not seem realistic to expect that all research concerned with use and consequences of herbicide should be paid for by the chemical companies. The relatively small market for aquatic herbicides in this country would place severe constraints on the amount that could be spent by industry on R & D to benefit both those responsible for maintenance of drainage channels and other water bodies and those concerned with the environmental impact of herbicides.

Mr. D.F. Westlake asked whether herbicides at the normal concentrations had any effect on young fish. This was particularly important because the herbicides were being used when spawning was normally taking place. Mr. Tooby replied that this was being studied but the information available was not complete on all chemicals since it was not required by the PSPS.

Mr. D.J. Eagle queried the low mammalian toxicity but high fish toxicity of glyphosate. Mr. Tooby stated that there was often a considerable difference between mammalian toxicity and that to fish.

Mr. D.H. Spencer-Jones commented that although dichlobenil was just above copper sulphate in Mr. Tooby's list of factors of safety it was evident that at the normal rates of use there was a five times margin of safety and dichlobenil was still quite satisfactory for use in waters containing fish. Five times the normal dose in water 1 metre deep would mean that nearly a quarter of a ton/acre would have to be spread and it was highly unlikely that anyone would ever use such a large amount. Mr. Tooby agreed with these comments, but pointed out that the accumulation of dichlobenil in fish was the most important factor not the concentration in the water. Stresses applied to the fish after herbicide application, such as low dissolved oxygen, might affect the residue uptake rate which could result in a lethal tissue residue being accumulated.

Dr. J.M. Hellawell said that although the toxicity of the chemicals used might not affect fish or fry, it had to be recognised that there could be indirect effects, such as the removal of weed by chemicals allowing easier predation due to the removal of cover for fry. Mr. Tooby said that large scale weed clearance by any method within a fishery could lead to these indirect effects; clearly, if the object was to remove the weed in any area then fisheries would be affected.

Mr. N.O. Crossland stated that the risk of deoxygenation when using triazine herbicides was not necessarily greater than with other aquatic herbicides. It depended on the kind and quantity of weed present, the flow rate and the prevailing temperature of the water. Unlike contact herbicides, the action of triazines on aquatic plants was very slow. The rate of death and decay of plants was therefore also slow and the BOD associated with their decay was spread over a relatively long period. On the other hand, the triazines inhibited photosynthesis of both filamentous algae and vascular plants. Therefore, in circumstances where the photosynthetic input of oxygen was vital, the dissolved oxygen could be severely depleted. In drainage ditches in Kent the diurnal variation of dissolved oxygen had been measured before and after treatment with cyanatryn in spring and in summer. In a ditch infested with Callitriche stagnalis and Enteromorpha spp, the concentration of dissolved oxygen varied diurnally between 2.5 and 7.5 mg/l in May 1975. Treatment with cyanatryn was successful in controlling 100% of the filamentous algae and 95% of the vascular plants but there was little effect on the diurnal oxygen cycle. On the other hand in an untreated ditch, the dissolved oxygen decreased to less than 0.2 mg/l in June and remained at this very low level throughout the summer months.

These and other experiments showed that there was little or no risk of deoxygenation following the use of cyanatryn in drainage ditches in spring. Treatment of dense weed infestations in static water in summer may lead to severe oxygen depletion and fish deaths, but this is a possibility with many aquatic herbicides. In field trials designed to investigate the effect of aquatic herbicides on dissolved oxygen, it was necessary to use equipment which was capable of monitoring diurnal variation. Spot readings of dissolved oxygen could be very misleading and give no information concerning the rates of change of diffusion, respiration and photosynthesis. The fish species present in drainage ditches in Kent were mainly eels, sticklebacks, rudd and tench. Mr. Tooby said that these fish were adapted to tolerate very low concentrations of dissolved oxygen prevailing in the summertime. He agreed on some of the points made concerning the effect of triazines in photosynthesis and use as algicides but stated that in experiments he had carried out he had not recorded the wide range of dissolved oxygen values that Mr. Crossland had experienced.

Mr. T.O. Robson stated that dissolved oxygen levels following the use of both cyanatryn and terbutryne had been monitored in WRO field experiments. There was a severe drop in oxygen levels within the first week of the application of each chemical. Since the triazines were effective algicides as well as herbicides, it seemed likely that the severe decreases in oxygen levels could be due to the algae also being affected. With other herbicides, the algae may not cease photosynthesis or may recover quickly and replenish concentration by photosynthesis.

The Chairman, Dr. N.W. Moore queried whether the fact that both toxic and deoxygenation effects can occur together in so many instances, meant that there was a need for routine testing under the PSPS to determine in more detail the effects of chemical treatment, with particular reference to residue data. Mr. Tooby hoped that the provision of residue data from field experiments by the manufacturers would help in the matter.

Mr. R. Lloyd queried the need for extensive toxicity data on many of the herbicides that had been mentioned. The amount of toxicity data required was related to the size of the safety margin between the toxic levels and the normal rates of usage. There was obviously a need for extensive testing when the margins of safety were small as occurred with dichlobenil and this was the reason why particular reference had been made during the symposium to this herbicide.

Dr. J.M. Way supported Mr. Tooby in his concern about extensive use of herbicides compared with the relatively restricted use that had been practised in the past. The ease with which chemicals could be applied, in contrast to mechanical and hand methods of weed clearance, meant that very much greater areas of water could be treated at any one time (or in any one season) than had ever been possible before.

He felt that not enough information was available on wide-spread use of herbicides in running waters. There was also the point that there was little information on the release of residues from weeds after they had died. It was possible that the uptake of residues in fish could still arise subsequent to release from decaying vegetation. He considered that there was also a need to define more than a margin of safety in the use of any chemical. For instance, a one hundred times margin of safety could be far more important for a highly toxic liquid formulation than a lower margin of safety on a less toxic compound. With the highly toxic compound a small accident could have a more serious effect than a larger accident with the less toxic compound, regardless of the levels of margin of safety.

Mr. T.G. Cave queried whether it was practicable to treat half the width of a river channel with aquatic herbicides. He had serious doubts whether it was a

possibility in narrow channels where dispersion of chemicals would readily take place. Mr. Newbold thought that part-treatment of a channel would be possible with herbicides such as diquat or dichlobenil, but agreed that it would not be satisfactory with the triazines.

Mr. R.W. Noakes gave some details of the calculations that were required when carrying out a land drainage dredging operation. Normally the drainage engineers allow one metre freeboard in the channel and any growth of weed could give rise to an increase in the co-efficient of friction by a factor of 5 which would thereafter give rise to serious flooding. He doubted whether it was therefore possible to treat only part of any watercourse with aquatic herbicides without causing serious repercussions on normal designs. Any damage to the under-drainage system that a farmer had installed would be severely criticised. Mr. Newbold replied that use of a total herbicide often gave rise subsequently to an algae-dominated system. He queried whether sufficient work had been carried out to determine the co-efficient of roughness due to macrophytes and algae.

Mr. W.D. Miles, commenting on Mr. Noakes' contribution, stated that a lot of work had been done on the co-efficients of roughness of dredged channels. A figure of 0.025 was quoted by Buckley and others for open channels when they were in good condition. The co-efficient could be as much as 0.20 with very weedy conditions but it was only under maximum flow conditions following heavy rainfall that the difficulties really arose. With lower velocities under dry conditions, the co-efficient of friction was not so important.

Mr. W.D. Miles stated that his Drainage Board assisted with the management of a wetland site for a nature conservancy body where some relatively rare aquatic weeds occurred. He was sure that if an approach to the Internal Drainage Boards in the Fens were made, they would be prepared to consider the management of certain dykes without any use of herbicide whatsoever. He doubted that there was much return of nutrients to the water when weeds were removed and left to rot on the top of the banks. It was not possible to move the weeds any further away from the watercourse because this would affect farming and the weeds had to be dealt with on IDB land itself. Dr. George stressed that the best management of waters to meet all the demands, would come from amicable agreement between the parties involved. The extent of the dykes that the N.C.C. and other conservation bodies were able to safeguard was negligible when compared with their total length, but many IDB'S seemed anxious to co-operate.

Mr. J.B. Shearer stated that his Board only dealt with the waterway area of the large drainage channel and that the banks were left untreated. This did depend however on the neighbouring farmers who became concerned about problems with weeds such as thistles seeding across their land and often the banks were dealt with by tenants. The costs of carrying out maintenance in such a way were obviously less than if the banks were cut regularly and kept in a trim condition. As far as small watercourses are concerned which generally dry out in summer, his Board roded or flailed everything below top water level and sprayed the bottom of the dry channels, but even then a margin of two to three feet towards the top of the banks was usually left in its natural state. Dr. George commented that whilst some "wilderness" areas were of value, he appreciated the need for satisfactory management in most cases.

Too great a use of chemicals however was expensive and could cause soil erosion problems if the soil surface were denuded of vegetation.

Dr. J.F. Newman commented on Dr. M.P. Brooker's work on "Replacement of Resistance Species" saying that ICI's recommendations concerning partial treatment of lakes had been deliberately ignored in some of the experiments in order to see what the effect would be. In normal circumstances one should certainly not aim to treat more than one third of a lake area at any one time and not more than 2/3 in any one year. This was primarily to reduce the possible effects of deoxygenation but also

to allow some recolonization afterwards.

Mr. D.F. Westlake took up the point of resistance to run-off by weeds being most relevant when flows were high, by querying whether some channels should be treated only for emergent vegetation. As long as the upper banks of the channel were still clear, satisfactory run-off without flooding might still occur. He queried whether a solution to some of the problems in the areas drained by a grid system might be possible by allowing 10% of the channels to be given very little treatment, 10% to be treated for the banks only, and for the other 80% to be fully treated to cope with flood flows.

Mr. R.W. Noakes commenting on this proposal stated that he did not think it was a very practicable one because someone would have to decide which farmers were going to be flooded whenever there was any rainfall. It would be all right if the 10% that was only treated in a minor way were at the upstream end of the channels in some cases, but not in other circumstances.

He felt that there was a considerable lack of understanding by many people of the needs of Drainage Boards and what they do. There had been much discussion about the Drainage Boards in Norfolk but these represented only a small number of the total number of Boards. There were many with completely different characteristics on their channels with elevations up to 200 feet and where the channels were completely dry in summertime. In these cases the channels were small, narrow and in the winter-time the depth of flow was no greater than three feet. Generally speaking most of the Drainage Boards did not own any land whatsoever and they were dependent on the farmers to accept dredge material on the adjoining banks. There were no fishing rights on the channels since they were so small and dry in summertime, and in any case Drainage Boards and landowners were not keen on anglers being present on their land. In such circumstances with many miles of small channels, it was a choice between the use of chemicals for weed control or no maintenance whatsoever and the loss of valuable productivity from the land.

Mr. C. Newbold stated that the Nature Conservancy were mainly concerned with intermediate sized drains, where the conservation value was much greater, and with the large drains. Unfortunately a lot of plants had disappeared in the past, not necessarily due to the use of herbicides.

Mr. T.G. Cave stated that drainage channels were usually designed to take a 1 in 20 year flood without problems. It was up to the IDB's to maintain such a standard, and any reduction would mean that the engineer was failing in his duty. Dr. George accepted that floods should be avoided but thought that some growth of weeds, particularly submerged species, could be left in drains without causing potentially dangerous conditions for flood run-off and pumps. Mr. Cave commented that this could only be accepted in drains that were designed larger than normally required. This did not happen in many instances but there might be some cases where emergent weeds could be allowed to grow at the edges.

Dr. J.M. Way said he thought the whole point of the meeting was to show that herbicides were useful "tools" for IDB's and other water managers to use, provided they understood their effects and were aware of their benefits and drawbacks. He also enquired about the value of macrophytes in preventing erosion of the channels. Mr. W.D. Miles considered they were not of great value underwater but roots were important on the sides of the banks.

Mr. D.B. James questioned whether it might be possible to recommend the growing of macrophytes in water supply reservoirs to help in controlling algae

because there was no satisfactory algicide available.

Dr. George said that macrophytes could be used in this way to remove nutrients and thus control algae. They would also increase the zooplankton.

SUMMARY OF SYMPOSIUM AND RECOMMENDED ACTION

In his introductory remarks the chairman, Prof. L. Broadbent, chairman of the British Crop Protection Council, mentioned that the BCPC was set up seven or eight years ago and its representatives included the Ministry of Agriculture, Fisheries and Food, (both Headquarters and the Plant Pathology Laboratory), the Department of Agriculture for Scotland, the Department of Agriculture for Northern Ireland, the Department of the Environment, and the Ministry of Overseas Development. Two Government research organizations were also represented: the Agricultural Research Council, and the Natural Environmental Research Council; farmers were represented by NFU and industry by the British Agro Chemicals Association, the Society of Chemical Industry, the British Association of Seed and Agricultural Merchants, and the Association of Agricultural Contractors. University scientists are represented by the Association of Applied Biologists.

The Council has three functions: a) education in and communication of all aspects of crop protection, b) co-ordination of the crop protection activities of all the bodies represented on the Council, and c) promotion of research to improve methods of crop protection and its safe and effective practice.

Prof. Broadbent said this session was primarily a co-ordinating one and he then asked Mr. J.D. Fryer, Director of the Weed Research Organization, to suggest the main points arising from this symposium and point to those which particularly require further discussion or investigation.

Mr. Fryer classified the main conclusions into four groups: objectives of herbicide usage, safety, cost effectiveness, training and education.

1. Objective and general aspect Many contributors have drawn attention to the dangers of generalisation. There is a great diversity in aquatic weed problems and each situation requires to be studied individually and specific recommendations made for its solution. Objectives must be clearly defined in each case. The standards of weed control considered necessary should be re-examined. They vary between IDB's and it may be that in some instances slightly lower standards may provide adequate land drainage and also meet nature conservation requirements. Co-ordination of the varying requirements at local level should be given priority and recommendations made to management who are responsible for channel maintenance. Consideration should be given to the development of a national classification system for showing management objectives and priorities.

The role of aquatic plants in fisheries needs further attention, in view of suggestions that they are not essential for fish food. This is particularly so in the case of modern "put and take" trout fisheries and multi-use waters. Where plants are needed to provide spawning sites spring application may endanger certain species of fish and this hazard may be overcome by partially controlling the weed in a lake or channel.

Herbicides are not a panacea for all weed problems but a tool to be used intelligently in an integrated system of water management. Those responsible for the manufacture and regulation of herbicides would be greatly assisted in their work if there were more feed-back from the users. It is generally agreed that there is a need for further meetings of all interested on the same lines as the symposium and a frequency of two to three years was suggested.

2. Safety Although PSPS is the instrument of central government for protecting health and safety its activities are not adequately publicised and more positive attempts are required to do so. In particular it was not clear whether all Regional Water Authorities were aware of the PSPS activities, and whether they accepted that further guidelines are unlikely to introduce additional safeguards. Now that a representative of the National Water Council attends the meetings of the PSPS Scientific sub-committee when herbicides are being considered for aquatic use the position may improve. Representatives of various water authorities agreed to draw attention to PSPS activities but also asked for earlier notification of the clearnace of new aquatic herbicides under PSPS to be made available to the National Water Council which would then include this information in its internal Bulletins. Although it appeared from all the evidence available that there was no significant health risk from correct use of cleared herbicides it would be difficult to convince the public. Consideration should be given to a policy of positive publicity for use of herbicides where chemical control had given good results without undesirable side effects. In the long run it would be preferable to be open about their use rather than to give the impression that the less said about them in public the better.

The possible taint and odour effects of herbicides in public water supplies need further investigation to establish the limits which are acceptable and the methods of measurement. At present neither PSPS nor ACAS seem to be responsible for considering effects of herbicides which make water supplies unpalatable although not dangerous. More information is needed on the interpretation of the word "wholesome" in the relevant legislation. Information is also needed on the maximum permissible levels of herbicides, their major metabolites and additives in drinking water so that RWAs would have definite criteria to work on. Data on residues and metabolites are examined by PSPS when considering clearance of any aquatic herbicide.

If Regional Water Authorities could feed back to the PSPS and the Freshwater Fisheries Laboratory details of authenticated cases of fish death following herbicide application it would provide a valuable way of accumulating useful information. It might also be possible for water authorities and others to supply ACAS with reports on the efficacy of aquatic herbicides.

3. Costs Some of the figures given for the cost of weed control in waterways differ widely from each other and probably reflect the differences in standards of weed control and of accounting adopted by the Boards concerned. It is unlikely that a survey to compare the costs of the different methods would be of much value. Long term case history studies of the effects of weed control, monitoring inputs, results and attitudes would be of more value. A project such as this would however require a multi-disciplinary approach which is difficult to organize and which may be difficult to finance. It was thought that further consideration should be given to the idea but that a large scale programme would probably prove impracticable.

4. Training and Education Throughout the symposium it was clear that there was a need for technical training of staff at three levels likely to be involved in the use of herbicides: i) managerial and scientific staff, ii) field supervisory staff, iii) weed control operators.

Of the various bodies who might provide training, the Agricultural Training Board seemed the most appropriate. The information which should be imparted particularly to operators, included objectives of weed control, weed identification, details of approved herbicide products and how they work, methods of herbicide application and precautions to be taken. It was also thought that consideration should be given to the need for a certificate of competence or licence for operators and contractors.

Interest was also expressed in the possibility of setting up a central advisory service which could provide information on aquatic herbicides to potential and actual users. Another need stressed during the symposium was for better education of the general public including those who use the waterways for recreation. Herbicides tend ed to be an emotive subject and a positive programme to inform the public of their use and the precautions taken was needed.