AGRICULTURAL RESEARCH COUNCIL

WEED RESEARCH ORGANISATION

T. O. ROBSON

A SURVEY OF THE PROBLEM OF AQUATIC WEED CONTROL IN ENGLAND AND WALES

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INTRODUCTION

1. Throughout England and Wales the cutting and removal of water weeds to unblock rivers and drainage channels has been an annual task for centuries. Little attention was paid to these operations which have continued almost unchanged down the years until, during the last decade or so, pressure for new, more modern methods built up through a growing shortage of men willing to use the traditional scythe and rake.

2. To relieve this pressure local attempts have been made by engineers of the river and drainage authorities to mechanise cutting operations but these have not resulted in satisfactory answers for all situations. More recently firms dealing in agricultural chemicals have tested a number of herbicides with variable results. Uncertainty of the hazards and the degree of risk involved has led to caution in the acceptance and sometimes to the rejection of chemical techniques.

3. It was felt that much of this *ad hoc* work was not adequately based on biological facts and it was, therefore, agreed that the A.R.C. Weed Research Organization should carry out a survey of present water weed control practices from an ecological point of view and then prepare an appreciation of those problems which need further investigation.

4. The survey was started in October, 1963 and an interim summary report was prepared in May, 1965. This is a revised version of the final report submitted to the A.R.C. in September, 1965.

PRESENT PRACTICES IN AQUATIC WEED CONTROL OPERATIONS

The need for aquatic weed control

5. The growth of vascular plants in water-ways obstructs the flow of water and, by reducing the velocity, increases the flood risk and the accumulation of silt. The prevention of flooding and channel deterioration is the main reason for aquatic weed control. Others of less importance are the improvement of conditions for navigation for game and coarse fishing and for other public or private amenities. The relevant importance of these is shown in Table I.

TABLE I

The relative importance of reasons for aquatic weed control in rivers

Reason	No. of River Boards	No. as % of total
a) to prevent summer floods	5	8.6
b) to prevent general deterioration due to accumulation of silt	10	17.2
c) both a) and b)	45	74.0
d) to facilitate fishing	11	19.0
e) to facilitate navigation	5	8.6
f) to provide other services (Irrigation 3, gauging 2, winter flow 2, drainage at all times 1, fence 1, seed drift 1, boating and regatta 2, urban amenities)	12	20.7

N.B. - A number of River Boards had more than one reason for weed clearance.

6. Flood prevention includes not only surface flooding of urban and agricultural land but also sub-surface waterlogging due to impeded underground drainage. The latter affects crop production in all artificially drained areas including farmland with clay sub-soils that need land drainage as well as fen-land and marshland areas. Sir Harold Sanders (then Dr. H. G. Sanders) in his address to the 5th British Weed Control Conference in 1960 stated that "roughly half of our farmland suffers to some degree from inadequate drainage". The position is improved annually by grants to farmers for capital works from the Ministry of Agriculture, but good sub-surface drainage depends ultimately on efficient surface drainage from the open farm ditch to the river and the sea, and the maintenance of conditions which ensure a satisfactory flow in these channels is essential to obtain benefit from these improvements.

7. River Authorities*, each covering the catchment of one or more principal river systems, are responsible for generally supervising land drainage in England and Wales and are directly responsible for improving and maintaining those stretches of watercourse designated as main river by the Minister of Agriculture. They are also concerned with water use, fisheries and river pollution.

8. In low-lying areas where land drainage and flood prevention are of particular importance, Internal Drainage Boards (I.D.B.'s) are set up to maintain arterial watercourses other than main river. These boards are financed by rates levied on their areas and are elected from the ratepayers. Individual farmers are responsible for the upkeep of their own ditches.

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*Under terms of the Water Resources Act 1963 River Boards became River Authorities with wider responsibilities on 1st April, 1965.

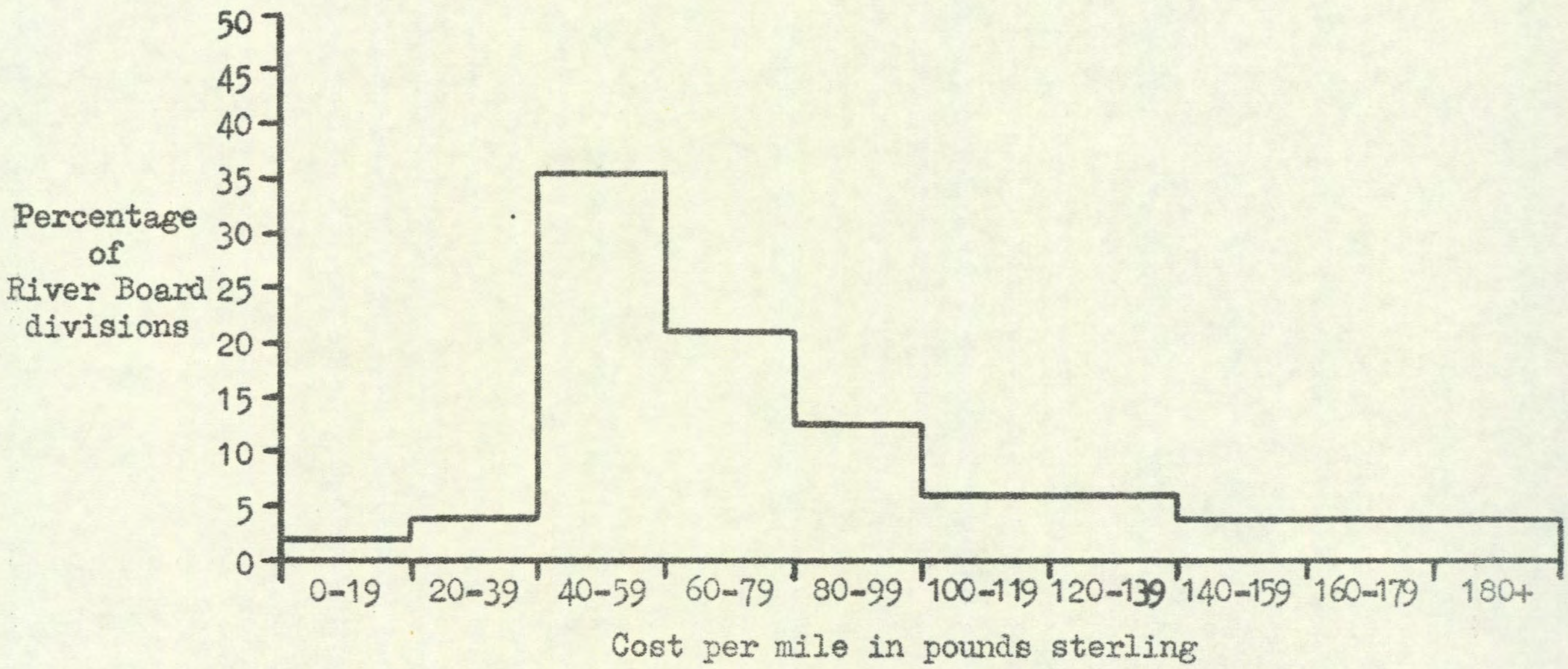

Figure 1 - The cost of water weed control per mile on main rivers in 1963

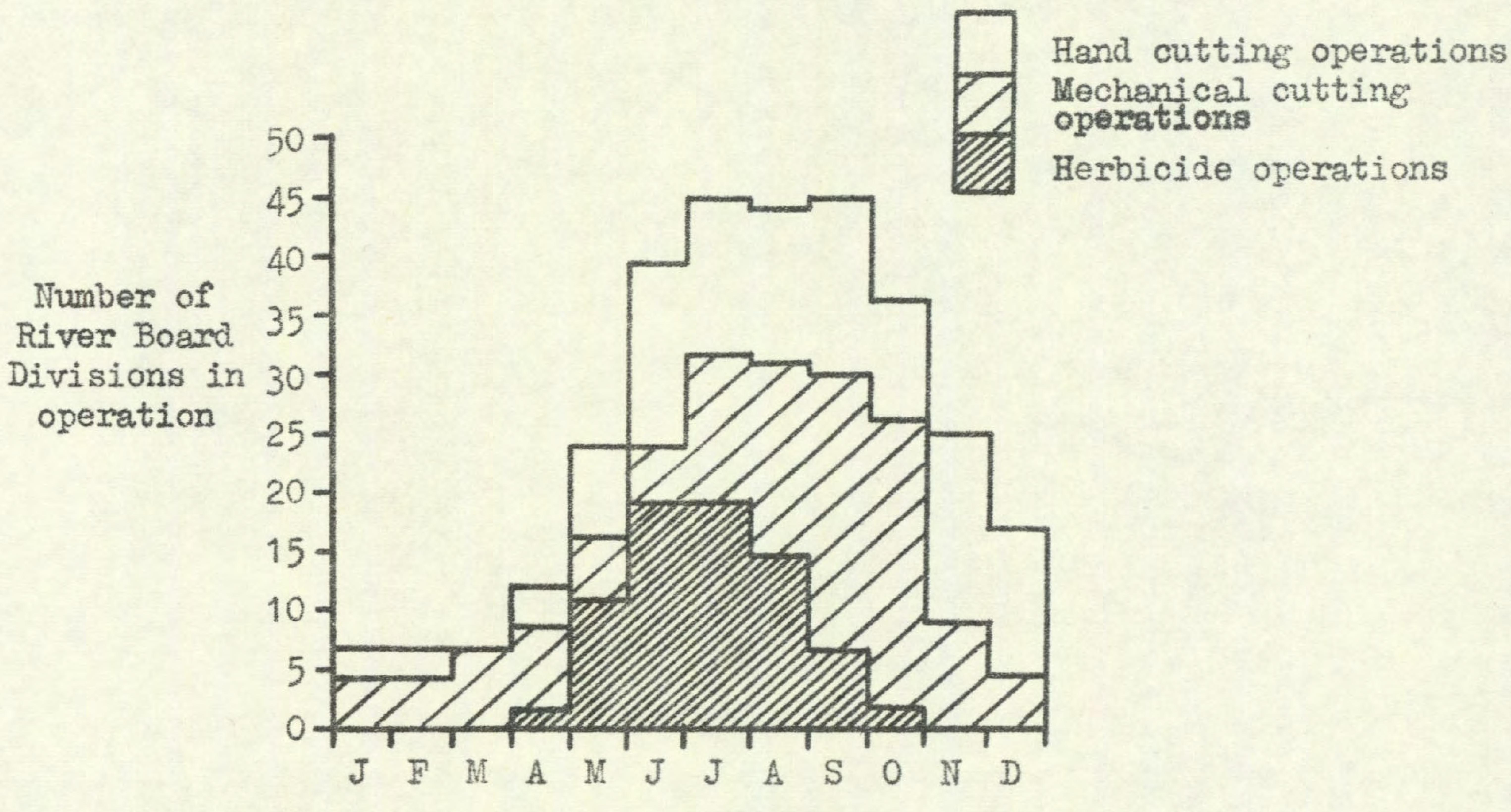

Figure 2 - The number of River Board divisions engaged in weed control operations each month

The extent and cost of annual weed cutting operations

9. Data supplied by River Boards in 1964 showed that weed control operations were necessary over 5,500 miles of main river at an estimated cost of £382,000 per annum, giving an average annual cost of £69 per mile. A closer look at the figures reveals, however that the category containing the greatest number of Boards have a mean annual expenditure per mile of between £40 and £60 (Table II). But it should also be noted that only 6% spend less than £40 per mile while 58.3% spend over £60 per mile.

10. No correlation could be found between the cost per mile and the numbers of miles treated nor the number of times the weed was cut each year. The density of weed growth, the standard of channel clearance to be achieved, the efficiency of the methods used and the local labour costs are considered to be the main factors influencing costs.

TABLE II

Mean annual cost of aquatic weed control per mile - 1963

Cost per mile	No. of River Boards divisions & IDB's	Percentage
£0-19	1	2.1
£20-39	2	4.2
£40-59	17	35.3
£60-79	10	20.8
£80-99	6	12.5
£100-119	3	6.25
£120-139	3	6.25
£140-159	2	4.2
£160-179	2	4.2
£180-199	0	0
£200-219	0	0
£220-239	0	0
£240-259	1	2.1
£260-279	0	0
£280-299	0	0
£300-319	1	2.1

11. For practical reasons it was not possible to collect data on the operations of all independent I.D.B.'s which number about 360, but a few were selected by the Drainage Division of the Ministry of Agriculture as being those most active in attempting to solve the problems of water weed control. These cannot, of course, be considered as a representative sample and their data on costs is therefore of limited interest. The ideas and new methods being tried by them, however, have been included in the appropriate section.

12. Internal Drainage Boards cover an area of 3,225,000 acres in England and Wales and it is estimated that within this area there are 20,000 miles of channel maintained by I.D.B.'s and 60,000 miles of farm ditches. The cost of weed control in arterial channels in I.D.B. districts cannot be very different from that of main rivers and if the average is taken as £50 per mile or 12/6 per chain, an estimate of the total annual cost is £1,000,000. Farm ditches do not receive the same attention as arterial channels, but most of them are cut at least once a year at a cost of about 5/- per chain or a total of £1,200,000 per annum. The annual expenditure in these low-lying areas and rivers could thus exceed £2,500,000. To this must be added the cost of clearing the many thousands of miles of farm ditches on land with impeded drainage not included in any of the internal drainage districts.

13. The importance of the problem, however, cannot be properly assessed from the annual expenditure alone. The problem is not solely to reduce the cost of the maintenance operations, but more particularly to ensure that those responsible for this work have adequate and safe tools with which to prevent the occurrence of the very serious crop losses and damage to property that could occur from surface and sub-surface flooding.

The Weeds

Classification and grouping

14. Vascular plants which grow in watercourses may be placed in three categories according to whether their leaves are emergent, floating or submerged (Chancellor, 1962). Algae form a fourth important group.

15. Emergent plants have erect aerial leaves arising from open water or mud. Some, such as Phragmites communis (common reed), have only aerial leaves while others, like Sagittaria sagittifolia (arrow head) have floating and submerged foliage as well. Because they also obstruct flow in times of high water dry land plants growing above the water line have often to be controlled and, although they are not true aquatics, are grouped with the emergent species for the purpose of this report.

16. The floating leaved group may be divided into those which are rooted in and obtain nutrients from the substrate and those which are free-floating and absorb all their mineral requirements directly from the water through roots or rhizoids, e.g. Lemna minor (duckweed). Some of the rooted species have only floating leaves, as Nymphaea alba (white water lily) while others like Nuphar lutea (yellow water lily) have submerged leaves as well.

17. In the group with submerged leaves some are free-floating, e.g. Lemna trisulca (ivy leaved duckweed) and others, like Hippuris vulgaris (mare's tail) are rooted to the bottom. All are wholly submerged except for those that flower on or above the water.

18. The algae are very varied in size, form and colour. Those that concern land drainage authorities most are the filamentous kinds that grow in long often branched threads or filaments and when matted together are known as "blanket weed" or "cott". These not only obstruct the flow of water but also make it difficult to use weed cutting boats.

19. Aquatic plants are mainly perennials and re-establish themselves vegetatively each spring. Many have rhizomes or tubers, e.g. Phragmites communis and Nuphar lutea, while others produce winter buds (turions) which detach themselves from the parent plant in autumn and remain dormant in the mud until conditions are suitable for growth in the spring, e.g. Myriophyllum spicatum (milfoil).

20. It is believed that only the emergent plants produce viable seed in any quantity and some of these plants have the capacity of spreading at a very rapid rate. Typha latifolia (great reedmace) for instance has been shown to produce 222,000 seed in a 7 inch pistillate spike and in 6 months one established seedling built up a network of rhizomes covering an area 10 ft in diameter (Yeo, 1964).

21. Many aquatic plants grow very rapidly. Ranunculus fluitans (water crowfoot) for example begins growth in April or May and reaches lengths of over 20 ft by the end of June. Regrowth after cutting is often equally rapid. In the New River, Crowland, in 1964 Sparganium erectum (bur-reed) grew 4 inches in 3 days after being cut in mid-May. Four weeks later the plants were 3 ft 6 in tall having grown about 3 ft and the river was blocked almost as seriously as it had been before clearing operations took place.

22. The relative importance of plants as water weeds was assessed from information supplied by the River Authorities and Internal Drainage Boards in the survey (Table III). Phragmites communis (common reed) is by far the most troublesome weed. Another emergent plant, Sparganium erectum is the next important and is followed by Typha spp. (reedmaces), Potamogeton spp. (pondweeds), filamentous algae, and Ranunculus spp. (crowfoot). A number of submerged plants then occur grouped closely together indicating equal importance and these data support field observations that submerged populations are usually very mixed. The higher rating of Potamogeton spp., and Ranunculus spp. is probably due to the numerous species of these two large genera occurring over a wider range of environmental conditions than those of the smaller genera and no differentiation being made between species in the survey.

23. Where Phragmites communis and other emergent plants are controlled for the whole growing season, submerged weeds increase in bulk and importance probably as a result of the increase in the amount of light available.

TABLE III

Relative importance of aquatic plants as weeds

(1964 survey)

Plant	Frequency of occurrence	Importance rating*
Phragmites communis	34	174
Sparganium erectum	15	86
Typha spp.	14	78
Potamogeton spp.	19	78
Filamentous algae ("Cott")	14	76
Ranunculus spp.	11	66
Carex spp. (sedges)	13	59
Iris pseudacorus	11	47
Callitriche spp.	10	41
Elodea canadensis	9	40
Juncus spp.	7	35
Nasturtium spp.	10	35
Lemna spp.	10	33
Hippuris vulgaris	8	32
Myriophyllum spicatum	7	28
Glyceria maxima	9	26
Schoenoplectus lacustris	6	25
Nuphar lutea	8	24
Ceratophyllum demersum	5	24
Sagittaria sagittifolia	6	20

*Frequency x score for importance

The Watercourses

24. Plants may be found in some form or other in all watercourses but only in certain situations do they constitute a nuisance and require removal. The main factor governing the distribution and growth of water weeds is the fertility of the bed of the watercourse (Butcher, 1933a). This in turn is determined to a great extent by the current and it is possible to use this fact to classify river habitats into:

a) bedrock - very fast current - over 1.0 metres per second
b) stoney - fast current - 1.0-0.6 metres per second
c) gravel - moderate current - 0.6-0.25 metres per second
d) sand - slow current - 0.25-0.1 metres per second
e) mud - very slow current - less than 0.1 metres per second
f) mud - negligible current - less than 0.02 metres per second

25. Little weed control is needed in (a) and (b), but in (c) and (d) it is often necessary to cut at least once a year. Categories (e) and (f) provide the most fertile conditions for plant growth and are the main source of trouble. Types (e) and (f) occur in flat, low-lying country where annual flooding would be a normal, natural occurrence if it were not for man's efforts to prevent it. Thus the greatest weed growth and obstruction to flow is found where the need to maintain maximum flow and minimum silting is greatest.

26. Man-made drainage channels with controlled out-falls, that are used intermittently to maintain a certain water level, fall into category (f).

27. Other factors affect the growth and distribution of plants. Depth of water is probably the most important because it generally determines the distribution of the three main groups of plants in standing water. Emergent occur in the shallow water, submerged in deep water and floating in intermediate depths (Tansley, 1953). Below a certain depth, dependent upon the turbidity of the water, light intensity is inadequate for photosynthesis and green plants cannot exist.

28. Temperature, the chemical status of the water, the amount of dissolved oxygen and biotic factors - especially man's activities - also influence the growth of plants to some extent but more particularly they affect the distribution of the different species.

Present Methods of Control

Weed Cutting

29. The most usual method of control is by cutting. This operation starts when the weed is well grown or when it is considered that there is a risk of excessive rainfall and floods. The most important period is in July and August, at the height of the growing period, and towards the end of the summer when increased rain is often expected. Most rivers have to be cut at least twice each year and some as many as 4 times.

30. By Hand The commonest method of cutting is by hand and of the total 5,500 miles cut by River Boards in 1963, 3,965 miles (73%) were cut in this way. Scythes and brush hooks are the usual implements for bank weeds and chain scythes, (10 or more scythe blades bolted end to end and pulled back and forth across the bed of the channel) for those in the water. Less frequently men wade into the channel and cut the weed in the water by scythe.

31. By Machine - Howard & Dennis Launches The most frequently used machine is the Howard & Dennis weed cutting launch which has been available for many years. The cutting mechanism is a serrated V-shaped knife attached to the stern of the boat by a stout, hinged shaft. The knife

can be lowered into the water to the extent of the shaft and is then oscillated back and forth. If the angle of the knife is adjusted correctly and it travels parallel to the bottom of the channel or with its leading end pointed slightly upwards, it will cut most rooted plants. But the knife must be kept sharp, otherwise it tends to ride over some weeds and others, such as Callitriche stagnalis wrap themselves around it.

32. The launch is propelled and steered by an efficient system of paddles at the forward end which do not become fouled by cut weed.

33. A number of different models have been built with cutting widths from 3 ft to 24 ft. The commonest of these have a single knife giving an 8 ft cut, while larger craft have 2 or 3 knives. As an alternative a hydraulically operated, reciprocating 6 ft cutting bar is available for attachment in place of the V-knife. So far it has only been fitted to models sent overseas.

34. Wilder/Powell Launch Another weed cutting boat with a different cutting mechanism was invented by a New Zealander, Mr. G.B. Powell, and with the support of the British Ministry of Agriculture and the National Research Development Corporation is now being produced in this country. This is the Wilder/Powell aquatic mower. It has a wide U-shaped spring-steel blade mounted on the stern of a light-weight fibre-glass boat. Its main advantages are the curved reciprocating cutter bar that cuts the plants cleanly and can be raised, lowered and tilted while operating to meet unevenness in the channel and even to cut weeds on the lower part of the bank. Its lightness enables it to be moved easily from channel to channel. A disadvantage is the form of propulsion which depends on two outboard motors which are easily fouled by floating weed. Attempts are being made by the manufacturers to remedy this.

35. Other Cutting Machines An assortment of mowing machines, many of which have been modified locally, are used for cutting the weeds and grass on the bank. Where access is possible along the top of the bank, tractor-mounted mowers, including flail and rotary types on arms that reach to some distance from the tractor, are used. One or two authorities have mounted reciprocating blades on boats but most use small self-propelled machines on the bank itself. There is a growing interest in pneumatically operated scythes that have a reciprocating cutting blade operated by compressed air from a small compressor pushed along the bank and are handled in much the same way as an ordinary scythe.

"Cotting"

36. The removal of "blanket weed" (filamentous algae) and the intermixed submerged weeds is commonly known as "cotting". A tangled mat of blanket weed on the surface of the water prevents cutting by boat. This mat has to be dragged out. This is normally done by men on the bank with handrakes, but draglines with special buckets with tines are used by one or two authorities.

Dredging

37. Ditches have to be re-shaped periodically and this involves the use of an excavator or dragline to remove the silt and weed from the bed and sides of the channel. Being a slow and expensive operation only a very limited amount is possible each year.

The Removal and Disposal of Cut Weed

38. The law requires that cut plant material is removed from the water to prevent pollution. This operation is normally done by men with rakes. It is a heavy, tedious and expensive job, which in the case of some Authorities accounts for as much as 60% of the expenditure on weed control operations. In the majority of cases, however, it is less than 50%.

TABLE IV

Proportion of mean annual cost incurred by operations to remove the weed from the water

	Percentage of mean cost			
	0-25%	25-50%	50-75%	75-100%
Percentage of River Authorities	58%	29%	13%	-

TABLE V

Method of removing weeds from channels

Method	Percentage of River Authorities
Handrake	78%
Dragline	14%
Elevator	4%
Other	2%
Not removed	4%

39. Normally cut weed floats to the surface and is left to accumulate at a boom across the channel. Draglines, and to a lesser degree weed elevators, are used to lift it out where access is possible.

40. In most cases the weed is piled on the banks and left to rot down. Attempts have been made to use it for compost, but so far without much success.

Biological Methods

41. Only once was biological methods of control noted. At Deeping Fen

sheep were used on the banks of a large drainage channel and they controlled the growth of grass and reeds successfully. The effects of sheep grazing were also noticed in the Romney Marsh where pasture is bordered by drainage ditches but here the effect is incidental and not intentional.

42. The possibility of using a fish, the herbivorous Chinese grass carp (Ctenopharyngodon idella), in British waters is being considered by the Freshwater Fisheries Department of the Ministry of Agriculture, Fisheries and Food and the A.R.C. Weed Research Organization.

Chemical Methods

43. In recent years certain chemicals have been adopted as a routine measure of control, but most are still in the experimental stage. Only dalapon has been cleared under the Pesticides Safety Precautions Scheme (P.S.P.S.) for use on water weeds, but diquat has been given limited clearance to the extent that it can be sold to selected users and the firm must supervise its use. The clearance of 2,4-D amine and maleic hydrazide is being considered.

44. Dalapon Dalapon applied at between 15 and 25 lb a.i. (active ingredient) per acre is used as a foliar spray on emergent monocotyledons. In 1963 24 river and drainage authorities used it on a total of 450 miles of watercourse. The majority consider the results to be good and none reported damage to other interests.

45. Dalapon spraying is usually done in July and August. The dead top growth of most plants - and especially Phragmites communis (common reed) - has to be cut as usual in the year of treatment. The expense is offset to a certain extent by the reduction of regrowth and the need for no further treatment for two seasons or longer.

46. Where common reed is controlled in this way resistant and less susceptible weeds take advantage of the reduced competition and spread rapidly the following year. Glyceria maxima and the more robust species of sedge are particularly troublesome in this way because dalapon only scorches their leaves and regrowth quickly occurs even in the year of treatment. Sparganium erectum and Typha latifolia are usually controlled for the remainder of the year of treatment, but regrow during the following season. Dicotyledons are not affected by dalapon and frequently nettles and other dicotyledonous plants increase on the banks following the control of reeds. 2,4-D is often added to dalapon to counteract this.

47. With the increase in light available to submerged plants a wide variety can grow rapidly and choke the watercourse. The commonest are Potamogeton lucens, P. natans, Ranunculus circinatus and other Ranunculus spp., Callitriche spp., Ceratophyllum demersum, Myriophyllum spicatum and Hippuris vulgaris. Very often filamentous algae (Vaucheria spp. or Cladophora spp.) develop and if left undisturbed form mats on the surface over one foot thick. With the sparsity of information available it has

not been possible to correlate the occurrence of different species with substrate or water conditions. Vascular plants that are already present are of equal potential importance as weeds because most are able to spread rapidly. Filamentous algae become a serious nuisance only in water which has little or no movement.

48. Dalapon also kills some of the short grasses growing on banks of channels and this has occasionally resulted in erosion, especially when animals have been allowed access.

49. Maleic hydrazide Although not yet cleared under the P.S.P.S. the growth retardant maleic hydrazide has been applied to the banks of 200 miles of drainage channel in the Fens over the past 2 or 3 years. Reports on its usefulness vary and it is often mixed with 2,4-D to control broad-leaved plants (5 lb a.i. maleic hydrazide and 3 lb a.i. 2,4-D per acre). The Welland River Authority has developed a 20 ft spray boom that can be carried by two men for applying maleic hydrazide and 2,4-D to the very long and steep banks of their drainage channels. This is attached to a conventional tractor-mounted sprayer and is very satisfactory where access is possible. The Witham Fourth Internal Drainage Board also uses maleic hydrazide and 2,4-D, but apply it through a long boom from a boat with a pump so arranged that it draws water direct from the channel and the chemicals are metered into the delivery pipe. The boat was built in the Drainage Board's workshop.

50. 2,4-D Little 2,4-D is used on its own, but it is often mixed with dalapon or maleic hydrazide to broaden the range of emergent plants controlled. A total of 13 authorities used it in 1963 and applied it to the banks of approximately 250 miles of watercourses at a rate of about 2 lb per acre.

51. The only instance of 2,4-D damage was reported from West Sussex where the herbicide was applied with conventional spray equipment from a helicopter.

52. MCPA In tests in 1963 MCPA was applied to approximately 7 miles of emergent plants. The results were considered satisfactory and no damage to other interests was reported.

53. 2,4,5-T and 2,4-D Two miles of bank were treated in 1963 with a mixture of 2,4,5-T and 2,4-D.

54. Aminotriazole Emergent weeds were treated with a mixture of aminotriazole, dalapon and 2,4-D over a length of 2 miles with good results. (Because of its persistence aminotriazole has not been cleared for use on aquatic weeds under the P.S.P.S.)

55. Copper sulphate One drainage authority in the Fens has adopted regular copper sulphate treatments as a routine control measure for filamentous algae in 30 miles of drainage channel. It is maintained in

the spring at a level of at least 1 ppm copper for a period of seven days and this may be repeated later if there are signs of the algae developing.

56. 'Cott' formation is controlled, but other submerged weeds are normally unaffected and cutting operations with a launch are necessary. However, cutting would not be possible without the control of the algae.

57. Few fish have been killed by direct poisoning, but eels usually succumb. However fish become markedly more active at the time of treatment. The angling society with fishing rights on these channels is pleased with the result. Only one instance of deoxygenation causing fish-kill has occurred and this followed the treatment of a very heavily cott infested channel. Another authority used 1 ppm copper sulphate to control algae over 8 miles of channel in 1963 without any damage to other interests.

58. Lime One River Board has used unslaked lime at the rate of 1 cwt per 15 yd of a 12 ft drainage channel over a length of 5,000 yds since 1957. Complete destruction of vegetation in the treated area has resulted.

PRESENT RESEARCH AND DEVELOPMENT

59. Very little is being done in this country to discover and develop new methods of aquatic weed control.

60. Ways of improving the performance of the Wilder/Powell water weed cutter are being investigated by the manufacturers. But apart from this, development of mechanical control is limited to local modifications of standard equipment and improvisations by land drainage authority engineers.

61. Chemicals are receiving little attention and apart from those mentioned above, only two herbicides, diquat and paraquat are being tested. The phytotoxicity programme on these two chemicals has been completed, but studies on the ecological aspects and problems of persistence in mud are continuing. The Toxic Chemicals Section of the Nature Conservancy at Monks Wood, Huntingdonshire laid down a trial in 1965 to investigate the effect of paraquat on aquatic flora and fauna and, with the assistance of the Water Pollution Research Laboratory, Stevenage, the effect of paraquat on the dissolved oxygen content of the water. An algicide "dimanin" is being considered for trial by its distributors. They are also testing maleic hydrazide for use on banks. Aquatic weeds are not as yet included in the standard tests for evaluating chemicals at the Weed Research Organization.

62. A method for the accurate aerial application of herbicides to narrow drainage channels is being developed by the Weed Research Organization and the Tropical Pesticide Research Unit, Porton (Little et al. 1964).

63. Preliminary observations on the usefulness of Chinese grass carp are being initiated by the Salmon and Freshwater Fisheries Laboratory of the Ministry of Agriculture and the Weed Research Organization. This constitutes the only investigational work on biological control in this country.

64. General biological and ecological studies of aquatic communities are undertaken by a number of University Departments, Fishery Research Establishments, the Water Pollution Research Laboratory, the Nature Conservancy and the Freshwater Biological Association (Frazer Committee, September, 1964). A list of organizations interested in freshwater biological research is given in Appendix II.

DISCUSSION

General considerations

65. Until comparatively recently river and drainage authorities have been content with cutting and removing water weeds whenever they form an obstruction to flow. Because of labour shortages and the need in many places for higher standards of flood control, this approach is now proving inadequate. Aquatic plants re-grow rapidly after they have been cut and it is not possible to clear the channels quickly enough to ensure that the required standard is maintained. In addition some authorities consider that the position is aggravated by a greater growth of weed resulting from the increased use of fertilizer on farms. Increased run-off is another factor aggravating the situation particularly in areas of rapid urban development where the risk of flash floods is greater and good clear drainage channels are essential.

66. More efficient weed control may be achieved either by more frequent cutting or by techniques which prolong the effect of the treatment by retarding re-growth. Under most circumstances the second of these is preferred because it usually involves a lower labour requirement.

67. However, despite the growing need for new methods of weed control to maintain water flow, the movement of water is not the only factor to be considered. In almost every situation the watercourse provides other services to man which must be taken into account. The maintenance needs of these services may clash to some extent with those of land drainage. The most important of these functions are the provision of domestic water supplies, facilities for livestock watering, irrigation, fishing, boating, bathing, wild life studies and preservation, public health, water purification and general aesthetic considerations. The problem, therefore, is not simply one of finding new ways of eradicating troublesome plants, but it is the much more complex one of providing conditions suitable for adequate drainage while, at the same time, maintaining the requirements for the perpetuation of whatever other interests are

involved. It is, in fact, not merely a problem of weed control but one of channel management.

68. To reach a satisfactory solution and develop an efficient system of management the problem must be viewed as a whole with particular attention being paid to the role played by weeds in aquatic ecosystems and the effect their removal would have on other forms of life.

69. Little attention appears to have been given to this aspect until recently and most plant ecologists in the past have tended to confine themselves to listing the plants found and following successional changes. Organizations concerned with freshwater biological research are listed in Appendix II and illustrate the comparatively small amount of attention being given to aquatic vascular plants as compared with other aspects of river ecology*.

70. However, certain functions of weeds have been noted by fishermen and others concerned with fisheries over many years and more recently by biologists working on the problems of water pollution (Edwards and Owens 1962). Butcher (1933 b) considered the main function of plants, from the fishing point of view, to be: a) aeration, b) shelter, c) consolidation of the bed, and d) collection of silt and food.

a) Aeration Through photosynthesis the dissolved oxygen content is increased. However, all green plants including algae have this effect and it is not confined to the weeds alone.

b) Shelter Providing a refuge for animals is an important function of weeds in swiftly flowing rivers, protecting them against the current as well as against predators. In sluggish or standing water protection from predators is important, although other factors may also attract animals to weeds. They may require a higher oxygen regime than is available in the highly organic mud of the bed or they may simply find food easier to obtain there. The fate of these animals when the weed is cut and removed or more permanently destroyed is unknown.

c) Consolidation Plants anchor gravel and stones and make the river bed more habitable for invertebrates.

d) The collection of silt and food Weeds collect both mineral silt and plant debris which accumulate and gradually raise the level of the bed of a watercourse. The accumulation of

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*Dr. Sculthorpe's authoritative book "The Biology of Aquatic Vascular Plants" was published in May 1967 and gives a full account of the subject based on world-wide publications.

silt and organic matter increases the fertility of the water and the substrate and through this the weed and algal populations grow. Weeds also provide additional surfaces on which the sessile algae that form the basis of many food chains can develop and in this way encourage animal populations to increase.

71. This progress is cumulative and if left undisturbed plant and animal communities and habitats will gradually change and develop along the normal road of succession towards marsh and dry land. This ultimate development is certainly not desired by drainage engineers nor by any other bodies interested in watercourses, including those concerned with wild life preservation (George 1965). Whatever use is to be made of a watercourse it is necessary, except where the current is swift enough to prevent the accumulation of silt, for some form of management to be introduced. The form this management takes can only be determined by local assessment of the relative importance of conflicting interests. This should be in terms of the aquatic biological requirements and the effect on the aquatic communities of available tools and techniques for weed control. Under certain conditions, land drainage interests will have to be considered to the exclusion of all others while in other circumstances they will be incidental to the maintenance of another interest such as a particular wild life habitat. Usually a compromise must be reached between conflicting interests.

The development of better methods

72. In the development of suitable techniques for water weed control two different aspects must be taken into account.

a) The efficiency of the technique from the point of view of controlling weeds. This is assessed from the way in which it meets the requirements for:-

   i) the removal of weeds from the channel,
   ii) the control of regrowth,
   iii) the speed of operation,
   iv) the economic limitations.

b) The risk of adverse side-effects affecting other interests,

   i) the biological uses of the watercourse, e.g. fisheries, etc.
   ii) the uses other than those directly concerned with the biology of the watercourse, e.g. domestic water supplies, irrigation water, bathing, etc.,
   iii) the crops and plants of value or interest adjacent to the watercourse.

a) The efficiency of the technique

Cutting

73. In the larger rivers and drainage channels cutting operations have been speeded up by the use of weed-cutting launches on submerged and floating-leaved plants, but a number of experienced foremen in charge of weed-cutting gangs hold the opinion that hand-methods give better and longer lasting results. There are indications in observations on Ranunculus fluitans in the River Perry in Shropshire that the height up the stem at which the plant is cut affects the rate of regrowth and this may account for the better control obtained with scythes and chain scythes, which usually cut the plants nearer the base of the stem.

74. It is supported by the fact the height of cut also affects the re-growth of some perennial terrestrial plants in the same way. Experimental work is needed to confirm this and to exploit it.

75. Another important factor likely to influence the rate and amount of regrowth is the stage of growth at which the plant is cut. Again there is no information available and work is needed to investigate this aspect.

76. Data on these two points could improve the performance of existing machines and provide a basis for ideas for new machines. However, this work must be given a low priority in a programme of research because the improvements that would result would be small in relation to the time taken to develop them and the present performance of the weed-cutting launches is adequate where they can operate.

77. A profitable line to follow would be the development of more versatile weed-cutting machines that can be easily adapted to different situations of channel width and depth, emergent and submerged vegetation and even other tasks such as spraying herbicide, in much the same way as a tractor is used in agriculture.

78. The main problems occur where difficulties of access by land or water make mechanisation difficult. Where this occurs hand-cutting is still the main method employed and it is these situations which provide the greatest problems for the drainage engineer. These conditions are most frequently encountered in the smaller channels and farm ditches where there is insufficient water for boats and the close proximity to crops and the numerous cross-drains make them difficult to reach by machines on land. That these present the greatest difficulties is borne out by the fact that the weeds that the engineers themselves consider to be the most troublesome, Phragmites communis (common reed), Sparganium erectum (bur-reed) and Typha spp. (reedmaces), occur in these situations.

79. In some places casual labour is available and the immediate need is not necessarily to reduce the labour demand but to find methods requiring less skill so that casual unskilled labour may be employed. The

use of pneumatic scythes seems to meet this need to a large extent although access may still present problems if a large air-compressor has to be used. Where labour is not available the solution must lie in methods that require fewer man hours to achieve satisfactory results, although manually applied, e.g. herbicides and flame-weeding.

The removal of cut material from the water

80. A serious consequence of more rapid cutting is that cut material accumulates and has to be removed more quickly. Mechanisation of this operation is one of the most pressing needs. Where access is possible along the bank draglines are probably the best solution found so far. The weed elevator is adequate where the weed is not excessive and where men are available to feed the material to it. Work is needed to investigate this and also the companion problem of finding a use for, or in some other way disposing of the weed that is removed. Attempts to turn it into compost and silage have failed, probably because of the high moisture content and the failure of suitable bacteria to grow. If it were possible to remove excessive water from the plants as they are lifted from the channel it would lighten the work as well as make the material more suitable for converting into a useful product.

81. Recently some work has been done in America on methods of harvesting and drying submerged aquatic weeds. Analyses show the dried product to have a high protein value and to be particularly rich in xanthophyl (Lange, 1965) which could make it useful for poultry feeds. It is unlikely that it could be processed cheaply enough to compete with the normal sources of this material such as lucerne.

Biological control

82. Certain situations lend themselves to safe biological control. An example is found in the maintenance by grazing of a short grass cover which offers little resistance to water flow on the high, sloping banks of large drainage channels. Frequent defoliation is needed to do this but the steep slopes make mechanical cutting difficult and sheep or some other herbivorous animal can sometimes provide an answer.

83. In initial field trials the Chinese grass carp (Ctenopharyngodon idella Val) has shown promise against submerged weeds and has kept Elodea canadensis (Canadian pondweed) in check by defoliation. During 4 months they gained on average 50% in length and 300% in weight (Pentelow, 1964).

84. This type of biological control demonstrates the possibility of finding some method which not only controls the weed but also converts it into something useful. However, more than with any other technique strict control is required over biological methods. Usually adequate defoliation requires dense populations, which are only reached when the introduced organism is well suited to the environment and is free of excessive predation. This being so, there is a serious risk that it may

escape and become a pest itself unless it is strictly controlled. In the case of sheep the numbers and the amount of defoliation are entirely determined by man. In the case of the grass carp there is hope of a natural barrier. It has not been known to breed naturally outside certain rivers in China and Russia and as the first step in the project, starting in 1965, it is hoped to establish that it will not do so in British watercourses.

85. The introduction of snails, insects and pathogens is sometime advocated as a possible line of research. Some work on these lines is being done with insects and snails in the United States (Anderson, 1965).

86. Another biological approach exploits plant competition and is illustrated by the practice in the United States of fertilizing standing water to encourage planktonic algal "bloom" which by reducing light intensity prevents the growth of plants from the bottom. There is no record of this technique being used in this country and from observations at sites where blooms have occurred there appears to be little control of submerged growth in shallow water. This does not necessarily mean it will not work, although timing will be a critical factor.

<u>The alteration of the habitat</u>

87. The alteration of the habitat in this and other ways, (not necessarily biological) is an important approach which must repay further investigation. The environmental factors which can be altered in practice are the available light (an example of this has already been given), the substrate and the temperature.

88. <u>The light factor</u> Aquatic plants are adapted to make use of much lower light intensities than land plants. A fuller knowledge of the range of light intensity and quality required by different species might indicate a possible method of control, but it is difficult to see where it could be of practical importance at present. One possible exception to this is where a channel can be altered to give a sufficient water depth to prevent adequate light intensities reaching the bottom.

89. <u>The substrate</u> Although it is generally accepted that the substrate is the main factor governing the distribution of aquatic vegetation there is little information on the properties responsible. On land edaphic factors are recognised as important and have been thoroughly studied in relation to the development of plant communities. But in aquatic conditions this has not been so. Butcher has recognised a number of communities associated with different riverbeds but does not examine the substrates in any detail to discover the factors responsible for their distribution. Nevertheless, his useful work could form a satisfactory basis for more detailed investigation.

90. From present evidence it would seem that the most profitable approach to a practical solution is to devise methods of maintaining infertile

substrates by preventing the accumulation of silt and organic matter. The alteration of channel design to increase velocity of flow may be possible where the gradient is adequate while intermittent dredging is the only cure for silt accumulation where gradients are low.

91. A wide variety of machines for removing mud and detritus from channels are available commercially, on the Continent if not in this country, and many of these are demonstrated annually at the National Ditch Clearing Demonstration in the Netherlands. The two difficulties encountered with all of them are access and the disposal of the spoil; but in the majority of cases these operations are carried out in the winter when the difficulties are less important.

92. The temperature Temperature variations do not have so much effect on submerged aquatic plants as they do on those with aerial leaves because of the "cushioning" effect of the water. However, changes in temperature appear to be the main factor in breaking dormancy in the spring and in causing senescence in the autumn. All aquatic plants are susceptible to frost to some degree and it may be possible in certain conditions to exploit this for their control.

93. Greater knowledge of the degree of frost tolerance of troublesome plants and of different plant parts might possibly lead to control methods such as the draining of bodies of water at critical times to expose underwater rhizomes to frost.

Chemical control

94. The use of chemicals implies to many the complete destruction of treated plants. This is by no means true particularly where they are used on rooted perennials. On these plants a kill is more the exception than the rule with present herbicide practices and the effect usually varies between a temporary defoliation and a prolonged retardation of bud development. The degree of control is regulated by the type of chemical and its formulation, the rate at which it is applied, the length of exposure to the chemical, the method of application and uniformity of distribution, the species of plant and its stage of growth. By varying these factors a variety of results can be obtained.

95. This versatility and the low labour requirement for application make the use of herbicides a most attractive proposition. Because this has been appreciated a number of authorities and chemical firms have carried out *ad hoc* trials and these have led to the present situation with regard to the use of herbicides. However, none of these chemicals has been sufficiently investigated to enable the full potential of its phytotoxic properties to be assessed and exploited in the field. Neither have the risks of side-effects been fully investigated and although reports on field work to date show no serious hazards, the majority of records are the result of casual observations on fish-kill and complaints of spray-drift damage. That some authorities use chemicals which have

not been cleared for use under P.S.P.S., e.g. 2,4-D, is an indication of their appreciation of the potential usefulness of herbicides. It also emphasises the urgent need for more work to ensure that properly tested, effective and safe treatments are available to meet the demand.

96. Water weeds are included in some of the chemical manufacturers' initial phytotoxicity tests, particularly in America where their control is a more attractive commercial proposition than in this country, but these often give little indication of their potential value in the field because the test plants are frequently only small floating species.

97. The next stage is to test those chemicals selected, for their phytotoxicity on a wide range of aquatic plants. There are, satisfactory techniques for doing such tests in the laboratory on rooted, submerged and free-floating plants. With emergent species, however, the problem is more difficult because they must be treated with a foliar application when fully developed and, being perennial, the effect must be assessed from the rate of re-growth. This can only be done with present techniques in the field, but the plastic pool technique of Lawrence (1964) may be of some value here. It may also be possible to develop techniques for measuring the effects of treatment at any time of the year.

98. The ultimate assessment must be done in the field where environmental factors, seasonal development and growth differentials between species are able to play their part and the reaction of the plant community as a whole can be assessed.

Application techniques

99. New methods of herbicide application are required to reduce the risk of spray-drift damage to adjacent crops while increasing the speed of application so that as much as possible of the weed can be treated at its most vulnerable stage of growth. The development of safe systems of channel, ground and aerial application are already being investigated and in some cases are being developed. The long spray booms and the use of water direct from the watercourse which were mentioned in para. 49, illustrate this. The accurate application of dalapon to ditches from a helicopter (Little *et al.*, 1964) gave encouragement to aerial spraying. This would overcome many of the difficulties of access and also have the advantage of affording rapid treatment at the most effective stage of growth.

100. An argument often brought up against the use of herbicides is the high cost of the chemicals and of their application, but many of the chemical treatments have a long-term effect on the vegetation and annual treatment is not therefore usually necessary. In the case of dalapon on *Phragmites communis* regrowth is delayed and for 2 or even 3 seasons it may not be necessary to give it any further treatments. This is not so marked on other species such as *Sparganium erectum* where control appears to be limited to 12 months. Chemical treatment does not always cause the

collapse of the erect aerial stems of emergent plants and in many cases it has to be followed by cutting to remove the obstruction to flow in the year of treatment. Under these conditions long-term control is essential to make the use of herbicides a practical proposition. From the point of view of economy in chemical and labour, more careful consideration of the factors governing longer-term control and the effectiveness of a chemical treatment, including biological and autecological studies of the most troublesome species, must form an important part of a research programme.

101. None of the practices at present adopted can be said to give adequate long-term control of all species and thus annual treatment of some sort is usually required.

(a) Dalapon is satisfactory if applied at the right time to Phragmites communis, but appears to give no more than 12 months control of any of the other weeds. On the other hand it can eliminate some of the smaller grasses and lead to erosion on the bank. More work is essential to study any correlation between selectivity and time and rate of application.

(b) Maleic hydrazide is claimed to encourage the development of a fine grass sward. So far there appears to be little scientific evidence of its having satisfactory results when applied to any of the tall emergent weeds. It is being tried at present on grass swards on banks.

(c) 2,4-D and MCPA are effective against annual broad-leaved weeds, but the treatment must be repeated annually to have any control over perennials and germinating annuals.

(d) 2,4,5-T and 2,4-D have been used against woody plants on banks and are not considered for water weeds proper.

(e) Aminotriazole trials have shown that this herbicide used with dalapon might provide satisfactory long-term control of a wider variety of emergent plants, but it is considered unsafe by the P.S.P.S.

(f) Copper sulphate quickly becomes inactivated and treatment must be repeated whenever the filamentous algae start to grow. It can eventually eliminate algae and thus have long-term effects.

(g) Diquat and paraquat are not included in the list of herbicides used by River Authorities, nonetheless they have been used in increasing quantities against submerged weeds in standing water such as ponds and lakes. Of all chemicals these two have received the greatest amount of attention and testing as possible aquatic herbicides. Despite this attention, it has not been possible to study in detail the reaction of different species to treatment at various stages and it is usual to find one or two species recovering more rapidly than the others.

The biology of weeds in relation to their control

102. Reference has already been made to the importance of the stage of growth of a plant and the environmental factors (particularly light intensity, temperature and substrate) in the way a weed reacts to treatments. Much experimental time would be saved if more were known of the general biology of the plants to be controlled.

103. Studies that would throw light on the problems of control are:

(1) the autecology, especially the relationship of individual species to light intensity, temperature and substrate,

(2) the morphology and physiology, particularly in relation to herbicide up-take and translocation and bud development,

(3) methods of perennation and factors affecting the inducement and breaking of dormancy,

(4) phenology and the relationship to the seasonal development of other species,

(5) the dissemination of seed and vegetative methods of spread.

104. Much useful basic information of this kind is being brought together in various publications such as the "Biological Flora of the British Isles", an example of which is the useful paper by Cook on Sparganium erectum (Cook, 1964).

b) The risk of adverse side-effects

105. Adverse side-effects may result either from direct toxicity of herbicides, or indirectly from the disturbance of biological systems. They can affect:

(a) biological uses of the watercourse, e.g. fisheries,

(b) uses not directly concerned with the biological system, e.g. irrigated crops, domestic water supplies, bathing, etc.,

(c) crops and plants of value or interest adjacent to the watercourse.

Side-effects within the watercourse

106. Weeds have a role to play in the biological system of a watercourse which their removal disrupts to a varying degree depending upon the rate at which the plants and other dependant communities recover and reform into

the original complex. The more permanent the control of plant regrowth the greater will be the change that can be expected in the biological system.

107. Where annual weed cutting has been carried on over many years, the periodic removal of weeds has become a factor of the environment and the plant and animal communities have become adjusted to it.

108. Under these conditions the uncontrolled growth of weeds may be less desirable for the maintenance of a suitable environment for fish and other biological interests than is the complete removal of the macrophytes.

109. The biological uses of watercourses of most importance are fisheries (coarse and game), the protection of other animals and birds of particular interest and the purification of polluted water.

110. In the case of fish and other animals the removal of weeds from the channel reduces the shelter and alters the quality and quantity of food available. With the increase in velocity of flow, bottom-living organisms are eroded from the bed, although it has not been possible to find any account of this in the literature examined. Slower changes will follow if the weeds are permanently controlled and the organic matter of the mud is decreased. Records of changes in populations under these conditions are needed to follow the reactions and the adaptability of fish to the changing circumstances of shelter and diet.

111. Similar observations must be included in the examination of chemical methods of control because these may, in addition to increasing velocity and erosion have a direct toxic effect on fish and their food chains. An assessment of the toxicity to fish is obtained from the standard tests carried out by the Ministry of Agriculture, Fisheries and Food. Although some guide can be obtained of the toxicity to invertebrates and algae in the laboratory, it is not possible to cover all the important species and any laboratory screening work must be supported and supplemented by sampling and observing the behaviour of these communities in field trials. This must be continued for some time after any direct effects have shown up and where possible should be compared with a parallel set of data from untreated water. With experience and the accumulation of data it may be possible to devise and develop a system of monitoring biological reactions to experimental field treatments using key organisms as indicators of environmental changes.

112. Another important function of weeds is the maintenance of a satisfactory dissolved oxygen concentration in the water. However, as already mentioned, this is a function of all green plants and where submerged weeds are removed oxygen will be produced by the photosynthetic processes of algae.

113. Perhaps the most serious side-effect of herbicide treatments is the de-oxygenation of the water by the increased oxygen demand during the

bacterial breakdown of excessive amounts of plant material. Techniques for avoiding this or ensuring that it has no adverse effects on the fish and other animals must be developed. Ways to promote and hasten the reoxygenation also require investigation.

114. The control of emergent plants on the banks is likely to cause little disturbance to other interests except where they form an essential part of a habitat of rare plants and interesting birds, animals and insects.

Side-effects through water use outside the watercourse

115. The cutting and removal of weed is unlikely to have any more serious effect on domestic water supplies than temporarily increasing the turbidity. There is a chance of cut material blocking pump intakes but this is usually avoided by the removal of the weed from the watercourse.

116. There may be risks of side-effects when chemicals are used and where there is a likelihood of abstraction for domestic purposes it is necessary to ascertain the position regarding mammalian toxicity, the minimum permissible concentration in drinking water and possible taints and odours. This information may be available from the manufacturers but because of the limited market it is often inadequate.

117. Also data is required on the persistence of the chemical in water and mud and the period after treatment during which restrictions should be imposed on the use of water for domestic, bathing and irrigation purposes. This is required not only for those substances that are introduced directly into the water but also for those applied to emergent weeds a proportion of which might be washed into the channel in run-off or may fall into the water at the time of application.

118. The development of herbicide techniques to control weeds on the bank must include studies on the susceptibility of and selectivity between different species to ensure that the banks are not denuded and eroded. With recent work on the selectivity of chemicals in pastures it may be possible to find a treatment which will encourage the establishment of a short grass sward while eliminating the taller species.

Side-effects on crops and plants of value adjacent to the watercourse

119. Precautions must be taken to avoid damage to adjacent crops and plants of value. The most likely source of damage is from the use of herbicides and may be caused by spray-drift at the time of application, the up-take of herbicide by plant roots in the water channel, or the lateral movement of the chemical in the water through the soil.

The influence of local circumstances on side-effects

120. These side-effects of weed control operations are not necessarily

important in every situation. Their significance depends on the relative importance of the main functions of the watercourse and varies from the situation where drainage and water movement are of paramount concern and there is no other use made of the channel, to a situation where the maintenance of a particular wild life habitat is the main objective and drainage is of minor importance.

121. In the first instance complete weed control is the answer and a persistent chemical could be safely used to sterilise the channel while, in the second, selective cutting may be the only answer. With this wide range of variation in the requirements for weed control, a variety of treatments must be available to achieve a high standard of efficiency and acceptability. To enable the fullest use to be made of new methods, and particularly to take advantage of the versatility of chemical techniques, a classification of the more important situations from the point of view of land drainage and hazards to other interests found in the field is needed so that methods can be recommended for well-defined easily recognisable situations.

The possible decontamination of water treated with herbicide

122. A possible practical way of reducing the risk of side-effects is by the decontamination of treated water. A study of the properties of the chemicals, their capacity for adsorption, their method of breakdown, and their reaction to other compounds which may be safely introduced into the water might reveal practical ways of removing the toxicity from the original treatment.

CONCLUSIONS

123. The control of the growth of water-weeds in drainage channels and other watercourses is essential to maintain efficient land drainage and to prevent flooding of urban and agricultural land. The growing shortage of labour willing to use the traditional hand tools for water-weed control is creating an increasingly urgent need for the development of new labour-saving techniques.

124. There is also a demand for labour-saving methods from freshwater fishing interests, sailing clubs, aquatic sports groups and those responsible for the upkeep of private lakes.

125. There is no planned and co-ordinated research programme. Most of the work is of an ad hoc nature and the biological aspects are not always fully appreciated.

126. The potential market for new techniques in Britain is limited and attracts little commercial interest in their development. In most cases only sufficient experimental work has been done to persuade those faced

with the problems of water-weed control to appreciate the phytotoxic properties of a chemical. Only in one case have ecological studies been carried out adequately.

127. Information on developments and experience gained in other parts of this country and abroad is not always available to those concerned with water-weed control.

128. There is thus a need for a centre of research and information which would:

a) study and develop new methods of aquatic weed control,

b) maintain contact with research and field experience in this country and abroad, and

c) disseminate information on new developments.

129. The most pressing problems of weed control occur where traditional cutting operations cannot be easily mechanised and are found mainly in the inaccessible small channels and ditches, on the sloping banks of drainage channels and where filamentous algae prevent the use of machines. In these situations herbicides offer the most promise and the development of safe chemical techniques should form the main part of a research programme (paras. 22, 78, 79, 94-101).

130. The use of herbicides in water is restricted and regulated by the risks of pollution and adverse side-effects as much as by phytotoxic considerations. A programme of research should, therefore, include work to determine the conditions under which each chemical treatment can be used with safety (paras. 67-72, 105-122).

131. In the larger drainage channels and rivers where mechanisation of the cutting operation is possible, the most difficult and sometimes the most expensive operation is the removal of the cut material from the water. The development of new methods and machines either to speed up the disposal of the cut material or to reduce the rate of regrowth is more important than the development of more rapid methods of weed cutting (paras. 38-40, 80, 81).

132. In both sets of circumstances methods other than chemical and mechanical may prove useful and the following need investigation:

a) the use of flame weeders on emergent and bank vegetation, (para. 79),

b) the use of herbivorous fish, snails and other invertebrates to control submerged vegetation and the use of herbivorous animals on the banks, (paras. 41, 42, 63, 82-86),

c) the alteration of the conditions of the habitat to prevent the growth of weeds, e.g. reduction of light intensity by deepening the channel (paras. 87-93).

133. Basic information on the seasonal growth and development; methods of perennation; reproduction and dispersion; and autecology of many of the most important weeds is lacking or requires supplementing. This type of work would lend itself well to study by post-graduate students working for higher degrees (paras. 102-104).

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APPENDIX I

AN OUTLINE OF A COMPREHENSIVE RESEARCH PROGRAMME

The main aspects that would require investigation in a comprehensive programme of research may be summarised as:

1. Chemical

(a) Phytotoxicity

(i) Laboratory screening of herbicides in standing and flowing water using selected submerged and floating weeds and filamentous algae.

(ii) Further studies with selected chemicals to establish the relationship between concentration of chemical, length of exposure and phytotoxicity.

(iii) Studies on the modification of phytotoxicity by formulation of the active chemical.

(iv) The field evaluation of phytotoxic value of herbicides by assessing the effect different concentrations, time of application and frequency of application of promising herbicides have on the regrowth of:

1. emergent weeds - particularly Phragmites communis, Sparganium erectum and Typha spp.,

2. submerged and floating weeds, including filamentous algae.

(b) Toxicity to other important organisms

(i) Laboratory tests with selected invertebrates to indicate the effects of potentially useful herbicides on fish food-chains.

(ii) Laboratory tests with selected algae to assess the effect on fish food-chains.

(iii) Field sampling.

(c) Persistence of the chemical in the water and the assessment of the risk of contamination following foliar application to emergent plants.

(i) An assessment of the persistence of the herbicide in water and in mud in relation to the use of water for irrigation, livestock or domestic purposes and the determination of the maximum amount permissible in water to be used for these purposes. When it is used for domestic purposes the likelihood of persistent taints and odours must also be investigated.

(ii) The possible release of the herbicide from plant detritus as it decomposes.

(iii) The estimation of the quantity of herbicide applied to emergent weeds as a foliar spray that enters the water and the risks involved.

(iv) The investigation of possible methods for decontaminating treated water.

(d) Application techniques

The development of methods of application to:

(i) avoid spray-drift and damage to adjacent crops and valuable plants,

(ii) increase speed of application to take advantage of any benefits of time of treatment,

(iii) economise on man hours,

(iv) economise on the amount of chemical applied.

(e) Experimental techniques

New techniques are required to reduce the time needed to assess phytotoxicity tests on perennial plants and to assess and record changes in submerged vegetation.

2. Biological

(a) Herbivorous fish

The study of Chinese grass carp and other fish with particular reference to:

(i) the species of plant eaten and those left untouched,

(ii) the quantity of vegetation consumed and stocking densities.

(b) Herbivorous animals

Observations on the effect of sheep and other grazing animals on important emergent weeds.

3. Mechanical

(a) The development of improved methods of:

(i) removing the cut weed from the water,

(ii) disposing of the plant material on the bank by either converting it into useful products or accelerating its breakdown.

(b) The improvement of the effectiveness of cutting for the retardation of regrowth by determining:

(i) the effect of cutting at different stages of plant growth,

(ii) the effect of the height of cut,

(iii) the development of machines capable of more precise action to enable (i) and (ii) to be put into practice.

(c) The development of weed-cutting launches that can be adapted for different channel conditions and for different tasks, e.g. cutting on the bed, cutting the banks, spraying, raking.

(d) The testing of machines for cutting the vegetation on sloping banks.

(e) The testing of flame weeders on emergent weeds.

4. Ecological studies

(a) The regular recording of environmental factors and changes in important floral and faunal populations and their relationships.

(b) The role played by macrophytes in selected aquatic ecosystems.

(c) The assessment of the effect of promising treatments on the biological systems of typical watercourses by recording:

(i) changes in macrophytic vegetation,

(ii) changes in algal populations (filamentous, planktonic and sessile),

(iii) changes in invertebrate populations,

(iv) changes in environmental factors (dissolved oxygen, substrate, light intensity),

(v) the persistence of these changes,

(vi) the adaptation of fish and other organisms of importance to these changes.

5. Biology of main weeds

(a) Morphology and physiology in relation to herbicide uptake and translocation within the plant - as a guide to methods of application and the need for wetters and perhaps other additives.

(b) Perennation - methods of perennation, factors affecting commencement and breaking of dormancy.

(c) Dissemination by seed and vegetative spread in relation to reinvasion of cleared areas and the effect of control operations on spread.

(d) Autecology - the importance of environmental factors of:

(i) substrate and water quality,

(ii) light intensities,

(iii) temperature and frost tolerance,

(iv) competition from other plants.

APPENDIX II

INSTITUTIONS IN ENGLAND AND WALES CONCERNED WITH

FRESHWATER BIOLOGICAL RESEARCH

1. Plants

(a) Vascular plants

Freshwater Biological Association, River Laboratory
(growth and productivity in relation to environment)
Water Pollution Research Laboratory
(effect of plants on dissolved oxygen)
Birmingham University (genecology of *Nymphaeaceae*)
Leicester University (morphogensis in *Lemna*)
Liverpool University (biosystematics; gas exchange)
University of Wales, University College of Wales, Aberystwyth
(*Callitriche*)

(b) Algae

Freshwater Biological Association, Windermere Laboratory
(ecology, physiology)
Bristol University
(algology)
Cambridge University
(taxonomy, morphology, culture)
Liverpool University
(taxonomy)
London University
Bedford College (physiology)
Birbeck College (physiology)
Queen Mary College (taxonomy)
Royal Holloway College (taxonomy, ecology, physiology)
University College (physiology)
Westfield College (physiology)
University of Wales, University College of N. Wales, Bangor
(algology)
Northern Polytechnic
(taxonomy)
Sir John Cass College
(ecology)
Plymouth College of Technology
(taxonomy of *Cladophora*)

(c) Fungi

London University
Queen Mary College (physiology and ecology)

Sheffield University
(ecology)

2. Animals

(a) Fish

Freshwater Biological Association (population dynamics and ecology)
Freshwater Fisheries Division of the Ministry of Agriculture, Fisheries and Food (population dynamics, behaviour, physiology and effects of pollution)
Water Pollution Research Laboratory (effect of pollution)
Cambridge University
Leeds University (histology)
Leicester University (physiology)
Liverpool University (physiology, conservation, parasites)
London University
    Queen Elizabeth College (taxonomy)
Nottingham University (physiology)
Oxford University (behaviour studies)
Reading University (population dynamics)
Southampton University (physiology)
Chelsea College of Science and Technology (diseases of fish)

(b) Other vertebrates

Liverpool University (amphibia)
London University
    Guy's Hospital Medical School (Lampreys)
Bristol College of Science and Technology (Lampreys)

(c) Invertebrates

Freshwater Biological Association (population dynamics and ecology)
Durham University (ecology of insect larvae)
Keele University (ecology, taxonomy)
Liverpool University (mollusca, benthic organisms)
London University
    Bedford College (Rotifera)
    Queen Mary College (molluscs)
    Royal Holloway College (physiology)
Manchester University (crustacea, insects, plankton)
Nottingham University (insects)
Reading University (anatomy, physiology, ecology, population studies)
University of Wales, University College of N. Wales, Bangor (triclads)
Sir John Cass College (crustacea)

3. <u>The ecology of the river biotic communities</u>

Freshwater Biological Association, River Laboratory
(ecology and the flow of energy through aquatic ecosystems)
Water Pollution Research Laboratory
(effect of water pollution on biotic communities)
The Nature Conservancy, Monks Wood Experimental Station
(effect of insecticides and herbicides on biotic communities)
Liverpool University
(ecology of mountain streams)
University of Wales, University College of N. Wales, Aberystwyth
(ecology of rivers: biology of water pollution)
University of S. Wales and Monmouthshire (stream ecology)
I.C.I., Ecology Section, Jealott's Hill Experimental Station
(effect of diquat and paraquat on biotic communities)

AGRICULTURAL RESEARCH COUNCIL

WEED RESEARCH ORGANIZATION

Technical Reports

1. Susceptibility of ornamental plants to simazine and other chemicals. Trees and shrubs. November, 1964. G. W. Ivens. Price - 5s. Od.

2. 3,5-Di-iodo-4-hydroxybenzonitrile. A progress report on experimental work by the A.R.C. Weed Research Organization. May - October, 1963. K. Holly and J. Holroyd. No charge.

3. Chemical control of bracken. 1964. G. L. Hodgson. Out of print.

4. Susceptibility of ornamental plants to simazine and other chemicals. Annuals, biennials and herbaceous perennials. April, 1965. G. W. Ivens. Price - 2s. 6d.

5. A survey of the problem of aquatic weed control in England and Wales. October, 1967. T. O. Robson. Price - 5s. Od. post free.

6. The botany, ecology, agronomy and control of *Poa trivialis* L. - rough-stalked meadow-grass. November, 1966. G. P. Allen. Price - 5s. Od.

7. Flame cultivation experiments 1965. October, 1966. G. W. Ivens. Price - 3s. Od.