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Impacts of Mechanical Macrophyte Removal Devices on Sediment Scouring in Littoral Habitats: I. Historical Survey of Operations in Minnesota Lakes

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PURPOSE: The objective of this research was to evaluate the impacts of a mechanical macrophyte removal device on changes in littoral sediment substrate.

BACKGROUND: Commercially available mechanical macrophyte removal devices have become a popular tool for controlling localized aquatic plant growth near docks and swimming areas. Some use a floating pivot arm with attached dangling underwater rakes to entangle and sweep macrophytes from an area. Others consist of an underwater roller arm located on or immediately above the sediment surface that is attached to a pivot arm and motor mounted on a boat dock or nearshore structure. Paddles are often attached to the roller arm to dig into sediments and uproot macrophytes. Mechanical removal devices can be run continuously for several weeks to clear the area of macrophytes, then run intermittently throughout the growing season (up to 10 hr or more per week) to maintain macrophyte control.

Advantages of this type of macrophyte control technique include macrophyte removal in a specific area, low operational costs, and mechanical rather than herbicidal control. One negative impact of mechanical macrophyte removal devices that use an underwater arm with paddles is disturbance and scouring of silty sediment and associated nutrients and contaminants in shallow littoral regions. In particular, movement of the roller arm over flocculent sediments may cause instances of resuspension, turbidity clouds, nutrient recycling, and physical displacement of sediment from the area. Flocculent sediment removal from shoreline areas, while desirable to riparian property owners, may have an undesirable impact on littoral biota (fishes, invertebrates, etc.) and water quality, depending on the density and frequency of use along shoreline areas. Concerns over these issues led to a permit requirement for use of mechanical macrophyte removal devices in the State of Minnesota. Use of the WeedRoller® (Crary WeedRoller®, TarraMarc Industries, West Fargo, North Dakota, USA) on Minnesota lakes is popular and widespread. Therefore, a need exists to evaluate the impacts of its operation on sediment displacement so that the Minnesota Department of Natural Resources (DNR) will have a basis for developing guidelines and criteria for managing both the extent of mechanical macrophyte removal device use on lakes and its use under differing conditions of sediment type.

The objectives of this research were to quantify the sediment displacement potential of mechanical macrophyte removal devices such as the WeedRoller® as a function of littoral sediment characteristics for a number of lake sites in Minnesota using this device. Findings from this study may be applicable to other commercially available mechanical macrophyte removal devices that remove macrophytes using an underwater arm and paddle design.

METHODS: Study locations were selected in the Fergus Falls-Alexandria region and the Brainerd region of the State of Minnesota for evaluation of the impacts of Weed Roller® operations on sediment characteristics and sediment displacement. Twenty-six lakeshore sites, located in the

Fergus Falls-Alexandria region and Brainerd region, were selected for evaluation (Table 1). Sites chosen in these regions had Weed Rollers® in operation by private property owners. The extent and timing of operation of the devices were controlled by the property owners.

Site selection was stratified primarily with respect to a priori qualitative information on sediment type determined by area DNR personnel during initial permitting for Weed Roller® use. The four qualitative sediment type categories were a) sand and gravel, b) 5 to 8 cm of fine-grained sediment consistency, c) greater than 8 cm of fine-grained sediment consistency, and d) marl consistency. A posteriori analysis of sediment indicated that there were ranges in characteristics such as percent moisture content, sediment bulk density, and particle size distribution at individual sites.

A shoreline area on a particular lake was divided into a site impacted by Weed Roller® operation (i.e., treated site) and an immediately adjacent (i.e., within 5 m) reference site. For sampling protocol 1 (i.e., between-site variance), adjacent reference and treated sites were visually divided into four sections of equal area and a station was established in the center of one of the sections (Figure 1). Sections for station establishment were randomly chosen. Stations in reference and treated sites were positioned the same distance from the shoreline using a metered transect. Triplicate sediment cores were collected at each station for analysis. Eleven locations in the Fergus Falls-Alexandria region and twelve locations in the Brainerd region were sampled using protocol 1. Sediment sampling was conducted in each region in August 1999.

For sampling protocol 2 (i.e., within-site variance), a transect was established perpendicular to the shoreline for treated and reference sites (Figure 1). Along the transect, three equally spaced stations were established for sediment sampling purposes in both sites. At each station, triplicate sediment cores were collected for analysis. Two locations in the Fergus Falls-Alexandria region and one location in the Brainerd region were sampled using protocol 2.

Intact sediment samples were collected at each station with a Wildco KB sediment core sampler (Wildlife Supply Co., Saginaw, Michigan). In the laboratory, sediment cores were carefully extruded onto aluminum foil and visually examined for changes in sediment texture throughout its length before sectioning. For most sediment cores collected at sites in the Fergus Falls-Alexandria and Brainerd regions, particularly those cores collected in reference sites, a very distinct layer of surface sediment (i.e., finer grained sediment with a higher moisture content) was observed overlying a layer of very coarse-grained, sandy to gravelly sediment. This sediment stratification pattern is likely attributed to stabilization of the sediment by aquatic macrophytes and recent accretion (i.e., over a period of decades) of fine-grained material over previously eroded substrate (see discussion). For these vertical textural trends, the depth of the surface layer was measured to the nearest millimeter and then the sediment core was sectioned at the interface where the textural change occurred. The entire surface layer section and first 5 cm of the coarser-grained sublayer section was used for analytical purposes. For sediment cores that did not exhibit distinct layering of different textural types, the upper 5 cm of sediment was sectioned for analysis. Sediment cores that fell into this latter category were either entirely very sandy-gravelly or entirely fine-grained.

Table 1
Summary of Weed Roller® Sites in the State of Minnesota[1]

Lake	Region	WeedRoller Site No.	(Permit)	Year Permit First Issued	Typical Range of Hours of Operation / Month	Months of Operation	Stations/site	Station Distance from Shore (feet)	Station Depth Range (cm)
Cowdry	Fergus Falls-Alexandria	1	99F-1193	1996	<20-144	Jun, Jul, Aug	1	40	101-104
Darling	Fergus Falls-Alexandria	1	99F-1158	1996	<20	Jul, Aug	1	35	110-127
Heilberger	Fergus Falls-Alexandria	1	99F-1418	1998	<20	Jun, Jul, Aug	1	18	100-105
Heilberger	Fergus Falls-Alexandria	2	97F-1428	1997	25-72	August	3	16, 28, 36	73-132
Lakota	Fergus Falls-Alexandria	1	97F-1120	1997	10-24	Jun, Jul, Aug	3	12, 18, 24	40-59
Miltona	Fergus Falls-Alexandria	1	99F-1179	1996	50-144	Jul, Aug	1	40	60-64
Miltona	Fergus Falls-Alexandria	2	99F-1392	1999	<20-50	Jun, Jul, Aug, Sep	1	90	75-83
Prairie	Fergus Falls-Alexandria	1	97F-1415	1997	<20-50	May thru Sep	1	15	54-70
Prairie	Fergus Falls-Alexandria	2	97F-1151	1997	20-50	Jun, Jul, Aug	1	15	54-80
Prairie	Fergus Falls-Alexandria	3	99F-1264	1996	<20-50	May, Jun, Jul, Aug	1	45	72-74
Union	Fergus Falls-Alexandria	1	99F 1030	1996	<20-50	Jun, Jul	1	32	66-77
West Lost	Fergus Falls-Alexandria	1	99F-1380	1998	20-50	Jun, Jul	1	30	145-157
West Lost	Fergus Falls-Alexandria	2	99F-1241	1997	<20	Jun, Jul, Aug	1	34	103-113
Cross	Brainerd	1	97F-3122	1997	<20-50	Jun, Jul, Aug	1	20	103-126
Daggett	Brainerd	1	98F-3022	1998	<20	Jul, Aug	1	25	81-110
Daggett	Brainerd	2	99F-3693	1998	<20-50	Jun, Jul, Aug, Sep	1	90	103-130
Daggett	Brainerd	3	(Crary Weed Roller was not used here)	N.D.	N.D.	N.D.	1	55	85-120
Gull	Brainerd	1	97F-8026	1996	N.D.	N.D.	1	48	130-154
Gull	Brainerd	2	99F-3008	1999	<20	Jul	1	38	45-70
Gull	Brainerd	3	98F-3154	1997	<20-50	May thru Sep	1	12	30
Gull	Brainerd	4	97F-3946	1997	<10	Jul	1	40	95-98
Gull	Brainerd	5	99F-3343	1997	N.D.	N.D.	1	50	104-115
Ossawinnanakee	Brainerd	1	98F-3185	1997	<20	Jul, Aug	3	16, 22, 28	68-190
Ossawinnanakee	Brainerd	2	97F-3619	1997	11-24	Jun, Jul, Aug	1	20	53-85
Ossawinnanakee	Brainerd	3	98F-3095	1997	N.D.	N.D.	1	60	74-90
Whitefish	Brainerd	1	99F-3237	1999	N.D.	N.D.	1	50	75-90

[1] ND = not determined.

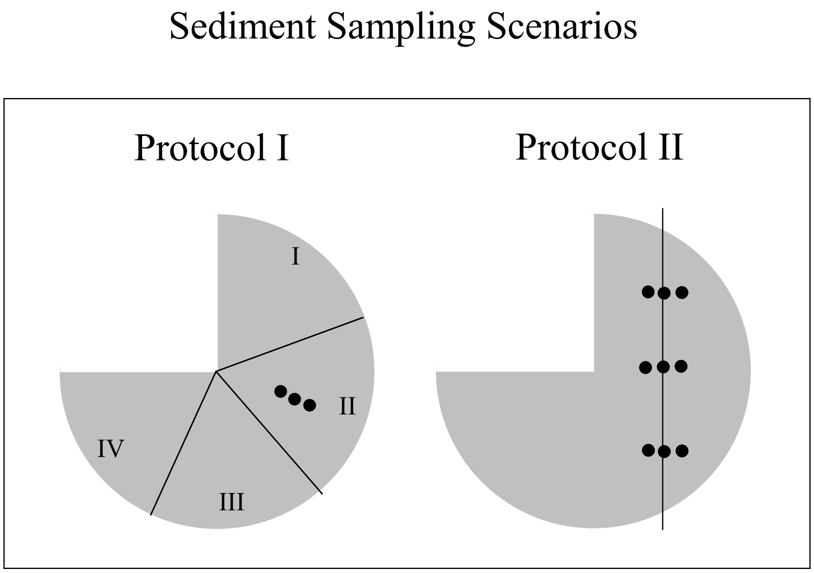

Figure 1. Sampling protocols used to examine between-site (protocol I) and within-site variation (protocol II) at sites employing mechanical macrophyte removal devices to control macrophytes. The shaded area represents the 270^{o} arc the roller arm of the device traverses. Roman numerals represent sections of equal area used to determine random sampling for protocol I. Solid circles represent replicate sediment core sampling locations for each protocol

All sediment core sections were dried at 105 ^{o}C to a constant weight for determination of moisture content and sediment bulk density, then a portion was combusted at 550 ^{o}C in a muffle furnace for determination of particulate organic matter content (POM). Remaining replicate dried sediment core sections were then combined for analysis of the particle size distribution, total nitrogen (N; mg/g) and total phosphorus (P; mg/g). The percent compositions of sand (i.e., > 63 µ), silt (i.e, > 2 µ and < 63 µ), and clay (i.e., < 2 µ) were determined on combined samples using a combination sieving and pipet technique according to Plumb (1981). Total N and P on combined samples were determined using automated analytical methods (Lachat QuikChem Analyzer; Hach Company, Loveland, Colorado) after digestion with red mercuric oxide (Plumb 1981).

In addition to sediment core collection, replicate measurements of in situ sediment penetration depth were obtained at each station in reference and treated sites using a penetration rod provided by the Minnesota DNR. The penetration rod consisted of a 2.3-m- by 3.8-cm-diam schedule 40 PVC pipe that was capped on both ends. Prior to capping, the penetrometer was filled with enough sand (i.e., ~ half the length of the rod) to make it neutrally buoyant in water. Affixed to the outside of the rod was a scale (in inches) used to measure the depth of sediment penetration. The rod was carefully lowered to the sediment interface and the depth of the water column was determined. It was then held out at arm's length and pushed into the sediment until it could no longer move. The change in depth as a result of penetration into the sediment was recorded. Sediment penetration depth was calculated as the difference in depth before and after pushing into the sediment. Additional measurements and observations included the water column depth at each site and the distance each station was located from shore.

RESULTS: In Latoka Lake, a prominent surface layer that was a mean 23 cm (± 0.6 S.E.) in depth, with a mean moisture content of 68.9 percent (± 2.3 S.E.), was observed in the reference station (Figure 2). The sublayer in the reference station had a much lower mean moisture content of 18.1 percent (± 1.4 S.E.) than the surface layer. The mean moisture content of the surface layer in the treated station of 24.3 percent (± 3.2 S.E.) was similar to the mean value observed in the sublayer of the reference station. No discernable sublayer was observed in sediment cores collected in the treated station. Mean sediment bulk density was low at 0.352 g/mL (± 0.038 S.E.) in the surface layer and greater than 1.0 g/mL in the sublayer of the reference station. In contrast, the sediment bulk density of the surface layer of the treated station was much higher with a mean 1.486 g/mL (± 0.104 S.E.). This mean value for the treated station was similar to the mean sediment bulk density value observed in the sublayer of the reference station. Sediment penetration was a mean 12.3 in. (± 0.9 S.E.) in the reference station and a mean 0.4 in. (± 0.1 S.E.) in the treated station.

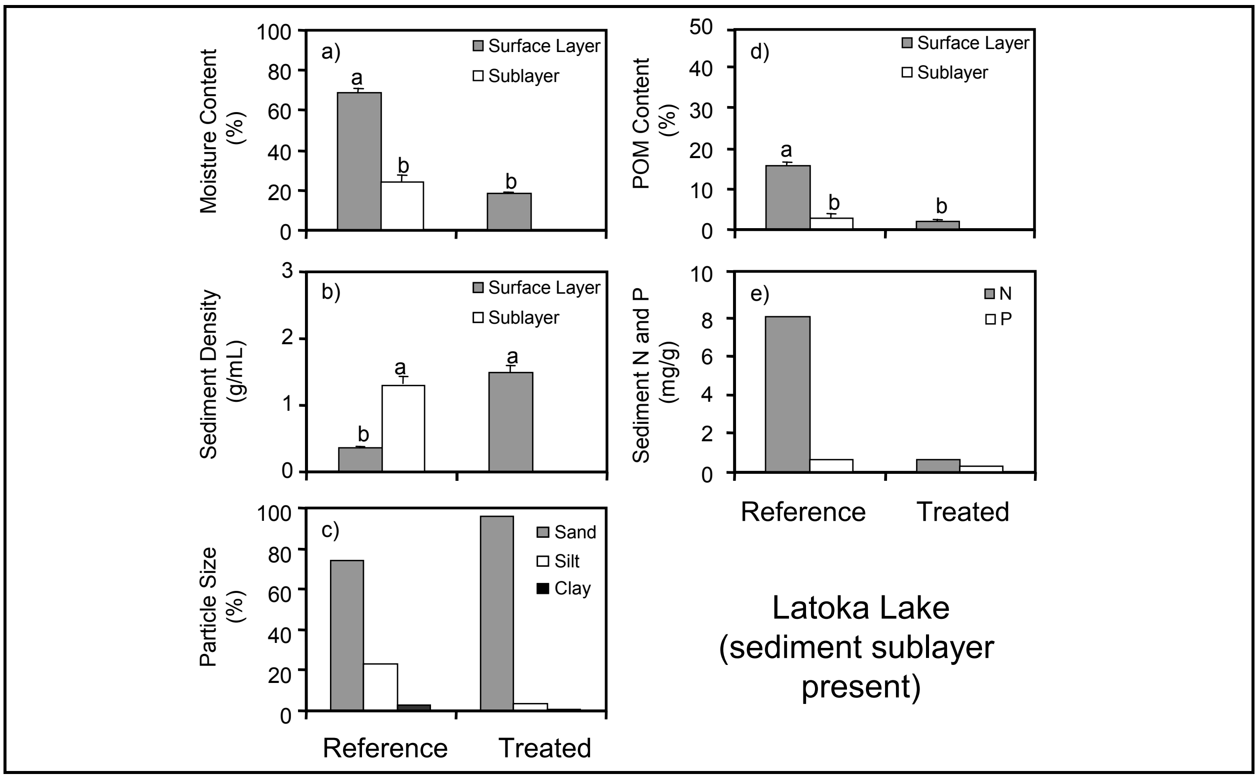

Figure 2. Variations in a) mean moisture content, b) mean sediment density, c) particle size distribution (composite of three replicate samples), d) mean particulate organic matter (POM) content, and e) sediment concentrations (composite of three replicate samples) of total nitrogen (N) and phosphorus (P) for sediment cores collected in a reference (i.e., no mechanical macrophyte removal device) and immediately adjacent treated (i.e., use of a mechanical macrophyte removal device) area of the shoreline of Latoka Lake, Minnesota. Letters above mean values denote significant differences in means between reference and treated sites (ANOVA; Statistical Analysis System (SAS) 1994). Vertical lines above mean values represent 1 Standard Error

The particle size distribution in the surface layer of the reference station was a mixture of 74 percent sand, 23 percent silt, and 3 percent clay (Figure 2). The particle size distribution shifted to 95.5 percent sand, 3.7 percent silt, and 0.8 percent clay for the surface layer of the treated station. Coincident with changes in the distribution of particles between reference and treated stations were declines in the sediment POM, N, and P concentrations in the surface layer of the treated station, relative to the reference station (Figure 2).

Other reference sites on Cowdry, Daggett, Gull, Heilberg, Prairie, West Lost, and Whitefish Lakes exhibited a distinct sediment surface layer and sublayer included sites. Patterns of change in sediment characteristics between reference and treated sites for these lakes were similar to those observed in Latoka Lake. These patterns suggested that the surface layer was in large part being removed in treated stations subjected to Weed Roller® operations, thus exposing a sublayer.

In contrast to Latoka Lake, the surface layer in Miltona Lake exhibited a low mean moisture content in both the reference (28.5 percent ± 0.6 S.E.) and treated (22.2 ± 1.7 S.E.) stations (Figure 3). No

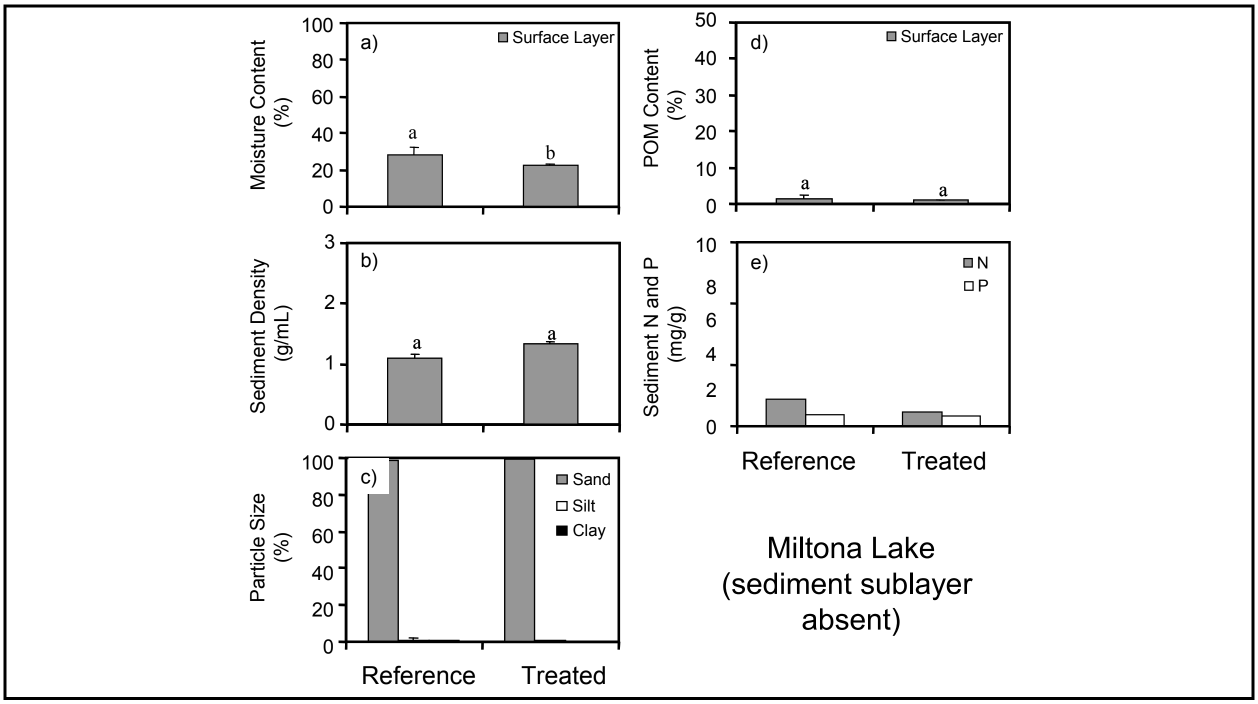

Figure 3. Variations in a) mean moisture content, b) mean sediment density, c) particle size distribution (composite of three replicate samples), d) mean particulate organic matter (POM) content, and e) sediment concentrations (composite of three replicate samples) of total nitrogen (N) and phosphorus (P) for sediment cores collected in a reference (i.e., no mechanical macrophyte removal device) and immediately adjacent treated (i.e., use of a mechanical macrophyte removal device) area of the shoreline of Miltona Lake, Minnesota. Letters above mean values denote significant differences in means between reference and treated sites (ANOVA; SAS 1994). Vertical lines above mean values represent 1 Standard Error

discernable sublayers were observed in sediment cores at either station. Mean sediment bulk density of the surface layer was high and similar between the reference and treated stations. Sediment penetration depth was negligible at both stations, which was attributed to the nearly 100 percent sand content of the sediment. POM, N, and P concentrations in the sediments were low and similar at both stations. Reference and treated sites on other lakes that exhibited no distinct sediment layering and a very low sediment moisture content included sites on Darling, Latoka, and Union Lakes. Since the sediment type was sandy for these lake sites, sediment scouring by the roller arm could not be estimated via comparison of sediment physical characteristics.

The depth of the surface layer in the reference stations (for those sites that exhibited flocculent surface sediments) was used as a conservative estimate of the amount of sediment displaced in treated stations in conjunction with Weed Roller® operations (Figure 4a). This estimate assumed that the sediment composition was similar at reference and treated stations before the initiation of Weed Roller® operations and that Weed Roller® operations were responsible for the majority of sediment removal, resulting in a change in the sediment composition at treated sites due to exposure of a sublayer. Wind-related resuspension and focusing via exposure due to macrophyte removal may have also contributed to sediment removal at these sites. Estimated sediment removal does not include loss of sediment originating from the sublayer that may have been removed in conjunction with Weed Roller® operation. Thus, total sediment removal associated with Weed Roller® operation may be underestimated. For some lake sites, net sediment removal could not be estimated because there was no defined subsurface marker with which to gauge sediment removal (i.e., stations in Ossawinnanakee Lake, Miltona Lake). Other techniques such as measurement of changes in bed elevation in reference and treated stations would have been required in order to determine net sediment removal at these particular sites (see James et al., in preparation). Thus, these stations could not be included in analyzing sediment removal associated with Weed Roller® operations.

There was a positive linear relationship between mean sediment penetration depth in reference stations and the mean estimated depth of sediment removed in the treated stations (Figure 4a). In general, mean sediment penetration depth measurements were greater than the mean estimated depth of sediment removed in the treated stations, indicating that the sediment penetrometer was being pushed into the sediment sublayer. Thus, there was not an exact (i.e., 1:1) relationship between sediment penetration and measurements of the depth of the flocculent sediment layer (i.e., the layer assumed to be removed via Weed Roller® operations) in reference sites.

Areal removal of sediment and associated constituents in Weed Roller® sites was estimated by determining the volume of sediment removed at treated stations, based on the depth of the surface layer that was removed. There were strong relationships between the mean sediment penetration depth in reference stations and the estimated amount of sediment, POM, N, and P removal in treated stations (Figures 4b-4f). These estimates represented conditions at the various stations (at the points where samples were collected) only and should not be extrapolated to represent the entire area impacted by the Weed Roller® roller arm at a given site (see below).

Within a site, there was variation in sediment physical and chemical characteristics as a function of variables such as depth and distance from shoreline (Table 2). For reference sites, there was a trend of increasing mean moisture content and decreasing mean sediment bulk density with increasing distance from shoreline and increasing depth, respectively. The percentage sand content generally decreased, while the percent silt and clay content increased, at these sites as a function of increasing distance from shoreline and increasing depth. Sediment penetration also tended to increase with

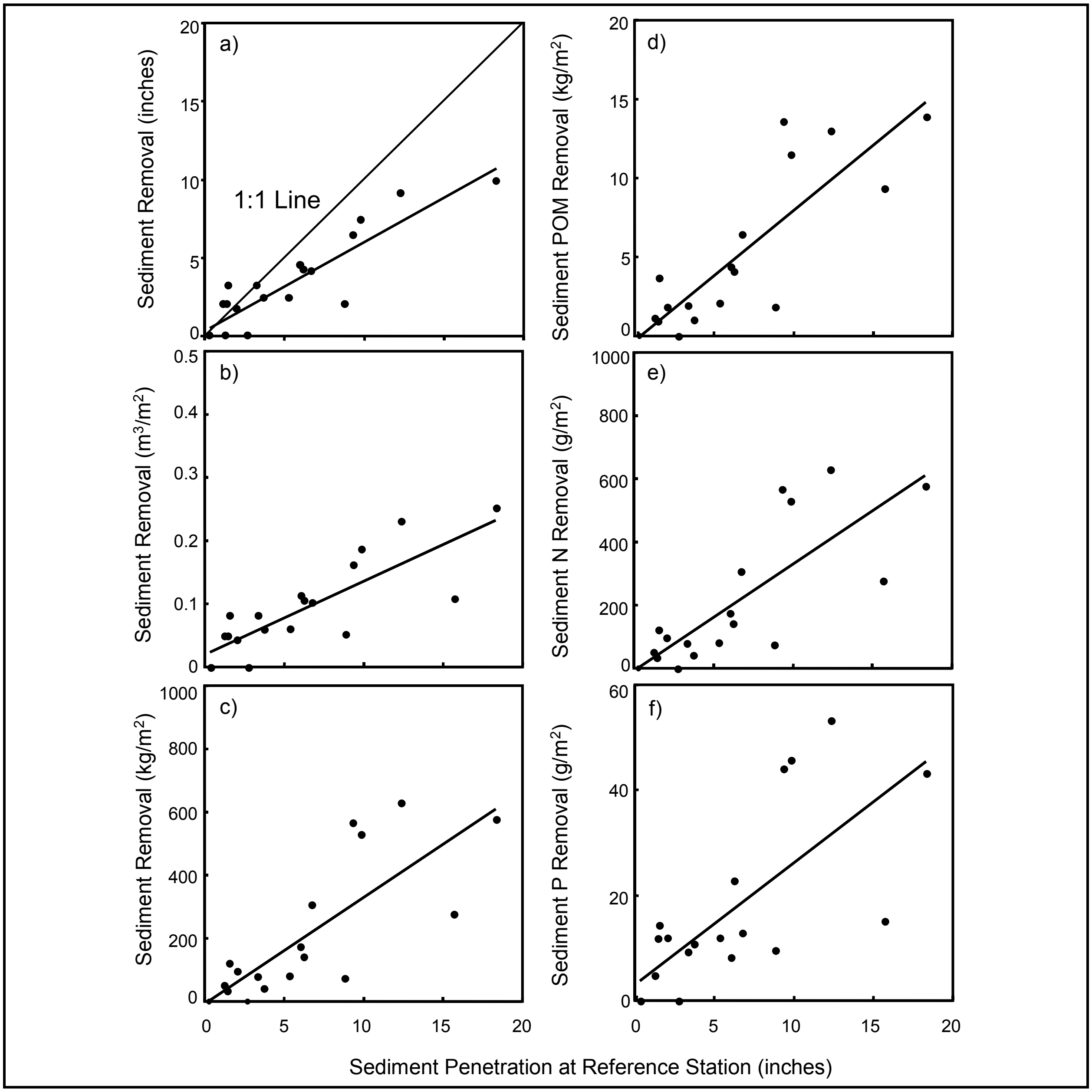

Figure 4. Relationships between sediment penetration depth in reference sites (i.e., no mechanical macrophyte removal device) and removal of sediment in treated sites (i.e., use of a mechanical macrophyte removal device)

Table 2
Variations in Physical and Chemical Characteristics of the Surface Sediment Layer as a Function of Distance from Shoreline and Depth at Reference (i.e., no use of mechanical macrophyte removal devices) Sites for Lakes in Minnestoa

Lake	Distance from shore ft	Water Column Depth cm	[1]Sediment Penetration inches	[1]Moisture Content %	[1]Sediment Bulk Density g/mL	[2]% Sand	[2]% Silt	[2]% Clay	[1]POM, %	[2]N, %	[2]P, %
Heilberger	16	81	4.5 (1.4)	61.2 (3.4)	0.48 (0.05)	76.6	20.3	3.1	15.5 (1.8)	5.17	0.51
Heilberger	28	114	5.3 (2.8)	42.5 (3.3)	0.82 (0.06)	81.5	16.4	2.1	7.5 (0.6)	2.94	0.30
Heilberger	36	143	7.0 (1.5)	79.8 (1.2)	0.28 (0.01)	61.9	33.3	4.8	20.7 (0.7)	8.90	0.60
Ossawinnanakee	28	70	1.3 (9.3)	51.8 (4.0)	0.63 (0.10)	87.3	12.2	0.5	10.1 (0.4)	2.74	0.19
Ossawinnanakee	22	92	17.3 (3.3)	67.8 (2.8)	0.44 (0.02)	56.6	41.1	2.3	9.7 (1.8)	3.59	0.20
Ossawinnanakee	16	142	> 25	71.6 (0.5)	0.39 (0.01)	51.1	45.2	3.6	8.1 (1.8)	4.42	0.27
Latoka	12	34	12.3 (0.9)	68.9 (2.3)	0.35 (0.04)	74.0	23.0	3.1	16.0 (0.5)	7.74	0.65
Latoka	18	38	9.8 (0.4)	74.1 (2.0)	0.32 (0.01)	69.5	26.1	4.4	19.0 (1.2)	8.75	0.75
Latoka	24	41	12.3 (0.4)	87.3 (0.3)	0.23 (0.01)	53.1	39.1	7.8	22.8 (0.2)	13.72	0.95

[1] Values represent means of three replicate samples (± 1 S.E.).
[2] Values represent a grand mean of the composite of three replicate samples.

increasing distance from shore and increasing depth at reference sites. Exceptions to this trend occurred at a reference site located on Latoka Lake.

Over all reference stations, there were strong correlations between physical sediment characteristics and sediment nutrient concentrations (Table 3). For instance, sediments exhibiting higher moisture content and lower sediment bulk density had higher concentrations of POM, N, and P. Percent sand content was negatively correlated, while percent silt or clay content was positively correlated, with sediment POM, N, and P. Sediment penetration depth in reference stations was also positively correlated to moisture content, and percent silt and clay content, and negatively correlated with sediment bulk density and percent sand content, suggesting relationships between the sediment penetration depth and sediment type. Similar correlations existed between sediment penetration depth and the concentration of POM, N, and P. Thus, sediment penetration depth measurements could be used to roughly estimate sediment type, the potential sediment depth that might be displaced, and the mass of organic matter and nutrients that could be removed as a result of Weed Roller® operation at a site (Table 4).

Table 3
Significant Correlations ($p < 0.05$; SAS 1994) Between Sediment Penetration Depth and Various Sediment Physical and Chemical Characteristics

Characteristic	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
(a) Penetration depth (inches)	0.71	-0.71	-0.52	0.55	0.77	0.62	0.60	0.64
(b) Moisture content (%)		-0.98	-0.72	0.73	0.85	0.87	0.87	0.80
(c) Sediment bulk density (g/mL)			0.66	-0.67	-0.79	-0.80	-0.79	-0.74
(d) Sand content (%)				-0.99	-0.81	-0.65	-0.64	-0.48
(e) Silt content (%)					0.78	0.63	0.62	0.47
(f) Clay content (%)						0.84	0.83	0.76
(g) POM content (%)							0.99	0.90
(h) Nitrogen content (%)								0.89
(i) Phosphorus content (%)								

DISCUSSION: Changes in sediment characteristics as a result of Weed Roller® operation were documented in shallow, littoral regions in the Fergus Falls-Alexandria and Brainerd region, primarily at sites where more flocculent sediments occurred (i.e., higher moisture content and lower sediment bulk density). Surface sediments in areas impacted by Weed Roller® operations often exhibited much lower moisture content and higher sediment bulk density, and a greater percentage of sand relative to reference stations. These compositional characteristics in treated sites were very similar to those observed in the sublayer of adjacent reference sites, suggesting excavation and removal by Weed Roller® operations of the more flocculent surface sediments down to a coarser-grained sublayer. At some sites (i.e., Prairie Lake; not shown), the moisture content was lower, and bulk density higher, than the sublayer of the reference site, suggesting that Weed Roller® operations continued to sort sediment after removal of the flocculent sediment surface layer. Also associated with the coarser-grained physical composition of sediment in areas impacted by Weed Roller®

Table 4
Regression Relationships Between Sediment Penetration Depth at Reference Sites and Sediment-Nutrient Displacement and Sediment Physical-Chemical Characteristics at Treated Sites

Variable	X = Sediment Penetration Depth (inches)	r^2
Sediment removal, inches	Y = 0.5691X - 0.3145	0.78
Sediment removal, m3/m2	Y = 0.0116X + 0.02	0.66
Sediment removal, kg /m2	Y = 33.786X - 8.274	0.63
Particulate organic matter removal, kg/m2	Y = 0.8265X - 0.3061	0.72
Total N removal, g/m2	Y = 33.786X - 8.274	0.63
Total P removal, g/m2	Y = 2.3144X + 3.0609	0.50
Sand content, %	Y = -1.8464X + 92.248	0.32
Silt content, %	Y = 1.6993X + 5.7865	0.36
Clay content, %	Y = 0.2148X + 0.7562	0.65
Particulate organic matter, %	Y = 1.5646X + 0.6016	0.51
Total Nitrogen, mg/g	Y = 0.5783X + 0.5555	0.47
Total Phosphorus, mg/g	Y = 0.0319X + 0.1536	0.48
Moisture content, %	Y = 3.0991X + 1.0995	0.57
Sediment bulk density, g/mL	Y = -0.05494X + 1.0995	0.55

operations were lower concentrations of sediment POM, TN, and TP relative to reference stations, suggesting removal of nutrients associated with the more flocculent surface sediments.

One of the important features of sediments at many sites in the Fergus Falls-Alexandria and Brainerd region was the occurrence of a distinct, coarser-grained, sublayer beneath a more flocculent surface layer. By comparing the depth of this interface in cores collected in reference versus treated sites, extent of sediment removal in areas apparently impacted by Weed Roller® operations could be quantified. For sites where apparent sediment removal via Weed Roller® operations could be estimated, there was a relationship between sediment penetration depth in reference sites, measured using a penetration rod, and conservative estimates of sediment, POM, and sediment nutrient removal in treated sites, measured via comparison of the sublayer interface in reference and adjacent treated sites. Thus, using sediment penetration depth information and regression relationships, potential sediment removal can be evaluated for other sites being considered for future Weed Roller® operation. Caution should be used in extrapolating sediment penetration measurements because although all regression relationships were significant, the r^2 value was often < 0.50. Other factors, such as sediment penetration technique (i.e., amount of downward force exerted for penetration measurement), probably accounted for a high percentage of the unexplained variance and limited the predictive power of these relationships.

The occurrence of distinct sediment layering in many reference sites in the Fergus Falls-Alexandria and Brainerd region was somewhat surprising given the fact that shoreline regions in lakes are generally exposed to wind-generated sediment resuspension and erosion (Håkanson 1977; Evans and Rigler 1983). Under these conditions, frequent turbulence and high energy typically favor net erosion of fine-grained particles from shallow regions and net accretion in deeper regions exhibiting lower energy environments (i.e., sediment focusing; Likens and Davis 1975). Thus, the sediments in exposed, high energy shoreline regions are often composed of very coarse-grained sands that are dense enough to withstand erosion (Evans and Rigler 1983). However, aquatic macrophytes can promote net accretion of fine-grained sediments in these environments by dampening wave activity and stabilizing the sedimentary environment from erosion (James and Barko 1990). Layering of more flocculent sediments over coarse sediments in shoreline regions of many of the lakes examined may be attributed to net accretion of sediment promoted by dense macrophyte stands.

Sediment penetration characteristics in reference sites were also related to other properties of the surface layer. For instance, sediment penetration was negatively related to sediment bulk density and percent sand content, and positively related to percent silt and clay content, POM, sediment N, and sediment P. Thus sediment physical and chemical characteristics, as well as the potential for excavation and removal, can be evaluated in the field using sediment penetration measurements.

Within-site variation in sediment characteristics was apparent at the sites located in Heilberg, Ossawinnanakee, and Latoka Lakes. This variation needs to be considered when evaluating sites for potential Weed Roller® use. For instance, moisture content of the sediments increased, while sediment penetration decreased, as a function of increasing distance from the shore and increasing depth at the reference site in Lake Ossawinnanakee. Thus, sediment penetration measurements should be taken along transects perpendicular to the shoreline across depth and distance gradients to ensure that variations in sediment characteristics are being documented.

The ecological implications of sediment displacement by mechanical macrophyte removal devices on water quality and littoral communities are complex and not entirely known. Disruption of sediment and associated nutrients by these operations may lead to eventual sediment transport to deeper portions of lake basins where nutrients can then be recycled back into the water column for algal uptake via redox reactions and vertical transport. Changes in sediment characteristics as a result of operations could have an impact on invertebrate densities and species richness, and littoral zone fish communities. Resuspension of nutrient-rich sediments could promote localized nutrient recycling and excessive algal growth. However, other aquatic plant control techniques such as herbicide treatment and mechanical harvesting can also promote nutrient recycling via decomposition and sediment resuspension, respectively. This study was not designed to differentiate the magnitude of impacts among various plant control methods. The potential for water quality impairment via sediment displacement will likely increase as a function of flocculent surface sediment volume (i.e., depth of surface sediment layer times the area of the treatment zone). While the likelihood of sediment displacement by operations can be estimated for various regions of a lake using sediment penetration depth estimates, factors such as overall density of mechanical macrophyte removal devices and operation schedule on a particular lake will need to be considered in management decisions. Other factors to consider regarding mechanical operations include an evaluation of the trophic state of the lake and its susceptibility to additional sediment and/or nutrient loadings.

The results of this study suggest that a simple sediment penetrometer is useful in rapid field assessment of sediments for decision-making and permit allocation for mechanical macrophyte removal devices. The amount of sediment, sediment type (i.e., sand, silt, clay), sediment mass, and concentration of sediment nutrients that will potentially be displaced at proposed sites for deployment of a mechanical macrophyte removal device can be estimated using the sediment penetrometer. For instance, this predictive capability could be used for making more informed decisions regarding estimation of the optimal density of mechanical macrophyte removal devices on a lake to ensure that adequate undisturbed littoral sediment substrate is still available for fish and invertebrate habitat. Sediment assessment techniques developed here may also be applicable for other localities seeking to evaluate potential impacts of mechanical macrophyte removal devices on sediment displacement.

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