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INTERIM REPORT ON THE DEVELOPMENT OF N-DIMETHYLAMINO SUCCINAMIC ACID IN CERTAIN VEGETABLE CROPS

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Summary Trials are described in which N-dimethylamino succinamic acid (dimas) is used to modify plant growth or size. Although varietal response varied in potatoes dimas at 2 lb formulation/ac increased the number of canning sized tubers in Arran Pilot at early but not at final harvest, whereas in King Edward the number of seed sized tubers was increased at normal harvest. Weight of final yields was not increased, however. Carrots cv. Chantenay gave little response to dimas although at early harvest canning size root numbers were increased. Conflicting results obtained by other workers are noted.

INTRODUCTION

Experiments with the growth regulant N-dimethylamino succinamic acid (proposed common name dimas, coded as B995 and named 'B-Nine' or 'Alar'*) have been undertaken by various workers on many vegetable crops. Thomas (1966) and Thomas and Golding (1967) reported that dimas-treated Brussels sprouts gave earlier and greater marketable yields. Marth (1965) showed that dimas-treated cabbage were more winter-hardy and could be harvested earlier in the spring. Bodlaender and Algra (1966) with Dyson and Humphries (1967) found that dimas treatment increased potato tuber weight at the expense of aerial growth. Further work by Bodlaender (1968) and Harper (personal communication) indicated that dimas may not always affect total tuber weight but modified the numbers produced. In 1968 we examined the use of dimas in Brussels sprouts, carrots and potatoes where there might be economic benefits to the farmer by modification of the size or growth rate of the harvested portion. This paper deals with results obtained before October and the conclusions reached may be modified when all harvesting is completed.

METHODS AND MATERIALS

The dimas formulation used was 'Alar', an 85% soluble powder (in the paper doses are given as lb 'Alar/ac for convenience), and it was applied in 50 gal water/ac. Trials were randomised blocks with 3 or 4 fold replication. Harvesting was by hand. Chemical studies on residues within the crops and their suitability for processing are under way.

* 'B-Nine' and 'Alar' are registered trademarks of Uniroyal Inc.

RESULTS AND DISCUSSION

Brussels sprouts

To date the trials show that plant height reduction is related to dimas dosage: on 10th September, 46 days after treatment, mean height untreated plants was 27.3 in. compared to 19.4 in. at 4 lb 'Alar'/ac. Treatment gave shorter internodes and larger, tighter sprouts.

Whitwell (personal communication) fround that 2 lb 'Alar'/ac in mid-August raised marketable yield with the increase nearly all in the pre-packed preferred 1½ in. to 2 in. grade. Three pounds per acre and September treatment did not give comparable results whereas 1 lb/ac in mid-September gave almost comparable results.

Carrots

The trial harvested in August (Table 1) showed little effect of dimas upon total yield but some increase in the ¾ in. to 1½ in. diameter roots (preferential canning size) occurred earlier in treated than in untreated plants. Dyson (personal communication) reported that cv. Autumn King, harvested in November 1967, responded to dimas treatment by an increase of 3.8 ton total yield/ac over untreated - the major increase being in the ¾ in. to 1½ in. size where the crop was not thinned (20 roots/ft) but in the thinned crop (4 roots/ft) the major increase came in the 1¼ in. size. Dyson's results may reflect the influence of dimas upon crop growth in cold weather as noted by Marth.

Table 1

The effect of dimas on the size and yield of carrot roots

Carrot variety: Chantenay. Treatment date: 18 June 1968 (finger root stage)

Harvest date	Rate of 'Alar' lb/ac	No. of carrots in various root diameters				Total root weight ton/ac
		¾ in.	¾-1 in.	1-1½ in.	1½ in.	
2 July	0	309	192	15	--	4.23
	1.0	260	224	9	--	4.32
	2.0	269	214	17	--	4.25
	3.0	271	223	11	--	4.26
16 July	0	100	232	224	--	10.06
	1.0	83	175	254	--	10.50
	2.0	101	192	278	--	11.54
	3.0	105	180	277	--	10.02
23 July	0	111	136	289	18	13.59
	1.0	81	117	297	44	14.43
	2.0	84	106	309	39	14.37
	3.0	86	128	291	41	14.87
20 Aug	0	46	64	248	142	23.15
	1.0	50	85	273	164	26.57
	2.0	34	63	223	182	23.61
	3.0	45	67	235	155	22.73

Potatoes

The time of dimas application had little beneficial effect upon Arran Pilot (Table 2) except at the first harvest date for the treatment made at full crop emergence where the yield in canning sized tubers ($\frac{3}{4}$ in. to $1\frac{1}{2}$ in.) was increased: this modification in tuber size did not persist. At the 17th and 30th July harvests tuber dry matter percentages did not differ although the yields did, suggesting movements of reserves from the tuber up into aerial growth. Bodlaender (1968) comments similarly on his work.

Table 2

Yield and grade of Arran Pilot following dimas treatment

Treatment dates:
1. 21 May (full crop emergence)
2. 7 June (tuber initiation)
3. 19 June (flowering)

Lifting date	Days after treat-ment	Rate of 'Alar' lb/ac	Yield in size grades as % of total yield				Total yield in ton/ac
			$\frac{3}{4}$-$1\frac{1}{2}$ in.	$1\frac{1}{2}$-2 in.	2-$2\frac{1}{2}$ in.	$2\frac{1}{2}$ in.	
Trial A							
27 June	--	0	45	42	3	-	4.4
	37	2	60	36	3	-	4.4
	20	2	53	40	2	-	3.6
	8	2	49	42	8	-	5.0
9 July	--	0	22	52	20	-	8.0
	49	2	30	55	10	-	6.1
	32	2	25	52	17	-	7.6
	20	2	26	46	22	-	7.0
17 July	--	0	16	52	24	3	8.9
	57	2	22	48	21	5	10.1
	40	2	16	51	28	4	9.3
	28	2	20	50	23	1	9.3
30 July	--	0	13	49	30	7	9.7
	70	2	17	49	31	-	7.7
	53	2	16	44	35	2	8.6
	41	2	15	48	33	3	8.6
Trial B							
30 July	--	0	--	--	--	-	11.1
	53	0.5	--	--	--	-	10.5
	53	1	--	--	--	-	11.1
	53	2	--	--	--	-	10.1
	53	4	--	--	--	-	9.7

Varietal response to dimas varies; in our trials treatment of early cv. Home Guard and Red Craig did not result in modified tuber size as found with Arran Pilot. The yield depressions, however, are in conflict with Bodlaender's work (personal communication) showing final yield increases in Holland over untreated of an average 2 tons/ac. King Edward responded differently to Arran Pilot (Table 3) in that increased doses gave smaller tubers without materially affecting total final yield. Cv. Record to date is showing a different response again in that treatment is increasing total yields (by increasing tuber numbers).

The increase in numbers of seed-sized tubers in King Edward is of interest where once-grown seed is produced. The effect of parent plant treatment upon subsequent seed growth is not yet clear; Harper (personal communication) notes that seed from plants treated the year previously is delayed by up to 2 weeks in emergence whereas Bodlaender (personal communication) observes in similar circumstances earlier emergence.

Table 3

Yield and grade of King Edward following dimas treatment

Treatment date: 19 June 1968. Harvested: 12/13 August 1968.

Rate of 'Alar' lb/ac	Yield in size grades as % of total yield				Total yield in tons/ac
	$1-1\frac{1}{2}$ in.	$1\frac{1}{2}-2$ in.	$2-2\frac{1}{2}$ in.	$2\frac{1}{2}$ in.	
0	6	39	40	14	10.2
0.5	8	36	41	15	9.9
1.0	10	49	41	11	9.6
2.0	9	45	37	8	10.2
4.0	12	45	37	6	9.9

Thus there are conflicting reports on the effect of dimas upon carrots and potatoes and of necessity further work should be undertaken to clarify fully the response of separate cultivars to various times of applications in different environments. That this work is desirable is demonstrated by the positive indication in our work that dimas can modify plant growth or harvest size to the economic advantage of the farmer in crops grown for processing where certain size grades are almost essential.

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THE BIOLOGY OF AQUATIC WEEDS IN RELATION TO THEIR MANAGEMENT

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Summary If a weed is 'a plant growing in the wrong place', different interests have different views on the 'wrong place'. Also some interests may consider excess growths undesirable while still wanting the presence of a moderate amount of plant. The management of most water-bodies has to be a compromise between conflicting interests. Most 'natural' river systems in England are the product of traditional methods of management and are far from truly natural. Any change in the management is likely to produce significant changes in the ecosystem. There will be changes in the extent and type of growth and these will in turn change the environment further. The previous stability may be replaced by an unstable situation. When the problem weed is a recent introduction it will often show rapid growth and create instability. Each species has its own growth pattern and particular role in the ecosystem. The main features of the physiology and growth of aquatic plants, relevant to their management, are discussed.

INTRODUCTION

If a weed is defined as a plant growing where it is not wanted, it is unfortunate that aquatic plants are called 'water weeds' in common parlance. In most situations aquatic plants are wanted. However, that does not imply that they can be allowed to grow without management or control. We do not call our lawn grass a weed because it requires hours of mowing. At a weed control conference the desirability of some aquatic plant growth needs emphasis and the first part of my paper discusses the role of aquatic plants in water-bodies and the influence of management regimes on aquatic life. Much of this has to be speculative because there is very little experimental proof. The quantitative assessment of the behaviour and effects of water plants depends on the rate of growth and the growth pattern of the individual species and a detailed knowledge of the growth patterns may help to improve management techniques. Finally the major factors influencing the growth of aquatic plants are surveyed in relation to the problems and possibilities they offer for the management of water weeds.

AQUATIC PLANTS IN THEIR ECOSYSTEM

An aquatic ecosystem comprises the water, the substrate, the larger animals and plants and the micro-organisms of the water-body. Let us consider first an organically closed ecosystem, that is one with no input or output of organic matter. In such a system all life is dependent on energy received from the sun. Radiant energy (approximately the visible light wavelengths) is utilized by the green plants for the photosynthesis of organic material containing high, potential, chemical energy. Some of this energy must be used for the growth and maintenance of the plants and is degraded to heat. The remainder accumulates in the organic matter of the plant and passes to the animals, fungi and bacteria in the ecosystem, either when the plant is eaten or when it dies and decays. As the organic matter passes through the food-chains the organisms must degrade more energy to heat in order to live, and ultimately no chemical energy remains. Life in the ecosystem can only continue if the degraded energy is constantly replaced by the photosynthetic fixation of radiant energy. It follows that the elimination of plants from such a system would make it sterile.

In practice the removal of water weed does not have such a drastic effect because microscopic algae remain and carry out photosynthesis and because most water-bodies have a large input of organic material derived from terrestrial photosynthesis, ranging from logs and dead cows, through leaves, to soil and dissolved organic matter. In quantitative terms very little is known about the relative importance of these other sources of energy and hence the effects of the removal of the larger aquatic plants cannot be predicted.

In most lakes, large rivers, and very fertile shallow ponds, algae suspended in the water probably make much more energy available than the larger plants, which are restricted to the margins, or are suppressed by dense algal blooms (Westlake, 1960; Straškraba, 1968) and in some rivers periphytic (attached) algae are most important (Newcomb, 1949). Cummins (1966) surveys a number of papers on streams which show the importance of external sources of organic matter. Chapman (1966) has shown that over half, and probably more of the fish flesh produced in a stream was derived from terrestrial photosynthesis. Maciolek (1966) traced 60% of the dead material suspended in a stream to terrestrial sources, and another 20% to suspended algae from an upstream lake. There is little doubt that in small tree-shaded, weed-free streams, like these examples, external sources of energy will be the most important. However there are no data for densely weeded ponds and streams which are the waters where weed management is needed. In such waters the annual production of submerged aquatic plants (in the temperate zone) is between 2 and 7 m.t dry wt/ha.yr (Westlake, 1963 and In press) and the fall of dead leaves in temperate forests is of the order of 4 m.t dry wt/ha.yr (Bray & Gorham, 1964) which suggests that about half the energy supply is external in unshaded streams. If these plants were consumed alive by particular organisms which were part of the food of the fish it would be relatively simple to assess their importance to the ecosystem. Unfortunately they are usually only consumed after death, when their remains are inextricably mixed with the remains of algae and terrestrial plants in the general organic detritus of the stream bed.

Even if it could be shown that aquatic plants are not an important source of energy for the ecosystem, it would not follow that they could be removed without effect. Weed beds contain large populations of aquatic invertebrates, often many more than in the same area of river or lake bottom (Whitcomb, 1965), and fish use them for shelter and spawning. Some of the invertebrates feed on material drifting by, some on algae growing on the surface of the plants and some on the organic material trapped among the weed shoots. Many use aquatic plants for laying eggs or emergence. Without the extra surface and friction afforded by the plants and the microhabitats created, these populations would be greatly depleted or eliminated. Shelford (1918) made the classic suggestion that the plants could be replaced by artificial plants, since they were not eaten. However different species of plant often have different algal and invertebrate populations and experiments with plastic materials have shown that they do not support the same invertebrate populations as natural weed beds (Whitcomb, 1966). Also aquatic plants have important effects on the physical and chemical properties of the river as a whole (Westlake, 1959 & 1960), in particular increasing depths, diversifying velocities and influencing diurnal fluctuations in oxygen, carbon dioxide and pH. In polluted streams the difference between the optimum amount of weed, and too little or too much, may make a profound difference to the oxygen balance, though the determination of the optimum is fraught with difficulties (Westlake, 1960 & 1966; Edwards, 1968).

MANAGEMENT OF AQUATIC ECOSYSTEMS

Few water bodies serve a single purpose. Most are used in a variety of ways and multi-purpose use will increase as the pressure on our water resources increases. First there is their general role as part of the urban and rural landscape. Specific uses range from observation by naturalists, through conservation, research, swimming, boating and angling to waste disposal, water supply, navigation and land drainage. Of all these probably only the last two or three never require the presence of aquatic plants. If the need for preservation of wild life is accepted then logically aquatic plants should be kept for their own interest and beauty even if the remainder of the ecosystem could function unchanged without them. All the other uses require some weed, but the amount will vary considerably and in almost every case will differ from that arising from unrestricted growth.

It tends to be assumed that the state of an ecosystem with which we are brought up is 'natural'. However, anywhere where man practices agriculture, forestry or, more obviously, industry, the 'natural' is in fact the product of adaptation of the wild life originally present to the artificial conditions imposed on it. When the management regime is maintained for a long time the situation becomes stable and is regarded as natural, but changes in management are immediately recognised as artificial. For example the truly natural chalk stream is probably a wide alder or willow swamp, not the well defined channel with island beds of *Ranunculus* spp. (Water Buttercup) that is now regarded as the right and proper state. This state, particularly in the smaller streams, is only maintained by regular cutting of the weed beds and grazing of the banks. A mere three months neglect of a small chalk stream used by the River Laboratory led to the *Ranunculus* disappearing under an equal weight of *Rorippa nasturtium-aquaticum* (Watercress) and *Apium nodiflorum* (Water Celery).

The management of a water body involves the selection and maintenance of a particular state and the reconciliation of the needs of each user. This will normally include the maintenance of specific types and an optimum amount of weed. If the predominant user proposes a change in management technique this may affect the whole ecosystem. Ecosystems are both stable in a general sense and unstable in particular senses. This means that a moderate change in the environment, or the removal of one component such as the aquatic plants, can lead to the establishment of different species in different proportions but not to a complete change. Another aquatic plant is likely to replace the eliminated one and invertebrates, fish and micro-organisms will still be present, but these may not be the species we were used to. Also the ecosystem may not immediately settle into a new balance. The new aquatic plants may grow even denser than before and certain invertebrates may develop into plague proportions. The accidental or deliberate introduction of a new species may produce similar effects. *Elodea canadensis* introduced into a new habitat often presents severe problems but eventually it seems to become less vigorous and ceases to be a nuisance.

GROWTH PATTERNS

This section will also be speculative because it mostly describes long term research now in progress and definite conclusions would be premature. Work at the River Laboratory is on *Ranunculus penicillatus* var. *calcareus* (Chalk Stream Water Buttercup) and various reedswamp species typical of river margins (Westlake, 1968 & In press). Reedswamp species are also being studied by Fiala *et al* (1968) and by Haslam (In press).

Butcher (1933) observed that some submerged aquatic plants died or died back to perennating organs in the winter, while others persisted throughout the year. In the case of plants with shoots present all the year the annual production can only be estimated from the midsummer maximum biomass if the shoots of the previous year have died before the maximum is attained. If they persist for longer the annual production may be overestimated, but another factor tends to underestimate the production. If the older leaves and shoots of the current year's growth die before the maximum biomass is attained it is necessary to correct for these losses. Such losses are known to be very important in some cases (Mathews & Westlake, In press) and may be of general occurrence. This is important if the production by plants is being calculated for comparison with the organic input from other sources.

The weight of *Ranunculus calcareus* in the River Frome between Dorchester and Wareham (43 km) has been determined by means of the River Authority's weed-cutting programme (Westlake , In press). The annual production estimated from the sum of the weed present at the time of the spring and summer cuts was 209 m.t. dry weight/ha in 1967 but it is probable that this should be increased to allow for losses of shoots and leaves. Both cuts showed a similar weight of weed which implies that rapid growth had taken place between May and August. At undisturbed sites observations suggest that Ranunculus grows mainly in the autumn, late winter and spring. After flowering in May, growth appears to decrease and there may be a spontaneous loss of weed by death and breaking of the older parts. If this natural pattern is confirmed it suggests that the spring cut stimulates extra growth. Yet the answer cannot be just to stop the spring cut, because the weed then present is sufficient to cause flooding.

Butcher (1933) also observed that the distribution of weeds in a river was subject to continual change and there was a tendency for individual clumps to move downstream. Preliminary observations in Dorset chalk streams suggest that if Ranunculus grows in one part of the river one year it is greatly reduced in the following year. This may be because the dense growths of Ranunculus create silted, stagnant conditions which are unfavourable. The plants weaken and are washed away by floods and take some time to re-establish.

Glyceria maxima, which is a common plant of river margins, shows great variation of its growth pattern under different conditions. When colonising a new area it produces many new vigorous shoots throughout the spring, summer and autumn. After two summers' growth one plant had over 100 shoots and 30 m of rhizome. When competing with itself in a long-established stand less shoots are initiated and many die before maturity. Many of these new shoots terminate long underground rhizomes. Isolated plants in deeper water with a very anaerobic substrate grow less vigorously, often do not spread so far by rhizomes and many new shoots are in the form of tillers (shoots arising directly from the lower nodes of older shoots).

Typha latifolia and Sparganium erectum, spread very rapidly by long rhizomes. When relatively free from competition a typical early spring shoot gives rise to 1-3 long rhizomes ending in summer shoots which in turn give rise to 1-3 rhizomes ending in autumn shoots or buds and sometimes the autumn shoots also have buds. In the case of Sparganium any buds emerging from the mud are killed by frost but some young Typha persist to form the earliest shoots the next year. After three summers' growth a plant of Sparganium had colonised 10 m^2, and 20 m^2 a year later, by which time there were over 150 shoots.

Phragmites communis is particularly sensitive to conditions and treatment (Hurlimann, 1951; Rudescu et al, 1965; Haslam, 1968 & In press). Most of the aerial shoots are produced rather late in the spring and further shoots are not common unless the first shoots are damaged. After July few shoots are produced even after damage. In some conditions nearly all the rhizomes are short and erect but usually there are some vertical rhizomes on longer, horizontal rhizomes. Sometimes the horizontal rhizomes are predominant and may become very long.

Schoenoplectus lacustris does not spread so fast from the site of the first shoot, but forms a very dense stand bound together by woody rhizomes and numerous roots which resist decay. There is more differentiation into main axes with lateral branches, many of which remain short. Aerial shoots are produced as the main axis extends but a few initiated in the autumn fail to develop.

These rhizome systems usually form a large part of the weight of the plant (Westlake, 1965) and persist for more than a year. The underground parts are 40 - 55% of Glyceria maxima and 75-90% of mature Schoenoplectus lacustris. The rhizomes of the former live 14-24 months and of the latter over 4 years; other species are intermediate. The age and weight of the underground parts need to be known if the annual production is to be estimated from the biomass of the plant.

FACTORS AFFECTING THE GROWTH AND MANAGEMENT OF AQUATIC PLANTS

Each of the major physical and chemical factors affecting plant growth is discussed, with some thoughts on their relevance to weed control. Often there are interactions between factors and one factor may have an indirect effect because of its influence on the factor directly affecting the plant. For example the main effect of the depth of water on the growth of submerged plants is through the reduction of light intensities at greater depths. Detailed reviews may be found in Gessner (1955 & 1959) and Sculthorpe (1967).

a) Water. By definition little can be done with this factor to directly manage the growth of submerged plants; it is always present in excess. The elimination of water weed is sometimes achieved by draining the water body and allowing it to dry out. Irrigation channels for example could be left dry until the crop requires water. The average depth, and the extent, duration and timing of changes in depth are very important for the emergent marginal vegetation however (e.g. Spence, 1967a), and it should be possible to change and control such populations by means of the water level. One current problem of weed management is the search for a plant which will tolerate the extreme and prolonged changes in level experienced around the edges of reservoirs and will eliminate the ugly expanse of bare mud often exposed during the summer. Few plants will tolerate alteration between complete immersion and drought at the roots, especially when the change can take place quicker than the plant can adapt itself.

b) Light. No green plant can survive for long without light for photosynthesis. Although experiments with single shoots show that photosynthesis does not increase above light intensities of 0·1 - 0·2 gcal/cm . min (Westlake, 1967), in natural situations, where the lower leaves are shaded by the upper leaves, photosynthesis continues to increase up to the highest surface intensities experienced in temperate latitudes (c. 0·7 gcal/cm . min visible irradiance; Westlake, 1966).

Light is attenuated by water and the depth limit of plant growth is usually set by the decrease in light intensity. Weed growths in reservoirs and canals can be reduced by avoiding large shallow areas. Trees will prevent dense weed growths developing in small streams and ditches. On a long-term assessment it may be cheaper to carry irrigation water in pipes or covered trenches than to pay for the cost of annual weed control. Turbidity in a water will reduce plant growth. On the other hand the photosynthetic production of oxygen by plants may need increasing downstream of an effluent and a clear effluent may be advantageous. For angling waters it has been suggested that opaque rafts floated on the water during the close season would provide clear areas for casting but I do not know if this has ever succeeded in practice.

While the colour of the light transmitted through the water will have some effects on photosynthesis these are unlikely to be of practical importance. Spence (1967b) has found that the germination of some aquatic seeds is affected by certain wavelengths.

c) Carbon. The third essential component in the photosynthesis equation is carbon. Although the concentration in water is higher than in air, the high resistance to diffusion afforded by water means that the carbon supply is often a limiting factor (Westlake, 1967). It appears that some aquatic plants prefer this supplied as free dissolved carbon dioxide while others can also use bicarbonates. Emergent plants of course use atmospheric carbon dioxide. The carbon source may have some influence on the distribution of aquatic plants. Since the inorganic carbon content of a water is controlled by the equilibria between carbon dioxide sources (air and mud) and dissolved carbon dioxide, and between dissolved carbon dioxide and the alkalinity of the water, there is little scope for drastic artificial control of this factor.

d) Oxygen. This is a by-product of photosynthesis and often accumulates in the water in supersaturated solution. Even at such concentrations inhibition of photosynthesis is not significant and may not occur at all. Oxygen is essential for the dark respiration of many plants and in theory plants could be killed by anoxia in the dark. However, deoxygenated waters are rarely desirable and most plants can survive overnight on reserves of oxygen in their inter-cellular spaces and by anaerobic respiration so this is unlikely to have practical applications.

e) Temperature. The rates of photosynthesis and respiration are influenced by temperature changes, although the acceleration of respiration by a rise in temperature is considerably greater than that of photosynthesis when light is the main other factor limiting the rate of photosynthesis. In aquaria plants sometimes die in the winter because the indoor temperatures remain high while the light decreases and respiration outstrips photosynthesis. It is possible that similar effects may be found in waters receiving hot effluents.

Many aquatic plants are frost-sensitive and exposure to air temperatures may kill them or delay their growth in the spring. This may be another reason for draining irrigation ditches in the winter. On the other hand, many aquatic plants have seeds and perennating organs resistant to freezing so recolonisation would be rapid. In England we are fortunate that the frost sensitivity of the notorious weeds *Eichhornia crassipes*, *Pistia stratiotes* and *Salvinia auriculata* prevents them from becoming established, though they might survive near power-stations. Such effluents are likely to change the dominant vegetation anyway, and exotics especially submerged types, may be encouraged.

f) Flow. The degree, or absence, of water movement, whether in the form of river flow or wave action has a profound influence on the nature of the substratum and the plant communities. Very rapid flows rarely permit more than a few mosses to grow but this is unlikely to afford a practical means of weed control. The rate of photosynthesis by *Ranunculus calcareus* is greatly reduced by decreasing the water velocity (Westlake, 1967) and this may be why this species fails to compete with *Elodea canadensis* when the velocity falls below about 20 cm/sec. The exact velocity probably depends on the degree of turbulence.

g) pH. There are many correlations between the pH of water and the plant species present but, except in extreme conditions, the effects are likely to be indirect, in particular through the carbon and nitrogen sources. Carbon dioxide exchanges during photosynthesis and respiration often cause diurnal fluctuations in the pH.

h) Mineral nutrients. Rooted aquatic plants may be expected to take up ions from either mud or water, whichever is the better source. Although such nutrients are rarely the most important limiting factor an improved supply usually improves growth. Both Spence (1964) and Seddon (1965) have found correlations between water chemistry and species present. Fertilisation of infertile lakes has produced an increase in the growths of aquatic plants (Brook & Holden, 1957; Holden, 1959). It is often said that weed growth in rivers has increased since the increase in input of fertilising ions from effluents and agriculture but there is little quantitative evidence of the composition of the water and the amount of weed growth before these changes started. In lakes extreme eutrophication often leads to algal blooms which suppress the higher vegetation by attenuating the light.

The moderately densely weeded and fertile R. Frome discharges about 500 m.t/yr of nitrate nitrogen to the sea, at an average concentration of about 2 mg/l. The annual production of weed (mainly removed) between Dorchester and the sea is 209 m.t dry wt and, assuming 5% to be nitrogen, the growth requires only 11 m.t/yr. This suggests that ample nitrogen is available, though it does not preclude the possibility that an increase in nitrogen could still increase the uptake and growth through concentration effects. There is a distinct fall in nitrate concentration between the springs and the sea which is not entirely accounted for by dilution by nitrate poor waters. Most of this fall occurs above Dorchester where there may be a greater proportion of weed to water. Also the sewage works at Dorchester supplies more than enough nitrogen to support the growth of weed downstream. In small streams studied by Normann (1967) and Stake (1967) the growth of plants removed 20% or more of the inorganic nitrogen supplied during the growing season. Schwoerbel and Tillmanns (1964 a & b) found that uptake by *Callitriche hamulata* and the moss *Fontinalis antipyretica* became saturated with ammonia nitrogen at about 5 mg/l.

The R. Frome discharges about 20 m.t/yr of phosphate phosphorus at an average concentration of about 0·09 mg P/l. and the plant growth below Dorchester requires about 0·5 m.t. Again there is ample available. The phosphate concentration increases downstream and a large part of the total output is derived from Dorchester Sewage Works. However, in the small stream studied by Normann (1967), even though the concentration of phosphate phosphorus was about 0.3 mg/l., the dense vegetation removed nearly 15% in 1.5 km. Schwoerbel and Tillmanns (1964c) found that phosphate phosphorus uptake of Ranunculus fluitans and Callitriche hamulata increased with phosphate concentration up to the highest level they used (2 mg P/l.). Normann (1967), also working with R. fluitans, appears to have found saturation developing at a higher level.

Other important elements are sulphur, potassium, magnesium, calcium and iron. Iron uptake in alkaline waters, where soluble ferric ions cannot exist, probably requires the presence of chelating agents or a reducing mud.

i) Salinity. A number of freshwater plants, including Myriophyllum spicatum, Potamogeton pectinatus and Zannichellia palustris will tolerate moderately brackish water, but most cannot tolerate more than 3 or 4 parts per thousand.

j) Dissolved organic substances. The possibility that competition involves the production of organic substances suppressing growth has often been discussed for terrestrial plants, particularly in relation to inter-specific competition. McNaughton (1968) has recently produced evidence of toxic effects of soluble organic substances from Typha latifolia upon its own seedlings, and other species are probably affected. Perhaps such effects could explain the reduction in growth of invading species after the initial burst, and afford clues to new control methods.

k) Hormones and inhibitors. Application of such herbicides to aquatic plants is based on knowledge of the metabolism of terrestrial plants and empirical experiments, and no specific studies of their metabolic effects on aquatic plants have been made.

l) Biotic factors. Competition may sometimes be exploited to control undesirable weeds. In fish ponds dense algal blooms are encouraged and stop higher plants growing. If any more desirable species can suppress others it could be deliberately planted and encouraged and this is likely to cause less violent changes in the ecosystem than alternative methods. However, successful species are often more vigorous than others and it is this very abundance of growth that is undesirable.

As noted above, few aquatic plants are significantly eaten while still alive, especially in England. Cattle will often graze and control marginal vegetation, especially Glyceria maxima. For submerged plants the only hope in Britain is the introduction of the grass carp (Stott, 1962).

m) Species. Ultimately weed management will depend on exploiting the behaviour of particular species to limit or stop their growth. Many aquatic species are morphologically plastic and change their appearance completely in different conditions (e.g. Cook, 1966, discussing the genus Ranunculus). This means that identification prior to the selection of a method is difficult and often cannot be confirmed in the absence of flowers or fruits.

GENERAL CONCLUSION

I expect that this paper will exasperate engineers and chemists, who are used to precise descriptions and accurate predictions of the effects of changes. Ecologists are not vague from choice but because there is not yet enough experimental evidence, because any ecological system is extremely complex, with feed-backs and amplifications at every level, and because any particular site differs significantly from most others. We know enough to describe the sorts of change that can occur, but not enough to say which will occur in a given situation, and generalisation over a number of situations is impossible. In this position ecologists prefer to oppose change. Confronted with a need for cheaper methods of weed control I would recommend finding cheaper ways of applying existing methods rather than trying new methods. For example I would prefer cutting to continue in chalk streams rather than the introduction of herbicides. In the future, when we have gathered the sort of data that the physical sciences take for granted, we may be able to make more confident predictions. Until then new and powerful techniques must be applied with great caution in any situation where more than one interest must be considered.

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THE FAUNA OF AQUATIC PLANTS

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Most bodies of water contain a dynamic community of plants and animals, in which numerous individuals interact with the physical properties of the habitat and with each other. As in a human community disturbance of any feature in the environment, or of any individual plant or animal will set up a reaction which will affect many other individual plants and animals. Some disturbances are barely noticeable, as when a few animals are removed, and are replaced by a succeeding generation; but large disturbances, such as the removal of the plants, may destroy the whole community.

All animals depend on plants for their food directly or indirectly. This is because plants are able to synthesise carbohydrates and amino-acids from inorganic material, but animals must obtain organic compounds. In a lake or river plants form the primary source of food material for the community. The higher plants, which are called macrophytes, provide food for fish and invertebrates in three ways. First, the plants are eaten by coarse fish, such as roach, dace and chub (1), and by moth, midge and caddis larvae, which mine or burrow in the leaves (2). Second, the plants are covered by a layer of algae, known as periphyton, which contains a community of protozoa and rotifers. Examination of the stomach contents of freshwater invertebrates has shown that many animals feed on both the algae and the microscopic animals (3). Third, decaying plants form detritus which is an important source of food for aquatic animals. The removal of plants from a body of water removes the food from a number of animals which are themselves a source of food for other animals and ultimately for fish.

The physical structure of the plants also affects the animal community. Emergent or floating plants act as a 'bridge' between the air and the water. Many caddis, dragonflies and mayflies (Ephemeroptera) climb up plant stems into the air to emerge; and several adult insects, notably caddis, dragonflies, olives (Baetis) and buffalo gnats climb down plant stems into the water to lay their eggs. Some of these insects are prized by anglers, and some river managers place fly boards in the river for the insects to crawl up and down.

Submerged plants obstruct the movement of water, therefore the fauna of plants in lakes are often sheltered from wave action, and the fauna plants in rivers, sheltered from the current. This is very important in fast flowing rivers, in which most animals are unable to withstand the full force of the current. The animal community in these situations lives mainly between stones, or within the moss or weed beds. Close examination of a clump of plants shows that the outer portions of the clump contain filter feeders such as buffalo gnat larvae and the caddis Hydropsyche; but inside the clump, where the water may be almost still, there are snails, shrimps, leeches and insect larvae. This community is an important source of food for many fish, and it cannot exist without the shelter of rocks, debris or plants. If the plants are removed the community of animals is decimated. It does not, as is popularly believed fall to the bottom and live there. It is swept away downstream with the plants (4).

(1) Cragg-Hine (1963), Leeming (1963).
(2) Moore (1913), Frohne (1938), Berg (1950), McGaha (1952).
(3) Slack (1936), Hynes (1941), Jones (1949, 1951, 1958), Dunn (1954), Scott (1958).
(4) Witcomb (1966).

Plants have such a great effect on the animal community that many people agree that a given area of lake or river bed covered with plants supports a quantitatively and qualitatively richer fauna than a similar area without plants, and figures supporting this theory are given in Table 1. However, as can be seen from Table 1, Baker (1918), Rawson (1930), Lindeman (1941) and Pearcy (1953) give results of surveys in which the non-vegetated areas supported a similar or greater fauna than the vegetated areas. This apparent contradiction may be explained by the fact that the first six sets of results were from samples obtained during the summer. The results obtained by Rawson, Lindeman and Pearcy include samples taken in spring, summer and autumn. In summer the animals were mostly in the vegetation, but in early spring and autumn they were mostly found in areas without plants. The decrease in the number of animals in the plants in autumn is mostly caused by the emergence of insects, but may also be caused by migration of animals to the bottom. I have also found a decrease in the number of animals in the plants in autumn. In L.Oneida in the summer Baker found that there were more animals in the non-vegetated areas than in the weed beds. He suggested that this was because the bottom of the lake was covered with a thick mat of filamentous algae which are eaten by herbivourous animals. Before the productivity of weed beds and non-vegetated areas of lakes and rivers can be compared further investigation is needed especially in winter.

To find out whether the animal community varies between plant species, I counted and weighed the animals in five species of plants in the R.Itchen, Hants. once every three months for two years. I found that, although the size of the animal community fluctuated with the seasons, and with weed cutting operations, the weight of animals per ten grammes of plant material showed no significant difference at the 0.05 level of significance. The five plants species were *Ranunculus pseudofluitans* Syme., *Zannechellia palustris* L., *Apium nodiflorum* (L.) Lag., *Groenlandia densa* (L.) Fouvi, and *Callitriche* sp. As plant dwelling invertebrates are eaten by trout and young salmon, the five plant species contained a similar weight of potential fish food.

In summer, when the plants contain a large community, the structure of the invertebrate community varies between plant species. The plants which live in exposed positions in the river, for example *Ranunculus pseudofluitans*, contain a community with a large proportion of filter feeders such as buffalo gnat larvae, and plants which live in sheltered positions such as *Callitriche* sp. contain snails, freshwater shrimp, caddis larvae, dragonfly nymphs and leeches. If all species of invertebrates are of equal value to the fishery, the differences between the communities will not be important from the management point of view; but if as seems likely, further investigation shows that some species are of higher nutritive value, or are more accessible to trout, the production of fish food may be improved by propogating the appropriate plants.

In aquatic habitats it is not often possible to predict the effect of cutting or removing the plants. Sometimes the removal of plants turns the area into an aquatic desert, sometimes it is followed by an increase in the concentration of chemicals in solution which leads to an aquatic bloom and an increase in the number of zooplankton, and sometimes, when there is plenty of plant detritus from the land it may have little effect on the animal community. We need careful records of the biology of areas before and after weed control operations before we can assess the overall effect of various methods of weed control.

Table 1. Results of surveys comparing the number, weight or volume of animals in vegetated and non-vegetated areas.

Author		Location	Number animals/sq. metre	
			No Vegetation	Vegetation
Percival and Whitehead	(1929)	Rivers Aire, Nidd and Wharf, Yorkshire	3,375	245,972
Murray	(1938)	Indiana Streams	1,630	2,339
Needham	(1938)	Streams, New York State	10	398
Shockley	(1949)	Sugar Creek, Indiana	605	1,410
Wohlshlag	(1950)	Lake Wabee, Indiana	546	1,964
Eggleton	(1952)	Lake Douglas	162	3,466
Baker	(1918)	Lake Oneida, New York	2,705	684
Rawson	(1930)	Lake Simcoe, Toronto	579	690
Lindeman	(1941)	Cedar Bog Lake, Minnesota	gm/m^2	gm/m^2
		May - July	1.1	24.4
		September	0.7	0.2
Pearcy	(1953)	Clear Lake, Iowa	ml/sq. ft	ml/sq. ft
			1.1	1.3

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THE RELEVANCE OF AQUATIC WEED RESEARCH IN THE UNITED STATES TO PROBLEMS IN BRITAIN

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In May 1968 I had the opportunity of visiting some of the leading aquatic weed research centres in the United States in order to discuss problems of weed control with scientists who have been working in this field for many years. One of the main purposes of the visit was to try to assess how applicable the findings in the United States are to the problems encountered in Britain and to decide where supplementary studies are required.

MAIN BODIES INTERESTED IN THE CONTROL OF AQUATIC WEEDS IN THE UNITED STATES

Agricultural Research Service, United States Department of Agriculture

One of the most active groups in aquatic weed research is the United States Department of Agriculture (USDA) team led by Dr. F. L. Timmons. This forms part of the Crop Research Division of the Agricultural Research Service and has its main research centres at:

a) LARAMIE, Wyoming: evaluation of herbicides for controlling *Carex* spp., *Phalaris* sp., *Typha latifolia*, *Potamogeton pectinatus* in ponds and irrigation canals.

b) DENVER, Colorado: greenhouse and field studies with herbicides in flowing and standing water and some herbicide absorption and translocation studies with submerged aquatic plants. Latterly almost all the research effort has been put into residue determinations in water and crops.

c) FORT LAUDERDALE, Florida: herbicide evaluation on *Alternanthera philoxeroides*, *Eichhornia crassipes*, *Pistia stratiotes*, *Hydrilla verticillata* (previously referred to as *Elodea*), *Egeria densa* (previously referred to as *Elodea densa*) and *Najas guadalupensis*; studies on the weed control capabilities of snails *Marisa cornuarietis* and *Pormacea australis*; biological studies of *Alternanthera*; nutritive requirements of aquatic plants with particular reference to *Potamogeton pectinatus*.

d) DAVIS, California: herbicide evaluation in flowing water and the biology of *Potamogeton* sp. and *Alternanthera philoxeroides*.

e) PROSSER, Washington: the persistence and fate of herbicides in water and aquatic soils and the effects of herbicides in irrigation water on crop plants; biological studies of *Potamogeton pectinatus*; survey of submerged vascular plants in ponds and lakes.

f) LOS LUNAS, New Mexico: the use of herbicides for the control of *Tamarix* sp. (salt cedar).

Corps of Engineers, Dept. of Defense

Among its various duties the Corps of Engineers is responsible for the maintenance of navigable channels within the United States and has for many years been concerned with the control of *Eichhornia crassipes* and other plants. The Corps has established its own field teams working chiefly in the southern states and has sponsored research projects on the use of herbicides at the Agricultural Research Service (ARS) centre at Fort Lauderdale and at Auburn University. Recently Dr. R. A. Scott of the Redstone Arsenal has been appointed co-ordinator of aquatic weed research for the Corps and has made various novel suggestions including the possible use of laser beams for the destruction of weeds.

Bureau of Sport Fisheries and Wildlife, Fish and Wildlife Service of the Department of the Interior

The bureau is concerned with two aspects of pesticide (insecticides, fungicide and herbicide) use. Firstly, the pest control research programme covers the development of herbicides and other chemicals for the efficient management of fisheries and secondly Fish-Pesticide research provides information on the possible adverse consequences of pesticide use including data on toxicity, fate, persistence, degradation and residues in fish and aquatic ecosystems. In this work they are not only concerned with the effects on fish and fisheries but provide the Food and Drug Administration with information on residues in fish for pesticide regulatory purposes.

The bureau's main effort is directed towards developing satisfactory fish toxicants for controlling fish populations but one of the other primary objectives is the establishment of guidelines for the safe and effective use of herbicides in aquatic environments. Much of the herbicide work has been done at laboratories at La Crosse, Wisconsin, on a wide range of plants including Elodea canadensis, Myriophyllum heterophyllum, Ranunculus circinatus, Ceratophyllum demersum, eight American species of Potamogeton and the algae Cladophora spp. and Chara vulgaris, and at the Patuxent Wildlife Research Center, Laurel, Maryland, where the primary concern is the control of Myriophyllum spicatum in the tidal, estuarine areas of Chesapeake Bay.

Bureau of Reclamation, Department of the Interior

The Bureau of Reclamation is concerned with the control of aquatic weeds in irrigation systems. The main research laboratory is at Denver, Colorado where a herbicide evaluation programme in standing and flowing water has existed for some years. The main weeds are Potamogeton pectinatus, P. nodosus, Elodea canadensis and the algae Rhizoclonium spp. The Bureau co-operates with the ARS programme for studying herbicide residues and is also obtaining information on the fate of copper sulphate used as a herbicide.

Tennessee Valley Authority

The Tennessee Valley Authority (TVA) controls the flow and use of water throughout the catchment area of the Tennessee river. This is achieved by means of 32 major dams across the river and its tributaries which regulate the flow. In recent years weed problems have arisen around the edges of the impoundments and field trials with herbicides have been carried out by the Reservoir Ecology Branch to control the growth and spread of Myriophyllum spicatum (Smith, 1963).

Biologists in the Water Quality Branch are studying the factors affecting the growth of rooted aquatic plants with particular reference to Potamogeton pectinatus.

Commercial Organizations

The main commercial interest is in the development of an outlet for the sale of herbicides. A number of firms have developed programmes for the evaluation of their own compounds. Others sponsor evaluation at Universities or Federal research centres. At present, because of the uncertainty of the tolerance levels to be set by the Food and Drug Administration and the extent of the work required to provide the necessary residue data, few firms are willing to spend money on aquatic weed studies.

Some commercial interest continues in the possible harvesting and processing of aquatic weeds and the promotion of machines developed for this purpose.

State Agencies and Universities

Many of the State Universities have some interest in freshwater ecology and from time to time undertake sponsored programmes on methods of control. Auburn University in Alabama had until recently an extensive programme on the primary evaluation of herbicides, but this has now ceased and weed control studies are limited to the evaluation of the chinese grass carp and the occasional project sponsored by the Corps of Engineers or a chemical company.

Nine State Universities are engaged in co-operative studies on methods of control with the USDA and 18 State agencies or universities receive Federal funds for weed control studies in their sport fish and wildlife research programmes (Walker, 1968).

Much of the work done at universities is not directly concerned with methods of control but more with study of eutrophication and the limnological or ecological aspects of weed control.

THE APPLICATION OF AMERICAN RESULTS IN BRITAIN

Most of the work discussed during the visit was concerned with the evaluation of herbicides and the problems of their use in water. Interest in herbivorous fish and snails continues at one or two centres and increasing attention is being given to the more general, long-term studies of eutrophication and the nutritive requirements of aquatic plants.

In Britain aquatic weed control is needed for much the same reasons as in the United States - the maintenance and improvement of flow, navigation, recreational amenities and wildlife habitats. However, factors that determine the effectiveness and acceptability of aquatic weed control measures - climate, species and water use - can differ widely between the two countries.

In the United States the major weed problems occur in the southern part of the country where the high temperatures and lack of frost enables the tropical and sub-tropical plants Eichhornia crassipes, Alternanthera philoxeroides, Najas guadalupensis and Hydrilla verticillata, to thrive. Because of their susceptibility to frost none of these is able to persist in the open in Britain. In the northern more temperate parts of the United States many of the troublesome species are also common in Britain, but they have to survive more severe and longer winters and because of this they have shorter growing seasons and may have differences in methods of perennation. Both of these factors can influence plant response to control treatments and it is, therefore, necessary to investigate the effect new American techniques have on the same species under British conditions. There are also certain plants that are considered troublesome or do not occur in the United States, but are important weeds in Britain e.g. some filamentous algae and Nuphar lutea, and their control will have to be studied.

Other factors of importance are those associated with water use. In comparison with the United States Britain is a small, densely populated country with limited water resources that are intensively used. Before it reaches the sea, the water in some rivers is abstracted and used several times by man. While it remains in the river or where it occurs in ponds, lakes and even land drainage channels in sufficient quantity, water is valued highly for fishing and other recreational pursuits. Almost invariably therefore weed control must be regarded as part of a system of management designed to meet the needs of several, often conflicting, interests. While this is also the case in some situations in the United States, usually one interest takes precedence over the others e.g. in irrigation channels, and the choice of treatment is more straight forward than is generally the case in Britain.

HERBICIDES

Phytotoxicity Primary evaluation was seen at the Agricultural Research Service centre at Fort Lauderdale and at Amchem Products Inc., Ambler. At both places the submerged plant species included in the tests are not found growing naturally in Britain. However the plants under test do have a similar habit of growth and these studies provide a useful indication of possible materials for further evaluation work. (It should be noted that the 'Elodea' mentioned in some previous publications from these centres is not the Elodea canadensis found in Britain but either Egeria densa or Hydrilla verticillata.)

Apart from the work done by the Bureau of Reclamation at Denver on Rhizoclonium sp. the filamentous algae which are such a nuisance in Britain are not included in evaluation programmes in the United States.

The secondary evaluation of herbicides is usually carried out on well-established plants in tanks or plastic-lined pools with the purpose of determining the response to changing dose and to obtain application data for use in planning field experiments. The plant species involved are mainly those found in the part of the country served by each research station.

In the temperate parts the test plants include Potamogeton pectinatus, Elodea canadensis, Lemna spp., Myriophyllum sp., Ceratophyllum sp., Ranunculus circinatus and Chara vulgaris. Some of these species with some of emergent plants also common to Britain, Typha latifolia, T. angustifolia, Phragmites communis and Carex spp., are important in the field experimental programmes of the ARS at Laramie, the Bureau of Reclamation at Denver, the Tennessee Valley Authority and the Bureau of Sport Fisheries and Wildlife. Because the plant species are the same much of the research is of direct value to workers in Britain. However, other conditions differ. At Laramie, where the work is mainly concerned with farm ponds, herbicide persistence is regarded as an advantage while in Britain it is usually undesirable; the weed problems in the large reservoirs of the TVA have no equivalent in Britain; the Bureau of Sport Fisheries and Wildlife is concerned with maintaining suitable habitats for useful American fish and wildlife; and the Bureau of Reclamation at Denver and the ARS at Davis are primarily interested in the maintenance of flow in irrigation channels and are not concerned about fish. None of these situations corresponds in detail to the common conditions of multi-use found in most of the intensively used rivers and other water courses in Britain and this may mean discarding or modifying a technique found suitable in America.

Possible hazards to man, fish and wildlife In recent years more rigid requirements for the registration of herbicides for use in water have been introduced in the United States. The Food and Drug Administration of the U.S. Department of Health and Education now requires data of herbicide residues in water, mud, fish (including edible shell fish) and irrigated food crops. About 40% of the research effort of the aquatic weed scientists in the ARS team is devoted to residue studies. Although some of their valuable findings are widely applicable in Britain, many are not because residue levels and the persistence of herbicides are often affected by water quality, light, temperature and the micro-biological community. It would be inadvisable to accept such evidence without substantiation under British conditions.

The procedures in the United States and in Britain for testing the toxicity of herbicides to fish are not entirely comparable because they are carried out with different species, water and methods. The standard British test used by the Salmon and Freshwater Fisheries Laboratory of the Ministry of Agriculture, Fisheries and Food, provides a comparison between two herbicides but it does not necessarily give an indication of acceptable field levels. The field data obtained by the U.S. Fish and Wildlife Service is perhaps a better guide, but the species of fish and the environmental conditions are usually different from those in Britain. A more satisfactory arrangement than the present one would be to have a programme of field tests in Britain to fill in the gaps in the information provided by the two systems.

Biological control The main biological methods of control being currently tested in the United States are the use of chinese grass carp at Auburn University and two tropical snails (Marisa cornuarietis and Pormacea australis) at Fort Lauderdale. The chinese grass carp is also being studied in Britain with the emphasis placed on its biology and possible adaptation to river conditions here. Studies at Auburn University on its eating habits and potential as a weed control agent will be complementary to similar work in Britain.

The tropical snails are very sensitive to low temperatures and unless they are found to be useful in the temperate parts of the United States their potential in Britain seems limited. The same applies to the beetle, Agasicles sp. released in some of the southern states to control Alternanthera philoxeroides.

Other methods of control The other methods of control are mainly concerned with the mechanical destruction of the weeds. There appears to be little research and development work being done in the United States along these lines apart from the activities of the Corps of Engineers. It was not possible to see any of this work, but usually new developments of this type are more independent of climate and biological considerations than are herbicides, fish or snails, although water flow and the stage of growth of the plants may influence their performance.

Weed biology and environmental studies Biological studies of plant species that are common to both countries provide valuable basic information although there may be differences in detail. Of particular interest is the work being done on the nutrient requirements and uptake of Potamogeton pectinatus at Fort Lauderdale and by the Water Quality Branch of the TVA at Chattanooga. The long term studies on the processes of eutrophication that have been started at Cornell and Auburn Universities are expected eventually to yield data useful for general application.

Conclusions

A great deal of research effort is being put into aquatic weed research in the United States. In general the final results are not directly applicable in Britain because of differences in biological and environmental conditions. This applies to the evaluation of all methods of control and in every case some degree of confirmatory work will be needed before it can be accepted for general field practice.

Herbicides are receiving most attention and much valuable data on their properties and activity are being obtained which may have universal application. This is particularly true of the initial evaluation studies done under controlled conditions, of residue determinations where the process of inactivation is known or does not involve biological degradation and of basic information on formulations and application techniques.

The secondary evaluation on local weed species and field projects are less relevant and results are often not applicable in Britain. There appears to be a clear need for research to examine the effects of herbicides under British conditions with supplementary laboratory studies on those weeds such as the filamentous algae, Callitriche spp., Nuphar lutea and Carex spp., that are widespread in Britain but are not included in American herbicide evaluation programmes.

The objects of weed control in Britain are not always identical in detail to those in the United States. Often situations are encountered where a system of management has to meet the conflicting needs of land drainage, domestic water supplies, fish and wildlife. In these circumstances partial control may be preferable to total control and the treatments developed for conditions in large expanses of water in the United States may not be appropriate. This is especially true with non-selective herbicides: in Britain more precision may be needed in their application and it may be necessary to develop alternative compounds or techniques if none of the American methods is suitable.

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