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AQUATIC PLANTS IN THE QU'APPELLE LAKES

Recommendations for Ameliorative Operations and Future Research

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EXECUTIVE SUMMARY

At the request of the Inland Waters Directorate, Western and Northern Region, a reconnaissance survey of the Qu'Appelle Lakes was undertaken in September 1989 to examine the problem of excessive aquatic macrophyte growth. Information obtained from this survey along with previously-collected data were analyzed to provide recommendations for ameliorative operations or, if necessary, additional research to improve water quality and reduce the abundance of nuisance aquatic weeds in the lakes.

Examination of the previously-collected data indicated that open-water phosphorus concentrations (total and soluble reactive) have decreased in the Fishing Lakes between the periods 1970-1976 and 1982-1988, despite a three-fold decrease in annual discharge which would tend to concentrate nutrients in the lakes. However, chlorophyll a and Secchi depth transparency did not change over the same period, despite the reduction in open-water phosphorus concentrations.

Relatively little historical data are available on aquatic macrophyte abundance in the Qu'Appelle Lakes. Examination of discharge records for the Qu'Appelle River indicates that recent increases in aquatic macrophyte abundance are likely related to a decrease in flow through the lakes and may be caused by an increase in the area available for colonization by submerged vegetation or changes in nutrient chemistry. However, data collected during the 1989 survey suggest that, despite their relative abundance, growth of aquatic macrophytes in several of the Qu'Appelle Lakes may be nitrogen or phosphorus limited. These results suggest that relationships between nutrient concentrations and aquatic macrophyte and algal productivity for the Qu'Appelle Lakes are very different from those of many other lakes. These differences may be due to the somewhat saline conditions (i.e. oligohaline: > 1000 mg/L total dissolved solids) of all the Qu'Appelle Lakes with the exception of Buffalo Pound. At present, little is known of nutrient dynamics and factors controlling productivity of inland saline lakes.

To determine if chlorophyll a levels in the Qu'Appelle Lakes are related to nutrient concentrations and flushing rates, a thorough and integrated analysis of the existing data on water quality (chemistry, chlorophyll a and Secchi depth) and quantity (discharge) should be undertaken . This will serve as a first step towards elucidating factors controlling algal productivity and provide the groundwork for decisions regarding the need for future research on water quality. As there is, at present, no long-term solutions to the problem of excessive aquatic macrophyte growth, selective harvesting aimed at removing nuisance

aquatic weeds from sites of greatest public concern is one of the better methods for short-term control of aquatic weed growth and could be undertaken in the Qu'Appelle Lakes. Future research on aquatic macrophytes in the Qu'Appelle Lakes should focus on the unusual relationship between nutrient concentrations and plant biomass, and developing innovative management strategies for controlling nuisance aquatic weed growth.

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INTRODUCTION

The Qu'Appelle River and associated lakes are located in south-central Saskatchewan. They represent a major recreational and economically-valuable resource for the people of southern Saskatchewan, and are used for commercial (whitefish, ciscoe and buffalofish) and game (northern pike, walleye, yellow perch) fishing, recreation, irrigation, livestock watering, drinking water supply, and sewage discharge. In addition, they are important in flood control and as waterfowl habitat. Approximately one-third of Saskatchewan's population lives in the Qu'Appelle River basin, including the cities of Regina and Moose Jaw. In addition, there were also 3,500 cottages and three provincial parks in the Qu'Appelle system as of 1968.

Site Description

The Qu'Appelle River originates in south-central Saskatchewan and flows east for about 400 km before joining the Assiniboine River approximately 20 km east of the Saskatchewan-Manitoba border. The latter flows via the Red River into Lake Winnipeg, eventually draining into Hudson Bay through the Nelson River. The Qu'Appelle River basin drains an area of approximately 52,000 km^2 and includes eight lakes: Buffalo Pound, Crooked and Round Lakes, and the four Fishing Lakes (Pasqua, Echo, Mission and Katepwa) on the main river channel, and Last Mountain Lake which discharges into the Qu'Appelle River through Last Mountain Creek (Fig. 1). Hereafter, only the lakes on the main river channel will be discussed.

The Qu'Appelle Lakes were formed as a result of the deposition of alluvial fans by tributaries to the main-stem of the Qu'Appelle River. These fans served as natural dams and, in conjunction with more recent man-made dams, determine the size and depth of the lakes. Buffalo Pound Lake, however, was enlarged in 1958 to meet the demands of the Cities of Regina and Moose Jaw for drinking water. Water was pumped from the South Saskatchewan River into the Qu'Appelle River from 1958 to 1964. With the completion of the Qu'Appelle Dam in 1966 and the filling of Lake Diefenbaker, water from the latter has been released continuously to maintain the level and improve the quality of Buffalo Pound and downstream lakes.

Flushing action is considered to be one of the major factors determining nutrient concentrations in the Qu'Appelle Lakes, particularly the Fishing Lakes (Allan 1980, Allan & Roy 1980). Since these four lakes are contiguous, low run-off and/or precipitation events simply shift water from an upstream lake to the next downstream lake. However, under flood conditions, these four lakes represent essentially four basins of one large lake. In addition to the effect precipitation has on flushing rates, precipitation also affects the effective drainage area, such that in a dry year the effective drainage basin may be only 50 % that of a wet year (Tones 1981).

Eutrophication and Review of Previous Studies

The Qu'Appelle Fishing Lakes appear to have been eutrophic well before European settlement of the prairies (Munro 1986a,b). Reports from early explorers who observed algal blooms on the lakes during summer as well as high levels of phosphorus in sediment cores from depths representing pre-settlement deposition (Allan et al. 1980) support this conclusion.

Scientific research on the Qu'Appelle system was first undertaken in the 1930's by Rawson and Moore (1944) who focused on the relationship between salinity and biotic diversity and abundance. Subsequently, Hammer (1964, 1971, 1973) conducted studies to assess the impact of nutrient loading on algal abundance and chemistry of the lakes. These studies indicate that while the Qu'Appelle Lakes are historically eutrophic, increasing human activity has contributed to a decline in water quality and impairment of recreational and economic activities. To develop a long-term management programme for the Qu'Appelle Valley and balance the demands of various user groups, the governments of Canada, Saskatchewan and Manitoba signed an agreement in 1970 and appointed a study board to prepare "a comprehensive framework plan to develop and manage the water and related land resources of the basin for social betterment and economic growth". The resulting Qu'Appelle Basin Study Board Report (1972) identified excessive algal and macrophyte growth as major water-related problems which interfered with recreational use of the lakes and contained 64 recommendations, including:

1. the need to decrease nutrient loading from the cities of Regina and Moose Jaw, and from livestock operations located throughout the basin, and
2. the need for further water quality monitoring and research to clarify the problems and determine solutions.

To follow through on the recommendations of the Qu'Appelle Basin Study Board Report (1972), the governments of Canada (Departments of Regional Economic Expansion, Environment, Indian Affairs and Northern Development, and Trade and Commerce) and Saskatchewan (Departments of Environment, Industry and Commerce, and Tourism and Renewable Resources) signed the 10-year Qu'Appelle Agreement in 1975. The objectives of the agreement were to protect and improve the Qu'Appelle Valley's environment, resources and cultural heritage, and to promote economic growth in the region by developing tourism and recreational activities. As part of the Qu'Appelle Valley Agreement, Regina upgraded its sewage treatment facilities in 1976 from aerated lagoons to tertiary treatment, with a resulting 85 % decrease in total phosphorus loading from the plant (Munro 1986a). In 1982, Moose Jaw began spray irrigating with sewage effluent during the summer months and by 1987, all sewage was diverted to agriculture and none was discharged into the Qu'Appelle river system. Over 1000 livestock operations in the Qu'Appelle River basin were also assessed and 184 of the 322 needing improvement were relocated or upgraded in the early 1980's. In addition to nutrient abatement programmes, Saskatchewan Environment initiated an on-going programme to monitor water quality of the Qu'Appelle Lakes and Environment Canada (National Water Research Institute, Western and Northern Region) undertook a variety of research related to water pollution. These included studies on internal and external nutrient loading (Allan & Kenney 1978, Allan & Williams 1978, Cross 1978, Lakshman 1979, Allan et al. 1980, Munro 1986a, Munro 1986b), paleolimnology (Warwick 1979a), benthic fauna (Warwick 1979b), and bacterial abundance (Dutka 1977).

While blooms of blue-green algae have been prominent in the Qu'Appelle Lakes for at least two decades and the focus of much public and scientific attention, more recent concern has focused on excessive growth of rooted aquatic plants, particularly in Buffalo Pound and several of the Fishing lakes (e.g. Katepwa). Reports of "weeds and other assorted slime" on the surface of the Qu'Appelle and other shallow lakes in southern Saskatchewan, as well as the problems associated with excessive aquatic macrophyte growth (i.e. fish kills, impairment of navigation and recreational activities, blockage of water flow, taste and odour problems), have raised public concern over deteriorating water quality. In an attempt to reduce aquatic weed abundance, the province of Saskatchewan, cottage owner associations and individuals undertook aquatic weed harvesting on Buffalo Pound Lake, while the Sakimay Indian band (located near Crooked Lake) spent approximately $130,000 to purchase an aquatic weed-harvesting machine.

Objective

The objective of this report is: (1) to synthesize the existing and recently-collected (September 1989) data on water quality of the Qu'Appelle Lakes with respect to the problem of excessive growth of rooted aquatic plants, (2) to provide recommendations for additional research, if necessary, and (3) identify ameliorative operations to reduce the abundance of aquatic weeds in the Qu'Appelle Lakes.

ANALYSIS OF DATA

Open–Water Chemistry

Data on open-water chemistry, particularly nutrient concentrations, are readily available for all the Qu'Appelle Lakes after 1970, and were collected as part of routine monitoring by Saskatchewan Environment and Public Safety (unpubl. data) or for specific research studies by Environment Canada (e.g. Cross 1978, Allan & Roy 1980). Prior to 1970, water chemistry data are limited to periodic measurements by Rawson & Moore (1944) between 1938 to 1941 and Hammer (1964, 1971, 1973) in the 1960's. To compare trends in water quality of the Qu'Appelle Lakes, all phosphorus (total, TP; total dissolved, TDP; soluble reactive, SRP), nitrogen (total, TN; ammonia, NH_4; nitrate and nitrite, NO_2+NO_3), total dissolved solids (TDS), and chlorophyll a (Chla) concentrations, and summer Secchi depths collected as part of a single study were averaged for each lake (Tables 1 to 7). All data collected in each study were included in the average, irrespective of season (with the exception of Secchi depth which are May-September values only), sample depth or sampling location in the lake. It is important to note that variations in precipitation and discharge from Lake Diefenbaker between years affects open-water nutrient concentrations and thus strict comparisons of annual water chemistry should only be made between years of similar discharge conditions (Allan & Roy 1980). Averaging nutrient concentrations over several years does, however, minimize the effect of anomalous years. Given the differences in sampling protocol and analytical methods between studies, the irregular sampling frequencies, and variations in discharge over the years, the comparisons of long-term changes in water chemistry presented in this report provide only a general indication of lake water quality.

Given these qualifications, comparison of TP and SRP concentrations for the Qu'Appelle Lakes (Tables 1 to 7) indicate that while all the lakes remain hypereutrophic (TP concentrations > 300 μg/L), phosphorus concentrations in the four Fishing Lakes generally increased (1977) and then decreased (1982-1988) relative to 1970-1976 values. The higher 1977 phosphorus concentrations were likely related to the extremely low flow conditions (Table 8), which would have concentrated nutrients in the lake basins. The reduction in phosphorus concentrations during 1982-1988, despite flows that were three-fold less than 1970-1976 (Table 8), suggests that 1976 implementation of tertiary sewage treatment at the Regina sewage treatment plant had an impact on lake phosphorus levels. Phosphorus concentrations in Buffalo Pound Lake appear to have decreased since water levels were stabilized in 1966. Long-term changes in phosphorus concentrations in Crooked and Round Lakes show no pattern.

While phosphorus concentrations appear to have decreased in many of the Qu'Appelle Lakes, there are no long-term patterns in nitrogen (TN, NH_4, NO_2+NO_3) concentrations in any of the lakes. Since the Regina sewage treatment plant represents a major source of nutrients to the Qu'Appelle system and implementation of tertiary treatment has little impact on nitrogen levels, the lack of any change in open-water nitrogen concentrations is not surprising. Overall nitrogen concentrations are surprisingly low relative to phosphorus, such that TN:TP ratios are less than 7 for all the lakes except Buffalo Pound.

Comparison of total dissolved solids (TDS) data for the Qu'Appelle Lakes indicate that while Buffalo Pound Lake can be considered to be a fresh water lake (< 700 mg/L TDS), TDS concentrations in Pasqua, Echo, Katepwa and Crooked Lakes are considerably higher - approaching 1000 mg/L TDS or more. While there is as yet no clear definition of the boundary between fresh and saline waters based on biological criteria, Bierhuizen & Prepas (1985) suggested that a TDS concentration of 1000 mg/L separates lakes with freshwater biota and standard ratios of Chla to TP (Dillon & Rigler 1974) from those with salt-tolerant species and lower ratios of Chla to TP (Prepas & Trew 1983). On the basis of this classification, Pasqua, Echo, Katepwa and Crooked Lakes can be considered to be marginally saline (i.e. oligohaline), at least during drier years when flushing times are long and salts become concentrated in the lake basin.

Chla values for the Qu'Appelle Lakes are also low relative to the open-water TP concentrations. Comparison of Chla and TP concentrations for the Qu'Appelle Lakes with empirical relationships developed for freshwater lakes of eastern Canada (Dillon & Rigler 1974) and north-central Alberta (Prepas & Trew 1983) show that these models consistently overestimate Qu'Appelle Chla concentrations. This may be due to the fact that the Dillon and Rigler (1974) model was determined for lakes with TN:TP ratios greater than 12, while for the Prepas and Trew (1983) model, 24 of the 25 lakes had TN:TP ratios greater than 12. The failure of these models to predict Chla levels, the poor correlation between TP and Chla, and the low TN:TP ratios in the Qu'Appelle Lakes has led several investigators to suggest that nitrogen, rather than phosphorus, limits algal productivity in these lakes (Allan & Kenney 1978, Cross 1978). While the relationship between Chla and nitrogen has yet to be examined for the Qu'Appelle Lakes, Bierhuizen & Prepas (1985) reported that for eight saline (TDS > 1000 mg/L) Alberta lakes with TN:TP ratios less than 12, Chla showed no correlation with either TN or TP. This suggests that the relationship between Chla, TN and TP is very different in inland saline lakes with low TN:TP ratios than in freshwater lakes. Since Buffalo Pound Lake is the only one of the seven Qu'Appelle Lakes with TDS concentrations well below the critical value of 1000 mg/L, algal productivity in these lakes may not be controlled by either phosphorus or nitrogen. Recent work by Marino et al. (in press) suggests that low algal productivity of inland saline lakes is due to high sulphate concentrations in the lake water which inhibit molybdate assimilation by phytoplankton. Low intracellular concentrations of molybdate would, in turn, reduce nitrogen fixation and nitrate assimilation, processes which require molybdenum. In a study of 13 Alberta saline lakes with SO_4^{2-} concentrations ranging from 163 to 6240 mg/L, Marino et al. (in press) found that nitrogen-fixing blue-green algae were much less abundant than would be expected from the relationship between TP concentrations and blue-green algal abundance derived for freshwaters. Sulfate concentrations in the Qu'Appelle Lakes range from about 200 mg/L (Buffalo Pound Lake, Hammer 1971) to about 800 mg/L in Echo, Pasqua and Katepwa Lakes (Hammer 1971) and are well within the range observed by Marino et al. (in press) to affect algal productivity. While sulfate-molybdate interference is one possible explanation for the low Chla-TP ratios for the Qu'Appelle Lakes, other possibilities such as light limitation (due to algal self-shading or suspended sediments) or inaccurate Chla measurements (due to heterogeneous distribution of the algae throughout the lake) cannot be discounted.

Aquatic Macrophytes

Little information is available on the aquatic macrophytes of the Qu'Appelle Lakes and the factors controlling their distribution. Rawson & Moore (1944) reported that in 1940 Potamogeton pectinatus was the dominant macrophyte in Echo Lakes, with Ruppia maritima, Chara sp., Potamogeton richardsonii and Myriophyllum sp. also present. Hammer (1973) noted that after water supply to Buffalo Pound Lake was augmented by discharge from Lake Diefenbaker, blue-green algae decreased while aquatic macrophytes increased in abundance. More recently, Jones & Cullimore (1973) measured percent abundance of the various aquatic macrophyte species in the Qu'Appelle Lakes and reported that P. pectinatus and P. richardsonii were the dominant species, with Myriophyllum exalbescens, Potamogeton vaginatus, and Ceratophyllum demersum also present. A survey of the macrophytes in Buffalo Pound, Pasqua, Katepwa and Crooked Lakes on September 6 and 7, 1989 confirmed that P. pectinatus and P. richardsonii are the dominant species in Pasqua, Katepwa and Crooked Lakes, with M. exalbescens also present. C. demersum was not observed, however R. maritima (a species characteristic of saline conditions) was present. Buffalo Pound Lake contained a more diverse flora: M. exalbscens was the dominant species, with Elodea canadensis and P. richardsonii present in moderate quantities, and Lemna trisulca and Alisma sp. less frequently. The greater species diversity of the macrophyte flora in Buffalo Pound Lake than in the other Qu'Appelle Lakes is likely due to the lower salinity (i.e. TDS) of the former. The reduction in species diversity and the presence of R. maritima in Crooked and the Fishing Lakes suggest that salinity levels are approaching or beyond the tolerance limits of some freshwater plant species.

Data on aquatic macrophyte biomass are not available for the Qu'Appelle Lakes, however reports of excessive aquatic macrophyte growth and the fact that several tonnes of plants were removed in 1988 from Buffalo Pound Lake, alone, indicate that rooted aquatic plants are very abundant. This proliferation of submersed aquatic weeds during recent years appears related to a decrease in water inputs to the Qu'Appelle system (Table 8). Between 1970 and 1976, annual discharge of the Qu'Appelle River below Craven Dam and at the outlet of Katepwa Lake averaged 314,895 and 350,132 dam^3, respectively, with values as high as 677,192 dam^3 recorded in 1974. By comparison, annual discharge in 1977 was only 49,340 and 47,243 dam^3, respectively, and in 1988, when aquatic macrophytes were most abundant, annual discharge was less than 19,000 dam^3 at the outlet of Katepwa Lake. The increase in the area colonized by aquatic macrophytes may be due to a decrease in water levels in the lakes and a corresponding increase in the area available for colonization by submersed vegetation or it may relate to changes in open-water chemistry or particulate loading to the sediments as a result of lowered flushing rates. The fact that R. maritima is now present in several of the Qu'Appelle Lakes is consistent with the hypothesis that flushing rates have decreased, thereby increasing salinity and favouring the growth of a salt-tolerant species.

While aquatic macrophytes are reportedly increasing in abundance in the Qu'Appelle Lakes, phosphorus and nitrogen concentrations of plants collected from Buffalo Pound, Pasqua, Katepwa and Crooked Lakes are surprisingly low for plants that are growing prolifically (Table 9). Gerloff & Krombholz (1966) reported that plant phosphorus and nitrogen concentrations below 1.5 and 15 mg/g, respectively, are indicative of nutrient-limiting conditions. While there is some question as to the variability associated with these figures, phosphorus concentrations for plants from Katepwa, Pasqua and, to a lesser extent, Buffalo Pound Lake are only marginally greater than the critical value, while nitrogen concentrations are below the critical value for plants from Katepwa Lake. These results suggest that, in contrast to their reported abundance, aquatic macrophyte growth may be nitrogen and/or phosphorus limited in several of the Qu'Appelle Lakes. The bottom sediments of lakes and rivers are the primary source of nutrients for aquatic macrophytes (Carignan & Kalff 1980, Chambers et al. 1989). In the Qu'Appelle Lakes, sediment nitrogen and phosphorus concentrations are moderate (Table 9), averaging midway between sand (about 0.25 mg P/g and 0.1 mg N/g) and sediments collected from freshwater eutrophic lakes (about 1.3 mg P/g and 15 mg N/g) (Barko 1982, Chambers 1987), and are therefore unlikely to limit aquatic macrophyte growth. Thus, while data on aquatic macrophyte biomass and plant and sediment nutrient concentrations are limited, it appears that the inconsistency associated with algal productivity-nutrient relationships also applies to the rooted aquatic plants. However, few, if any, studies have considered factors controlling aquatic macrophyte growth in inland saline lakes.

CONCLUSIONS AND RECOMMENDATIONS

Open–Water Quality

Analysis of existing data on open-water chemistry of the Qu'Appelle Lakes suggests that phosphorus concentrations have decreased since 1970-1976. However, nitrogen and chlorophyll a concentrations, and summer Secchi depth transparency show no appreciable change over the same period. The reason for the lack of correlation between Chla and phosphorus may be due to either:

1. the analysis of the data. Trends were obscured because of variations in discharge between years, variations between the data sets (i.e. surface-water collections vs. depth profiles, number of samples collected during winter and spring), or problems in comparing long-term means.
2. factor(s) other than nitrogen or phosphorus control algal productivity.

(1) Recommended Strategy

To clarify the factors controlling algal productivity, a thorough analysis of the existing data should be undertaken, including simple and multiple correlations involving Chla, TP (spring and mean summer) and TDN (spring and mean summer) concentrations and loading rates, discharge rate and TDS for data collected under similar conditions (i.e date, sampling depth, location). There is a vast array of Chla and nutrient data available from 1970 to the present. Little is known of Chla-nutrient relationships of inland saline lakes and before further research on the Qu'Appelle Lakes is initiated, the existing data needs to be compiled and analyzed more thoroughly. If these analyses fail to demonstrate relationships to algal productivity, further research aimed at identifying factors controlling algal productivity in the Qu'Appelle Lakes may be warranted.

Aquatic Macrophyte Abundance

Data are not available on either the biomass or distribution (percent surface cover) of aquatic macrophytes in the Qu'Appelle Lakes. However, the reported increase in aquatic macrophyte abundance and distribution during recent years appears related to a decrease in water levels in the lakes and may be due to an increase in area available for aquatic macrophyte colonization or changes in water chemistry or particulate loading as a result of decreased flushing rates. While increased light penetration would also increase macrophyte abundance, there is no evidence to suggest that reduced phosphorus loading to the Fishing Lakes has decreased Chla and increased Secchi depth transparency.

(1) Control Strategies

At present, there are no ideal long-term management strategies for controlling aquatic macrophyte abundance. All current methods are largely cosmetic in that they temporarily reduce the abundance of aquatic weeds but do little to remedy the source of the problem (e.g. high nutrient concentrations in the sediments). These methods include: harvesting, water-level drawdown, surface and sediment covers, sediment removal, and biological introductions.

Harvesting is widely used as a technique to control nuisance aquatic weed growth. It produces few, if any, negative impacts on the environment and the treatment is under the complete control of the operator. The main disadvantage with harvesting is that cut vegetation must be collected and removed from the water to prevent aesthetic problems and avoid re-establishment and growth of the cut fragments. Initially, large-scale harvesting was hoped to aid in reversing eutrophication through the removal of nitrogen and phosphorus incorporated into plant tissue. However, most eutrophic lakes have external and internal nutrient loads well in excess of the amount that can be removed by harvesting. Nevertheless, Wile et al. (1979) estimated that a quantity equivalent to 92 % of the net external phosphorus load was removed from Chemung Lake, Ontario during the first year of harvesting. This was possible because the lake had a relatively low loading rate of phosphorus (1190 kg/year external phosphorus load), macrophyte biomass was high, and plants covered most of the lake surface.

Water-level drawdown, when conducted during the winter months, subjects the shoot and below-ground portions of the plants to freezing-desiccation causing death. Problems associated with this management strategy include:

1. species-specific responses such that species composition of the community may be altered while total macrophyte biomass remains unchanged,

2. the need for the exposed sediments to be well-drained (plants left in only a few cm of water may survive), and

3. the need to lower water levels about 2 m for at least three weeks. This may reduce fish habitat

and cause fish kill because of increased risk of oxygen depletion.

Surface and sediment covers entail covering rooted vegetation with sand, gravel or, more recently, polyethylene sheeting or screening. While this method has proven effective for specific problem areas, sediment covers are expensive, difficult to apply, and require cleaning every 1-3 years to remove accumulated sediments and prevent recolonization by rooted vegetation.

Biological control of nuisance aquatic macrophyte growth through the introduction of exotic species or the manipulation of endemic flora or fauna is a promising tool for the future. Grass carp (Ctenopharyngodon idella Val.) has been widely recognized for its potential to control nuisance aquatic weeds and its efficacy at reducing macrophyte abundance has been demonstrated for several American lakes (Mitzner 1978, Shireman & Maceina 1981, Van Dyke et al. 1984). However, drawbacks to this approach may include negative impacts of the fish on other organisms and nutrient recycling, and the possibility that the fish will reproduce and become a nuisance species.

(2) Recommended Strategy

At present, there are no simple solutions to the cause of excessive aquatic macrophyte growth - namely high nutrient concentrations in the sediments. As a cosmetic solution to the problem of excessive weed growth, aquatic weed harvesting is a viable management strategy. It is effective on the short-term, environmentally sound, and relatively inexpensive when compared with other remedial methods. The decision to harvest (as well as number of cuttings and area to harvest) will rest upon the trade-off between cost and the need to improve the appearance of the lakes. However, selective harvesting at sites deemed by the public to present the greatest problem is usually the most effective in terms of both cost and public response.

(3) Recommended Future Research

In order to develop effective long-term solutions to the problem of excessive aquatic macrophyte growth in the Qu'Appelle and other prairie lakes, it is necessary to attain a clear understanding of the environmental factors regulating the distribution, abundance and productivity of submersed vegetation in these systems. Armed with this knowledge, management strategies could then be developed which target the factor(s) responsible for excessive aquatic weed growth. To accomplish this goal, a three year research programme which focuses on controls of aquatic macrophyte growth in the Qu'Appelle Lakes should be undertaken. The research programme would be divided into three projects aimed at establishing:

1. the extent of aquatic macrophyte growth in the Qu'Appelle Valley Lakes (Year 1),
2. the environmental factors causing excessive aquatic weed growth in these lakes (Year 2), and
3. the appropriate management strategies to regulate the factors responsible for this excessive weed growth (Year 3).

Year 1 - The Extent of Aquatic Macrophyte Growth

At present, there is little, if any, quantitative information on the distribution, abundance, species composition and nutrient status of aquatic macrophytes in the Qu'Appelle Lakes. The extent of our knowledge is limited to observations on species occurrence by Rawson & Moore (1944), a 1971 survey of aquatic macrophyte species composition (Jones & Cullimore 1973), and reports of excessive aquatic weed growth by lakeside property owners. As a first step towards establishing factors controlling aquatic macrophyte growth in the Qu'Appelle Lakes and as baseline data to evaluate the success of any ameliorative efforts, the present extent of aquatic macrophytes in the Qu'Appelle Lakes must be established.

To establish the distribution, biomass, species composition and nutrient status of the submersed plant community, an extensive survey of the Qu'Appelle Lakes (Buffalo Pound, Pasqua, Mission, Katepwa, Echo, Crooked and Round) should be undertaken in July and August . To establish plant distribution, mapping of aquatic weed beds could be done in July by either infra-red aerial photography or SCUBA divers, who would swim transects from shore to the maximum depth of aquatic macrophyte colonization at a variety of sites on each lake and identify presence/absence or relative abundance of aquatic macrophytes. To determine species and total plant biomass, SCUBA divers would need to harvest aquatic macrophytes from within quadrats of known area at selected sites and depths on each lake between the end of July and mid-August (the period of peak macrophyte abundance). The plant samples would then be separated to species, dried to constant weight and weighed. Selected dried plant samples would also be analyzed for total phosphorus and nitrogen content to determine the nutritional status of the plants. This information is necessary to establish the extent of the aquatic macrophyte problem and provide baseline data to test the success of future ameliorative efforts.

In addition to collecting data on the macrophyte community, a monitoring programme should also be undertaken in Year 1 of the project to identify factors (e.g. light, nutrients, wave action) that may be controlling aquatic weed production. Open-water samples should be collected weekly at four or more stations on each lake and analyzed for nitrogen (total (TN) and total dissolved (TDN) nitrogen, NH_4, NO_2+NO_3) and phosphorus (total (TP), total dissolved (TDP) and soluble reactive (SRP) phosphorus) concentrations; once each month, dominant ion (Na^+, K^+, Ca^+, Mg^{2+}, SO_4^{2-}, Cl^-) and total dissolved solid (TDS) concentrations, alkalinity and conductivity should be determined. Secchi disc transparency and underwater light (photosynthetically active radiation) attenuation should be measured each time open-water samples are collected. Sediment samples from sites showing a range in aquatic macrophyte biomass should be collected monthly and analyzed for total and exchangeable phosphorus and nitrogen and sediment particle size. Weather data on wind speed and direction and solar irradiance should be collected daily from stations located near several of the lakes. Bathymetric maps, with a contour scale of less than 1 m for littoral areas, should be produced for each of the lakes. From the data collected in Year 1 of the project, correlation coefficients should be determined relating macrophyte distribution, biomass, and nutritional status to open-water and sediment nutrient concentrations, underwater light levels (calculated from surface irradiance and underwater light attenuation), wave action and exposure (calculated from wind speed and direction and lake bathymetry), and shoreline slope. Results from these analyses would demonstrate which environmental factors are correlated with aquatic macrophyte growth and distribution, and thus provide direction for Year 2 of the research programme.

Year 2 - Environmental Factors Causing Excessive Aquatic Weed Growth in the Qu'Appelle Lakes

Having established the extent of the aquatic weed problem and identified environmental factors relating to excessive aquatic macrophyte growth, the aim of Year 2 of the research programme would be to establish, by means of controlled experiments, the factors promoting excessive aquatic weed growth in the Qu'Appelle Lakes. Environmental factors which, from Year 1 of the study, proved to be correlated with aquatic macrophyte biomass, distribution and/or nutritional status would be manipulated under controlled conditions to determine their role in controlling aquatic macrophyte growth. This may entail growing plants in situ at several depths in pails containing a variety of natural lake sediments to establish the relationship between sediment nutrient concentrations and irradiance and to identify sediment nutrient concentrations which limit aquatic plant growth. In addition, laboratory experiments would likely be necessary to identify the effects of variations in salinity on nutrient availability and uptake by aquatic macrophytes. Results from these experiments would provide a clear understanding of the factors controlling aquatic macrophyte growth in the Qu'Appelle Lakes.

Year 3 - Development of Management Strategies

Having established the factors causing excessive aquatic weed growth in the Qu'Appelle Lakes in Year 2 of the programme, the aim of the Year 3 study would be to develop appropriate management techniques. This would involve determining whether the factors controlling aquatic macrophyte growth were amenable to alteration directly (i.e. by reducing nutrient loads, if nutrient levels were the controlling factor), or indirectly (i.e. by dredging the littoral zone, if the bottom sediments were the controlling factor). One innovative management strategies that should be tested if sediment nutrient levels are found to determine aquatic plant growth is the use of lime or ion exchange resins to render nutrients in the bottom sediments unavailable for plant growth. Field experiments have already indicated a marked reduction in macrophyte biomass in hypereutrophic Figure Eight Lake, Alberta, following the application of lime to the surface waters in order to reduce Chla concentrations (Prepas et al., in press). In Year 3 of the research programme, potential management techniques would be tested in the laboratory and in situ to determine the efficacy of any new management strategies. Cost-benefit analyses should also be undertaken to determine the perceived success of the new technique relative to its capital and operating costs.

By gaining a clear understanding of the environmental factors regulating aquatic macrophyte growth in the Qu'Appelle and other prairie lakes, innovative new management strategies can be developed for successful long-term control of nuisance aquatic weed growth. The development of management techniques aimed at controlling the source of the aquatic macrophyte problem, rather than cosmetic solutions which temporarily remove the problem, is also essential for establishing water quality and quantity guidelines to prevent or reduce future aquatic weed problems in areas undergoing development or changes in land use.

SUPPORT REQUIRED FOR YEAR 1 OF THE QU'APPELLE LAKES MACROPHYTE PROJECT

1. Chemistry

a. Open Water

seven lakes @ four stations/lake @ one depth-integrated sample per station per week for 19 weeks (May 1 to September 4, 1990):

=532 samples for each of TP, TDP, SRP, TN, TDN, NH_4 and NO_2+NO_3

=140 samples for each of alkalinity, conductivity, TDS, and dominant ions (Na^+, K^+, Ca^+, Mg^{2+}, SO_4^{2-}, Cl^-)

b. Sediments

seven lakes @ 18 sampling locations/lake @ one sample per location per month for 3 months:

=378 samples for each of total nitrogen, total phosphorus, exchangeable nitrogen, exchangeable phosphorus and sediment particle size

2. Manpower

a. Weekly open-water and monthly sediment sampling:

2 people @ 2 lakes/day for 7 lakes each week

= 7 person-days/week x 19 weeks (May 1 to Sept. 4, 1990)

b. Harvesting aquatic macrophytes:

field work: 3 people @ 3 days/lake for 7 lakes

= 63 person-days between the end of July and mid-August, 1990

lab work (speciating, drying and weighing plant samples):

3 people @ 15 days = 45 person-days from mid-August to Sept.

c. Bathymetric mapping of lakes:

field work: 2 people @ 3 days/lake for 7 lakes

= 42 person-days at any time during the 1990 summer

mapping: 1 person @3 days/lake for 7 lakes = 21 person-days

3. Equipment and Vehicles

a. Equipment: integrated water sampler, Secchi disc, sediment corer or dredge, macrophyte quadrats, SCUBA gear, transect lines, underwater light meter, thermistor, sediment and water containers, echo-sounder

b. Vehicles:

-vehicle and boat for collection of weekly open-water and monthly sediment samples

-vehicle and boat for three weeks (end of July to mid-August) for macrophyte harvesting

-vehicle and boat for three weeks at anytime during the summer for bathymetric mapping

4. Other

a. Macrophyte Distribution

3 people + vehicle and boat for July to survey aquatic macrophyte distribution

OR contract for aerial photography of Qu'Appelle Lakes

b. Weather Stations

irradiance and wind data can be obtained from existing weather stations at Swift Current (irradiance data) and Regina Airport, Moose Jaw Airport and Broadview (wind data)

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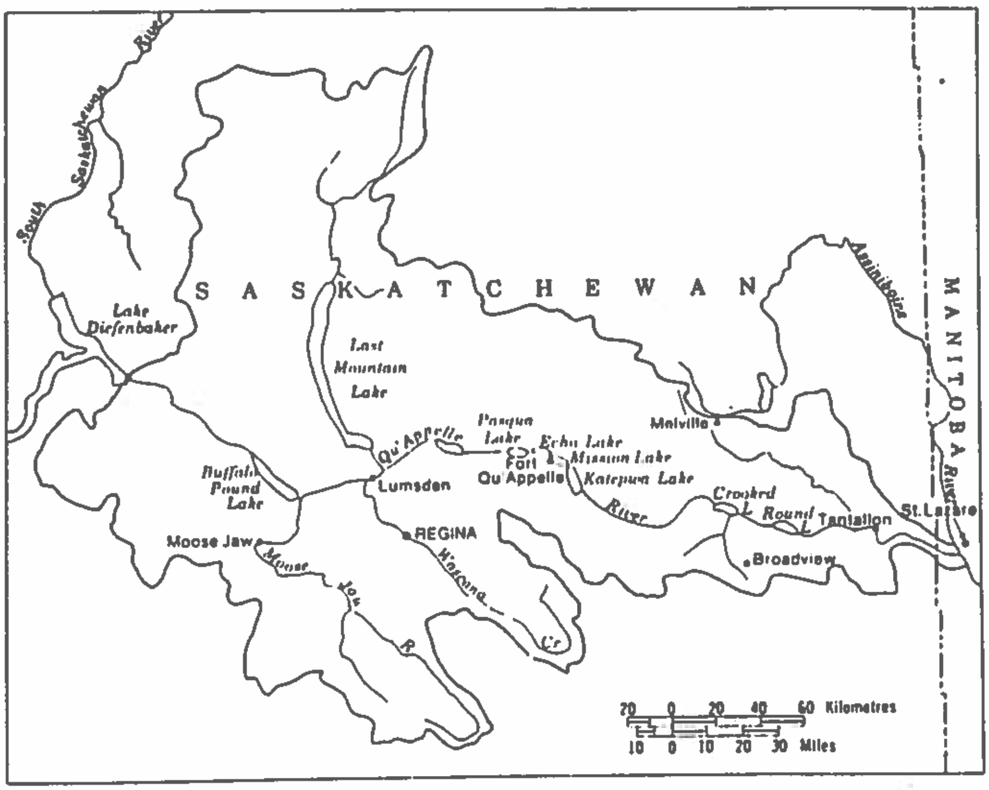

Figure 1. Qu'Appelle River basin.

Table 1. Mean values for phosphorus and nitrogen fractions, TDS, Chla, and Secchi depth for Buffalo Pound Lake.

	1938-41	1959-68[2]	1971[2]	1977[3]	1982-88[4]
TDS (mg/L)		644	310		
TP (μg/L)					102
SRP (μg/L)		400	20		53
TN (μg/L)					1099
NO_2+NO_3 (μg/L)		280	70		49
NH_4 (μg/L)		230	290		151
Chla (μg/L)					28
Summer Secchi (m)		0.9			1.2

[1]Rawson & Moore (1944)

[2]Hammer (1971, 1973)

[3]Allan & Roy (1980)

[4]Saskatchewan Environment & Public Safety (unpubl. data)

Table 2. Mean values for phosphorus and nitrogen fractions, TDS, Chla, and Secchi depth for Pasqua Lake.

	1938-41[1]	1960-67[2]	1970-76[3]	1977[3]	1982-88[4]
TDS (mg/L)	995	1586			
TP (μg/L)			647	848	615
SRP (μg/L)		2710		444	267
TN (μg/L)			2994	1381	4232
NO_2+NO_3 (μg/L)		430		142	72
NH_4 (μg/L)		310		471	2360
TN:TP			4.63	2.50	
Chla (μg/L)			26	35	25
Summer Secchi (m)		1.6		1.3	1.0

[1]Rawson & Moore (1944)

[2]Hammer (1971, 1973)

[3]Allan & Roy (1980)

[4]Saskatchewan Environment & Public Safety (unpubl. data)

Table 3. Mean values for phosphorus and nitrogen fractions, TDS, Chla, and Secchi depth for Echo Lake.

	1938-41[1]	1960-67[2]	1970-76[3]	1977[3]	1982-88[4]
TDS (mg/L)	1294	1743			
TP (μg/L)			556	629	325
SRP (μg/L)		1300		412	250
TN (μg/L)			1989	1389	1860
NO_2+NO_3 (μg/L)		350		80	91
NH_4 (μg/L)		320		174	244
TN:TP			3.58	2.80	
Chla (μg/L)			34	23	16
Summer Secchi (m)	2.9	1.6		1.4	2.4

[1]Rawson & Moore (1944)

[2]Hammer (1971, 1973)

[3]Allan & Roy (1980)

[4]Saskatchewan Environment & Public Safety (unpubl. data)

Table 4. Mean values for phosphorus and nitrogen fractions, TDS, Chla, and Secchi depth for Mission Lake.

	1938-41[1]	1960-67[2]	1970-76[3]	1977[3]	1982-88[4]
TDS (mg/L)					
TP (μg/L)			516	673	426
SRP (μg/L)				598	301
TN (μg/L)			1801	1259	1723
NO_2+NO_3 (μg/L)				15	63
NH_4 (μg/L)				133	148
TN:TP			3.49	1.93	
Chla (μg/L)			26	26	24
Summer Secchi (m)				1.2	1.4

[1]Rawson & Moore (1944)

[2]Hammer (1971, 1973)

[3]Allan & Roy (1980)

[4]Saskatchewan Environment & Public Safety (unpubl. data)

Table 5. Mean values for phosphorus and nitrogen fractions, TDS, Chla, and Secchi depth for Katepwa Lake.

	1938-41[1]	1963-67[2]	1970-76[3]	1977[3]	1982-88[4]
TDS (mg/L)	973	1549			
TP (µg/L)			531	532	379
SRP (µg/L)		580		446	274
TN (µg/L)			1880	1312	1797
NO_2+NO_3 (µg/L)		320		130	67
NH_4 (µg/L)		260		147	288
TN:TP			3.54	2.56	
Chla (µg/L)			21	18	10
Summer Secchi (m)		2.1		1.5	1.6

[1]Rawson & Moore (1944)

[2]Hammer (1971, 1973)

[3]Allan & Roy (1980)

[4]Saskatchewan Environment & Public Safety (unpubl. data)

Table 6. Mean values for phosphorus and nitrogen fractions, TDS, Chla, and Secchi depth for Crooked Lake.

	1938-41[1]	1960-67[2]	1970-76[3]	1977[3]	1982-88[4]
TDS (mg/L)	1008				
TP (µg/L)			252	735	379
SRP (µg/L)				506	252
TN (µg/L)			1827	1090	1949
NO_2+NO_3 (µg/L)				33	32
NH_4 (µg/L)				63	179
TN:TP			6.64	1.77	
Chla (µg/L)			15	101	31
Summer Secchi (m)				1.1	1.1

[1]Rawson & Moore (1944)

[2]Hammer (1971, 1973)

[3]Allan & Roy (1980)

[4]Saskatchewan Environment & Public Safety (unpubl. data)

Table 7. Mean values for phosphorus and nitrogen fractions, TDS, Chla, and Secchi depth for Round Lake.

	1938-41[1]	1960-67[2]	1970-76[3]	1977[3]	1982-88[4]
TDS (mg/L)	887				
TP (µg/L)			219	358	270
SRP (µg/L)				246	198
TN (µg/L)			1586	915	1545
NO_2+NO_3 (µg/L)				24	10
NH_4 (µg/L)				16	70
TN:TP			6.75	2.72	
Chla (µg/L)			9.3	16	26
Summer Secchi (m)				5.6	1.5

[1]Rawson & Moore (1944)

[2]Hammer (1971, 1973)

[3]Allan & Roy (1980)

[4]Saskatchewan Environment & Public Safety (unpubl. data)

Table 8. Annual discharge of the Qu'Appelle River below Craven Dam and at the outlet of Katepwa Lake (Environment Canada Surface Water Data - Saskatchewan).

	Annual Discharge (dam^3)	
	Craven	Katepwa
1970	293,573	317,000
1971	204,761	235,599
1972	97,200	113,482
1973	77,957	70,186
1974	652,522	677,192
1975	414,456	513,136
1976	463,796	524,328
1970-1976 mean	314,895	350,132
1977	49,340	47,243
1982	226,000	213,000
1983	201,000	236,000
1984	86,300	69,300
1985	93,800	125,100
1986	63,100	63,100
1987	64,800	52,800
1988	37,000	18,700
1982-1988 mean	110,286	111,143

Table 9. Total phosphorus and nitrogen concentrations ($\bar{x} \pm$S.E.; n=3) for plant and sediment samples collected September 6 and 7, 1989 from Buffalo Pound, Pasqua, Katepwa and Crooked Lakes. Plant and sediment samples were collected at the same site on each lake; water depth was between 1 and 2 m. (Plant species: Me, Myriophyllum exalbscens; Pp, Potamogeton pectinatus).

	Plant Species	Phosphorus (mg/g DW)	Nitrogen (mg/g DW)
Plants			
Buffalo Pound	Me	1.96 ± 0.03	24.48 ± 0.58
Pasqua	Pp	1.75 ± 0.08	22.21 ± 0.24
Katepwa	Me	1.60 ± 0.14	11.72 ± 0.19
	Pp	1.63 ± 0.15	12.60 ± 0.27
Crooked	Me	2.36 ± 0.07	24.52 ± 0.61
	Pp	2.79 ± 0.27	19.03 ± 0.62
Sediments			
Buffalo Pound		0.86 ± 0.13	5.98 ± 0.46
Pasqua		0.67 ± 0.06	2.50 ± 0.28
Katepwa		0.53 ± 0.10	2.04 ± 0.07
Crooked		0.43 ± 0.07	2.48 ± 0.20