Macrophyte management: an integrated perspective

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Abstract A concept of aquatic macrophyte management that integrates the positive and negative aspects of vegetation in lakes and rivers is discussed. This integrated approach involves three factors: macrophyte control, macrophyte enhancement, and identification and resolution of the conflicts created by multiple use of a waterbody. The primary decision in macrophyte management programmes must be whether to optimise for single-purpose or for multipurpose use of the waterbody. Both technical (macrophyte control and enhancement) and social (conflict resolution) procedures are required to solve problems associated with the macrophyte status of multipurpose waterbodies.

Keywords macrophyte; management; control; enhancement

INTRODUCTION

Weed management in terrestrial habitats usually involves choosing the least expensive or most efficient technique(s) to eliminate an undesirable plant. Ecologically, whether or not the plant should be eradicated is seldom in question; rather, economic and practical considerations decide if a programme of "control" or eradication is implemented. There are few conflicts because almost all terrestrial habitats are single-purpose, e.g., a corn field is rarely used for golf. Exceptions generally involve situations where a secondary use involves minimal impact on the principal use as, e.g., with limited recreational use of the watershed for a town's water supply. In contrast, aquatic habitats are frequently and sometimes unavoidably multipurpose (e.g., duck hunters, fishermen, waterskiers, boating enthusiasts, industry for effluent disposal, and a hydro-electric station may all use the same lake). This multiple use of lakes and rivers creates user conflicts in terms of vegetation management, because some uses require the presence of macrophytes whereas others may require their absence. Scientists in North America and Europe have recognised for over a decade that lake and river management must address and solve such conflicts (Westlake 1968; Cole 1973; Lively et al. 1973).

Another important difference between management of aquatic and terrestrial vegetation derives from the available, state-of-the-art technology. Selective herbicides are routinely employed against terrestrial weeds, reflecting a long history of research and practical use (Wain 1965). In contrast, at least for submersed vegetation, there are no satisfactory (i.e., entirely predictable) selective herbicides or selective biological control agents having a resolution finer than that of the broadest taxonomic categories, i.e., algae and vascular plants (Marshall 1984). (The potential for species-specific biological control exists, because there are numerous species-specific herbivores of submersed macrophytes in the tropics (Pemberton 1980; Balciunas & Minno 1985), and temperate-zone examples may also exist (Kangasniemi 1983; Newroth 1984).) Even with available techniques, however, species-specific control of submersed macrophytes is not impossible. For example, when the pest species is a vegetatively reproducing form, such as Lagarosiphon major in New Zealand, selective control can be achieved through "total control" (eradication of all macrophytes) followed by re-establishment of seed producing species (which are, frequently, the more desirable types) from sediment seed banks. Although Van Zon (1982) has suggested that selective aquatic plant control is undesirable, this suggestion has little relevance except to single-purpose systems such as irrigation canals. Lake and river users normally object to a particular plant species rather than to the aquatic vegetation *per se*. Thus, selective control of the nuisance species appears to be the management option which, through the avoidance of complete elimination of the vegetation, could solve many of the user conflicts in multipurpose waterbodies.

Coherent management programmes for aquatic macrophytes are rarely formulated because, I suggest, an integrated perception of the beneficial and
nuisance attributes of these plants is usually lacking. Some authors view aquatic plants primarily as weeds (Hall 1961; Holm et al. 1969; Soerjani 1977; Gangstad 1978; Lembi 1980), whereas others stress useful aspects of aquatic macrophytes — especially as a source of biomass — either to humans (Pirie 1970; Boyd 1971; Gaudet 1974; Ad Hoc Panel 1976; Heckman 1982) or to the environment (McLachlan 1969; Ikusima 1983; Rabe & Gibson 1984; Gregg & Rose 1985), or to both (Pandit 1984). Although several authors have briefly noted both the positive and negative aspects of aquatic plants (Ridout 1980; Van Zon 1982), with few exceptions (e.g., Dawson & Haslam 1983) this integrated perspective has not been adopted in practice. The term “water-weed management” generally implies only weed control (or eradication) as, e.g., in the “management” scheme discussed by Mitchell (1980: fig. 14). Thus, most management programmes fail to recognise their dual role, involving either control or enhancement, depending on the species involved and the waterbody uses.

The problem of macrophyte management in aquatic systems primarily involves a conflict between the need of some user groups for control versus the requirement by other users for aquatic plant enhancement. This interaction is illustrated by Fig. 1. User conflicts are avoided if a single-use approach is adopted. However, most aquatic habitats are multipurpose (on a de facto or legislative basis), and therefore macrophytes may have to be managed to meet the needs of several users. This paper reviews, within the context of Fig. 1, the reasons for management, factors relating to the control or enhancement of aquatic vegetation, and potential techniques for the resolution of user conflicts in multipurpose waterbodies.

**REASONS FOR MACROPHYTE MANAGEMENT**

Macrophytes require managing when either too much or too little vegetation, for a given use, exists in a lake or river. Therefore, the initial step in a management programme will be to determine the types and quantities of macrophytes present, whether the macrophyte populations are expanding or declining, and the relationship(s) between the vegetation and the lake use(s).

Generally, uses of aquatic habitats can be divided into those that depend on the presence of vegetation (e.g., assimilative capacity, lakeshore and streambank erosion control, sediment stabilisation, nutrient stripping (a temporary function in many lakes; see Moore et al. 1984; Morency & Edwards 1985), commercial macrophyte harvesting, wildlife and fisheries habitat, the conservation of rare plant species, etc.) and those that do not either directly (e.g., waterskiing, hydro-electric generation, cooling, irrigation, barge transportation, etc.) or indirectly (e.g., bilharzia-free habitat; see Van Schayck 1985) require the presence of plants. For uses depending on the presence of vegetation, determination of the optimal quantity and type of desired plants can be difficult, and precise answers are often unknown. Even the relationship between macrophytes and fish production, possibly the most studied macrophyte-use interaction, is relatively poorly quantified (Tevyashova & Tevyashova 1973; Swales 1982; Shireman et al. 1983; Tucker et al. 1983; Durochee 1984; Mikol 1985; Theurer et al. 1985; and see Ploskey 1982), although the difficulty in defining this relationship may simply reflect the recent recognition that in some situations there appears to be no relationship between macrophyte abundance and fish biomass (Shireman et al. 1985).
Table 1 Conflicts caused by selected macrophyte control strategies. These examples are an oversimplification for many practical situations, because conflicts also exist within user groups. For example, it is not necessarily true that all swimmers prefer concrete lake bottoms or that all local residents may not benefit from cattle grazing on lake weed.

<table>
<thead>
<tr>
<th>User</th>
<th>Problem</th>
<th>Cause</th>
<th>Solution</th>
<th>Non-acceptable control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro-electric generation</td>
<td>Blockaded penstock intake screens</td>
<td>Drifting weed</td>
<td>Protective control or total control</td>
<td>Weed cutting without harvesting</td>
</tr>
<tr>
<td>Wildlife</td>
<td>Lack of appropriate food species</td>
<td>Exotic macrophyte species replacing native species</td>
<td>Quarantine of lake or species-specific control</td>
<td>Residual herbicides or total control</td>
</tr>
<tr>
<td>Boating (including sailing &amp; waterskiing)</td>
<td>Fouled propellers and centreboards</td>
<td>Surface-reaching weeds</td>
<td>Species-specific control</td>
<td>Lake-level fluctuations</td>
</tr>
<tr>
<td>Recreational fishing</td>
<td>Small fish; flies caught in weed</td>
<td>Surface-reaching weed, lack of habitat diversity/prey refuge</td>
<td>Patchy weed growths</td>
<td>Surface screens, total control, grass carp</td>
</tr>
<tr>
<td>Commercial fishing</td>
<td>Net clogged with weed</td>
<td>Any macrophytes</td>
<td>No macrophytes</td>
<td>Spraying with rapid increases in BOD</td>
</tr>
<tr>
<td>Water supply (potable)</td>
<td>Taste (algae)</td>
<td>Nutrient availability for algal blooms</td>
<td>Prolific macrophyte growths</td>
<td>Fertilisation</td>
</tr>
<tr>
<td>Water supply (irrigation)</td>
<td>Blocked pipe intakes; water loss</td>
<td>Drifting weed; transpiration</td>
<td>No macrophytes</td>
<td>Residual herbicides</td>
</tr>
<tr>
<td>Swimming</td>
<td>Drowning in weed</td>
<td>Macrophytes</td>
<td>Concrete lake bottom</td>
<td>Rotovating, dyes</td>
</tr>
<tr>
<td>Hunting</td>
<td>No ducks</td>
<td>Nymphaeids</td>
<td>Elodeads only (species-specific control)</td>
<td>Harvesting during hunting season</td>
</tr>
<tr>
<td>Tourists</td>
<td>Lack of aesthetic appeal</td>
<td>No nymphaeids</td>
<td>Plant nymphaeids</td>
<td>Lake-level fluctuations</td>
</tr>
<tr>
<td>Winter sports (e.g., ice skating)</td>
<td>Plants protruding through ice</td>
<td>Emergent macrophytes</td>
<td>Deepen lake or fall harvesting</td>
<td>Nam Ngum technique†</td>
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<tr>
<td>SCUBA diving</td>
<td>Poor visibility</td>
<td>Plankton</td>
<td>Phosphorus control</td>
<td>Dyes</td>
</tr>
<tr>
<td>Lake shore residents</td>
<td>Smell</td>
<td>Rotting weed on beach</td>
<td>Weed removal</td>
<td>Grazing cattle on beached drift</td>
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<td></td>
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<td>Suitable breeding habitat</td>
<td></td>
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<tr>
<td>Thermal power generation</td>
<td>Blocked cooling water intakes</td>
<td>Drifting weed (abundant growth due to elevated water temperatures)</td>
<td>Protective control</td>
<td>Lake lowering below level of cooling water intakes</td>
</tr>
<tr>
<td>Organic waste disposal</td>
<td>Inadequate assimilative capacity (low O\textsubscript{2} level)</td>
<td>Not enough submerged macrophytes</td>
<td>Macrophyte enhancement</td>
<td>Any control of submersed species</td>
</tr>
</tbody>
</table>

† That is, leaving the forest in place when a reservoir is filled (as in the case of the Nam Ngum Reservoir, Vietnam) so a natural barrier to weed drift is provided in the shallow areas of the lake.
**USER CONFLICTS**

Various, often conflicting weed control methods are required by different user groups (Table 1). (User conflicts are not limited to weed management: for a “fisheries” perspective of conflicts similar to those in Table 1, see Layher (1984).) Conflicts also arise with the choice of enhancement methods. These various conflicts exist because not only is the quantity of vegetation important for a given use, so too are the individual species and types of plant life form present. For example, elodeads contribute significantly to oxygen levels in the water column, whereas nymphaeids do not. Thus, in terms of the assimilative capacity of lakes and rivers (Thyssen 1982; Chapra & Reckhow 1983; Deb & Bowers 1983), elodeads are more desirable than nymphaeids. This use-plant relationship is often difficult to manipulate because, as noted above, few practical techniques for the selective control or enhancement of aquatic macrophytes exist.

**Control: the solution to nuisance plants**

An extensive literature exists on methods of aquatic weed control. However, techniques are seldom coherently classified in terms of management. Terrestrial weed control methods can be conveniently classified into six general categories based on how plant death is effected (Klingman & Aston 1982: 18). But a similar (non-ecological) classification is poorly suited to aquatic control techniques. A user/environment-based classification is more appropriate and more useful for waterbody management. The need for such a classification arises because macrophyte control is, from a system perspective, environmental manipulation. Macrophytes are an integral component of the aquatic environments they inhabit. They modify their environment (Morin & Kimball 1983; Reddy et al. 1983); thus, their death or removal (harvesting) effects ecological changes (Fish 1966; Getsinger et al. 1982; Carpenter 1983; Shireman et al. 1983). (Although these comments are also true for terrestrial systems, their relevance and importance, at least in the past, has largely been ignored for reasons beyond the scope of this review.) Fig. 2 gives a modified version of such a management-oriented, environmentally based classification of control options for the submerged macrophytes of hydro-electric reservoirs. This scheme allows the manager to readily identify major ecosystem impacts that will result from the alternative control methods available. The scheme does not substantially change if the “habitat” or “purpose” is changed from that shown in Fig. 2, but the control method selected may be different - and it is in this way that user group conflicts can arise.

Numerous examples of nuisance growths of macrophytes have been described, including free-floating species (Mitchell et al. 1980; Philipp et al. 1983), emergent species (Panchal & Sastry 1976; Ransom & Oelke 1983), and submersed species (Newroth 1979; Sanders 1980). Nuisance growths of macrophytes commonly occur under two conditions:

1. After a species has been introduced to an area outside its previous range (e.g., *Lagarosiphon major* in New Zealand, *Trapa natans* in North America, and *Salvinia molesta* in Ceylon).

2. After environmental disturbance has caused the habitat to change, either by human interference, e.g., the increase in *Potamogeton crispus* after “restoration” of Moses Lake (Washington); the assemblage dominance by *Nymphaea odorata* associated with irrigation-ditch maintenance in the New Jersey cranberry bogs (Else & Riemer 1984); the invasion by *Najas guadalupensis* of ponds following the control of *Hydrilla verticillata* (Cassani & Caton 1985) or through natural means, e.g., the activities of nest-building fish (Carpenter & McCreary 1985).

Essentially, in both situations the nuisance growths have resulted from plant “invasions” (sensu Johnstone 1986). In situation 1, the invasion was possible because no functionally similar species was present and thus the invader could occupy the entire habitat within its range of ecological tolerance. In situation 2, a “botanical barrier” to the plant’s establishment (or spread) was removed as part of the environmental disturbance, allowing the nuisance species to increase its “share” of space in the macrophyte assemblage. In the latter situation, the invading plant species may be taking advantage of assemblage gaps through its seed production/ dispersal strategy, or habitat characteristics may have changed to become conducive to the invading species’ growth and reproduction. Such habitat changes generally are relatively obvious, such as changes in water clarity; however, more subtle changes such as a change in the N/P ratio (where both these elements are limiting to plant growth) may be involved (Tilman 1982).

Unfortunately, traditional explanations of the “success” of nuisance aquatic macrophytes have concentrated on environmental factors related to plant growth rates such as watercolumn and sediment chemistry (Carignan & Kalff 1980; Brenkert & Amundsen 1982; Langeland et al. 1983; Chambers & Kalff 1985). The assumption that an aquatic plant’s nuisance status arises from its growth rate has an inherent flaw: it is the standing crop and life form of the invader rather than its growth rate which is most frequently the problem, at least for most recreational uses. A high standing crop may reflect minimal biomass loss rather than maximal growth in a unit time. For example, there is no
Fig. 2 Hierarchical classification of submersed macrophyte control methods. Terminology after Johnstone (1982a, in press).
evidence that the high standing crops of some submersed species reported for New Zealand (Brown 1975; Ward & Talbot 1984), including the world record claimed by Clayton (1982), are related to unusually high growth rates and, by implication, nutrient availability. In fact some of the highest reported values for standing crop are from oligotrophic lakes (Taylor 1971; Brown et al. 1973; Coffey 1974, 1980; Howard-Williams & Vincent 1983). Under New Zealand conditions a low rate of biomass loss (i.e., wave-protected sites and no herbivores) and a relatively long growing season appear to be much more important for high standing crops than growth rate per se (see Coffey 1970; Michaelis 1976). Nevertheless, in situations where growth is limited, release of the limitation can be critical in the development of a weed problem (Freedman & Canale 1977).

The historical emphasis in the literature on macrophyte-nutrient interactions has undoubtedly played a role in the paucity of published studies on the population biology of nuisance macrophytes and the dynamics of macrophyte assemblages. In fact, compared to the information available on terrestrial weeds (e.g., see Radovecich & Holt 1984), aquatic macrophytes remain virtually unstudied. Exceptions include Eichhornia crassipes (Watson 1984), Salvinia molesta (Room 1983), Typha latifolia (Yeo 1964; Dickerman & Wetzel 1985) and investigations of competition/co-existence (e.g., McCreary et al. 1983; Titus & Stephens 1983; Keddy 1984). Ultimately, both the population dynamics and environmental requirements of aquatic weeds must be understood for the “weed” problems of lakes and rivers to be solved. The recent review by Wetzel & Grace (1983), which discusses the impact of CO₂ on aquatic plants, is an example of a vegetation problem in which both environmental and population aspects are integrated in the search for answers.

In a management context, the environmental effects of macrophytes may be as much a “problem” as their mere presence. Indeed, the “macrophyte problem” may derive entirely from secondary effects of the aquatic plants. For example, with hydro-electric generation, where secondary effects of the macrophytes might be expected to be insignificant, under the appropriate conditions decomposing aquatic plants can make the water acidic, causing turbines and other equipment in contact with the water to undergo accelerated corrosion (Ridout 1980; Caufield 1983).

Enhancement: the solution to inadequate biomass
Until recently, the literature has mainly emphasised macrophyte control; today, macrophyte enhancement in both marine (McLaughlin et al. 1983) and freshwater systems (Moss 1983) is also receiving attention. Enhancement methods fall into two broad categories:

Watershed management
Watershed management for macrophyte enhancement includes lake isolation (Moss 1983), the control of non-point nutrient run-off (Boynton et al. 1981), the control of sewage discharge (Phillips 1984), and the various methods of eutrophication control generally considered in lake restoration programmes (Jorgensen 1980; Chapra & Reckhow 1983).

In-lake management
In-lake management for enhancement includes the planting of “desirable” macrophytes (Fulton et al. 1983; Johnston et al. 1983); the construction of shallow areas for emergents (Kelcey 1984); contouring and decreasing the invert slope (batter) of lake sides (Bjugstad et al. 1983) or rivers (Jackson & Van Haveren 1984); selective macrophyte control (Denike & Geiger 1974; Crawford 1979); phytoplankton control by the introduction of algal herbivores (Crisman 1981; Brabrand et al. 1983); the construction of constant-level polders in pumped-storage reservoirs and lakes or rivers subject to dewatering or low-flows (Thomas et al. 1984; Richards & Lake 1985); the use of baffles to dampen wave action and thereby reduce sediment resuspension; and construction of slow-flow oxbows beside power canals and aqueducts to serve as plant refuges.

Many macrophyte recessions have been reported for marine and brackish habitats (Kirkman 1978; Orth & Moore 1983, 1984; Cambridge & McComb 1984) and for freshwater systems (Anderson 1977; Dzwonko & Plazinska 1977; Jupp & Spence 1977; Phillips et al. 1978; Moret 1982; Moss & Leath 1982; Taylor 1983; Wharf et al. 1984; Bonner et al. 1985; Hejny 1985). This phenomenon is apparently happening more frequently and becoming more important to management (Liddle & Scorgie 1980; Hanna 1983; Ikusima 1983). Examples range from the classic recession resulting from water level manipulation of previously stable lakes for hydro-electric or irrigation purposes (Quennerstedt 1585), to the decline of rare species and their replacement by more successful aliens as, e.g., has occurred in many New Zealand lakes (Johnstone 1972; Graham 1976; Coffey 1980; Howard-Williams & Vincent 1983). Therefore, the problem of macrophyte enhancement, like macrophyte control, may be either a total-vegetation problem or a species-specific problem.

An enhancement programme must initially address the reason(s) for a macrophyte's apparent decline or absence. If macrophytes are absent, they
may never have been present (as would be the case for a lake formed in an abandoned strip mine or gravel pit). Alternatively, either the area occupied by the macrophytes or their density may have declined. Classifications of the dynamics of plant population declines have only recently been published (Manion 1981; Rorslett 1985), but the ultimate causes of decline have not, as yet, been functionally categorised in a non-time dependent form. From a proximate, environmental perspective, however, macrophyte recessions can be grouped into permanent and non-permanent events, as follows:

Non-permanent: species-dependent
(a) seasonal
— climatically induced (a function of plant phenology; but, in most examples, not monocarpic senescence sensu stricto) (e.g., Ham et al. 1981; Kunii 1982; Brock 1983; Bowmer et al. 1984; Getsinger & Dillon 1984).
— predator-mediated (seasonal predation) (Eichenberger & Wéilenmann 1982).

(b) aseasonal
— cohort senescence (Mueller-Dombois et al. 1983) in weakly seasonal habitats (e.g., the architecture-mediated synchronous decline of surface-reaching hydrocharitaceans in some New Zealand lakes (Johnstone 1982b)).

Permanent
(a) species-dependent
— macrophyte-macrophyte competition; e.g., surface-floating and submersed forms (Thomas 1981). (This phenomenon can have a desirable effect in situations such as rice cultivation (Satapathy & Singh 1985).)
— disease; e.g., fungal infection of water hyacinth (Martyn 1985).
— predators; e.g., muskrat invasion (Heine & Van der Velde 1978); crayfish invasion (Lodge et al. 1985).

(b) species-independent
— hydrological changes; e.g., lake level manipulations, low-flow conditions in rivers, tidal manipulations. These are factors that may affect either growth rates or reproductive success of the macrophytes (see Lieffers & Shay 1981; Groenendijk 1985).
— increased turbulence or wave action causing physical dislodgement of the plants (e.g., increased boat traffic, see Murphy & Eaton 1983).
— trampling by humans or cattle and disruption by general recreational activity (Sukopp 1971; Liddle & Scorgie 1980; Richter 1984).
— a high level of suspended solids (resulting in an inadequate light regime for the submersed plant species). Frequently turbidity is wind-generated and sometimes a consequence of macrophyte control (which increases the effective reach of a lake and thus wave amplitude); it may also derive from mine dewatering and storm generated watershed run-off (see Davis & Carey 1981; Gremillion et al. 1985; Canfield et al. 1983).
— increased external nutrient loading resulting in algae-macrophyte competition (Jupp & Spence 1977; Jones et al. 1983). The competition may be for light (Sand-Jensen & Sondergaard 1981), but plant death may be effected through oxygen stress to which the submersed macrophytes are subjected (Kadono 1978; Kelly et al. 1981). Alternatively allelopathic interactions may result (Van Vierssen & Prins 1985), or epiphytic, filamentous algae may place a mechanical load on macrophytes in lotic situations so that currents uproot the plants, e.g., as happened to the *Ottelia ovalifolia* — *Compso-pogon* assemblage at Huntly Power Station, Wai-kato, New Zealand (pers. obs.).
— pollution, e.g., heavy metals (Jana & Choudhuri 1982); acid rain (Roelofs 1983; Dillon et al. 1984; Roelofs et al. 1984); detergents (Agami et al. 1976) and possibly herbicide run-off from agricultural land (Cunningham et al. 1984; Kemp et al. 1985). Pollution effects are frequently site-specific, a characteristic that causes problems for management and legislation (Cairns 1985).
— increased organic matter in the lake sediment (Barbo et al. 1982), a phenomenon that appears attributable to organic toxins rather than organic content per se (Dorris & Martin 1985).
— an alteration to shoreline profile (Meredith 1984).

In any particular situation several of these factors may interact to cause a macrophyte decline. The above listing is not exhaustive, but it indicates the range of factors that can initiate declines and illustrates that declines are no longer the mystery they once were (Carpenter 1980). Explanations for specific declines are, however, not always easy to formulate. Osborne & Leach (1983) and Smeltzer & Swain (1985) have indicated that paleolimnological analysis may be useful in determining historical changes to a lake's flora.

Multiple-user satisfaction: conflict resolution and cost-benefit analysis
Cost-benefit analyses (Canale et al. 1983) for macrophyte control (Mitchell 1979) and for macrophyte enhancement (Boynton et al. 1981) are well known.

A few "environmental" conflicts involving macrophyte problems have been discussed in the literature; for example, the choice of control method
(Dearden 1983) and the rationale of utilisation versus destruction (Gopal & Sharma 1979). However, published examples of conflict resolution for multiple use of water bodies, where the conflict was caused by macrophytes, are practically non-existent, although the philosophy and procedures of conflict resolution could be extended to such situations (see Yeh & Becker 1982; Shamir 1983; Louie 1984). The “restriction procedure”, “trade-off method” and “surrogate worth trade-off (SWT) procedure” all have potential in this area (Becker et al. 1983). Multi-objective planning which uses habitat assessment is, perhaps, the most promising approach in this area (Herrick 1984). The only published, extensive management study that integrates macrophyte control and enhancement appears to be that of Tyndall et al. (1982) for the southern United States. These authors suggest that spatial separation of uses within a single facility (with the concomitant trade-offs that would occur) can go a long way towards realistic multipurpose use. Experimental studies aimed at developing macrophyte management methods for multiple-use situations are also exceedingly rare, being represented by the single, monumental study of Shimman et al. (1983).

In New Zealand, the control-enhancement conflict has only recently come to scientific attention, although the problem has existed for many years in a variety of situations. An illustrative example is the conflict between wildlife values, which require macrophytes (see Pike 1982), and boating enthusiasts who desire their absence, especially for waterskiing. Lake Waahi in the Waikato is a well known New Zealand example. A decade ago a macrophyte recession occurred, which reduced the lake’s wildlife value, but enhanced its recreational status for some users (Kingett 1984).

Interacting with the cost-benefit and conflict-resolution problems of lake management is the question of who should fund the management programme. Macrophyte management is expensive (Wunderlich 1968; Gangstad 1982: chapter 1). Perhaps the user obtaining the greatest economic benefit from the waterbody should contribute proportionately more funds to the programme than the importance of the macrophytes to them would strictly justify (especially when the minor uses of a waterbody have a “national” benefit which cannot be funded or is in conflict with local use perceptions (see Leitch & Scott 1984)). However, benevolent funding by the primary users of a waterbody (e.g., irrigation or flood-control authorities) for management of a multipurpose facility is usually non-existent without a legislative requirement.

The second main factor interacting with the problems of cost-benefit and conflict resolution is the trophic status of the waterbody. Macrophyte biomass and assemblage diversity are related in some, but not all, cases to the trophic status of a lake or river. Similarly, many uses, particularly recreational ones, are highly dependent on a system’s trophic status. For many years lakes have been classified trophically without considering the macrophytes (e.g., Taylor et al. 1980; Reckhow & Chapra 1983: chapter 8). Macrophyte control or enhancement, however, can alter the water quality of a lake. Therefore, for predictive management models, a trophic index incorporating macrophytes is essential. Progress in formulating such an index has recently been made (Canfield et al. 1983, 1984; Canfield & Jones 1984; Carlson 1984). The limnological differences between lakes and rivers (a subject that has received only minimal attention in the literature) can also be important in defining the trophic status of a system (Kimmel & Groeger 1984).

It has been claimed that, from a scientific perspective, some lake user conflicts cannot be resolved to effect multipurpose use, either by compromise or management (Wagner 1984; Wagner & Oglesby 1984; Shireman et al. 1985). Yet from the perspective of this paper, such resolution is the ultimate challenge. Is, then, the concept of multipurpose lakes and waterways a reality or must a single lake-use priority be established through (potential) user consensus (see Burden et al. 1985)? In essence, is “multiple use” appropriate only in trivial situations as a growing body of scientific opinion suggests?

For New Zealand, the literature on aquatic macrophytes has most recently been reviewed by Johnstone (1981) and, at this time, two further reviews are in press (Johnstone in press; Howard-Williams et al. in press). Most of the New Zealand literature is concerned with the causes of “excessive” weed growth and especially the relationship between macrophyte growth and eutrophication (see Hughes 1976; Ward et al. 1985). Recent progress has been made in understanding inter-lake macrophyte dispersal (Johnstone et al. 1986), invasions of lakes by weed species (Johnstone 1985), and assemblage structure (Ward & Talbot 1984); and botanically sensitive management guidelines that make possible a degree of multiple use have been discussed (Mark & Johnson 1985). However, at least in the New Zealand literature, macrophytes still seem to be principally perceived as “weeds”, with little or no appreciation for the critical role these plants play in aquatic ecosystems (e.g., Rowe & Schipper 1985).

**CONCLUSION**

By adopting an integrated perspective of aquatic macrophyte management, managing authorities can
clearly define user conflicts. Lakes and rivers are usually multipurpose, in contrast to the single-purpose use of most terrestrial systems. The resolution of the ensuing conflicts depends not only on technology, but also on the development of socio-political mechanisms to identify both priorities and possible trade-offs in lake use.

Disclaimer
Opinions expressed in this paper are those of the author and not necessarily those of the New Zealand Ministry of Energy (Electricity Division).

REFERENCES


Ploskey, G. R. 1982: Fluctuating water levels in reservoirs; an annotated bibliography on environmental effects and management for fisheries. Technical Report E-82-5, U.S. Army Engineers Waterways Experiment Station, Vicksburg.


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**ADDENDUM**

Several contributions relevant to the conflict between the control and enhancement of macrophytes in multipurpose aquatic habitats have become available since this review was written. The more significant are collated in this addendum; with a few exceptions, citations noted herein are either to reviews or to papers with extensive bibliographies of the recent literature.

In a New Zealand context three papers on macrophyte management have recently appeared: two on the chemical control of macrophytes (Clayton 1986; Wells et al. 1986) and one on macrophyte decline (Gerbeaux & Ward 1986).

Internationally, a number of significant contributions have recently appeared:

- Contributions relating to the ecological importance of macrophytes include two papers on riparian vegetation (Theurer et al. 1985; Behmer & Hawkins 1986) and a detailed analysis of macrophyte-environmental oxygen interactions (Hagebro et al. 1985).
- Biologically orientated contributions having a significant bearing on macrophyte management include papers on the role of seed banks and water level fluctuations in macrophyte dynamics (Keddy & Reznicek 1986), the role of temperature and light in the depth distribution of macrophytes (Dale 1986), macrophyte-dependent nutrient cycling in reservoirs (Filbin & Barko 1985), mechanisms of sediment-related limits to macrophyte growth (Barko & Smart 1986) and an ecobiomorphological classification of macrophytes (Papchenkov 1986).

In an extensive review, Nichols & Shaw (1986) provide a discerning analysis that integrates life-cycle biology with the nuisance status of several weed species, while Godshall & Barko (1985) have reviewed aquatic plant succession in a management context as it relates to reservoirs. The relationship between environmental factors (light, temperature, and nutrients) and macrophyte management has been reviewed by Barko et al. (1986).

- A variety of innovative techniques for the control or enhancement of macrophytes have been reviewed or described by Carter & Rybicki (1985), Dawson (1986), Hanbury (1986), Hertzman (1986), Hutto & Sabol (1986), Newroth & Soar (1986), Nichols (1986), Rybicki & Carter (1986), and Storch et al. (1986). Shireman et al. (1986) have reported on an experimental investigation into the cost of macrophyte control by means of a variety of techniques. A detailed, extensive and up-to-date analysis of potential and existing macrophyte control methods is given by Cooke et al. (1986).

Details of optimisation techniques such as the SWT (surrogate worth trade-off) procedure are described by Henderson (1982) and applications of such methods have recently been reviewed by Yeh (1985). Napier et al. (1986) provide a quantitative assessment of the uses of a multipurpose reservoir that provides a useful insight into both the conflicts that can arise with such facilities and the type of analysis that should (and could usefully) include a consideration of the macrophytes.
ADDENDUM REFERENCES


Henderson, J. E. 1982: Handbook of environmental quality measurement and assessment: methods and techniques. Vicksburg, Army Engineer Waterways Experiment Station.


Newroth, P. R.; Soar, R. J. 1986: Eurasian watermilfoil management using newly developed technologies. NALMS International symposium on applied lake and watershed management 5: 252-257.


