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19 (1990)

Aquatic weed problems and management in North America

(a) Aquatic weed problems and management in the western United States and Canada

L. W. J. ANDERSON

INTRODUCTION

AN understanding of aquatic weed impacts and solutions in the western United States and Canada is best gained from a general view of water catchment, storage and distribution. Although there are many thousands of kilometres of natural riverine systems and lakes, the most frequent and severe problems associated with aquatic macrophyte vegetation occur primarily in the man-made lakes, reservoirs, and canals throughout this region.

Much of the inhabited and agricultural lands in the West (especially in the far West) are arid or semi-arid, receiving only 25 to 50 cm annual precipitation. This fact, coupled with the generally excellent soils and favourable climate for temperate crops, together with the westward expansion of populations during the late nineteenth and early twentieth centuries, prompted the construction of immense, extensive (and expensive) networks of reservoirs, major high-capacity canals, and lateral (subsidiary) canals for agricultural, domestic, and industrial uses. In concert with these uses, the development of hydroelectric power production and recreational facilities has been an integral part of the overall water-delivery systems. Beginning in the late 1800s, but accelerating dramatically in the 1930s–1960s, federal (US Bureau of Reclamation (USBR) and US Army Corps of Engineers), and various state water projects were designed, financed and constructed to carry tremendous volumes of water from sources such as mountainous areas that receive heavy snowpack, and major rivers, to the more central and southern areas where population demands and optimal climates for crops exist. For example, in California, 70 per cent of the state's water resources are from north of latitude 38° (San Francisco) (Gurmukh, Gray, and Seckler districts purchase, treat, sell and distribute water for agriculture, industrial, and domestic needs. When these supply systems are included (where, it should be noted, the most persistent and serious aquatic weed problems occur), then the total of canals and laterals with weed problems probably exceeds 100 000 km in the west (Timmons 1960, 1966).

AQUATIC WEEDS OF PRIMARY IMPORTANCE

The most detailed and extensive survey of aquatic weed problems and impacts in the USBR system was published by Timmons (1960). This survey covered seventeen Western states and represented conditions in the late 1950s to early 1960s. Although there have been some increases in numbers of canals and their total length, particularly with the completion of the Central Arizona Project, the Delta Mendota Canal and California Aqueduct, and though recent problems with *Hydrilla verticillata* and *Eichhornia crassipes* did not exist then, many of Timmons' findings are probably still valid. Table 19a.2 summarizes data from Timmons' report and emphasizes the importance of the moderate to rapidly-flowing conveyance systems. Note that this report did not designate weeds by species but rather categorized them by 'life form' or 'ecological classification' (Sculthorpe 1967; Hutchinson 1975). No floating weed problems were noted in these irrigation systems at that time.

Table 19a.2. Summary of western US aquatic weed infestations in Bureau of Reclamation Systems *c.* 1960[a]

Type	Percent of total types	Canal Length[b] (km)	Infestation by canal type (%)[c]		
			Canal	*Lateral*	*Drain*
Algae (Primarily filamentous)	15.5	32 944	25	11	18
Submerged (*Potamogeton* spp.,[d] *Myriophyllum* spp., *Elodea canadensis*, *Ceratophyllum demersum*)	33.1	76 282	28	36	31
Emergent (Primarily *Typha* spp., *Phragmites australis*, *Phalaris arundinacea*[e])	16.5	36 911	6	16	25

[a] From Timmons 1960.
[b] Timmons' extrapolation to western United States based on 47 USBR Districts.
[c] Average capacities ($m^3 s^{-1}$): canal: 13.7; lateral: 1.1; drain: 0.6.
[d] Species indicated in italics are present author's additions based on other reports and personal observations. Averages for species are weighted by length of infested channel type.
[e] From Bruns 1973.

Based on a more recently published series of surveys and interviews (Tyndall 1982; Aurand 1983) a fairly complete listing of problem aquatic weeds is presented in Table 19a.3. Some additional weeds have been included based on other reports and on personal observations of the present author. No ranking of 'economic impacts' or 'frequency' by species based on surveys or published observations is available. However, from contacts with major irrigation districts, field observations and general frequency of inquiries for assistance, the most consistently

Table 19a.3. Aquatic plants causing problems in western US states

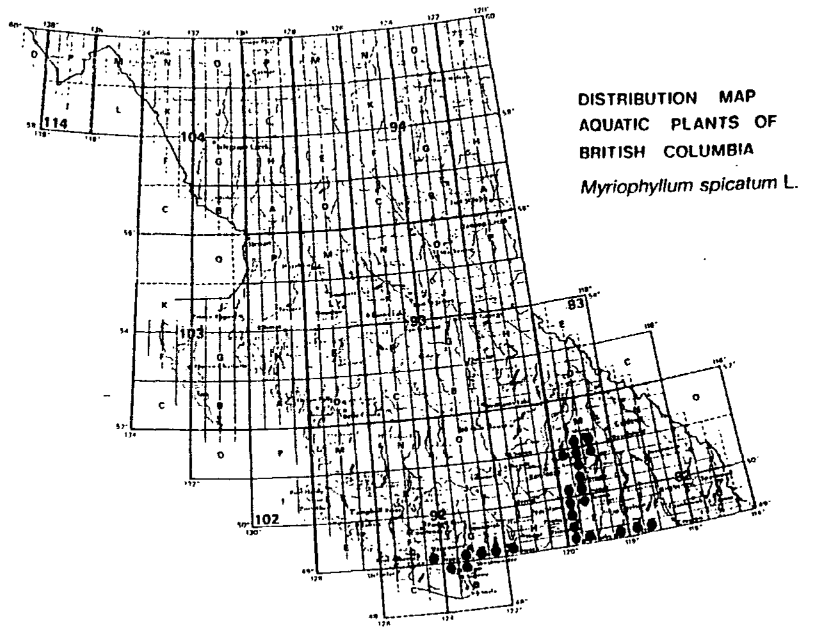
North-western United States[a]	South-western United States[b]
Brasenia schreberi	— *Alternanthera philoxeroides*
— *Ceratophyllum demersum*	— *Azolla* spp.
Chara spp.	— *Ceratophyllum demersum*
Elodea canadensis	*Chara* spp.[c]
Fontinalis spp.	*Cladophora glomerata*[c]
Lemna spp.	— *Egeria densa*[c]
— *Myriophyllum spicatum*	— *Eichhornia crassipes*
Myriophyllum spp.	*Elodea canadensis*[c]
Najas spp.	*E. nutallii*[c]
Nitella spp.	*Enteromorpha intestinalis*[c]
Nymphaea odorata	— *Hydrilla verticillata*
Phalaris arundinacea[c]	*Hydrocotyle umbellata*[c]
Potamogeton amplifolius	*Lemna* spp.[c]
— *P. crispus*	— *Ludwigia repens*[c]
P. natans	— *Myriophyllum aquaticum*[c]
P. nodosus	— *M. exalbescens*
— *P. pectinatus*	— *M. spicatum*
P. richardsonii	*Najas marina*
P. praelongus[c]	*N. guadalupensis*
Ranunculus spp.	*Phragmites australis*[c]
Scirpus spp.[c]	— *Polygonum amphibium*[c]
Typha spp.	*Potamogeton* spp:
Utricularia spp.	*P. amplifolius*[c]
Veronica spp.	*P. foliosus*[c]
Zannichellia palustris[c]	*P. gramineus*[c]
	P. nodosus[c]
Filamentous algae (N.W. & S.W.)	— *P. pectinatus*[c]
Chara spp[c]	*P. pusillus*[c]
Cladophora glomerata[c]	*P. richardsonii*[c]
Enteromorpha intestinalis[c]	*Ranunculus* spp.[c]
Pithophora spp.[c]	— *Ruppia maritima*[c]
Rhizoclonium spp.[c]	*Typha latifolia*[c]
	— *T. angustifolia*[c]
	Zannichellia palustris

[a] States: Alabama, Idaho, Montana, Nebraska, North Dakota, Oregon, South Dakota, Washington, Wyoming (Aurand 1983).
[b] States: Arizona, California, Colorado, Hawaii, Kansas, Nevada, New Mexico, Oklahoma, Texas, Utah (Tyndall 1982).
[c] Species which are current author's additions, based upon other reports and personal observations (Otto 1975; Bruns 1973).

problematic weeds appear to be: *Potamogeton pectinatus*, *P. nodosus* (Fig. 19a.2), *P. crispus*; *P. foliosus*, *Elodea canadensis*, *Myriophyllum spicatum*, *M. aquaticum*, *Ceratophyllum demersum*, *Typha latifolia*, *T. angustifolia*, *Ludwigia repens*, *Chara* spp. and *Cladophora glomerata*. Although both *Eichhornia crassipes* and *Hydrilla verticillata* are significant problems, they are not widespread in the western United States (except in Texas) and are discussed as special cases below.

FIG. 19a.2. A typical irrigation canal in the western United States, heavily infested with American pondweed (*Potamogeton nodosus*). These canal systems are seasonally drained from about November until April.

These lists do not include all weeds causing problems in rice, a major commodity in California (*c.* 145 000 ha were grown in 1987: US Department of Agriculture 1987). An excellent review of rice weeds was published by Barrett and Seaman (1980). These authors reported that the most frequently encountered weeds species were: *Sagittaria montevidensis* spp. *calycina*, *Ammania coccinea*, *Bacopa rotundifolia*, *Heteranthera limosa*, and *Echinochloa crus-galli*, the last of which probably causes the most serious problems. These weeds (and others in rice) are controlled primarily by variously timed applications of the herbicides molinate, thiobencarb, basagran, and MCPA. Another new herbicide, bensulfuron methyl (Londax™), is currently under intense testing for use in rice and possibly for other non-crop aquatic uses.



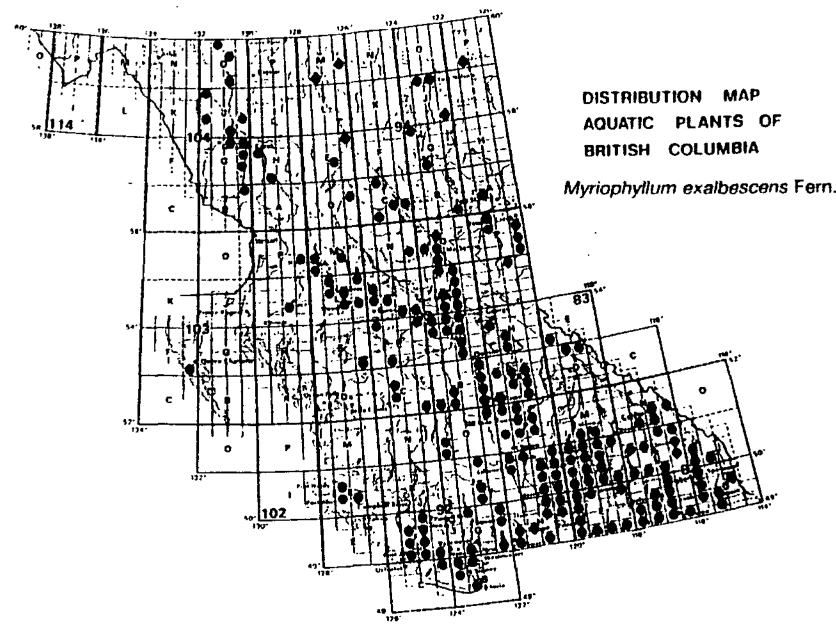


FIG. 19a.3. Distribution (*c.* 1987) of two most important aquatic weeds in western Canada, *Myriophyllum spicatum* and *M. exalbescens* (from P. D. Warrington and P. Newroth, pers. comm. 1985).

CANADIAN AQUATIC WEED PROBLEMS

Canadian aquatic habitats support a wide variety of vascular plants (Warrington 1980), but the most troublesome species are limited primarily to the genus *Myriophyllum*. In fact, *M. spicatum* and *M. exalbescens* account for perhaps more than 90–95 per cent of all economic losses and control costs associated with aquatic vegetation in Canada, and that is primarily focused in and around British Columbia and around Toronto (Anderson 1985). *M. spicatum* was reported in British Columbia in 1971 and by 1980 about 1 000 ha were infested (Dove and Wallis, 1981). As of 1985, estimates were 2 000–3 000 ha for British Columbia and 100 000 ha for the Toronto/Quebec area (Symposium discussion comments by P. Newroth and S. Painter in Anderson, 1985; Newroth 1985). Distribution of these two species in British Columbia as of 1987 is shown in Fig. 19a.3 (P. D. Warrington, pers. comm.)

Several recent papers presented at the First International Symposium on Watermilfoil document the general spread and occurrence of *M. spicatum* in the western-Canada/US region (Rawson 1985; Warrington 1985). It is apparent that from 1977 to 1978 the infestation in the Okanogan River breached the northern United States border and has been progressively invading the state of Washington ever since (Fig. 19a.4). However, other populations of *M. spicatum* were documented in 1973 in Washington state (Falter *et al.* 1974) and even perhaps in the 1960s (Couch and Nelson 1985).

In an archival survey done by the British Columbia Ministry of Environment

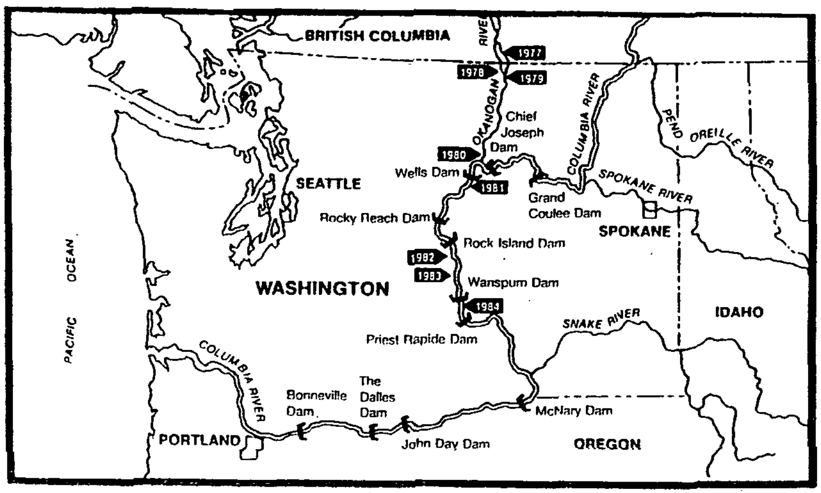


FIG. 19a.4. Chronology of *Myriopyllum spicatum* spread into Washington state from the Okanagan River system (from Rawson 1985).

for 1975–1981, *M. exalbescens* and *Potamogeton* spp. accounted for 60 per cent of logged aquatic weed complaints (*M. spicatum* was not included). Of lesser incidence were problems from *Elodea canadensis* (12 per cent) and *Ranunculus aquatilis* (7 per cent) (P. Newroth and P. Warrington, pers. comm.) Table 19a.4, which shows the frequency of occurrence of aquatic plants in British Columbia and Alberta, further illustrates the dominance of a few genera. It should be noted that unlike British Columbia, southern Alberta has thirteen irrigation districts whose 11 500 km of canals can support abundant aquatic plants much like those in the western United States (Burland and Catling 1986).

Table 19a.4. Relative prevalence of twelve aquatic weeds in British Columbia and Alberta, Canada

Rank	Species		
	British Columbia	Alberta: Irrigation Systems	Alberta: Recreational lakes
1	*Nuphar polysepalum*	*Potamogeton pectinatus*	*Myriophyllum exalbescens*
2	*Utricularia vulgaris*	*Potamogeton richardsonii*	*Potamogeton pectinatus*
3	*Myriophyllum exalbescens*	*Typha latifolia*	*Potamogeton richardsonii*
4	*Potamogeton gramineus*	*Phalaris arundinacea*	*Potamogeton vaginatus*
5	*Ranunculus aquatilis*	*Myriophyllum exalbescens*	*Ceratophyllum demersum*
6	*Potamogeton natans*	*Potamogeton vaginatus*	*Potamogeton praelongus*
7	*Typha latifolia*	*Ceratophyllum demersum*	*Lemna trisulca*
8	*Scirpus lacustris*	*Alisma gramineum*	*Potamogeton pusillus*
9	*Potamogeton pectinatus*	*Ranunculus circinatus*	*Elodea canadensis*
10	*Sparganium emersum*	*Elodea canadensis*	*Ranunculus circinatus*
11	*Polygonum amphibium*	*Potamogeton pusillus*	*Potamogeton zosteriformis*
12	*Potamogeton richardsonii*	*Scirpus spp.*	*Ruppia maritima*

Note: Data are from P. Warrington and P. Newroth (pers. comm.) for British Columbia and from Burland and Catling (1986) for Alberta. Both sources list other less prevalent species not included here. For Alberta, rankings take into account abundance and severity of problems caused by the weeds.

IMPACTS AND MANAGEMENT

It is not surprising that the main problems with aquatic plants in the western United States and Canada are caused by rooted plants (both emergent and submerged), given the extensive reaches of moderate to rapidly-flowing waters, both natural and man-made. Rapid spread of introduced plants occurs, facilitated by downstream proliferation and seasonal nutrient inputs from run-off and sedimentation. These flowing waters, together with the thousands of static-water storage reservoirs and natural lakes, sustain and disseminate plants causing severe economic impacts, which may be described as follows:

(1) direct blockage of flow (loss of canal capacity) and subsequent canal bank damage. These affect irrigation as well as drainage and flood control;

(2) loss of storage capacity in reservoirs, particularly small ones;

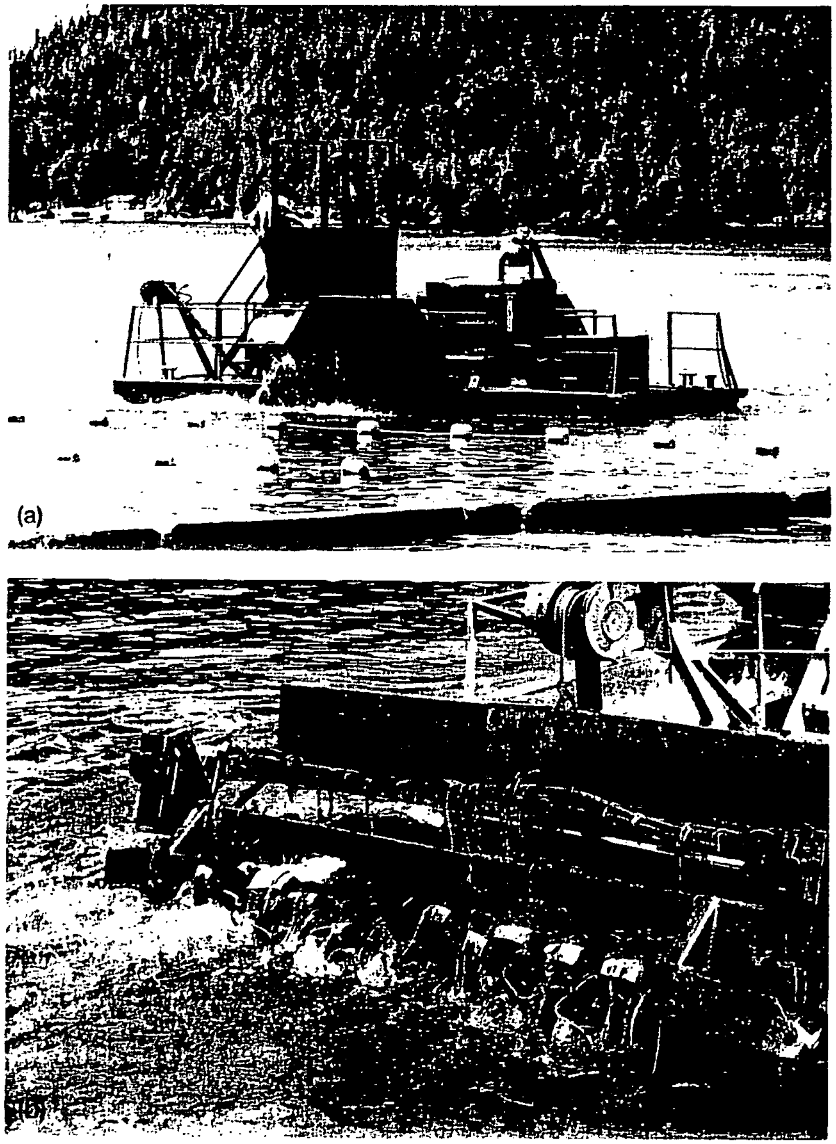


FIG. 19a.5. (a) Eurasian water milfoil is often removed mechanically in Canada using a 'rotovator'. Note the long floats in the foreground: these support a screen which is put in place to retain the many fragments provided by rotovation. (b) Close view of hydraulically operated rotavator 'business' end: note the rotating tines and the fragments of Eurasian water milfoil.

SPECIAL CASES: *HYDRILLA VERTICILLATA* AND *EICHHORNIA CRASSIPES*

Hydrilla verticillata

Since its introduction into the south-eastern United States in the early 1960s, *H. verticillata* has progressively spread into Texas, California, and Arizona, and these states constitute its current distribution in the West. Table 19a.7 summarizes the incidence of dioecious *H. verticillata* in these states and points out

Table 19a.7. Occurrence of dioecious *Hydrilla verticillata* in the western United States[a]

State	Year	Infested area (ha)
Arizona	1982	<2 (under eradication)
California	1975	None reported
	1976	12 (Lake Ellis, now eradicated)
	1977	200–250 (Increase due to infestation and spread in Imperial Irrigation District where it is currently under successful management with triploid grass carp)
	1984–1986	250–320 (Additional sites in Santa Rosa and Shasta counties; Santa Rosa site eradicated in 1985)
	1987–1988	320–330 (Additional 10 sites in Calaveras county and a 0.8 ha lake in San Francisco)
Texas	1976[b]	~500
	1984	4900
	1986	>24 000

[a] Modified from Anderson (1986*a*). Note that these are maximum areas. Weed coverages at several sites have been reduced, especially in California.
[b] From Tyndall (1982).

that the California introductions are the most recent. Fig. 19a.6 shows the distribution and size of infestations in California by County. Note that the most northern site (Shasta county) is located adjacent to the Sacramento River, a major source of water for northern California domestic and agricultural uses and also a major contributor to the Sacramento Delta. This infestation is the most immediate and current threat to the extensive water transport systems in the state since water from the Sacramento Delta is exported to central and southern California via the California Aqueduct and the Delta Mendota Canal.

As evidence that not all hydrilla in California has been located (or that it may still be spreading) eleven 'new' infestations were discovered in 1988. All except one (McLaren Park, San Francisco) are in Calaveras County on fairly remote tracts of land where these small ponds are used for fishing and some irrigation. Although the Calaveras sites are 50 to 60 kilometres from the Sacramento Delta, there is potential for movement into the expansive Delta waterways via a small, seasonally flowing tributary. As in the Shasta County sites, these infestations,

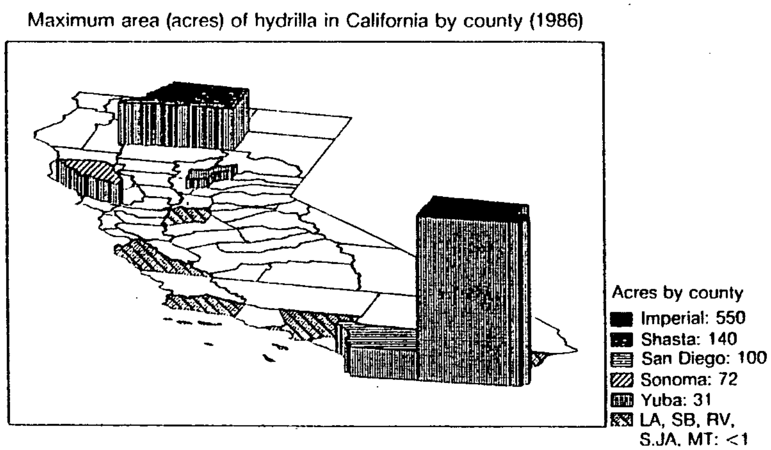


FIG. 19.6. Distribution of *Hydrilla verticillata* in California showing the greatest areal coverage reported at any one time prior to 1987. Note that much of the acreage shown has now been reduced and that infestations in Shasta county and Imperial county are the only remaining large populations (from Anderson 1986a). In 1988, additional hydrilla infestations were discovered in northern California (10 sites in Calaveras county; one lake in San Francisco: N. Dechoretz, pers. comm.).

FIG. 19a.7. Aerial view of a hydrilla infested area of Sheldon Reservoir in southern California (1984). Fragmentation from upstream populations caused this reservoir to become 80 per cent covered with hydrilla within 6 months of its construction. A major canal system is seen to the left.

once found, were immediately treated with chelated copper (Komeen™) to remove above-sediment growth. Subsequent treatments with Fluridone (Sonar™) will be made to prevent regrowth from turions.

The impacts of *H. verticillata* infestations (Figs 19a.7, 19a.8) are not unlike those caused by excessive growth of many other rooted submerged aquatic plants: interference with water transport in canals, lost recreational revenues, higher costs of management and wildlife habitat impairment. A unique feature of the response in California to *Hydrilla* introduction was its classification as a 'Type A' pest. This designation dictated that the plant was to be eradicated whenever possible and that its sale, intrastate movement and importation is illegal. As a consequence, California has expended roughly $1.3 million annually since 1978 on various eradication efforts on several sites (Anderson 1986*a*).

FIG. 19a.8. A partially dewatered main canal in the Imperial Irrigation District in southern California (1979). *Hydrilla* occupied 50 to 75 per cent of the canal volume when water was flowing. This irrigation system was stocked with triploid grasscarp in 1986 and 1987 which has resulted in >90 per cent clearance of *Hydrilla*.

Results of these eradication programmes have been good (Fig. 19a.9) and only two major infestations remain: Redding (Shasta County) and the Imperial Irrigation District (IID) in the southern-most part of the state. The Redding sites will probably be eradicated by 1989 but the IID site is extensive and in rapidly flowing water. There, several thousand triploid grass carp were introduced in 1985–1987 and early results are extremely promising with >90 per cent

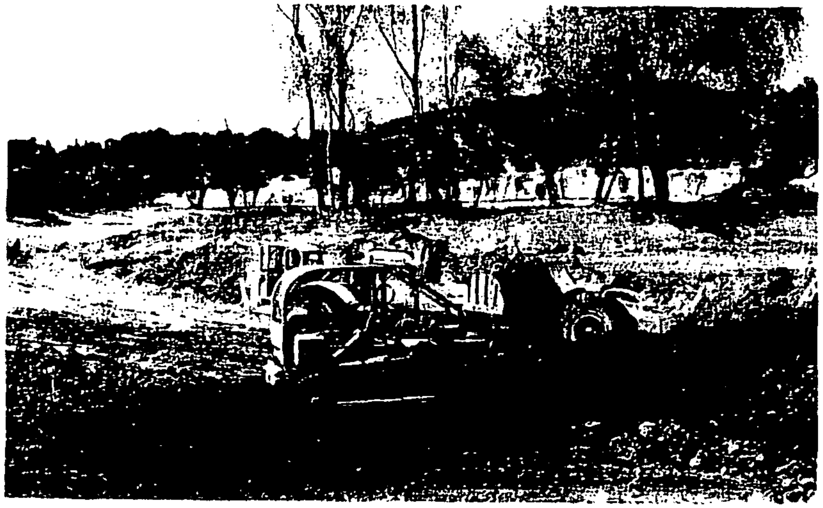


FIG. 19a.9. *Hydrilla* eradication has a high priority in California. Here the complete excavation and renovation of a 70 hectare recreational and flood control lake is being done in order to remove all plants and tubers. At a cost of about US $1 000 000 this lake was restored from 1985 to 1986 and is now in use again.

reduction in plant populations reported (Stocker 1987). It remains to be seen if the continued presence of the fish will eventually deplete the existing *Hydrilla* turion bank, and bring about at least near eradication. It should be noted too that, given the propensity for *H. verticillata* to spread, the expenses incurred with California's assertive eradication programme probably have saved many millions of dollars over the long-term since most of the potential sources for spread have been removed relatively quickly.

Finally, to complete the picture for the western distribution of *H. verticillata*, recently documented infestations in an irrigation system in the Mexicali Valley, Mexico (near the United States border at Calexico) should be mentioned (Stocker 1987). Surveys in 1987 revealed about 38 km of earthen canals infested with *Hydrilla*. An introduction of triploid grass carp is planned for *c.* 62 km in 1988–1989. This irrigation system is immediately south of the extensive infestation in the Imperial Irrigation District, though there is no direct waterway connection to the IID infestations.

Eichhornia crassipes

The problem infestations of water hyacinth in the western United States are primarily in Texas and in the Sacramento Delta of California (Fig. 19a.10a,b).

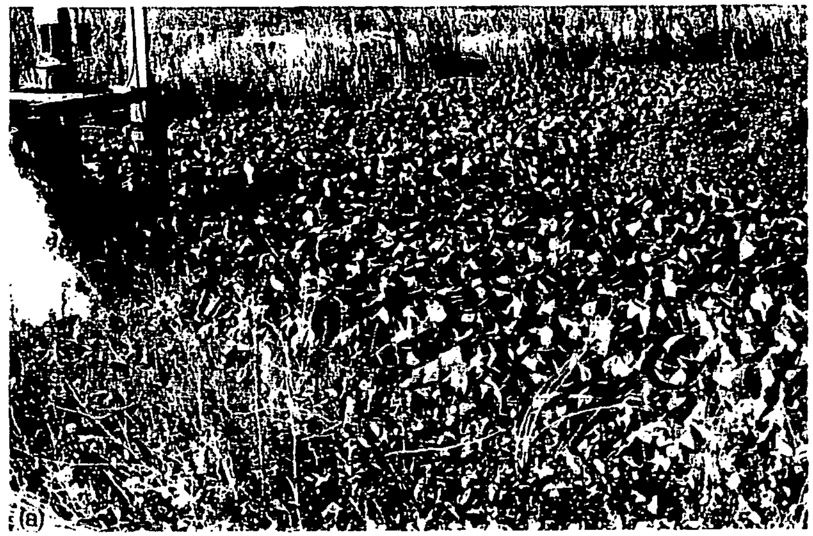


FIG. 19a.10. (a) Water hyacinth has become a menace in many regions of the Sacramento Delta where it blocks marinas and interferes with boat traffic. This picture shows a dense stand encroaching on an irrigation pump. Since 1984, the massive growths have been kept under control with the application of 2,4-D in a carefully monitored management programme.
(b) Before the herbicide programme was instituted, several hundred truckloads of water hyacinth were hauled away daily from the conveyer system on the Delta, a process costing hundreds of thousands of dollars annually. With the herbicide programme, costs have been cut by at least 90 per cent.

According to Tyndall (1982), this exotic species, which was noted as a problem in the 1930s, occurred on about 6 500 ha in Texas in 1981, and *c.* 7 000 ha in 1984 (Guerra 1984). In California, although *E. crassipes* was noted by the early 1900s, problems did not arise until the late 1940s and then again in 1980 (Thomas and Anderson 1984). The total area, even recently, has been small (*c.* 200 ha) compared to Texas or Florida (1985 Florida estimates: 494 000 ha according to Schardt 1986). However, the nature of the Sacramento Delta site with narrow sloughs, tidal movement, and large pumping stations made this infestation a serious problem. At the US Bureau of Reclamation pump works, tons of the plants were removed daily and had to be hauled away, a job costing several hundred thousand dollars annually. This expensive activity has not been required for the past 3 years since 2,4-D applications began.

In both Texas and California, foliar application of the herbicide 2,4-D has been used very effectively to reduce the growth and spread of the water hyacinth. About 4 300 ha of water hyacinth were treated with herbicides in Texas in 1987, and perhaps twice that area may need treatments in 1988 (Texas Parks and Wildlife Service, pers. comm.)

In addition, biological control agents (*Neochetina eichhorniae, N. bruchi, Sameodes albiguttalis*) have been released in California, but have not proved effective in the Sacramento Delta as yet. The key to management in this site has been the early spring applications of 2,4-D to prevent the formation of massive and mobile mats of the plants which would otherwise block commercial navigation, recreational uses, and the vital pumping system on which Central and Southern California depends. This strategy is coupled with regular monitoring for residues of the herbicide at strategic points in the Delta. In the four years of this programme, no 2,4-D residue problems have arisen.

THE FUTURE

The intensive urbanization, and expanded agricultural and industrial activities in the western United States over the past 30–40 years have placed greater and greater demands on the water resources of this region. These demands will intensify since the 1985 population for the seventeenth western states, about 71 million, is projected to increase to over 90 million by the year 2000 (USBR 1985).

Because general concerns for environmental protection are ever more intensely focused on water as a vital yet mobile resource, aquatic plant management strategies must become more tailored, sophisticated, efficient, and cost-effective. The public's concerns about groundwater contamination from industrial and agricultural chemicals, including herbicides, place more urgency on the development of non-chemical aquatic weed management approaches.

Experience has shown that key components of aquatic weed management in this age must include multi-agency co-ordination where public waters are concerned, and a highly effective public awareness and education programme. Managers in Canada have been especially thoughtful and diligent in their public education and quarantine efforts, and the western US states are increasing their activities here too. With these ingredients, and continued basic and applied research on the nuisance aquatic plants, it should be possible to reduce the economic and health impacts of aquatic weeds greatly in the next decade.

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(b) Aquatic weed problems and management in the eastern United States

K. K. STEWARD

THE total area of surface water in the eastern states of the USA, in which aquatic weed problems may occur, is approximately 86 937 km^2 (8.7 million ha, Table 19b.1). This is an area about the size of Austria, or slightly larger than the state of Maine in the USA. The geographical boundaries of this area are 24° to 47° N, and 67° to 92° W. There is a wide diversity of climatic and habitat conditions. The southern states with warmer temperatures, longer growing seasons, and generally hard, fertile water, tend to have more serious aquatic weed problems than do the northern states. As would be expected, aquatic plant management programmes have been established longer and are more active in the southern states. Table 19b.2 lists the aquatic plants which may create problems in the eastern USA. Each species is identified by a two-character symbol when reported as a problem (Table 19b.4). Table 19b.3 lists aquatic herbicides used to control various problem species and are also identified by a two character symbol when used on a particular problem species (Table 19b.5).

The largest proportion of the activities to manage aquatic plants is performed by public agencies of federal, state, county, and municipal governments. The US Army Corps of Engineers (CE) and the Tennessee Valley Authority (TVA) are

The Rawa Manumbo, a reservoir for the storage of irrigation water in West Java (Indonesia), covered by a dense vegetation of aquatic weeds (mainly water hyacinth, *Eichhornia crassipes*). (Photo: A. H. Pieterse)

Aquatic Weeds

The Ecology and Management of Nuisance Aquatic Vegetation

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