Use of Barley Straw for Algal Control in Prairie Dugouts

Final Report

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Executive Summary

Field applicability trials of the efficacy of rotting barley straw for algal control were carried out on eleven dugouts selected across western Canada. The objective of the work was to assess the applicability of the techniques reported in the literature for use by Prairie farmers.

To facilitate a paired study design, dugouts were divided into treated and control cells using an impermeable geotextile membrane. Barley straw was added using methods and doses found in the primary literature, and water quality parameters were measured to assess potential benefits of the technique for Prairie farmers.

This study indicates that when dosed according to the literature, the barley straw effectiveness was inconsistent and not substantial. Even in the most successful replicate, the maximum algal reduction of 10 ug/L chlorophyll-*a* was too small to be viewed as beneficial to a producer.

Two aspects may have hindered applicability of the technique, but due to limited observations separation of the confounding factors was not possible. The first aspect is related to climate (short treatment season) and the second aspect, which may be related to climate, is dose. Previous studies indicate that the barley straw must be rotting for six weeks at temperatures over 20^{o}C to be effective. In the present study only 3 dugouts maintained a temperature of 20^{o}C or higher for more than six weeks. The second factor is the effective dose. Although this study was unable to separate or quantify the effect, it is possible that with lower temperatures, much higher doses would be required to gain a significant effect. In the present study, the dosages used in 2003 were approaching the limit of practicality for producers.

In conclusion, although a small variable positive effect was obtained using the techniques developed in Europe, a stronger more consistent effect would be required to make this technique viable for Canadian prairie farmers. Certain positive results experienced in 2003 does suggest that if the effect of low water temperatures can be minimized, the efficacy of barley straw may be more apparent Future work, if attempted, could examine methods to utilize abundant solar radiation and air temperature to counteract low water temperatures, or investigate rotting of barley straw externally to the dugout and circulating the straw extract.

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1.0 Introduction

The efficacy of using barley straw as a beneficial management practice (BMP) to control algae in surface water impoundments has been well demonstrated in Europe, and is referenced in many university and government fact sheets in the United States. Emergence of the technology in the popular literature resulted in numerous requests to Agriculture and Agri-Food Canada (AAFC-ACC) from farmers on the applicability of this technique for use in Canada. Successful transfer of the technique could be beneficial to rural water users for managing their water supplies across Canada.

Very little field scale work has been done to verify the technique for use as a BMP in the Canadian context. From 2002 to 2004 AAFC-AAC undertook a prairie-wide, field-scale study of 11 farm ponds (dugouts), to evaluate the efficacy of barley straw as described in the primary literature of the UK. The goals of the study were to:

- Assess the effectiveness and applicability of the technique for use in dugouts of western Canada,
- Communicate the pertinent parameters (dose, timing, application process, treatment duration) to producers for safe and effective application of the technique.

This report presents the results of the study.

1.1 Client Requirements

Farmers in various regions across Canada harvest and utilize surface runoff in dugouts as an on-farm water supply. Despite the inherent water quality problems with these sources, dugouts are commonly used for farm water supplies. In some areas they are viewed as an inexpensive solution to periodic short term drought conditions, whereas in other areas they are the only water supply option available.

AAFC-AAC has invested considerable resources helping farmers manage water quality in dugouts, and has investigated and promoted BMPs for dugout water quality such as, gated inlets, remote watering, aeration, grassed buffer strips, and grassed waterways. Although implementation of these BMPs helps to limit algae growth, algae blooms can still occur and continued research activities are necessary to assist with *in situ* solutions to address the deteriorating water quality of farm surface water supplies. The presence of cyanobacteria (bluegreen algae) is of particular concern because cyanobacteria can produce toxins which can be lethal to humans and livestock.

Presently, farmers deal with algae outbreaks most commonly using various soluble forms of copper or aquatic herbicides. Lime has also been used to co-precipitate algae and phosphorus in dugouts (Prepas et al. 1992). The current practices have a few drawbacks.

Copper and herbicide treatments are a reactive approach as they are applied after the bloom has occurred. These chemical treatments can be toxic to other species and shift the ecology of the system, creating a dependence on chemical treatments. Over time, copper treatments can leave toxic deposits in the sediments (Prepas and Murphy 1988). Furthermore, these treatments can cause cyanobacterial cells to lyse or rupture, thereby releasing toxins into the water (Lam et al 1995). Lime treatments, although effective, are cumbersome and require specialized equipment (Prepas et al. 1992).

The barley straw technique as described in the literature is a preventive measure for controlling algal concentrations. The transferability of this technique to Canadian farmers will depend on the economic, operational and environmental benefits of this technique over the existing chemical treatment methods. To be adopted, ideally the method must be:

- Low cost in terms of labour and materials
- Robust - it should work consistently under a wide range of conditions
- Low maintenance with respect to producer intervention and time requirements
- Proactive, and not require the constant vigilance of the farmer, (i.e. it must prevent algal blooms rather than simply treating a bloom)
- Forgiving - minor dose differences should not result in algal blooms or toxic responses in the pond
- Sustainable - the technique should not affect the natural ecosystem balance of the water body

1.2 Background on Barley Straw Technique

Interest in the use of barley straw for algae control in lakes, rivers, reservoirs and drainage ditches has increased since the early 1990's. Much of this work including laboratory studies and field scale research was completed in the United Kingdom from about 1990 to present (Gibson et al. 1990; Welch et al. 1990; Newman and Barrett, 1993; Barrett et al. 1996; Everall and Lees 1996; Everall and Lees 1997; Ball et al. 2001).

Newman (1999) provides an excellent summary of the barley straw technique, including dose timing and other critical success factors based on his research of U.K. reservoirs. Doses were contingent on turbidity and the general condition of the water at the time of first application. Higher water temperatures (above 20^{o}C) were important for rapid decomposition of the straw for effective algae control. Newman's work also describes general effects on other portions of the aquatic ecosystem such as plants, invertebrates and waterfowl. Newman (1999) also suggests that the application of barley straw may help to permanently establish favourable invertebrates and macrophytes, and balance the reservoir ecosystem.

The exact mechanism causing the barley straw to inhibit algae growth is not fully understood, but researchers believe that there are bacterial and fungal reactions that free humic and fulvic acids from the barley straw, increasing the dissolved organic carbon in the water (Pillinger et al. 1992, Newman 1999). In the presence of sunlight and oxygen, the DOC reacts, and low levels of hydrogen peroxide are produced. Sustained low levels of hydrogen peroxide will inhibit algae growth (Newman 1999). Other researchers believe that the release of phenolic compounds and their oxidation to other phyto-toxic compounds are responsible for inhibiting algal growth (Everall and Lees 1997).

Many university and government extension offices have produced fact sheets on the use of barley straw for algae control (*e.g.* Butler and Terlizzi ND, Lynch ND, AAFRD 1999, Lembi 2002) and there are a number of companies that sell forms of barley straw extract or meshed barley straw for algae control in ponds. As a result there has been producer interest in the Canadian Prairies in using barley to control algae, but no studies have assessed the applicability of the barley straw technique for farm water supplies in the Canadian Prairies. Some demonstrations of the barley straw technique have taken place (Grainews 1995; Aquaculture in Alberta 2002) but no follow-up on its effectiveness was reported. There is a lack of local investigations that can address the effectiveness, or recommend the proper dose and techniques.

2.0 Materials and Methods

2.1 General Description

Eleven dugouts, geographically distributed across the prairies, were selected for study (Figure 1). Trophic status (OECD 1982) of the dugouts ranged from mesotrophic to hyper-eutrophic, with 9 of the 11 dugouts falling into the eutrophic and hyper-eutrophic states (Table 1). In the spring of 2002, each dugout was partitioned into two cells, treated and control, using an impermeable geotextile membrane. Each year, one side of each dugout was dosed with barley straw with doses and applications consistent with those found in the literature. Dugouts were monitored every two weeks, during the summers of 2002 and 2003, for specific physical parameters as well as selected water quality indicators.

2.2 Experimental Design

2.2.1 Response Variable

The objective of this study was to determine whether or not barley straw, applied to dugouts following the methods described in the literature, would reduce algae concentrations. As a result, algae concentrations were determined by measuring chlorophyll *a* concentrations, Secchi disk depth, and turbidity as surrogates. Budget constraints did not permit measuring nutrient or major ion concentrations. In-situ parameters, including temperature and dissolved oxygen were measured to ensure that aeration units were functioning.

2.2.2 Sample Size Requirements

Due to high pond to pond variability, and other natural variability, this study was designed to satisfy the criteria of a paired sample *t*-test, by dividing each study dugout into two cells. This permitted a paired study design in which each dugout provided its own experimental control.

Figure 2 shows the minimum sample size required to obtain a confidence level of 95% (alpha = 0.05) and power of 0.9, versus different coefficients of variation (CV). The minimum detectable change (MDC) that a producer will consider acceptable depends on the threshold algae level and initial algae levels in the dugouts. At this point there is no readily available data on the absolute or threshold level of algae that a producer would consider acceptable. In the absence of a proper "algae threshold" number from producers a MDC of 30% was selected such that marginal differences due to dugouts or treatment technique could be assessed. Based on a CV of 35% (established from chlorophyll *a* data from previous dugout studies) and a MDC of 30%, twelve dugouts would be required.

2.2.3 Dugout Site Selection

Dugouts were selected such that they would be representative of the typical prairie dugout. Only dugouts under acceptable Beneficial Management Practices (BMP's) were permitted in the study as the barley straw method was intended to supplement and not replace existing BMP's.

In order to minimize changes due to uncontrolled variables five criteria were used in choosing dugouts for this study. Dugouts selected were:

1. Actively used by the agriculture sector,
2. Managed at a reasonable level with regard to best management practices,
3. Aerated,
4. Not directly accessible by livestock,
5. Contained within acceptable buffer strips

In addition, to ensure that the technique was applicable to farmers in the varying prairie climate, dugouts were selected to give good geographical distribution across the prairies. Two dugouts in the Peace region of British Columbia, 4 in Alberta, 2 in Saskatchewan, and 3 in Manitoba were selected. One Manitoba dugout was removed from the study after one year, due to conflicting management needs of the owners. Operational problems occurred with installation of the curtains in two of the dugouts in Alberta. As a result, there were eight dugouts which were monitored for 2 years, and 3 dugouts which were monitored for only 1 year.

2.3 Barley Dose and Method

Doses and techniques consistent with recommendations found in the literature were used in this study. Every attempt was made to replicate the critical success factors cited in the literature such as dose, aerobic decomposition, and flow through / mixing.

2.3.1 Barley Dose

Previous field studies reference volumetric dosages ranging from 25-400 g/m^3, whereas the popular literature *(i.e.* fact sheets) suggest using areal dosages ranging from 25-50 g/m^2 (Table 2). Laboratory studies used dosages that were 1-2 orders of magnitude higher than field trials (Table 2).

Barley doses consistent with field trials and the popular literature were chosen for this study. The intended dose in the 2002 field season was 50 g/m^2. However, there was some variability in the doses that were actually achieved at each site (Table 3). Dose protocols were adjusted in 2003 because no appreciable response was observed in the first year of the study. The intended dose in 2003 was 75 g/m^2; however, again, actual dosages were often higher (Table 3). The dosages expressed volumetrically as g/m^3 are also given in Table 3.

2.3.2 Barley Straw Application Method

Barley straw was applied following the guidelines suggested by Newman (1999). In the spring the respective dose of barley straw was placed in mesh bags with floats and floated on the surface in the middle of each dugout (Figure 3). The straw was loosely packed inside commercial onion mesh bags and placed in the vicinity of the aerator where the water currents created by aeration allowed water to circulate through the decaying straw.

In 2002, midway through the summer, an additional dose of barley straw was added to the dugouts and four weeks later the original dose was removed. In 2003, only one dose of barley straw was added in the spring.

2.4 Data Collection Methods

Each dugout was visited biweekly from May to September. Field measurements and water samples were taken from both the control and treated sides of the dugout. Field measurements included vertical profiles of oxygen concentration and water temperature, turbidity measurements and Secchi depth.

Integrated water samples were collected for chlorophyll *a* and turbidity analyses from the euphotic zone (defined as twice the Secchi disk depth) of the control and treated sides of each dugout. Samples were filtered in the field, then frozen and sent to the University of Alberta for analysis. Chlorophyll *a* concentration was determined by cold ethanol extraction

(Bergmann and Peters 1980). Turbidity was measured in the field with a Palin 900 Turbidimeter.

3.0 Results

3.1 QA/QC

Chlorophyll *a* values represent the mean of values from replicate filters. Commonly triplicate samples are used because of the high variability in the distribution of algae cells in water samples. Due to budget restraints, we only analysed duplicate filters. An analysis of the variability among the duplicates showed that more than 50% of the samples had a coefficient of variation of less than 2%, more than 70% of the samples had a coefficient of variation of less than 5%, and 86% of the samples had a coefficient of variation of less than 10% (Figure 4).

The chlorophyll *a* analyses for the Washington dugout in 2002 were confounded due to high turbidity, and as a result the chlorophyll *a* results for Washington 2002 were removed from the data analysis.

3.2 General Chemistry

Throughout the open water period, chlorophyll *a* concentrations in the dugouts ranged from <2 µg/L to >130 µg/L over the length of the study. The mean summer chlorophyll *a* in the control sides of the dugouts was 22.1 µg/L in 2002 and 22.7 µg/L in 2003. In the treated sides of the dugouts, the mean summer chlorophyll *a* was 21.8 µg/L and 20.5 µg/L in 2002 and 2003, respectively (Table 4).

Turbidity values ranged from <1 NTU to 156 NTU over the length of the study. Mean summer turbidity values in the control sides of the dugouts were 21.6 NTU in 2002 and 16.7 NTU in 2003. The mean summer turbidity value of the treated sides of the dugouts was similar to the controls at 20.6 NTU in 2002 and 15.8 NTU in 2003 (Table 4).

Secchi depths ranged from 7 – 280 cm over the length of the study (Table 4). Mean summer Secchi depths for the controls were 113 and 80 cm in 2002 and 2003, respectively. For the treated sides, mean summer Secchi depths in 2002 and 2003 were 99 cm and 85 cm, respectively.

There was little variation in temperature between the control and treated sides of the dugouts. In 2002, temperature ranged from approximately 7^{o}C to 26^{o}C with a mean of 17.7^{o}C (Table 4). The mean summer temperature was slightly higher in 2003 at 18.1^{o}C (Table 4). With the exception of some of the more northern dugouts, most reached 15^{o}C early to mid-June and remained at or above 15^{o}C until the end of August (Figure 5). Fewer dugouts remained above 20^{o}C for an extended period of time (Figure 6). In 2002, only one dugout was above 20°C for more than a month, and the Washington dugout never reached 20°C. It was slightly warmer in 2003 and 3 dugouts remained over 20°C for at least 2 months.

Similar to temperature, there was little dissolved oxygen variability among control and treated sides of the dugouts (Table 4). Mean summer dissolved oxygen concentrations were 7.0 mg/L and 6.8 mg/L in 2002 and 2003, respectively (Table 4). Most dugouts remained well oxygenated throughout the study period (see Appendix A). With the exception of the Washington dugout, dissolved oxygen never fell below 2.0 mg/L in any dugout, and mean concentrations ranged from 4.4-11.0 mg/L. The first year of the study (2002) was the first year the Washington dugout was aerated, and it remained anoxic throughout the year; however, in 2003, dissolved oxygen concentrations were slightly higher and the mean summer concentration increased to over 1.5 mg/L.

3.3 Treatment Comparisons

3.3.1 Turbidity

Although the mean summer turbidity value was lower in the treated sides of the dugouts in both 2002 and 2003, the differences were not statistically significant (Table 5). The differences in mean summer turbidity between the treated and control sides ranged from -7.1 to 4.8 NTU over the length of the study (Figure 7).

3.3.2 Secchi Disk depth

The differences in mean summer Secchi depth between the treated and control sides ranged from -77 to 33 cm over the length of the study (Figure 8). When Secchi depths between the control and treated sides were compared in 2002 and 2003, neither year was significant at the α=0.05 level (Table 5). If α is increased to 0.10, then in 2003, the treated side had greater Secchi depths than the control side (p=0.09), whereas in 2002 the treated side had lower depths than the control side (p=0.07).

3.3.3 Chlorophyll a

The difference in mean summer chlorophyll *a* between treated and control sides of the dugouts ranged from -9.8 to +2.5 µg/L over the study period (Figure 9). When expressed as a percentage of the control mean values, the chlorophyll *a* in the treated sides of the dugouts ranged from 61-114% (Figure 10).

There was no obvious relationship between the degree of difference in chlorophyll *a* between control and treated sides and the concentration of chlorophyll a (Figure 11), the dosage (Figure 12) or the temperature (Figure 13). Limited numbers of observations did not allow comprehensive multivariate statistics.

When the chlorophyll *a* data were analysed by year, there was no significant difference between the control and treated sides (p=0.38) in 2002, but in 2003, the chlorophyll *a* concentration in the treated sides was significantly lower than the chlorophyll *a* concentration in the control sides (p=0.04), although the mean reduction was < 10% (Table 5). These patterns are similar to the Secchi depth data.

Both the mean surface water temperature and the barley straw dosages were higher in 2003 than in 2002 (Figures 14 & 15), hence it is difficult to attribute the better response to a single factor.

4.0 Discussion

The main objective of this work was to assess the applicability of the barley straw technique, as reported in the literature, to dugouts in the Canadian prairies. In the current study, following the protocols established in the literature, a small reduction (mean of < 10%) in chlorophyll *a* was observed in the second year of the two-year study.

The original published works document significant immediate reductions in algae concentrations of water bodies treated with barley straw. In a series of canals and locks in the U.K., chlorophyll *a* decreased by as much as 90% downstream of the treated locks (Welch et al. 1990) in the first year of treatment. In follow-up work at the same site, when straw was not replaced in the uppermost lock, algae populations recovered in the untreated portion, but growth continued to be inhibited further downstream where additional barley straw treatments occurred (Ridge and Barrett 1992). Similar results were illustrated in a Scottish potable water supply, where chlorophyll *a* decreased by 90% in the first year of treatment (Barrett et al. 1996).

On the other hand, some field-based studies in both the U.K and the United States have not been able to replicate the earlier results. Kelly and Smith (1996) found no impact on algal concentrations in a lake in central Scotland. Similarly Lembi (2002) describes barley straw experiments in Illinois and Nebraska which showed little or no impact on algal growth. Although Boylan and Morris (2003) had inconsistent results, they found that the technique was most successful in well oxygenated water bodies, which lends support to the original U.K. studies. Laboratory studies have also been inconsistent in terms of both the dosages required for effective control, as well as the species that were inhibited (Brownlee et al 2003).

Despite some conflicting results on species affected and strength of response, most studies, including the present work, have reported some inhibitory effect of rotting barley straw on algal growth. In particular, the evidence does suggest that under certain conditions barley straw has an inhibitory effect on various species of diatoms (e.g. Barrett et al. 1996), chlorophytes (e.g. Welch et al 1990, Ridge and Barrett 1992) and cyanobacteria (e.g. Newmann and Barrett 1993, Everall and Lees 1996, Ball et al 2001). While the present study did not assess phytoplankton assemblages in the dugouts, most eutrophic ponds and lakes in the Canadian prairies are dominated by diatoms in the spring, and various chlorophytes and cyanobacteria in the summer (Mitchell and Prepas 1990, Kotak et al 1993). Dose, temperature, as well as the PFRA aeration method could be factors which affected the response in the current study.

4.1 Dose and Temperature

In 2002 no statistically significant response ($p=0.38$) to the treatments was observed at a dose rate of 50 g/m^2. The study team was faced with a decision to either:

1. Leave the dose at 50 g/m^2, have a statistically sound study but stand to risk another year with no algal control, or
2. Increase the dose to the high range of the literature (100 g/m$^{2)}$, and perhaps find a key difference that could induce a response in the Canadian setting.

Although the primary objective of the study was to evaluate the technique as presented in the literature, the practical outcome of the work was to transfer a useful technique to the Canadian prairie farmer. To ensure that the work did not unfairly dismiss a potentially favourable management technique, it was decided to double the dose for the 2003 field season. Changes in the dose protocol from average recommended dose of 50 g/m^2 in 2002 to the upper range 100 g/m^2 in 2003 were made during the test. In implementation there was variability in this dose (see Table 3) which further limited separation of the dose effect.

Concurrent with the dose protocol change in 2003, the average temperature in the dugouts was also higher. Although there are not enough observations to separate or quantify the effects, some interesting observations can be made from the data. If temperature alone was the primary factor, Dugouts MZTRA 2003 (Time>20^{o}C = 9 weeks, dose 60 g/m^2), MJ1N 2003 (Time>20 ^{o}C = 8 weeks, dose 85 g/m^2) and MJ2S 2003 (Time >20 ^{o}C = 8 weeks, dose 100 g/m^2) would be expected to be the top performing dugouts as these dugouts were above the critical temperature of 20 ^{o}C for the longest time. Surprisingly Mielke 2003 (Time>20 ^{o}C = 2 weeks, dose 60 g/m^2) and Matychuk 2003 (Time>20 ^{o}C = 3 weeks, dose 75 g/m^2) both ranked high in terms of performance in 2003. Both of these dugouts achieved their maximum temperatures during the time when you would also expect blooms to occur. This would suggest that timing of the 20 ^{o}C period is critical.

Dose increase also does not seem to be able to fully compensate for temperature deficiencies. If this were the case Beausejour 2003 would be expected to perform better than observed as it was at 4 times the dose of many other dugouts; however, it is also only mesotrophic, and algae concentrations may have been below the point at which an observable impact can be found. On the other hand, MZTRA performed better in 2003 than in 2002 even though the dose was 40 g/m^2 lower in 2003.

Another possible confounding factor may be the effective dose of the barley straw in the mesh enclosure. At the end of the 2002 field season technicians reported that only the outer inch or so, of the barley straw in many of the mesh bags appeared to be rotting. Straw in the interior of the enclosures appeared fresh. In 2003 the density of packing of the barley was reduced to ½ that of 2002, allowing better water circulation through the straw and possibly increasing the effective dose.

4.2 PFRA Aeration Method

Newman (1999) suggests that higher doses are required in highly turbid water as soil particles tend to denature the active ingredient in the rotting barley straw. This raises the question that the PFRA aeration method could affect the barley process. The PFRA aeration method requires that air diffusers be located directly on the bottom of the dugout to achieve full turnover of the water body. This method was found to achieve the best nutrient reduction in the dugout. Aerated water in direct contact with the bottom sediments prevents anaerobic decomposition and generation of hydrogen sulphide and sulphuric acid. Under the PFRA method of aeration the water body turns over multiple times in a 24 hour period. This continuous contact with the bottom sediment may play a factor in the reduced performance of the barley technique.

5.0 Conclusions and Recommendations

This study confirms a statistically significant but operationally insignificant (from a practical perspective) reduction of algae due to barley straw. The Canadian Prairie climate, with low average water temperatures may be a contributing factor limiting the applicability of the technique. A slight response was experienced with increased temperature and dose, and this suggests that changes to the application techniques could possibly be used to overcome the limitations of water temperature.

Future work if attempted could examine means to overcome the temperature limitation. Suggestions include assessing the timing of the barley straw additions, or developing alternative dosing methods that utilize high air temperatures earlier in the season. One approach could be to construct a shallow section of a dugout where water temperatures will increase more rapidly. Another approach may be to use a trough or tank to rot the barley straw and add the straw leachate to the dugout.

The technique as cited in the literature appears to have limited applicability in the Canadian Prairies due to the lower average temperatures of the prairie dugout. Although a small and variable effect could be measured, a stronger more consistent algal reduction effect would be required to make this technique viable for widespread use by farmers.

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Table 1: Dugout Locations

Dugout	No.	Regional Location	Trophic Status[1]	Comments
Washington	1	Dawson Creek, BC	Eutrophic	High turbidity in 2002
Mielke	2	Dawson Creek, BC	Eutrophic	
Camrose	3	Camrose, AB	Hyper-eutrophic	Curtain problems in 2002
Hanna	4	Hanna, AB	Mesotrophic	Curtain problems in 2002
Matychuk	5	Peace River, AB	Eutrophic	
Krawchuk	6	Peace River, AB	Eutrophic	
MJ1 – North	7	Moose Jaw, SK	Eutrophic	
MJ2 – South	8	Moose Jaw, SK	Eutrophic	
Storey	9	Dauphin, MB	Eutrophic	Removed after 2002.
Mztra	10	Brandon, MB	Hyper-eutrophic	
Beausejour	11	Beausejour, MB	Mesotrophic	

[1]As defined in OECD 1982

Table 2: Barley Straw Doses Found in Literature

Scientific Literature			
Date	**Reference**	**Lab/Field**	**g/m^3**
1990	Welch I.M., Barrett P.R.F., Gibson M.T., and Ridge I. 1990. Barley straw as an inhibitor of algal growth I: studies in the Chesterfield Canal. Journal of Applied Phycology 2: 231-239	Field	400
1990	Gibson M.T., Welch I.M., Barrett P.R.F., and Ridge I. 1990. Barley straw as an inhibitor of algal growth II: laboratory studies. Journal of Applied Phycology 2: 241-248	Lab	4000
1993	Newman J.R. and Barrett P.R.F. 1993. Control of Microcystis aeruginosa by decomposing barley straw. Aquatic Plant Management 31: 203-206.	Lab	1600
1996	Barrett P.R.F, Curnow J.C. and Littlejohn J.W. 1996. The control of diatom and cyanobacterial blooms in reservoirs using barley straw. Hydrobiologia 340: 307-311	Field	44.5
1996	Everall N.C. and Lees D.R. 1996. The use of barley straw to control general and blue-green algal growth in a Derbyshire reservoir. Water Research 30: 269-376	Field	50
1997	Everall N.C. and Lees D.R., 1997. The identification and significance of chemicals released from decomposing barley straw during reservoir algal control. Water Research. 31: 614-620	Field	25
2001	Ball A.S., Williams M, Vincent D and Robinson, J. 2001. Algal growth control by a barley straw extract. Bioresource Technology 77: 177-181	Lab	5000
2003	Brownlee E.F., Sellner S.G., and Sellner K.G. 2003. Effects of barley straw (Hordeum vulgare) on freshwater and brackish phytoplankton and cyanobacteria. Journal of Applied Phycology. 15: 525-531	Lab	312.5 - 1250
Popular Literature			
Date	**Reference**	**Lab/Field**	**g/m^2**
No Date	Algae Control with Barley Straw. Ohio State University Extention Fact Sheet A -12-02. W.E. Lynch. 2p	Field	25
No Date	Integrated Pond Management for Maryland. Maryland Cooperative Extension Fact Sheet 766. B.R. Butler and D. Terlizzi. 8p	Field	10-35
1999	Algae Control in Ponds. Alberta Agriculture Food and Rural Development Fact Sheet: Agdex 485/716-2. 3p.	Field	10
1999	CAPM Information Sheet 3: Control of Algae Using straw. 1999. IACR-Centre for Aquatic Plant Management. J.R. Newman. 15p	Field	10-50
2002	Aquatic Plant Management: Barley straw for Algae Control. Purdue University Extension Fact Sheet APM-1-W. Carole Lembi. 8p.	Field	25

Table 3: Barley Doses Applied By Year

Dugout	No.	Date	Areal Dose (g/m2)	Volumetric Dose (g/m^3)
Washington	1	2002	50	25
		2003	75	37
Mielke	2	2002	40	22
		2003	60	33
Camrose	3	2002	0	0
		2003	50	21
Hanna	4	2002	50	21
		2003	50	21
Matychuk	5	2002	50	18
		2003	75	27
Krawchuk	6	2002	50	25
		2003	75	37
MJ1-North	7	2002	40	25
		2003	85	50
MJ2-South	8	2002	50	23
		2003	100	46
Storey	9	2002	100	45
MZTRA	10	2002	100	64
		2003	60	40
Beausejour	11	2002	100	53
		2003	200	106

Table 4: Minimum, Maximum, and Summer Mean values for various parameters for all Control and Treated Dugouts in 2002 and 2003

Parameter	Units	Year	Treatment	Min	Max	Summer Mean
Chlorophyll *a*	µg/L	2002	C	2.1	132.6	22.1
			T	1.7	89.6	21.8
		2003	C	1.8	95.9	22.7
			T	0.8	91.4	20.5
Turbidity	NTU	2002	C	0.4	155	21.6
			T	0.3	156	20.6
		2003	C	1.0	47.9	16.7
			T	0.6	48.3	15.8
Secchi Depth	cm	2002	C	7	280	113
			T	10	260	99
		2003	C	25	210	80
			T	20	260	85
Dissolved Oxygen	mg/L	2002	C	0.3	12.0	7.0
			T	0.3	12.3	7.0
		2003	C	0.3	14.5	6.8
			T	0.2	10.7	6.8
Temperature	^{o}C	2002	C	7.2	26.2	17.7
			T	7.2	26.2	17.6
		2003	C	7.4	25.2	18.1
			T	7.6	25.1	17.9

Table 5: Paired t-test comparisons for barley straw treatment effect on mean summer turbidity, Secchi depth and chlorophyll *a* concentrations by year ($\alpha = 0.05$)

Parameter	Year	Control	Treated	P-value
Turbidity (NTU)	2002	21.6	20.6	0.1772
	2003	16.7	15.8	0.2296
Secchi depth (cm)	2002	113	99	0.0714
	2003	80	85	0.0932
Chlorophyll *a* (µg/L)	2002	22.1	21.8	0.3886
	2003	22.7	20.5	***0.0373***

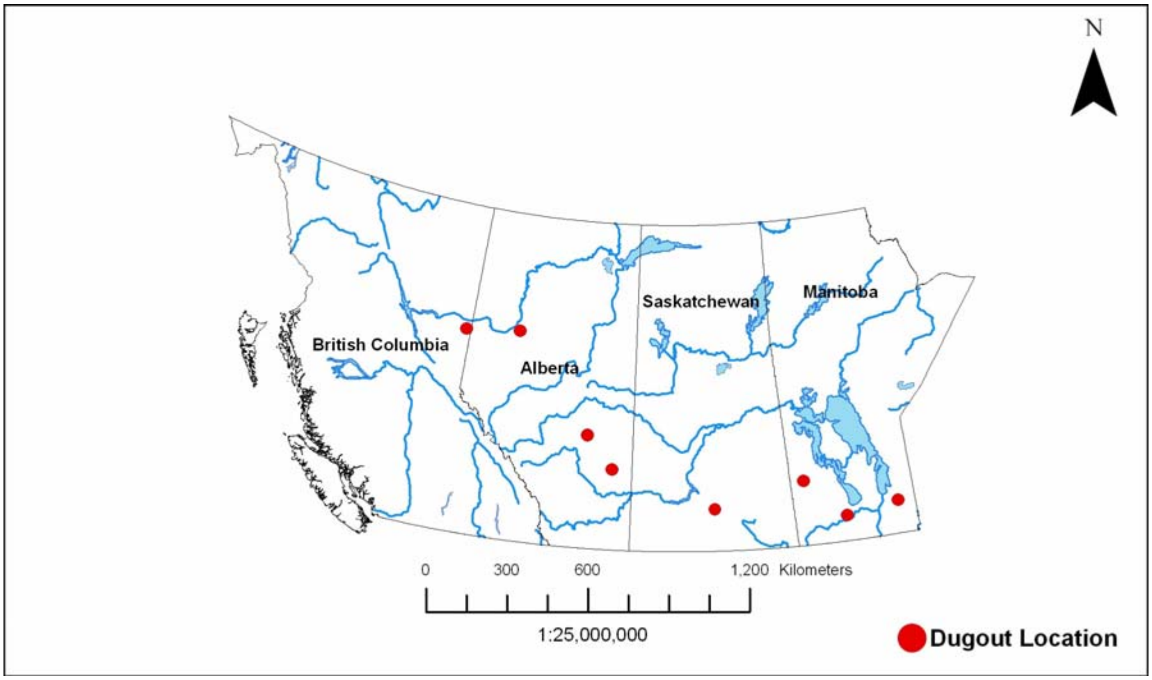


Figure 1: General Location of Study Sites. Note there are two dugouts in Dawson Creek, BC, two dugouts in Peace River, Alberta, and two dugouts in Moose Jaw, Saskatchewan.

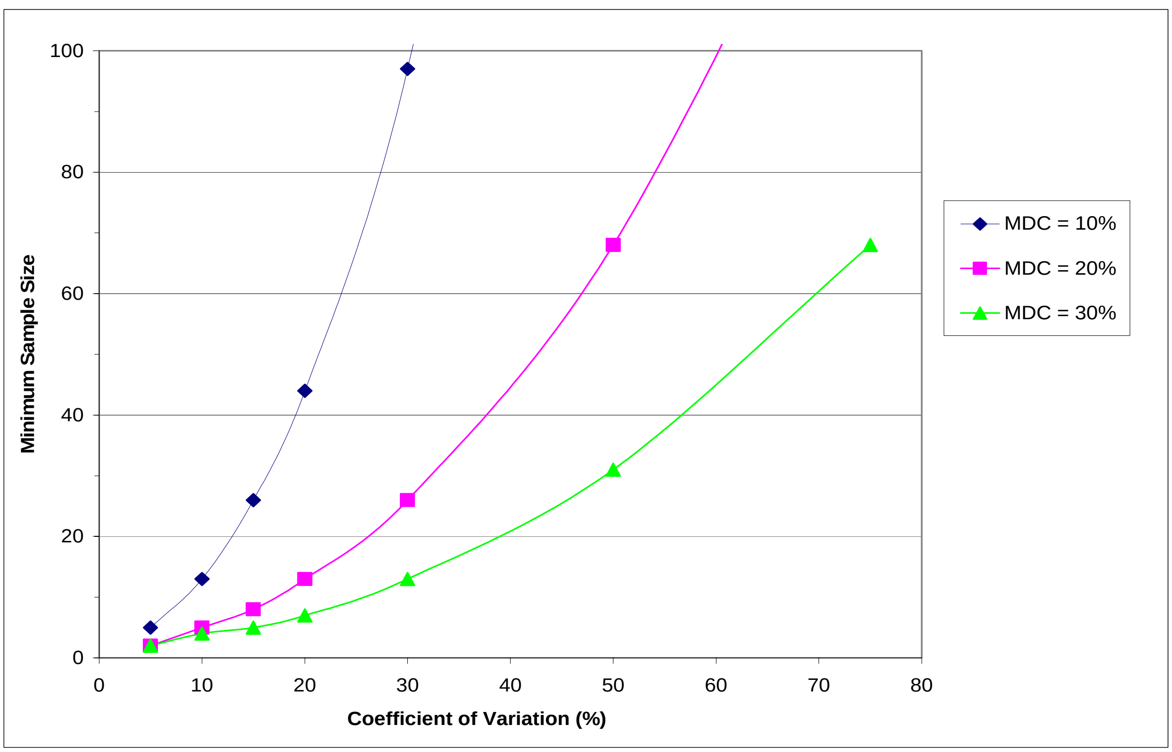


Figure 2: Sample Size as a function of Variation and Minimum Detectable Change (α=0.05 and β=0.9)

Figure 3: Adding barley straw to partitioned dugout.

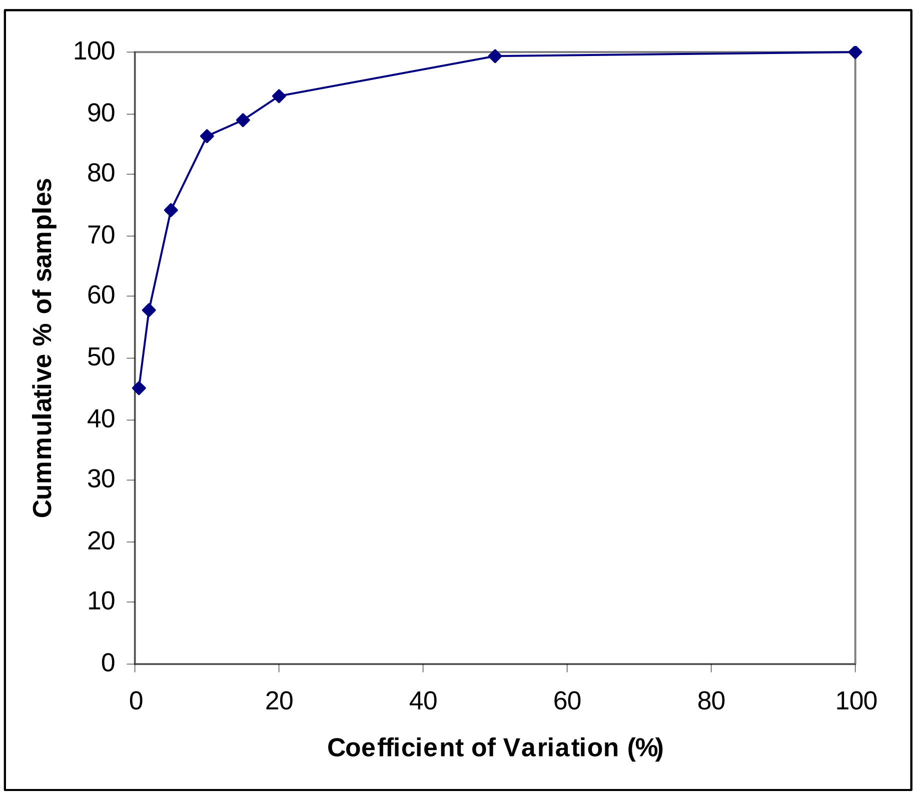


Figure 4: Coefficient of Variation on Duplicate Filters

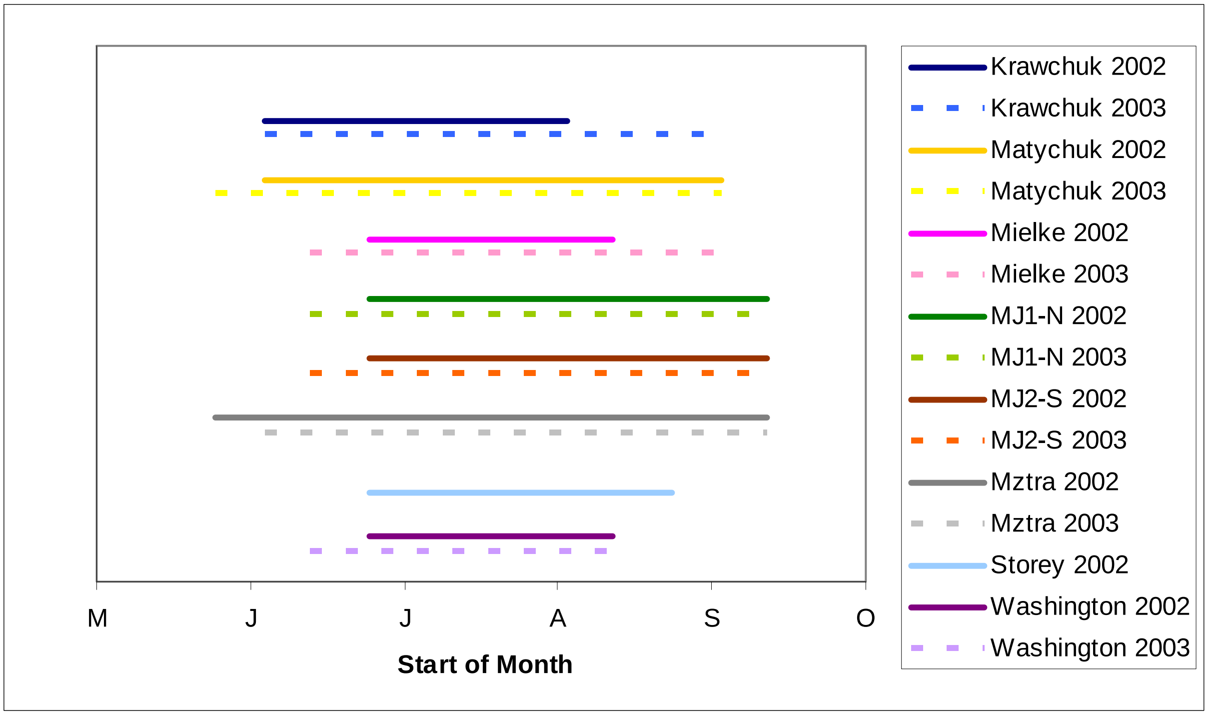


Figure 5: Approximate Time Periods when Temperature > 15°C. Note: Length of bar represents period of time temperature remained above 15°C.

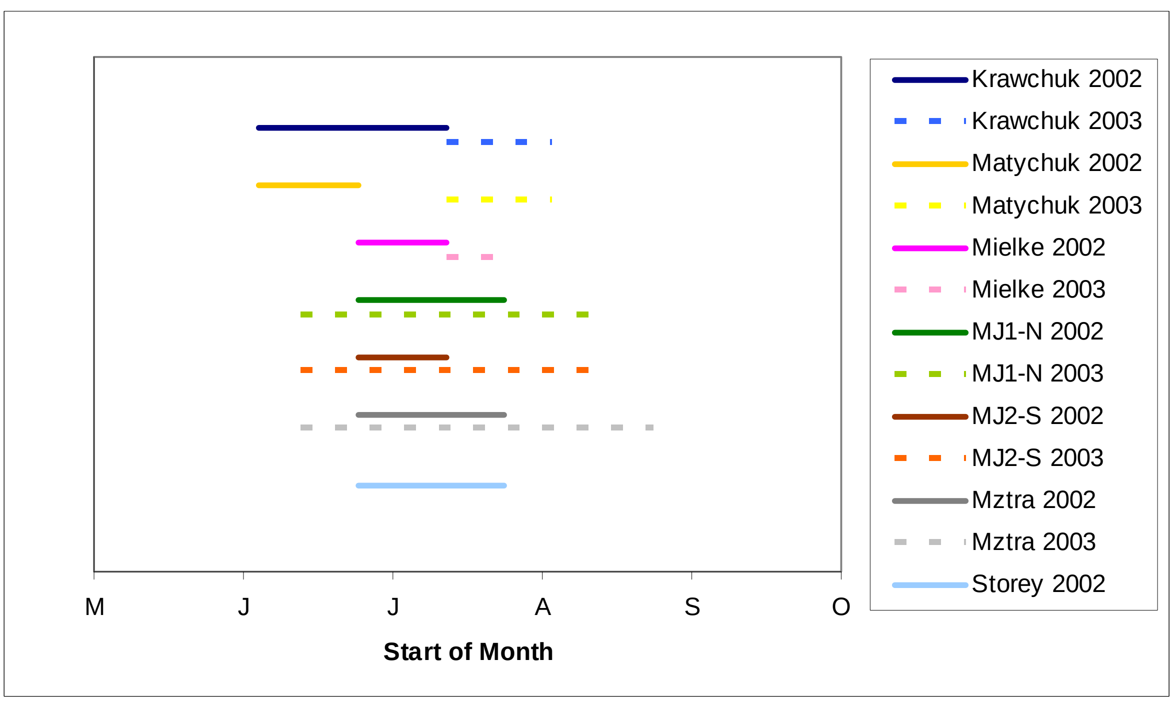


Figure 6: Approximate Time Periods when Temperature > 20°C. Note: Length of bar represents period of time temperature remained above 20°C.

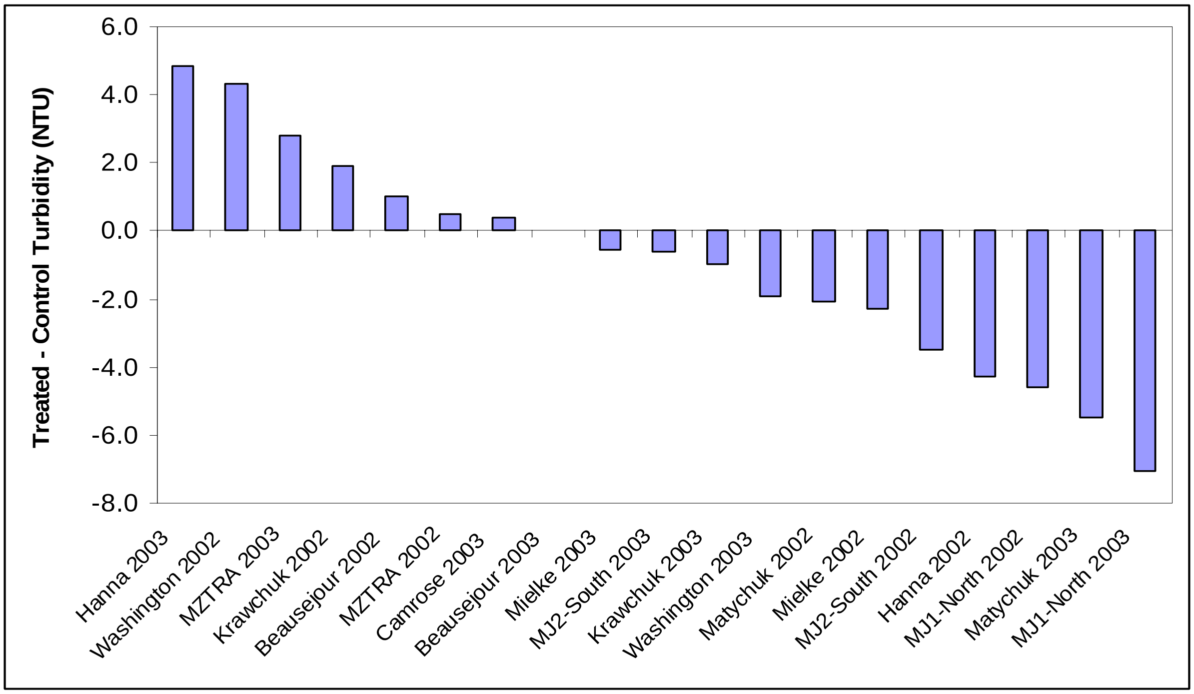


Figure 7: Difference in Mean Summer Turbidity (NTU) between Treated and Control Sides of each Dugout

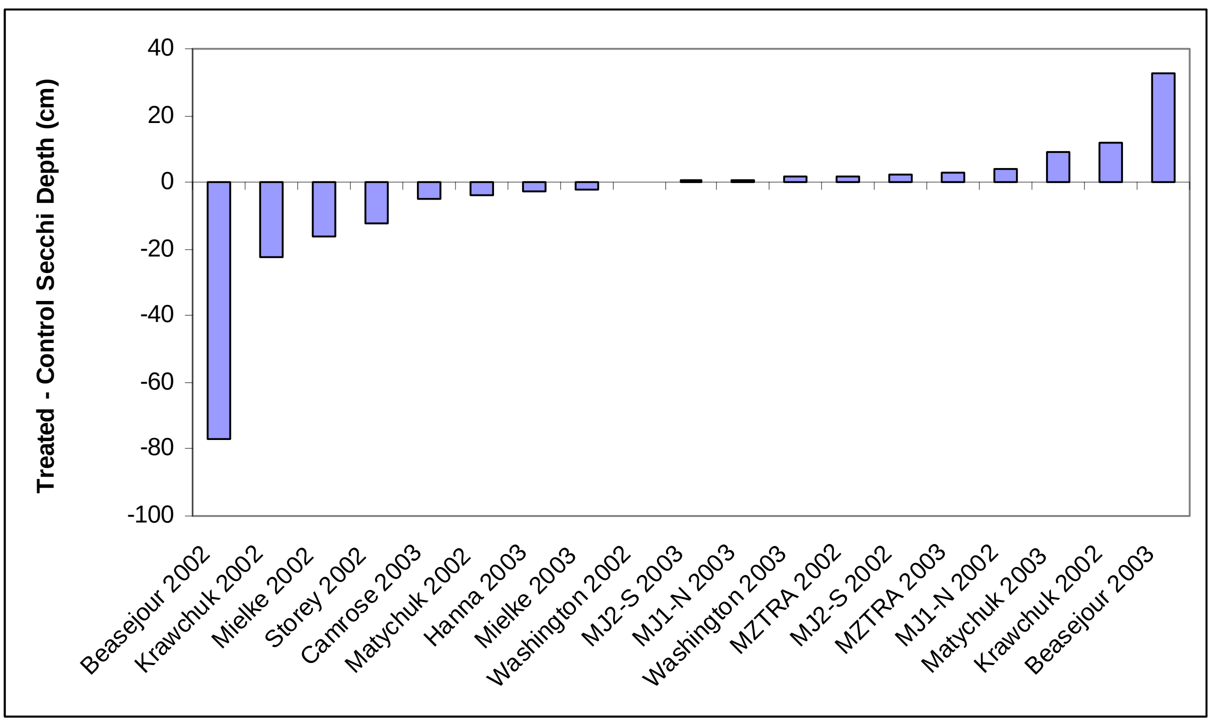


Figure 8: Difference in Mean Summer Secchi disk depth (cm) between Treated and Control Sides of each Dugout

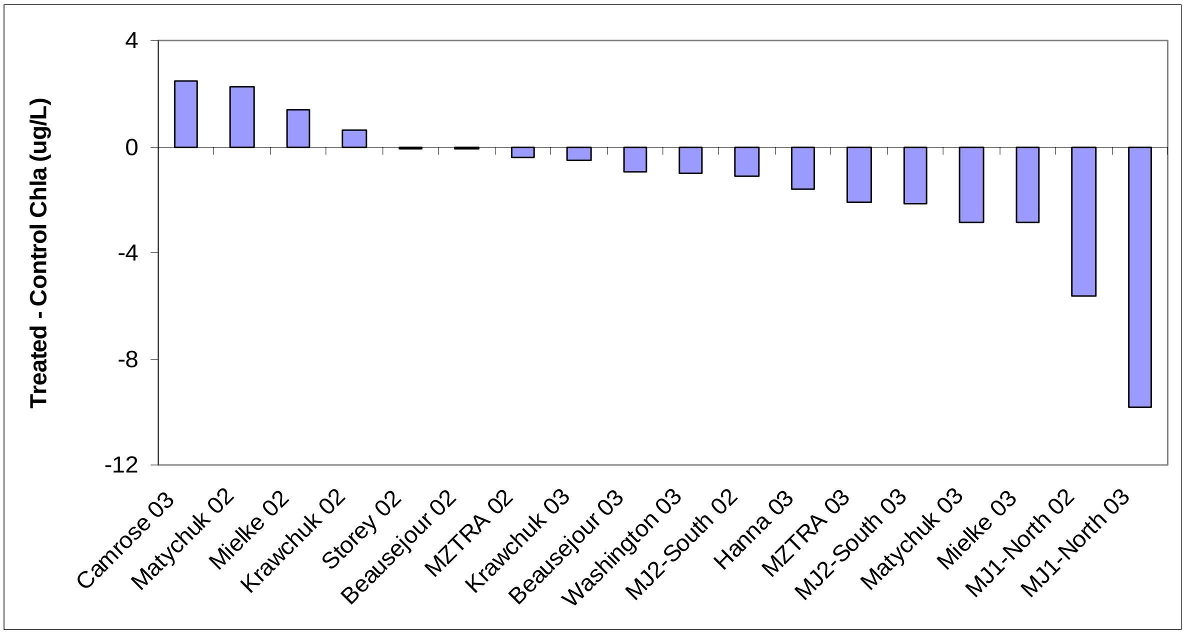


Figure 9: Difference in Mean Summer Chlorophyll a (µg/L) between Treated and Control Sides of each Dugout

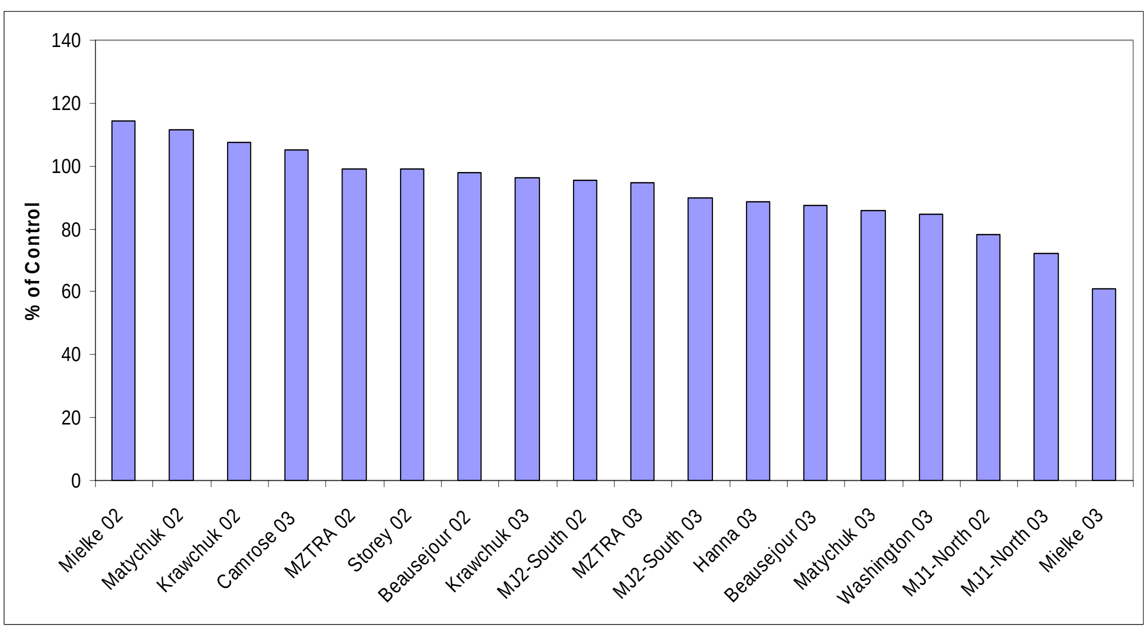


Figure 10: Mean Summer Chlorophyll a in the Treated Side of the Dugout, expressed as a % of the Control Side Mean Summer Chlorophyll a

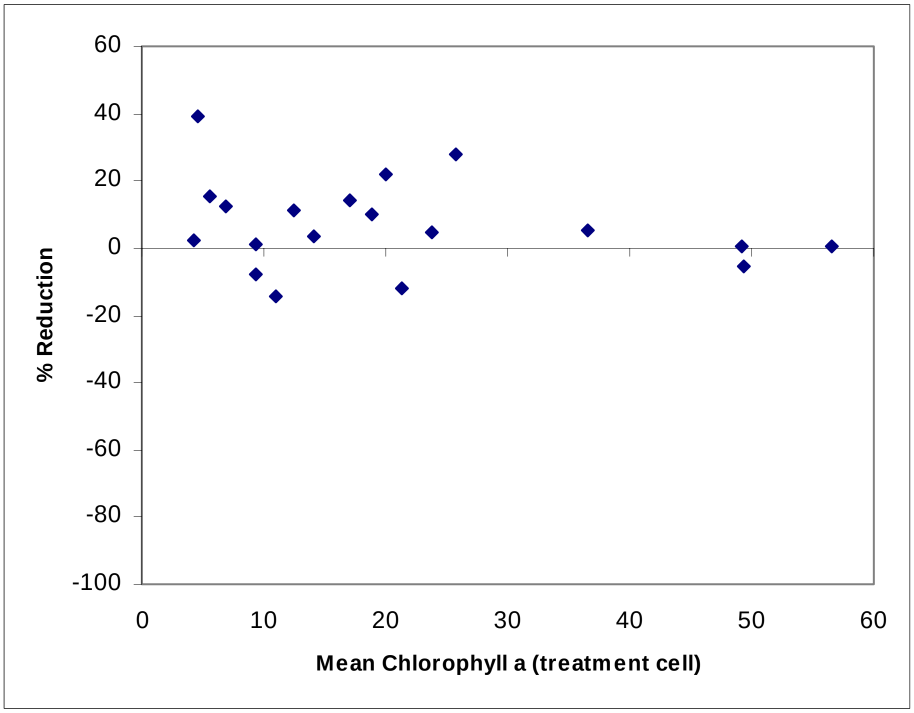


Figure 11: Plot of % Reduction in Chlorophyll a versus Mean Summer Chlorophyll a

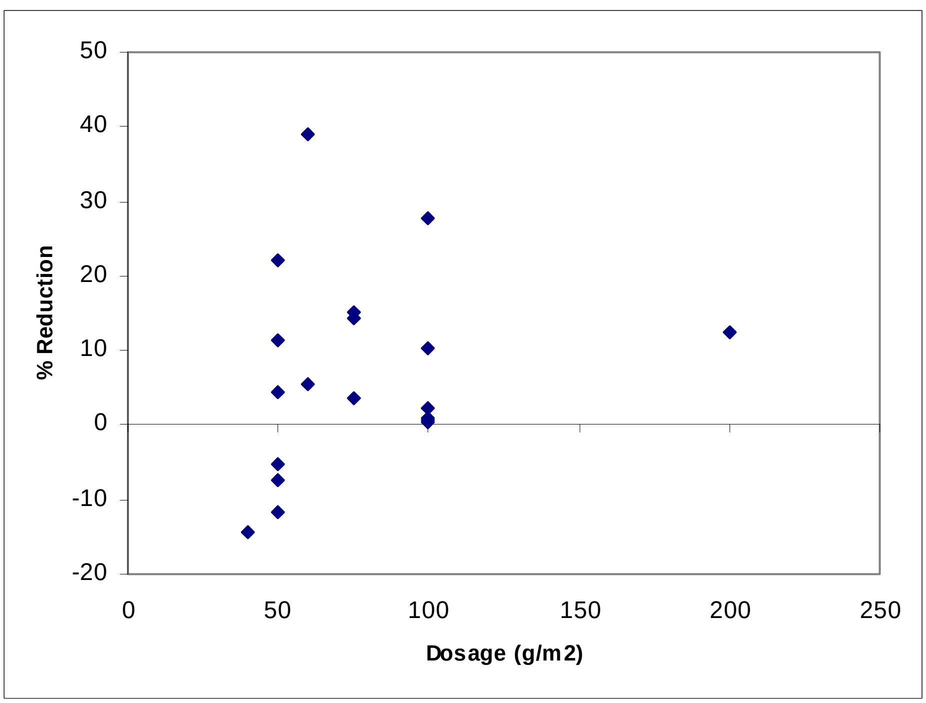


Figure 12: Plot of % Reduction in Chlorophyll a versus Barley Straw Dosage

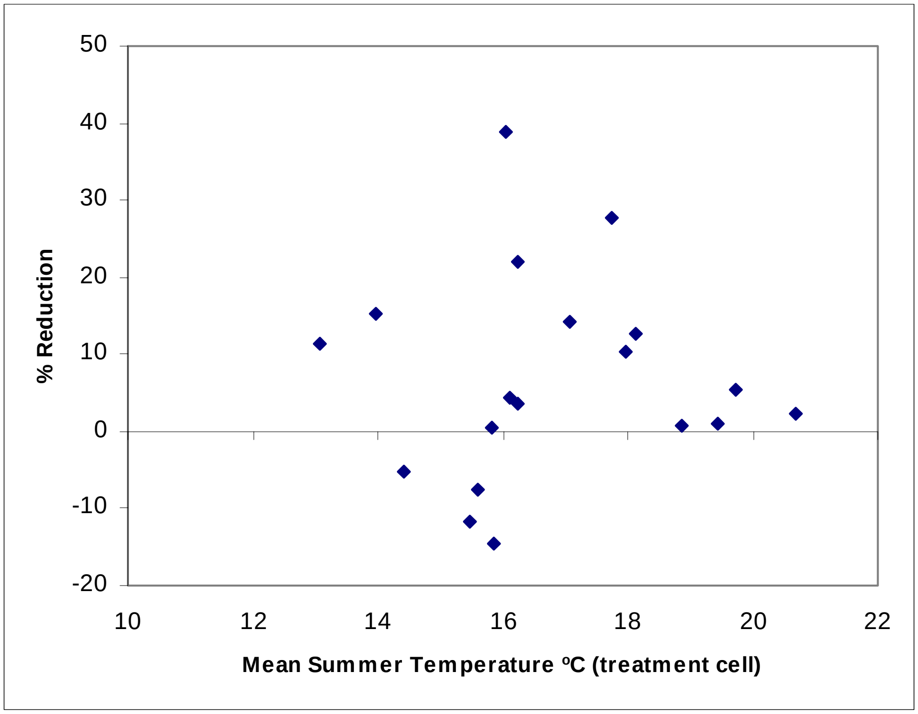


Figure 13: Plot of % Reduction in Chlorophyll a versus Mean Summer Temperature

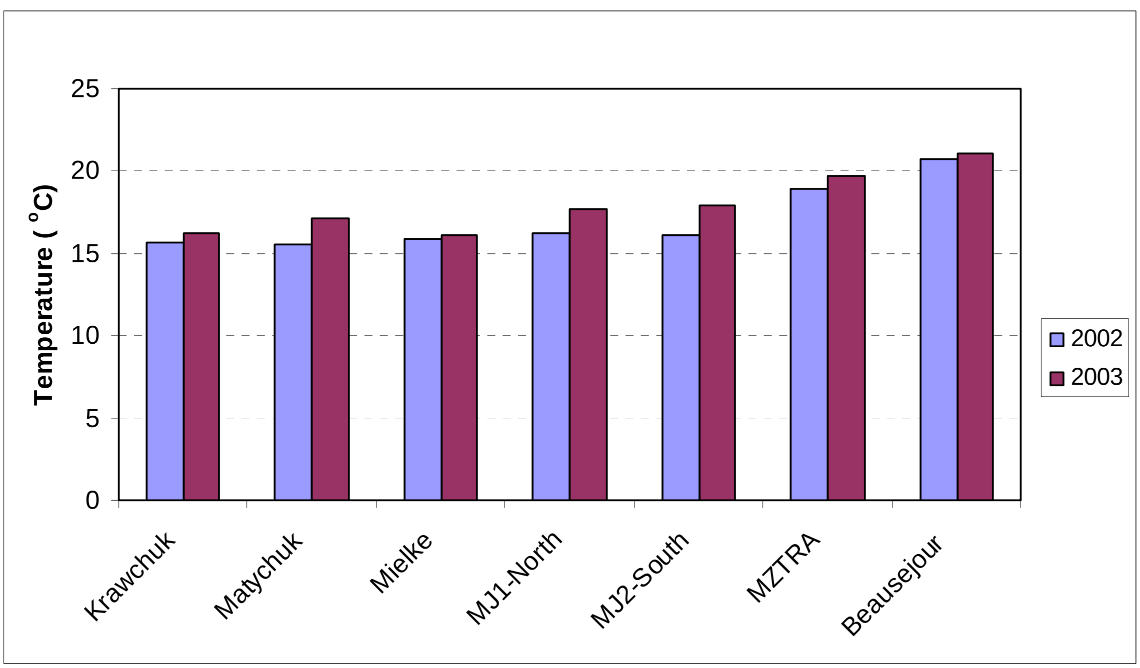


Figure 14: Comparison of Mean Summer Surface Water Temperature (°C) in 2002 and 2003

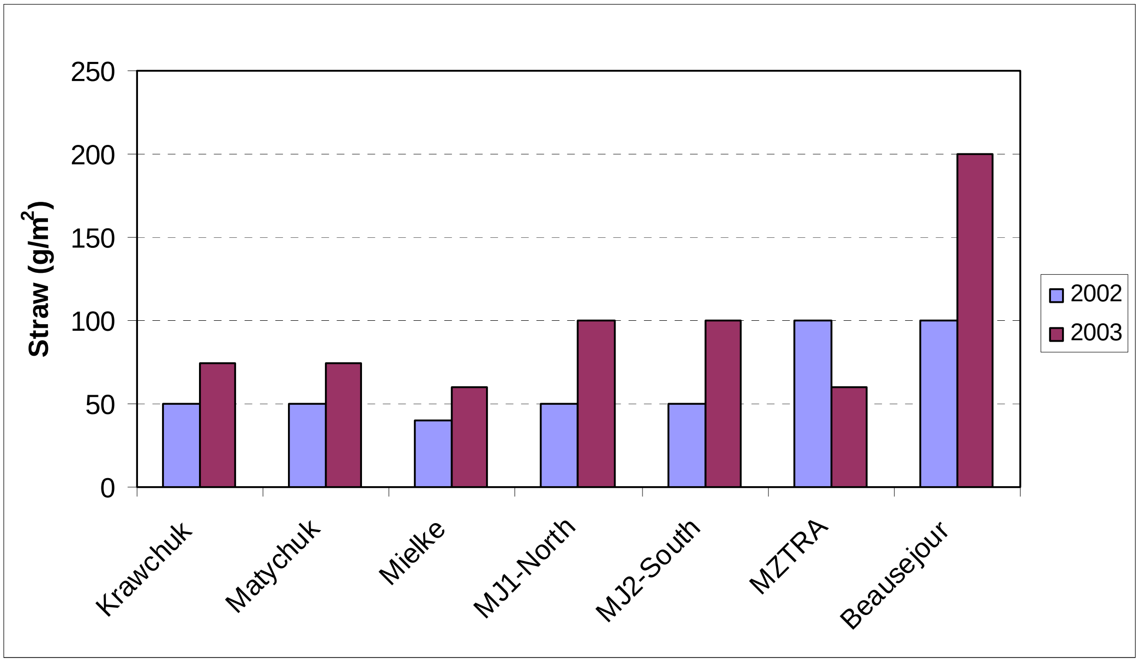


Figure 15: Comparison of Barley Straw Dosage (g/m^2) in 2002 and 2003

Appendix A

Field Data

(Turbidity, Secchi depth, Chlorophyll a, Surface Water Temperature)

Dugout	Date	Control Turbidity (NTU)	Treated Turbidity (NTU)
Beausejour	7/1/2002	4.0	4.0
Beausejour	7/17/2002	3.0	7.0
Beausejour	9/30/2002	2.5	1.5
Beausejour	5/22/2003	10.0	10.0
Beausejour	5/22/2003	10.0	10.0
Beausejour	6/16/2003	4.0	4.0
Beausejour	7/24/2003	9.0	11.0
Beausejour	7/30/2003	3.0	1.0
Beausejour	9/4/2003	1.0	2.0
Beausejour	9/15/2003	2.0	1.0
Beausejour	10/1/2003	4.0	2.0
Camrose	6/18/2003	5.2	5.2
Camrose	7/24/2003	3.5	3.8
Camrose	8/14/2003	4.0	4.1
Camrose	9/11/2003	7.5	9.2
Camrose	9/24/2003	10.3	9.9
Camrose	10/9/2003	10.9	10.1
Camrose	10/23/2003	7.4	7.5
Hanna	6/18/2002	52.2	52.2
Hanna	7/31/2002	47.6	42.3
Hanna	8/28/2002	22.2	18.8
Hanna	7/16/2003	7.5	12.7
Hanna	8/13/2003	11.3	12.4
Hanna	9/10/2003	20.5	29.0
Hanna	9/24/2003	25.2	29.7
Hanna	10/8/2003	27.6	28.4
Hanna	10/20/2003	30.2	29.8
Krawchuk	6/12/2002	0.4	1.2
Krawchuk	6/25/2002	1.6	1.5
Krawchuk	7/9/2002	1.2	2.0
Krawchuk	7/23/2002	1.3	4.6
Krawchuk	8/2/2002	4.4	4.6
Krawchuk	8/6/2002	2.6	3.2
Krawchuk	9/5/2002	5.0	8.8
Krawchuk	9/17/2002	9.2	12.2
Krawchuk	10/1/2002	8.9	6.5
Krawchuk	5/30/2003	6.1	4.9
Krawchuk	6/10/2003	6.7	7.3
Krawchuk	6/23/2003	4.6	4.7
Krawchuk	7/10/2003	8.8	8.7
Krawchuk	7/23/2003	18.5	11.3
Krawchuk	8/6/2003	19.2	16.1
Krawchuk	8/20/2003	8.2	9.9
Krawchuk	9/3/2003	6.0	10.0
Krawchuk	10/1/2003	5.5	4.3
Matychuk	6/12/2002	3.0	3.4
Matychuk	6/25/2002	5.6	10.4
Matychuk	7/9/2002	2.0	1.5
Matychuk	8/6/2002	5.6	6.3
Matychuk	8/20/2002	11.0	9.8
Matychuk	9/5/2002	6.4	6.2
Matychuk	9/17/2002	14.7	8.8
Matychuk	10/1/2002	14.7	10.2
Matychuk	5/30/2003	9.3	11.3

Dugout	Date	Control Turbidity (NTU)	Treated Turbidity (NTU)
Matychuk	6/10/2003	9.9	9.7
Matychuk	6/23/2003	12.4	14.8
Matychuk	7/10/2003	13.6	15.3
Matychuk	7/23/2003	22.9	13.5
Matychuk	8/6/2003	21.2	18.1
Matychuk	8/20/2003	25.2	18.2
Matychuk	9/3/2003	23.2	13.4
Matychuk	10/1/2003	21.3	17.2
Mielke	6/7/2002	5.6	6.8
Mielke	6/24/2002	4.4	6.3
Mielke	7/9/2002	3.1	3.7
Mielke	7/22/2002	20.1	2.1
Mielke	8/7/2002	3.1	3.6
Mielke	8/20/2002	4.7	5.0
Mielke	9/5/2002	4.2	6.1
Mielke	9/20/2002	3.6	4.5
Mielke	6/10/2003	3.0	1.3
Mielke	6/24/2003	3.4	1.4
Mielke	7/8/2003	3.3	3.6
Mielke	7/22/2003	3.2	3.7
Mielke	8/5/2003	3.7	0.6
Mielke	8/19/2003	4.0	3.1
Mielke	9/2/2003	3.8	3.7
Mielke	9/17/2003	5.2	4.2
Mielke	9/30/2003	5.5	5.8
MJ1-North	6/11/2002	45.9	39.4
MJ1-North	6/27/2002	55.0	69.0
MJ1-North	7/11/2002	33.3	36.0
MJ1-North	7/25/2002	63.0	45.3
MJ1-North	9/5/2002	11.7	9.1
MJ1-North	9/19/2002	8.0	7.2
MJ1-North	10/3/2002	3.0	0.3
MJ1-North	10/17/2002	4.2	3.7
MJ1-North	6/19/2003	22.4	27.8
MJ1-North	7/3/2003	39.3	30.7
MJ1-North	7/17/2003	47.9	38.1
MJ1-North	7/30/2003	37.7	31.3
MJ1-North	8/14/2003	30.1	32.3
MJ1-North	8/28/2003	40.8	22.8
MJ1-North	9/11/2003	39.4	35.6
MJ1-North	9/24/2003	34.0	28.9
MJ1-North	10/9/2003	24.6	20.7
MJ1-North	10/23/2003	25.2	17.1
MJ2-South	6/11/2002	61.0	100.0
MJ2-South	6/27/2002	96.0	89.0
MJ2-South	7/11/2002	155.0	156.0
MJ2-South	7/25/2002	106.0	90.0
MJ2-South	9/5/2002	8.3	8.7
MJ2-South	9/19/2002	11.4	12.0
MJ2-South	10/3/2002	3.4	3.3
MJ2-South	10/17/2002	9.5	10.2
MJ2-South	6/19/2003	38.5	33.4
MJ2-South	7/3/2003	35.8	33.9
MJ2-South	7/17/2003	27.9	22.9
MJ2-South	7/30/2003	20.7	18.8
MJ2-South	8/14/2003	21.9	24.4
MJ2-South	8/28/2003	28.6	30.1

Dugout	Date	Control Turbidity (NTU)	Treated Turbidity (NTU)
MJ2-South	9/11/2003	35.3	32.5
MJ2-South	9/24/2003	26.8	30.2
MJ2-South	10/9/2003	18.7	32.9
MJ2-South	10/23/2003	18.7	17.7
MZTRA	5/29/2002	8.4	8.7
MZTRA	6/11/2002	17.4	17.0
MZTRA	6/27/2002	16.4	22.6
MZTRA	7/8/2002	16.7	11.3
MZTRA	7/24/2002	36.8	37.6
MZTRA	8/21/2002	16.4	14.5
MZTRA	9/5/2002	15.9	14.7
MZTRA	9/7/2002	22.6	27.3
MZTRA	9/19/2002	13.0	19.2
MZTRA	6/5/2003	9.2	15.3
MZTRA	6/18/2003	10.8	12.0
MZTRA	7/3/2003	25.7	21.3
MZTRA	7/17/2003	19.4	18.8
MZTRA	7/31/2003	38.8	23.3
MZTRA	8/14/2003	36.9	37.8
MZTRA	8/27/2003	29.1	37.7
MZTRA	8/27/2003	29.1	37.7
MZTRA	9/10/2003	34.7	37.0
MZTRA	9/23/2003	25.6	48.3
Washington	6/7/2002	8.8	7.5
Washington	6/24/2002	8.0	9.7
Washington	7/9/2002	6.6	14.7
Washington	7/22/2002	21.3	11.7
Washington	8/7/2002	19.8	28.8
Washington	8/20/2002	13.5	1.9
Washington	9/5/2002	25.2	39.7
Washington	9/18/2002	24.1	33.1
Washington	9/30/2002	20.2	31.0
Washington	6/10/2003	1.8	1.9
Washington	6/24/2003	5.2	2.8
Washington	7/8/2003	6.9	4.1
Washington	7/22/2003	7.8	3.0
Washington	8/5/2003	3.3	3.2
Washington	8/19/2003	8.5	7.1
Washington	9/2/2003	6.5	6.3
Washington	9/17/2003	6.5	4.4
Washington	9/30/2003	6.9	5.0

Dugout	Date	Control Secchi Depth (cm)	Treated Secchi Depth (cm)
Beausejour	5/21/2002	240	240
Beausejour	6/6/2002	310	310
Beausejour	6/18/2002	310	310
Beausejour	7/1/2002	190	150
Beausejour	7/17/2002	260	70
Beausejour	9/30/2002	220	220
Beausejour	5/22/2003	145	145
Beausejour	5/22/2003	145	145
Beausejour	6/16/2003	250	220
Beausejour	7/3/2003	200	240
Beausejour	7/24/2003	90	80
Beausejour	7/30/2003	160	260
Beausejour	9/4/2003	210	210
Beausejour	10/1/2003	210	210
Camrose	6/18/2003	100	100
Camrose	7/24/2003	120	120
Camrose	8/14/2003	130	120
Camrose	9/11/2003	80	70
Camrose	9/24/2003	80	80
Camrose	10/9/2003	70	70
Camrose	10/23/2003	70	70
Hanna	7/16/2003	80	80
Hanna	8/13/2003	60	60
Hanna	9/10/2003	60	50
Hanna	9/24/2003	50	50
Hanna	10/8/2003	50	50
Hanna	10/20/2003	50	40
Krawchuk	6/12/2002	360	350
Krawchuk	6/25/2002	270	260
Krawchuk	7/9/2002	270	260
Krawchuk	7/23/2002	275	200
Krawchuk	8/2/2002	100	70
Krawchuk	8/6/2002	150	110
Krawchuk	9/5/2002	80	100
Krawchuk	9/17/2002	90	90
Krawchuk	10/1/2002	100	110
Krawchuk	5/30/2003	100	100
Krawchuk	6/10/2003	100	110
Krawchuk	6/23/2003	120	130
Krawchuk	7/10/2003	40	90
Krawchuk	7/23/2003	60	60
Krawchuk	8/6/2003	60	60
Krawchuk	8/20/2003	80	80
Krawchuk	9/3/2003	105	115
Krawchuk	10/1/2003	125	150
Matychuk	6/12/2002	100	100
Matychuk	6/25/2002	130	90
Matychuk	7/9/2002	160	100
Matychuk	8/6/2002	100	100
Matychuk	8/20/2002	70	70
Matychuk	9/5/2002	90	110
Matychuk	9/17/2002	80	100
Matychuk	10/1/2002	70	80
Matychuk	5/30/2003	105	90
Matychuk	6/10/2003	100	100

Dugout	Date	Control Secchi Depth (cm)	Treated Secchi Depth (cm)
Matychuk	6/23/2003	80	80
Matychuk	7/10/2003	75	75
Matychuk	7/23/2003	60	80
Matychuk	8/6/2003	60	60
Matychuk	8/20/2003	50	60
Matychuk	9/3/2003	60	75
Matychuk	10/1/2003	70	75
Mielke	6/7/2002	60	70
Mielke	6/24/2002	95	85
Mielke	7/9/2002	101	80
Mielke	7/22/2002	190	170
Mielke	8/7/2002	130	120
Mielke	8/20/2002	95	100
Mielke	9/5/2002	122	100
Mielke	9/20/2002	145	115
Mielke	6/10/2003	145	150
Mielke	6/24/2003	110	110
Mielke	7/8/2003	130	130
Mielke	7/22/2003	160	140
Mielke	8/5/2003	100	110
Mielke	8/19/2003	130	130
Mielke	9/2/2003	120	120
Mielke	9/17/2003	90	85
Mielke	9/30/2003	85	85
MJ1-North	6/11/2002	90	90
MJ1-North	6/27/2002	120	110
MJ1-North	7/11/2002	200	180
MJ1-North	7/25/2002	90	100
MJ1-North	8/8/2002	15	40
MJ1-North	8/21/2002	70	70
MJ1-North	9/5/2002	75	75
MJ1-North	9/19/2002	90	100
MJ1-North	10/3/2002	105	105
MJ1-North	10/17/2002	115	120
MJ1-North	6/19/2003	90	90
MJ1-North	7/3/2003	65	70
MJ1-North	7/17/2003	105	70
MJ1-North	7/30/2003	55	55
MJ1-North	8/14/2003	55	70
MJ1-North	8/28/2003	55	70
MJ1-North	9/11/2003	55	55
MJ1-North	9/24/2003	70	75
MJ1-North	10/9/2003	70	80
MJ1-North	10/23/2003	95	95
MJ2-South	6/11/2002	60	60
MJ2-South	6/27/2002	65	70
MJ2-South	7/11/2002	40	45
MJ2-South	7/25/2002	50	55
MJ2-South	8/8/2002	7	10
MJ2-South	8/21/2002	45	52
MJ2-South	9/5/2002	63	62
MJ2-South	9/19/2002	60	55
MJ2-South	10/3/2002	70	75
MJ2-South	10/17/2002	63	70
MJ2-South	6/19/2003	75	70
MJ2-South	7/3/2003	80	75

Dugout	Date	Control Secchi Depth (cm)	Treated Secchi Depth (cm)
MJ2-South	7/17/2003	85	95
MJ2-South	7/30/2003	90	90
MJ2-South	8/14/2003	95	85
MJ2-South	8/28/2003	70	70
MJ2-South	9/11/2003	60	60
MJ2-South	9/24/2003	80	90
MJ2-South	10/9/2003	95	100
MJ2-South	10/23/2003	90	95
MZTRA	5/29/2002	50	50
MZTRA	6/11/2002	42	45
MZTRA	6/27/2002	53	46
MZTRA	7/8/2002	47	55
MZTRA	7/24/2002	30	31
MZTRA	8/21/2002	36	36
MZTRA	9/5/2002	33	36
MZTRA	9/7/2002	40	40
MZTRA	9/19/2002	55	55
MZTRA	6/5/2003	80	60
MZTRA	6/18/2003	70	90
MZTRA	7/3/2003	35	42
MZTRA	7/17/2003	45	52
MZTRA	7/31/2003	30	40
MZTRA	8/14/2003	25	20
MZTRA	8/27/2003	35	34
MZTRA	8/27/2003	35	34
MZTRA	9/10/2003	34	30
MZTRA	9/23/2003	31	40
Storey	5/24/2002	0	0
Storey	5/31/2002	160	160
Storey	6/13/2002	210	210
Storey	6/27/2002	290	240
Storey	7/11/2002	180	180
Storey	7/25/2002	150	150
Storey	8/8/2002	160	170
Storey	8/22/2002	280	220
Washington	6/7/2002	45	45
Washington	6/24/2002	42	35
Washington	7/9/2002	42	42
Washington	7/22/2002	40	40
Washington	8/7/2002	35	40
Washington	8/20/2002	33	30
Washington	9/5/2002	28	25
Washington	9/18/2002	20	20
Washington	9/30/2002	25	25
Washington	6/10/2003	60	60
Washington	6/24/2003	50	50
Washington	7/8/2003	52	50
Washington	7/22/2003	40	50
Washington	8/5/2003	50	45
Washington	8/19/2003	45	38
Washington	9/2/2003	45	45
Washington	9/17/2003	55	65
Washington	9/30/2003	45	50

Dugout	Date	Control Chla (ug/L)	Treated Chla (ug/L)	Control Temperature (^oC)	Treated Temperature (^oC)
Beausejour	6/6/2002	0.82	0.82	18.3	18.4
Beausejour	6/18/2002	1.99	1.22	19.8	20.3
Beausejour	7/1/2002	2.35	1.91	25.6	25.4
Beausejour	7/17/2002	2.99	3.42	26.2	26.2
Beausejour	7/31/2002	4.10	9.49		
Beausejour	9/4/2002	17.00	12.80	12.7	13.1
Beausejour	9/17/2002	4.22	3.14		
Beausejour	9/30/2002	1.12	1.04		
Beausejour	16Jun2003	1.59	1.29	23.8	23.6
Beausejour	24Jul2003	33.50	34.46	23.7	22.8
Beausejour	30Jul2003	3.64	1.87	22.8	22
Beausejour	04Sep2003	3.48	0.77	18.7	16
Beausejour	15Sep2003	2.22	1.63		
Beausejour	01Oct2003	2.38	0.92	6.5	6.3
Camrose	7/24/2003	9.37	7.62	22.3	22.9
Camrose	8/13/2003	11.99	16.10	21.7	21.9
Camrose	8/28/2003	57.71	63.02	16.4	16.9
Camrose	9/11/2003	64.78	74.17	14.7	14.9
Camrose	9/25/2003	82.68	80.01	9.4	9.4
Camrose	10/9/2003	54.44	59.71	9.1	9.1
Camrose	10/23/2003	47.35	44.90	6	5.9
Hanna	7/16/2003	3.59	3.84	19.4	19.6
Hanna	8/14/2003	6.13	5.43	20.5	20.4
Hanna	8/27/2003	4.34	8.32		
Hanna	9/10/2003	6.52	7.86	13.3	13.2
Hanna	9/24/2003	11.32	10.60	8.3	8.6
Hanna	10/8/2003	32.46	26.46	10.4	10.3
Hanna	10/20/2003	34.66	25.24	6.6	6.4
Krawchuk	6/12/2002	2.09	1.76	20.6	18.2
Krawchuk	6/25/2002	9.04	5.70	20.1	19.9
Krawchuk	7/9/2002	4.08	5.84	17	16.9
Krawchuk	7/23/2002	4.51	10.80	20.1	19.9
Krawchuk	8/6/2002	7.01	9.75	14.8	14.9
Krawchuk	8/20/2002	12.60	13.40	15.5	15.4
Krawchuk	9/5/2002	19.10	15.60	14.1	13.9
Krawchuk	9/17/2002	11.20	13.10	13.4	13.1
Krawchuk	10/1/2002	8.13	7.66	8.3	8.2
Krawchuk	5/29/2003	16.77	15.43	13.1	14.5
Krawchuk	6/10/2003	11.81	9.85	17.6	17.1
Krawchuk	6/23/2003	13.96	18.63	15	14.9
Krawchuk	7/10/2003	15.81	17.31	21	19
Krawchuk	7/23/2003	15.61	14.84	20.7	20.1
Krawchuk	8/6/2003	29.85	24.94	19.6	19.5
Krawchuk	8/20/2003	9.46	9.86	17.8	17.5
Krawchuk	9/3/2003	8.82	9.15	15.9	15.8

Dugout	Date	Control Chla (ug/L)	Treated Chla (ug/L)	Control Temperature (^oC)	Treated Temperature (^oC)
Krawchuk	10/1/2003	9.44	6.74	7.8	7.8
Matychuk	6/12/2002	8.60	10.20	21.2	19.2
Matychuk	6/25/2002	17.10	41.90	21.2	20
Matychuk	7/9/2002	13.70	19.40	18	17.2
Matychuk	7/23/2002	11.80	22.60		
Matychuk	8/6/2002	19.00	22.10	15.8	14.9
Matychuk	8/20/2002	27.00	23.70	16.3	16
Matychuk	9/5/2002	24.20	17.10	14.9	14.5
Matychuk	9/17/2002	28.00	20.30	13.7	13.3
Matychuk	10/1/2002	22.40	14.60	8.8	8.8
Matychuk	5/29/2003	4.99	6.03	17.4	16.1
Matychuk	6/10/2003	11.23	8.02	17.5	18
Matychuk	6/23/2003	23.28	19.95	15.9	15.5
Matychuk	7/10/2003	12.66	13.51	19.7	19.8
Matychuk	7/23/2003	18.39	16.62	21	20.5
Matychuk	8/6/2003	27.03	23.38	20.6	20.5
Matychuk	8/20/2003	31.06	23.59	18.7	18.2
Matychuk	9/3/2003	26.49	21.85	16.7	16.5
Matychuk	10/1/2003	23.51	20.18	8.6	8.6
Melville	6/24/2003	22.20	28.80		
Melville	7/8/2003	52.45	57.99		
Melville	7/23/2003	42.69	20.96		
Melville	8/7/2003	43.13	39.90		
Melville	8/21/2003	21.58	21.63		
Melville	9/4/2003	10.52	9.96		
Melville	9/17/2003	16.06	13.87		
Melville	10/17/2003	7.37	11.98		
Mielke	6/7/2002	40.60	33.80	13.9	14.4
Mielke	6/24/2002	2.64	1.83	20.5	20.5
Mielke	7/9/2002	7.61	14.00	18	18.2
Mielke	7/22/2002	2.13	2.72	19.7	20.1
Mielke	8/7/2002	2.10	2.08	14	14.6
Mielke	8/20/2002	12.70	12.00	15.6	16.2
Mielke	9/5/2002	3.21	5.60	12.9	13.6
Mielke	9/18/2002	6.19	16.30	9.1	9.2
Mielke	9/30/2002	5.37	28.30		
Mielke	6/10/2003	3.00	2.59	17.4	17.7
Mielke	6/24/2003	3.13	2.30	17	17.2
Mielke	7/8/2003	5.01	3.18	17.8	17.9
Mielke	7/22/2003	3.52	3.92	20.2	20.5
Mielke	8/5/2003	4.18	3.24	18.9	19.6
Mielke	8/19/2003	2.86	3.09	17.5	17.6
Mielke	9/2/2003	12.84	6.44	15.2	15.5
Mielke	9/17/2003	9.81	6.75	9.3	10.1
Mielke	9/30/2003	22.30	9.21	8.5	8.4
MJ1-North	6/11/2002	27.70	22.70	11.5	11.3

Dugout	Date	Control Chla (ug/L)	Treated Chla (ug/L)	Control Temperature (^oC)	Treated Temperature (^oC)
MJ1-North	6/27/2002	16.50	12.40	24.4	24.8
MJ1-North	7/11/2002	4.94	4.76	22.2	22.5
MJ1-North	7/25/2002	28.50	22.90	23.1	22.8
MJ1-North	9/5/2002	54.40	41.50	19.4	19.2
MJ1-North	9/19/2002	37.30	26.30	16.2	15.9
MJ1-North	10/3/2002	21.60	17.20	8.8	8.5
MJ1-North	10/17/2002	14.20	12.30	5.1	4.9
MJ1-North	6/19/2003	32.03	23.30	20.9	21
MJ1-North	7/3/2003	31.90	21.25	22.2	21.7
MJ1-North	7/17/2003	49.08	33.45	22.2	22.7
MJ1-North	7/30/2003	48.40	39.29	24.2	23.5
MJ1-North	8/14/2003	43.86	25.67	24.8	24.5
MJ1-North	8/28/2003	42.00	42.81	17.8	17.7
MJ1-North	9/11/2003	37.45	26.18	17.3	16.5
MJ1-North	9/24/2003	24.05	14.42	10.6	9.4
MJ1-North	10/9/2003	23.57	13.53	12.1	12
MJ1-North	10/23/2003	22.87	16.96	8.2	8.3
MJ2-South	6/11/2002	24.40	28.80	11.3	11.1
MJ2-South	6/27/2002	21.30	16.80	24.5	24.7
MJ2-South	7/11/2002	34.80	25.60	22.6	22.8
MJ2-South	7/25/2002	9.71	15.60	23.4	21.3
MJ2-South	9/5/2002	31.20	28.50	19.3	19.4
MJ2-South	9/19/2002	31.30	28.80	16.5	16.1
MJ2-South	10/3/2002	22.10	22.00	8.8	8.6
MJ2-South	10/17/2002	23.60	23.50	5	5
MJ2-South	6/19/2003	17.49	20.90	22.1	21.4
MJ2-South	7/3/2003	19.38	14.79	21.8	21.6
MJ2-South	7/17/2003	10.92	6.92	22.8	23
MJ2-South	7/30/2003	18.35	8.07	24.1	24.1
MJ2-South	8/14/2003	26.39	29.18	25.2	25.1
MJ2-South	8/28/2003	33.80	25.94	17.9	17.9
MJ2-South	9/11/2003	27.04	22.70	17.3	16.7
MJ2-South	9/24/2003	20.87	23.43	9.9	9.4
MJ2-South	10/9/2003	17.34	18.19	12	12
MJ2-South	10/23/2003	19.00	18.80	8.2	8.4
MZTRA	5/29/2002	41.40	42.30	15.9	16
MZTRA	6/11/2002	49.70	45.40	13.5	13.7
MZTRA	6/26/2002	51.00	57.50	24	24.2
MZTRA	7/9/2002	67.30	79.60	20.8	20.6
MZTRA	7/24/2002	87.50	89.60	22.4	22.4
MZTRA	8/7/2002	59.10	43.70	21.1	21.3
MZTRA	8/21/2002	76.20	74.00	18	18
MZTRA	9/5/2002	49.90	47.00	18.6	18
MZTRA	9/19/2002	31.00	30.20	15.5	15.6
MZTRA	6/5/2003	9.29	8.51	18.4	17.5
MZTRA	6/19/2003	6.75	6.47	21.6	21.4

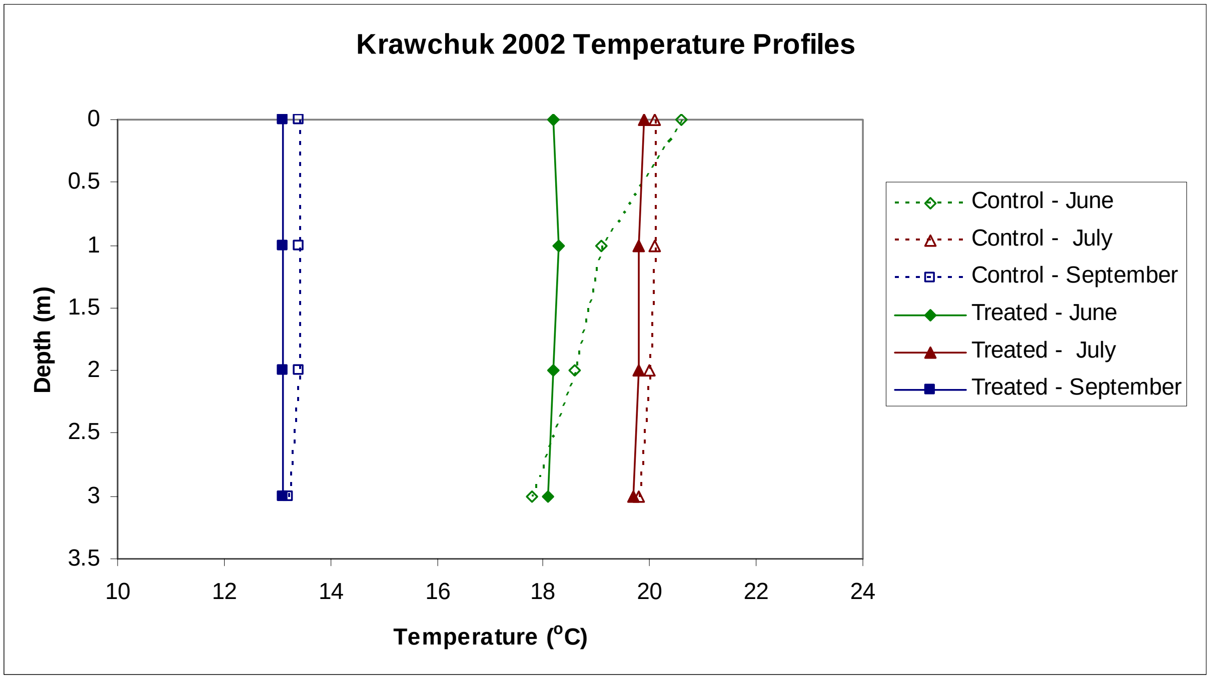
Dugout	Date	Control Chla (ug/L)	Treated Chla (ug/L)	Control Temperature (°C)	Treated Temperature (°C)
MZTRA	7/3/2003	26.22	21.26	21	21
MZTRA	7/17/2003	34.71	23.21	22.2	22.3
MZTRA	7/31/2003	43.46	26.79	23.4	23.2
MZTRA	8/14/2003	95.93	91.41	23.6	23.3
MZTRA	8/27/2003	49.98	56.45	20.1	19.7
MZTRA	9/10/2003	42.05	51.23	18	17.8
MZTRA	9/23/2003	39.78	43.99	12.2	11.4
Storey	5/31/2002	0.18	0.18	16.4	16.4
Storey	6/13/2002	2.76	2.40	14.6	14.2
Storey	6/27/2002	2.74	3.70	23.9	23.3
Storey	7/11/2002	5.03	6.00	22.1	21.8
Storey	7/25/2002	18.20	16.80	24.1	23.3
Storey	8/8/2002	22.30	24.60	18.7	19
Storey	8/22/2002	15.15	12.05	18.7	18.1
Washington	6/7/2002	188.30	119.60	13.4	12.8
Washington	6/24/2002	9.43	19.30	17.1	16.5
Washington	7/9/2002	14.80	10.80	14.9	14.6
Washington	7/22/2002	14.60	5.67	15.8	16.3
Washington	8/7/2002	38.50	18.9	11.9	11.7
Washington	8/20/2002	132.60	24.5	13.2	12.8
Washington	9/5/2002	59.90	17.3	10.7	10.9
Washington	9/18/2002	88.90	11.6	9.7	9.4
Washington	9/30/2002	82.20	1.65	7.2	7.2
Washington	6/10/2003	1.80	1.06	16.9	16.8
Washington	6/24/2003	1.49	1.09	15.4	15.2
Washington	7/8/2003	1.79	6.52	15.6	15.5
Washington	7/22/2003	2.57	3.48	17.4	17
Washington	8/5/2003	6.15	4.47	16.2	16.4
Washington	8/19/2003	8.76	5.35	15.1	15.5
Washington	9/2/2003	17.57	7.79	12.8	13.5
Washington	9/17/2003	7.54	7.39	7.7	8.2
Washington	9/30/2003	11.16	12.76	7.4	7.6

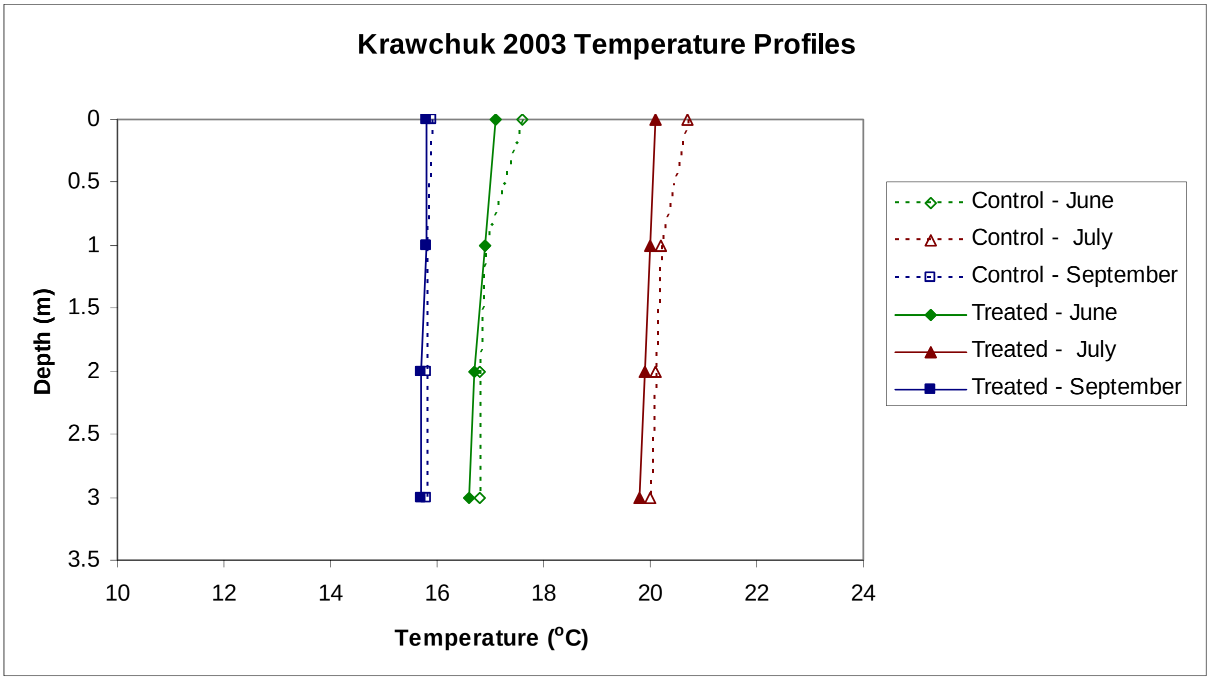
Appendix B

Typical Oxygen/Temperature Profiles

Temperature Profiles

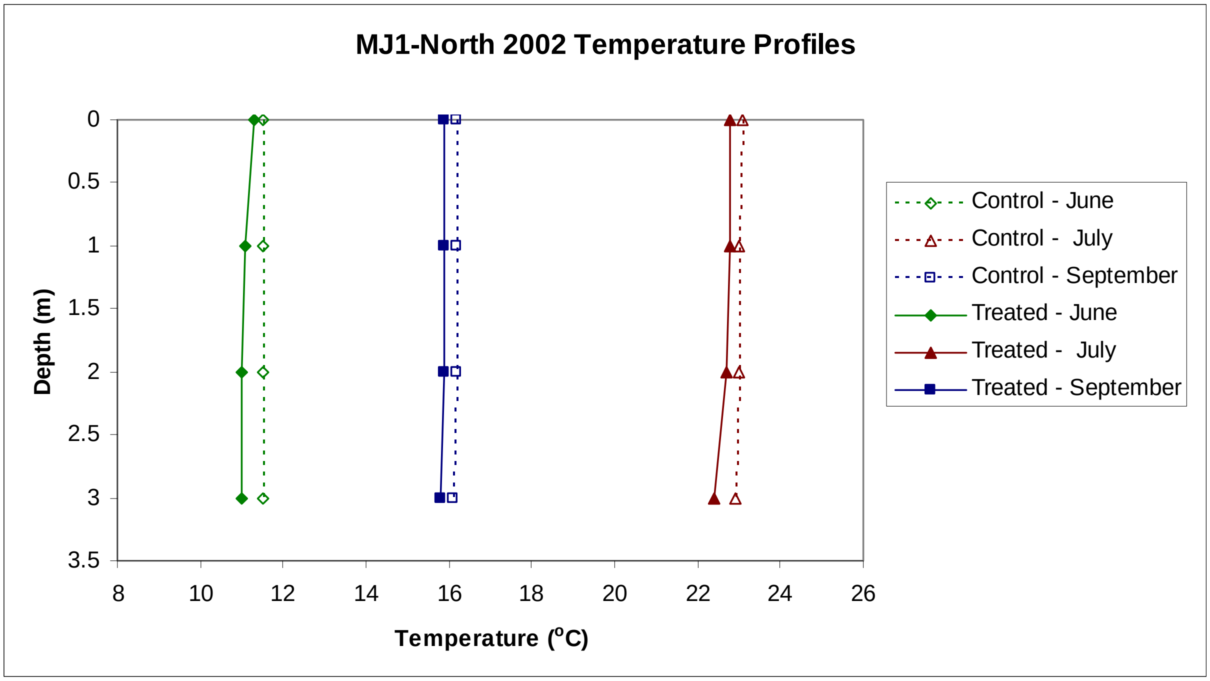
Northern Alberta (Krawchuk)

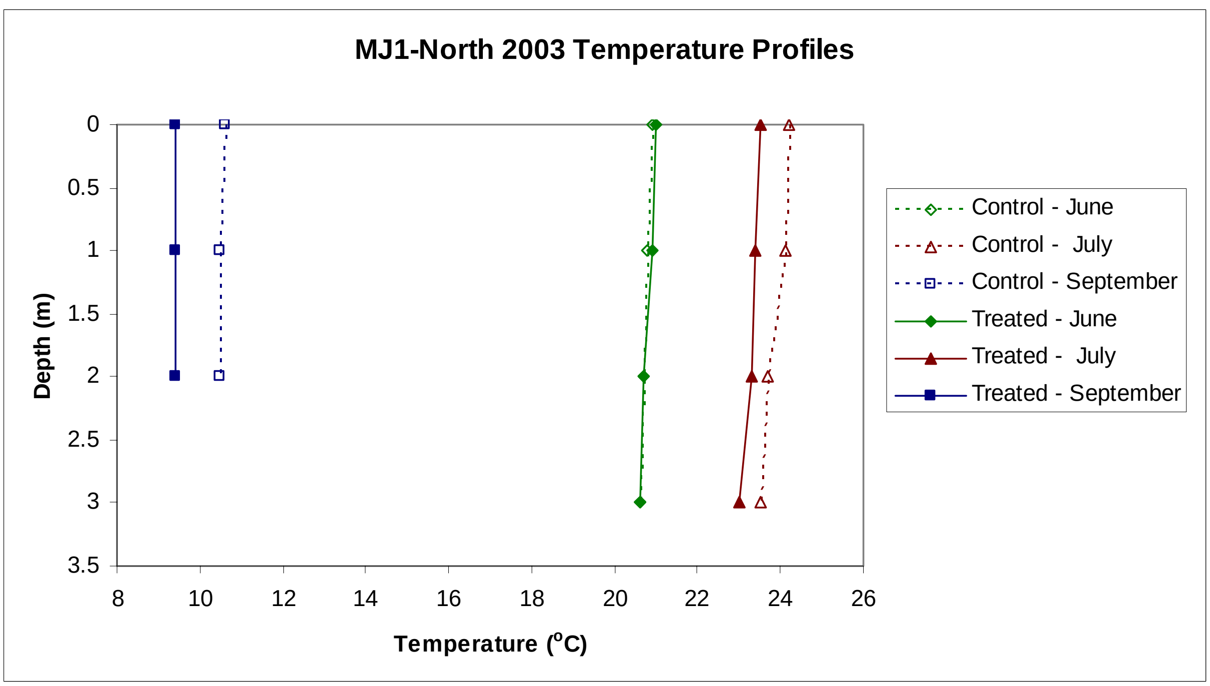




Temperature Profiles

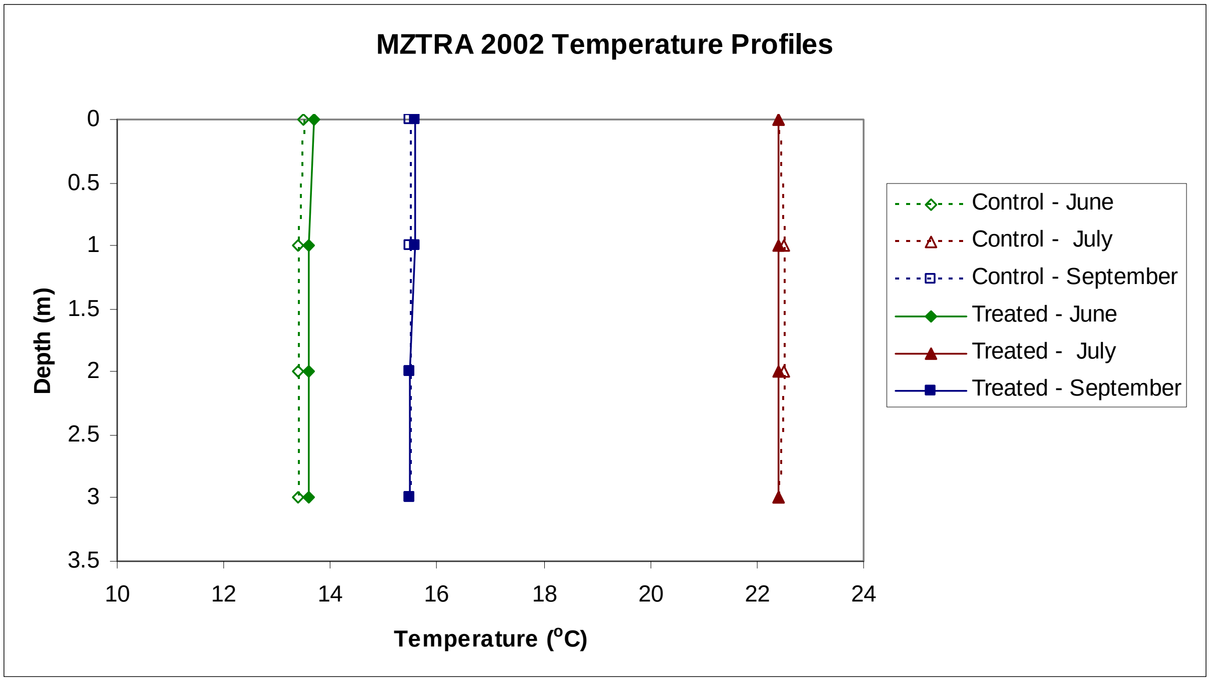
Southern Saskatchewan (MJ1-North)

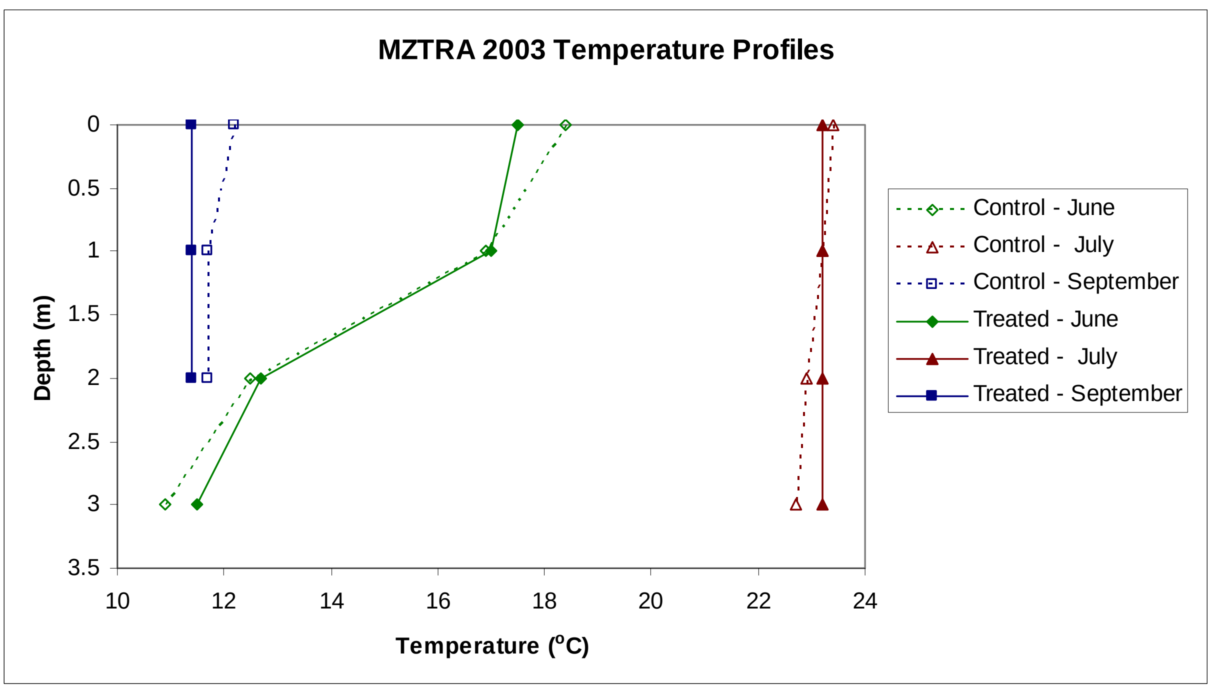




Temperature Profiles

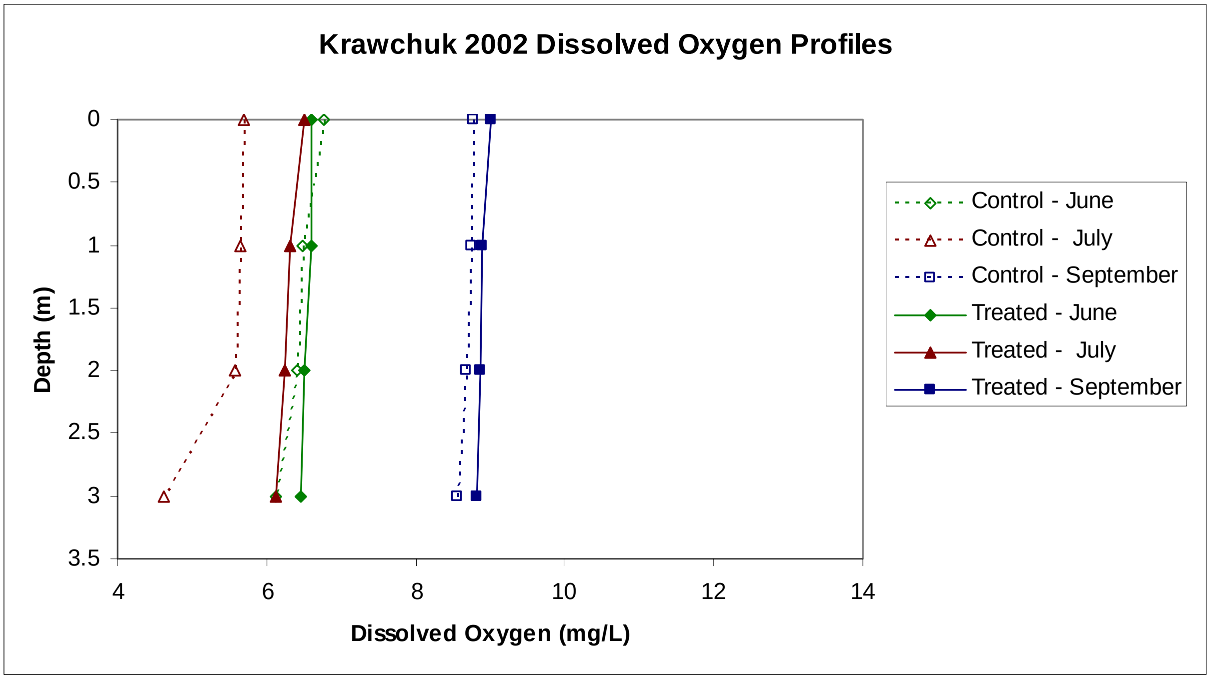
Southern Manitoba (MZTRA)

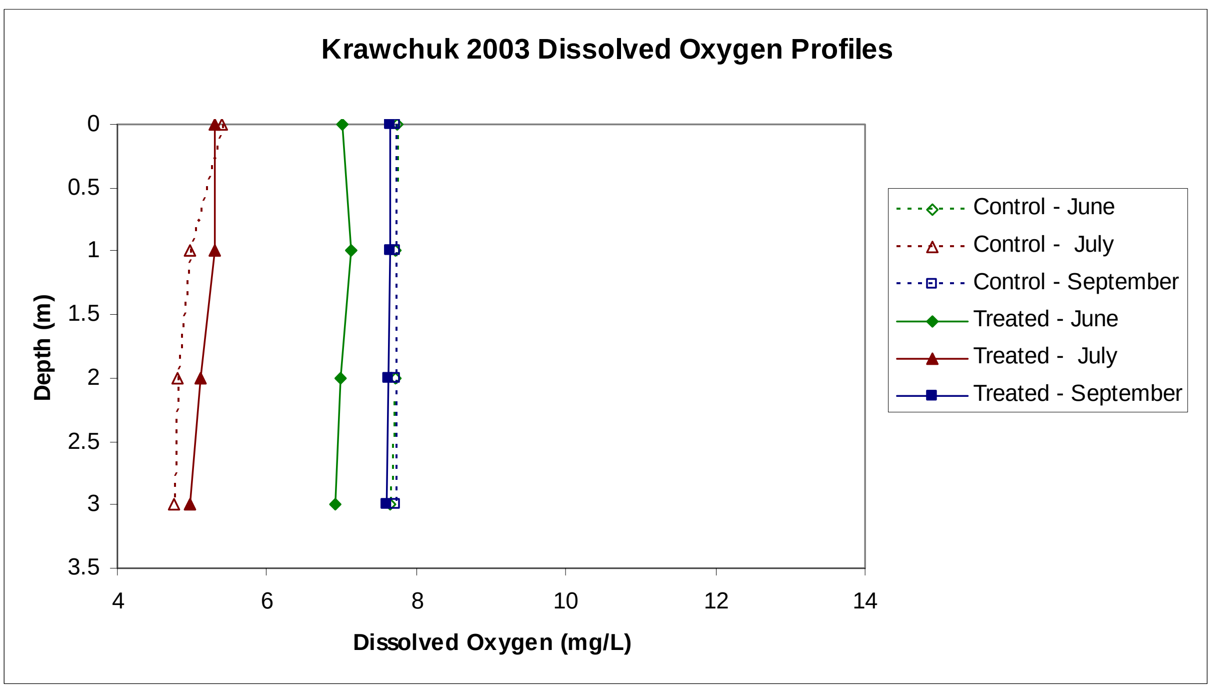




Dissolved Oxygen Profiles

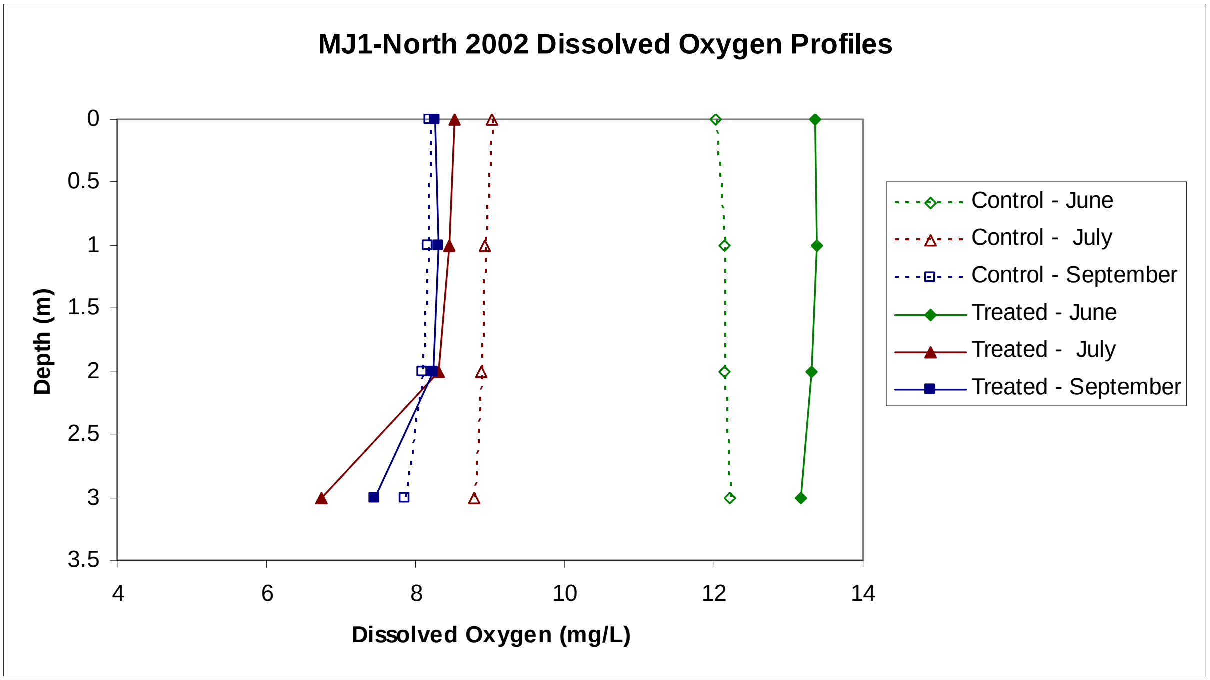
Northern Alberta (Krawchuk)

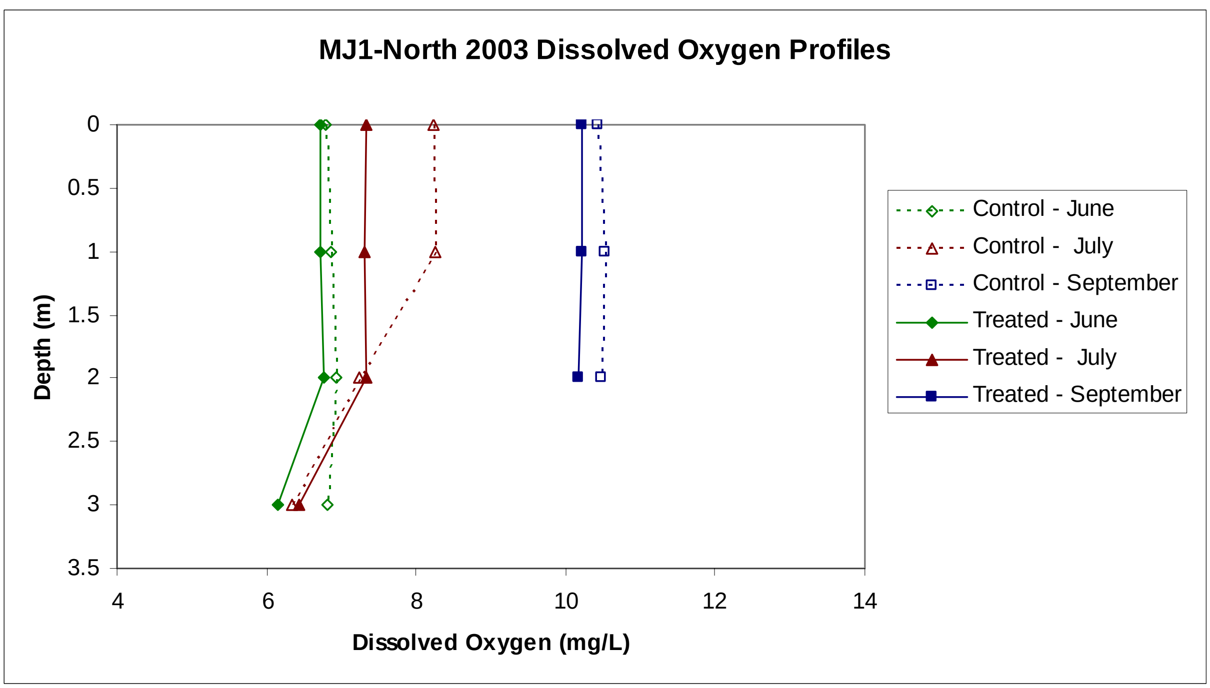




Dissolved Oxygen Profiles

Southern Saskatchewan (MJ1-North)





Dissolved Oxygen Profiles

Southern Manitoba (MZTRA)