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An Evaluation of Close-Cut Mechanical Harvesting of Eurasian Watermilfoil

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ABSTRACT

A conventional plant harvester was modified and equipped with a cutting bar that allowed plants to be cut near the sediment surface in water depths ranging from 1 to 6.5 m. Two hundred sixty two channels, 1.8 m wide and totalling 36,200 m in length, were harvested in a dense bed of Eurasian watermilfoil (*Myriophyllum spicatum* L.) as part of a whole-lake, fish management-research experiment designed to measure the effects of increasing the amount of plant bed, edge habitat on fish growth. We measured the immediate success of the close-cut harvester by comparing plant stubble height within the channels relative to a predetermined objective cutting height, and we measured the persistence of the cuts by comparing the length of channels remaining after 1, 2, and 3 yrs to the original length of channels harvested. The close-cut harvester was deemed successful based on meeting the objective cutting height of 0.6 m at 83% of sites surveyed. Channel persistence, 3 yrs following the one-time cut, averaged 46% of the original channel length in deep water sites between 3 m and 4.5 m, but only 4% in shallower water sites. Incidental fish mortality accompanying use of the close-cut harvester was low, with an estimated removal rate of only 36 fish ha^{-1}, consisting primarily of small bluegill (*Lepomis macrochirus*) less than 30 mm in length.

Key words: Aquatic macrophytes, selective removal, milfoil, fish mortality, management, control, mechanical harvesting.

INTRODUCTION

Excessive and dense vegetation is a common fish management concern in Wisconsin lakes (Engel 1987, Trebitz 1995). Historically, aquatic plant management has focused primarily on improving recreational opportunities in lakes and reservoirs via chemical treatment, dredging, or harvesting large areas of plant beds with little consideration given to the consequences for fishes or other aquatic biota (Carpenter et al. 1995). Complete removal of large areas of vegetated cover reduced density of major zooplankton taxa, reduced bluegill (*Lepomis macrochirus*) mean size, and caused a decline in the biomass of several phytophilic *Lepomis* species (Bettoli et al. 1993). Juvenile centrarchids are often associated with complex vegetative structure (Annett et al. 1996) important for survival (Miranda et al. 1984, Gutreuter and Anderson 1985). In contrast, open patches are used most often by adult centrarchids (Engel 1987, Annett et al. 1996), specifically largemouth bass (*Micropterus salmoides*) moving between food patches (Kilgore et al. 1989). Larger fish often associate with plant bed edges (Engel 1987) where macroinvertebrate prey resources are mostly concentrated (Sloey et al. 1997). Thus a reduction in dense vegetation, rather than eradication, should increase predator-prey interactions, improve fish growth (Bettoli et al. 1992, Bettoli et al. 1993) and augment fish production[3] (Smith 1993). Therefore, where fisheries are of concern to lake managers, the selective removal or treatment of monospecific vegetation stands to create the optimum amount of edge should be considered.

Selective cutting of channels, paths, or openings is an effective means of creating edge habitat (Engel 1995). Although mechanical cutting is a widely accepted tool for plant management, traditional machinery generally is limited to cutting at shallow depths, typically less than 2 meters below the water surface (Livermore and Koegel 1979, Cooke et al. 1986). Because such methods only serve to clip or trim the growing shoots of plants rooted in much deeper water, they only provide a temporary measure since regrowth is rapid (Strange et al. 1975, Perkins and Sytsma 1987, Wilson and Carpenter 1997). Cutting plants at the sediment surface is more successful for controlling regrowth than clipping plants higher along their shoots (Livermore and Koegel 1979, Cooke et al. 1986). Consequently, we used an experimental close-cut mechanical harvester to create edge habitat by cutting plant shoots near the sediment surface in a series of channels through a dense, largely monospecific, bed of Eurasian watermilfoil (*Myriophyllum spicatum* L.). The primary objectives of the study were (1) to measure the immediate success of the close-cut harvester in terms of achieving a cut below a predetermined objective height, and (2) to measure the long-term persistence of the close-cuts as indicated by the length of visible channel remnant and relative height of regrowth within channel remnants 1, 2, and 3 yrs. after harvesting. We also estimated the direct effect of the close-cut harvesting operation on the littoral zone fish community as measured by the number and size distribution of fish removed.

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[3] Miranda, L. E., K. B. Hodges, and L. L. Pugh. 1996. Aquatic vegetation influences on growth and recruitment of age-0 largemouth bass in Aliceville Lake. Mississippi Cooperative Fish and Wildlife Research Unit, Mississippi State University, Mississippi. Alabama Dept. Conservation and Natural Resources Completion Report. January 1996. 118 pp.

STUDY SITE

Studies were conducted on Fish Lake, a 101 ha seepage lake located 50 km nw of Madison, Wisconsin. The lake has a maximum depth of 19.5 m and a mean depth of 6.6 m. Water clarity (Secchi measurements) ranged from 1.5 m to 3.5 m during the summer months[4].The littoral zone was dominated by a dense stand of Eurasian watermilfoil, which formed a contiguous ring around the lake's perimeter at depths ranging from 1.5 m to 4.5 m (Lillie 1996). Milfoil comprised 90% of the total plant biomass and covered approximately 40% of the total lake bottom area (Budd et al. 1995, Lillie 1996). Estimated total dry weight plant biomass within milfoil stands at the time of harvest was 283 ± 13 g m^{-2} (Lillie 1996). The milfoil bed was essentially monospecific, with only sporadic occurrences of other species occurring within the dense interior. Coontail (*Ceratophyllum demersum*) formed a dense band at the deep water edge of the milfoil bed, and a mixture of native species, consisting primarily of watershield (*Brasenia schreberi*), white water lily (*Nymphaea odorata*), bushy pondweed (*Najas flexilis*), and other pondweeds (*Potamogeton* spp.), grew in shallow water, inshore from the milfoil bed. In order to avoid disturbing the native plant beds present in Fish Lake, cuts were restricted to the milfoil bed. The fishery was dominated by stunted bluegill and slow growing largemouth bass below age four[5].

METHODS

The Cut

A conventional plant harvester was modified by Dane County Parks Department by adding a hydraulic arm mounted at the rear and fitted with a 1.8 m wide cutting bar that allowed a variable cutting depth of 1 to 6.5 m (Figure 1). Depth of sediment surface was monitored by the driver using a hydroacoustic depth finder mounted near the steering unit. The cutter bar was raised or lowered according to depth to maintain a target cutting height of ≤ 0.6 m above the substratum.

A total of 262 channels, 1.8 m in width and ranging from 30 m to 1200 m in length, were cut with the modified close-cut harvester during a nine day period in August 1994. Channels were distributed among eight regions, each representing approximately a one day cutting effort. The number and total length of channels cut were derived from computer bioenergetics modelling which indicated that a 20-50% reduction in plant cover would improve fish predator-prey populations in Fish Lake (Trebitz and Nibbelink 1996, Trebitz et al. 1997, see also Olson et al. 1998). Channels were cut perpendicular to the shoreline in a radial pattern (Figure 2A). Additional channels were cut in the bays parallel to the shoreline along the 2 m and 3 m depth contours to interconnect with most perpendicular channels. Vegetation was harvested as close to the sediment surface as possible, at water depths ranging from nearshore at 1.5 m to the offshore edge at 4.5 m. Cutting operations ceased in shallow water before beds of native plants were encountered. Cut vegetation was picked up by a second, conventional, plant harvester that followed behind the close-cut harvester. When fully loaded, the conventional harvester returned to shore to unload plants into a truck for disposal on neighboring farm fields. The conventional harvester also was used to extend 14 channels into shallow water (from 2.0 m depth to nearshore) in one bay where dense plant growth (averaging 1000 g m^{-2}, dry weight, unpublished data), combined with residual mats of old sunken cattail bog, interfered with the operation of the close-cut harvester.

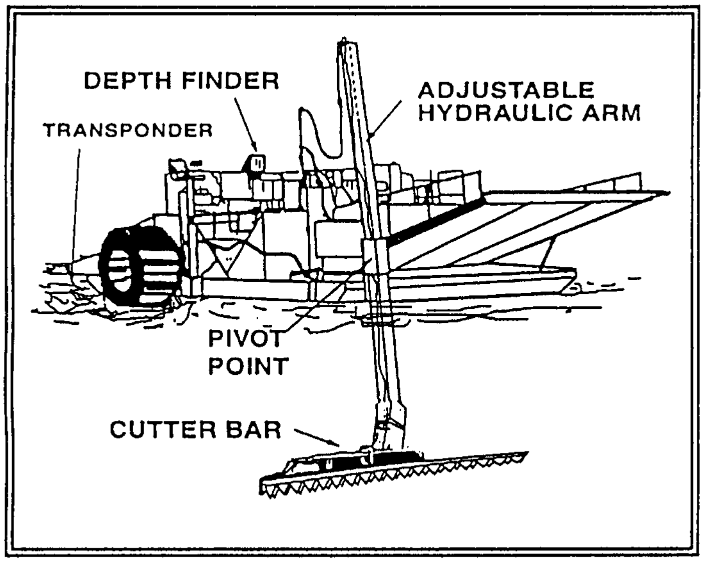

Figure 1. Modified close-cut mechanical plant harvester (not drawn to scale). Illustration by T. Pellett.

The Assessments

To assess the immediate success of close-cut harvesting as a tool for aquatic plant management, we systematically surveyed a total of 508 sites within 41 channels (16% of the total channels cut) using SCUBA. Approximately every sixth channel was chosen for assessment to assure an adequate sample around the entire perimeter of the lake. To categorize the quality of the cut, we established a criterion of 0.6 m plant stubble height as our objective. The 0.6 m cutting standard was chosen based on observations that milfoil plants in Fish Lake produce overwintering shoots that generally exceed 0.6 m in height by late summer (unpublished data, J. Budd, and personal observations). Cutting this close to the root crown removes the bulk of the main shoots and insures that, at the very least, the growing tips of overwintering shoots are trimmed back. Trimming overwintering shoots may hinder regrowth by interfering with carbohydrate resource reallocation (Perkins and Sytsma 1987, Madsen 1997) and root mass (Painter 1988). A secondary criterion of 0.3 m plant stubble height was chosen on the basis that most overwintering

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[4] Marshall, D. W., N. P. Nibbelink, P. J. Garrison, J. Panuska, and S. R. Stewart. 1996. A management plan to protect and improve the Fish Lake ecosystem. Dane County and Wisconsin Department of Natural Resources clean lakes grant management plan. 66 pp. & appendices.

[5] Unmuth, J. M. L., C. H. Storlie, and T. D. Pellett. 1997. Fish community assessment. In: T. D. Pellett (ed.) Pretreatment Results of the Fish Lake Project - Fishery and Aquatic Community Responses to Mechanical Harvesting of Macrophytes: Evaluating Edge Effect. Wisconsin Department of Natural Resources Publ-SS-924-97. Monona, WI. pp. 52-68.

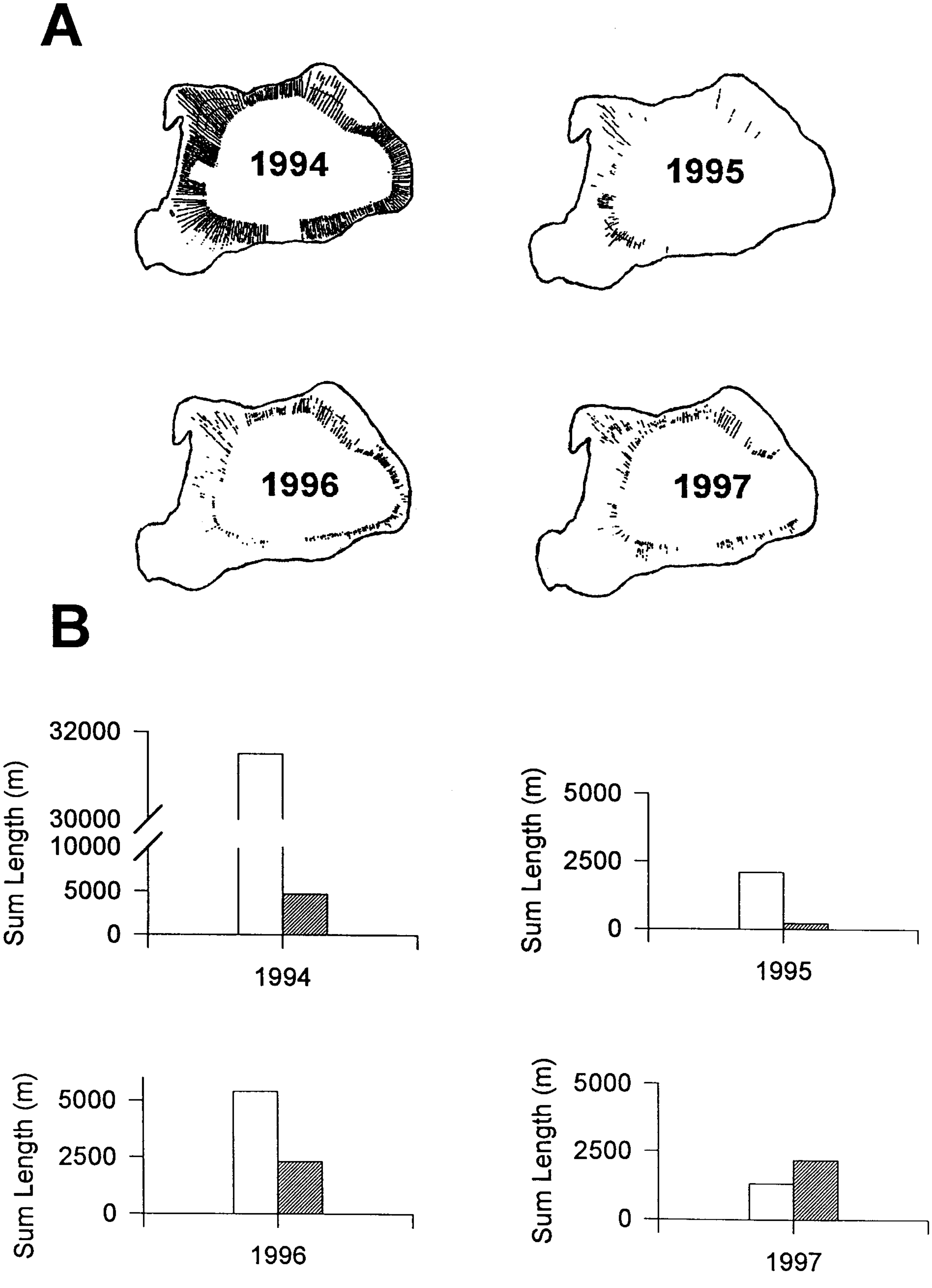

Figure 2. Channel persistence as indicated by (A) distribution of channel lengths visible on aerial photographs (shown for illustration only), and (B) total lengths of channel remnants by year and depth zone. Clear bars represent channel lengths in shallow water (< 3 m); hatched bars represent channel lengths in deep water (3 m-4.5 m).

shoots in Fish Lake grew as side branches which originated from the main stem at heights ranging from between 0.3 m to 0.6 m above the root crown (unpublished data, J. Budd). Therefore, cutting at 0.3 m from the sediment surface would remove most overwintering shoots altogether and likely have even greater impacts on regrowth than the 0.6 m standard. Divers started at one end of the channel and swam the entire length, stopping at 20 kick intervals to categorize the quality of the cut. Divers classified the height of stubble at each site into one of three categories; short = <0.3 m, medium = 0.3 to 0.6 m, and tall = >0.6 m, using a marked measuring rod that was color-coded to correspond to the 3 categories. The rod was placed next to the plant stubble in the middle of the channel. At the end of each channel, the diver surfaced and communicated survey results to an observer in a boat. All surveys were completed during the last week of the harvesting operations.

To assess the persistence of the close-cuts, we took a series of vertical aerial photographs of the milfoil bed using true-color 35 mm film and a polarizing filter from an elevation of approximately 1100 m above the lake in mid-summer during peak plant biomass in 1995-1997. We used a computer image analysis software program (Bioscan® by Optimus 1988) to measure the length of channels visible in each photograph. Linear distances were calibrated using an established list of baseline references based on groundtruth measurements taken from between fixed geographical landmarks about the lake perimeter. The precision of repeated length measurements of baseline reference distances varied inversely with the length of the reference distance applied, resulting in errors ranging from < 1.0% for most lines to a maximum of 3% for the shortest reference line used (e.g. ± 9 m using a 300 m reference line). Consequently, the accuracy of channel length measurements was highly dependent on the scale and baseline applied. The average accuracy of our channel measurements, at the scale and resolution most commonly applied, was estimated as ± 3 m. Because the ultimate objective of the aquatic plant management control program in Fish Lake was to create persistent edge habitat in dense plant beds via the establishment of channels[6],we measured the long-term success of the close-cut harvester by comparing the total length of visible channel remaining after 1, 2, and 3 years with the original length of channels created in 1994. To compare the persistence of channels in shallow water (< 3 m) versus deep water (3 m to 4.5 m), we overlaid tracings of channels representing a composite of aerial photographs for each year onto a hydrographic map of the same scale and, after recalibration, measured channel lengths in each depth zone.

To characterize the regrowth of milfoil in channel remnants, we conducted diver surveys in September 1995 (54 sites in 31 channels) and July 1996 (90 sites in 16 channels). These surveys were designed and conducted in a manner similar to that described above for the initial assessments of stubble height except as follows. At each site, divers qualitatively categorized the height of plant regrowth in the center of channel remnants relative to plant height in the surrounding uncut bed (i.e., no regrowth, minimal regrowth = <50% of the height of the adjacent bed, and moderate regrowth = >50% of the height of the adjacent bed). The resulting data provide an indication of the range in regrowth responses within visible channel remnants. We were not able to measure regrowth and recovery of milfoil in the channel segments that regrew completely because harvested channels were not clearly marked. Linear regression analysis using Sigma Stat® (Jandel Scientific 1994) was used to examine the relationship between the initial success rate within regions (i.e. percentages of sites meeting the 0.3 m and 0.6 m criteria) and channel persistence (i.e. percentages of channel length remaining after 2 and 3 yrs.).

To assess the impact of harvesting on fish mortality, we measured the removal rate and size structure of fish incidently harvested with the close-cut and conventional harvesters by randomly subsampling 1 to 3 tubs (0.06 m^3) of plants from each harvester load (3 m^3) during the off-loading process. A total of 93 tubs was examined, representing 4% of the total plant biomass removed from the lake. Fish in each tub were identified, counted, and measured, and the origin of each tub and harvester load was recorded by region and harvester method. We estimated the total number of fish removed during the combined operations by multiplying the fish removal rates by an estimate of the total m^3 of plants removed by each harvester method and summing the results. Fish size distributions were compared between the two harvester methods in one region. It was not the intent of this study to compare removal rates between the two methods of harvesters. However, because we also used the conventional harvester in one bay, we were obligated to measure fish removal by this second method. Comparisons of results between the two methods should be made with caution because water depth, substrata, and plant densities differed substantially in the areas cut.

RESULTS & DISCUSSION

Initial Assessments of Cutting Height:

Cutting 262 channels in the milfoil beds of Fish Lake created 36,200 m of channel length (Table 1) and removed 6.4 ha (15,000 kg dry wt milfoil in 46 harvester loads), which represented 19% of milfoil present by area and 18% of the original milfoil by biomass. The majority of channel lengths created were in water less than 3 m (31,515 m) while the remaining cuts were in the 3 m to 4.5 m depth zone (4,685 m).

The close-cut harvester was largely successful as indicated by the assessment of plant stubble remaining within the channels (Table 1). Assessment of cutting height showed that 83% of the sites were cut to within 0.6 m of the sediment surface and 45% were within 0.3 m of the sediment surface. The height of the stubble varied along the length of the channels due to difficulties involving operator control. Wind speed and direction influenced the operator's required ability to keep the harvester on a straight course. To counteract the effects of strong cross winds, the operator had to increase speed to maintain direction which decreased the operator's

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[6] Marshall, D. W., N. P. Nibbelink, P. J. Garrison, J. Panuska, and S. R. Stewart. 1996. A management plan to protect and improve the Fish Lake ecosystem. Dane County and Wisconsin Department of Natural Resources clean lakes grant management plan. May 1996. 66 pp.

Table 1. Assessment of the success of close-cut harvesting of channel habitat in Fish Lake, WI during 1994. Total operating time of the close-cut harvester, including plant pick up and removal operations, was 42.4 hours.

	Channels harvested				Assessment of plant stubble sampled during week of harvest				
Region[a]	(#)	Length (m)	Total Deep[b]	Area (ha)	Channels # (%) surveyed	Sites # sampled	Short[c] (< 0.3 m)	Moderate[d] (0.3-0.6 m)	Tall (> 0.6 m)
1	30	4600	530	0.8	8 (27%)	127	53%	38% (91%)	9%
2	21	3400	450	0.6	4 (19%)	56	18	34 (52)	48
3	32	1800	770	0.3	6 (20%)	71	55	34 (89)	11
4	23	4400	625	0.8	4 (17%)	46	57	30 (87)	13
5	14	1200	310	0.2	4 (24%)	53	57	30 (87)	13
6	41	3400	910	0.6	7 (17%)	71	42	41 (83)	17
7	55	3400	650	0.6	7 (13%)	77	35	44 (79)	21
8[e]	46	14000	440	2.5	1 (2%)	7	43	57 (100)	0
Totals	262	36200	4685	6.4	41	508	45	38 (83)	17

[a] Regions 1-8 as depicted in Figure 4.
[b] 3 m to 4.5 m depth zone
[c] Criterion 2; closest cut to root crown.
[d] Criterion 1 as shown in parentheses shows frequency of sites cut < 0.6 m above root crown
[e] Excludes 800 m of 14 channel extensions created using a conventional harvester, representing an additional 0.24 ha.

response time to raise or lower the height of the cutting bar relative to the lake bottom and resulted in a choppy, step type effect in the height of the stubble along some channels.

Assessments of Channel Persistence:

Early assessments of channel persistence during the summer of 1995 showed that only short remnants of 50 channels, representing 2,300 m of channel length (7% of original channel length cut), were readily visible even though water clarity was good. In addition, 72% of the sites surveyed within discernible channel remnants showed plant regrowth of over 50% of the surrounding bed height (Figure 3). The majority (91%) of visible channel length was at depths less than 3 m (Figure 2B). Incidently, regrowth in the channels cut using the conventional harvester was complete with plants reaching to the surface by the summer of 1995.

The longer term response to close-cutting was more pronounced as indicated by the channel assessments conducted in 1996 and 1997. In 1996, remnants of 170 channels, totalling 7700 m of channel length (21% of the original channel length cut), were clearly visible from the air. Approximately half of all sites surveyed within distinguishable channels had regrowth less than 50% of surrounding plant bed height and 20% had no regrowth at all (Figure 3). Only 30% of the total channel length remaining was at depths greater than 3 m; however, this value represented nearly 50% of the original channel length initially cut in the 3 m to 4.5 m zone (Figure 2B). By 1997, remnants of 123 channels, totalling 3500 m of channel length (10% of the original total channel length cut), remained detectable. However, 62% of the total channel remnant length was in the 3 m to 4.5 m zone (Figure 2), which still represented 46% of the original channel length cut at that depth. The length of channel remnants in the shallow depth zone declined to 4% of the original cut at that depth.

The long-term persistence of channels in the deep water zone varied considerably among regions (Figure 4), ranging from only 9% in regions 5 and 6 to 98% in region 4. No explanation for this disparity between regions is readily apparent. We know of no physical differences (e.g., slope or sediment composition) that exist between regions that might contribute to an explanation. We found no significant relationship between the success rate of the original cuts and long-term channel persistence at either the 0.6 m criterion (P = 0.79) or 0.3 m criterion (P = 0.64). However, we can not dismiss the possibility that in some cases the cutter bar may have reached into the substrate and damaged the root crowns, thus inhibiting their regrowth (Cooke et al. 1986) and contributing to the observed variation in persistence among our cuts.

Assessments of channel persistence based on aerial photographs were inconsistent among years. There appeared to be fewer channel remnants and less total channel remnant length visible during the 1995 assessment than during either of the later assessments in 1996 and 1997 (Figure 2). This response is highly unlikely; rather, we suspect that we underestimated the lengths and numbers of channel remnants

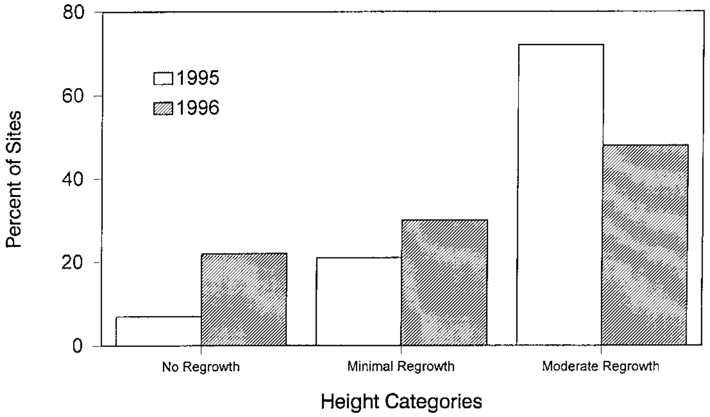

Figure 3. Milfoil regrowth in channel remnants during 1995 and 1996. Data represent percent frequency of occurrence by height class of plants within the channel remnant relative to height of plants in surrounding uncut bed as either no regrowth, minimal regrowth = < 50% surrounding plant height, and moderate regrowth = > 50% surrounding plant height.

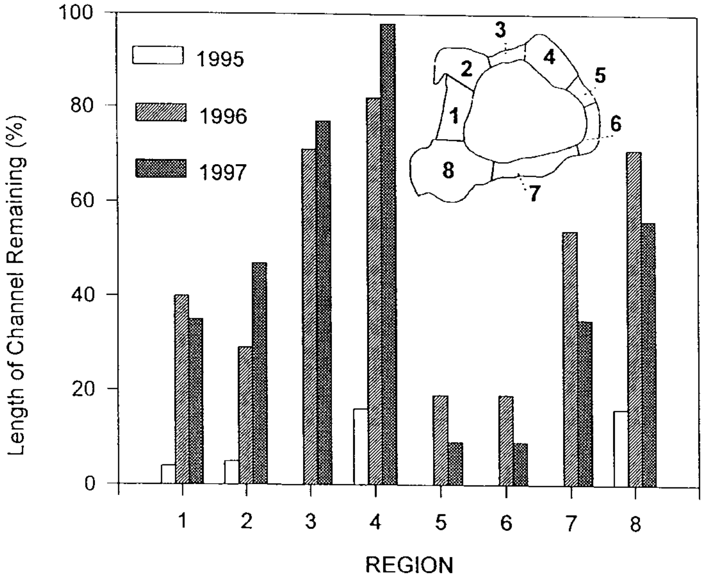

Figure 4. Comparisons of channel persistence at water depths between 3 m and 4.5 m by year and region. Data represent the percent of original channel length remaining as visible channel remnant within each region 1, 2, and 3 years following cutting. Locations of regions are shown in the inset figure.

during the 1995 survey. During 1995, we observed areas of the milfoil bed that appeared to be at various stages of collapse. Divers reported that some channels were covered by plants rooted in adjacent uncut areas that had fallen over or collapsed across channels. Additionally, large expanses of the plant bed exhibited signs of thinning. A series of intensive macrophyte biomass surveys of Fish Lake, conducted once annually during late July 1991 to 1997 (Lillie 1996, and unpublished data), showed that mean milfoil biomass during 1994 and 1995 was roughly 50% of means observed during 1991-1993 and 1996-1997. Initially a mystery, these conditions are now believed to be associated with an attack by the milfoil weevil, *Euhrychiopsis lecontei* (Dietz), which can cause the loss of buoyancy and sinking of milfoil stems (Creed et al. 1992, Creed and Sheldon 1993, Newman et al. 1996). We believe that the combined thinning and partial collapse of the milfoil bed produced by weevil activity masked channel detection (i.e. obscured the edge of channels as visible from the air) and caused us to underestimate the persistence of the close-cuts during 1995. In 1996 and 1997, milfoil biomass in Fish Lake recovered to pre-harvest conditions, thus creating greater contrast with remaining channel edges that resulted in a more accurate estimation of true channel persistence. Plants at the deep water edges of channels in regions 5 and 6 continued to show active signs of weevil activity during 1996 and 1997, which may account for the lower estimates of persistence in these two regions. Consequently, aerial photography was not reliable in assessing the presence of channels in areas affected by weevil damage.

This study demonstrates that the close-cut harvester is an effective tool to create habitat edge in dense beds of Eurasian watermilfoil. While conventional harvesters have achieved some degree of long-term success in maintaining boating access in shallow water through repeated cuttings during the growing season (review by Nichols and Shaw 1983, Painter 1988), the method is not effective in deeper water. The close-cut harvester was most successful in creating persistent channels (lasting up to 3 yrs) in water deeper than 3 m. Also, the close-cut harvester only required one cutting to achieve lasting impacts. Self-shading[7] by tall plants along channel edges likely contributed to the higher persistence of channels in deep water (Madsen et al. 1991). Alternatively, the timing of the cut may have coincided with the phenological control point (carbohydrate low point per Madsen 1997) of milfoil in the deep water zone, but may have been too late in the shallow water zone. Nichols and Cottam (1972) also reported more effective long-term effects of harvesting in deeper water and suggested that harvesting before growth peaks was critical to successful control of milfoil.

It is not clear why the responses varied among regions, although damage to root crowns can not be ruled out. Other mechanical methods are available to create persistent channels in deep water, but none is believed to be as easily applied as the close-cut harvester. Root crown removal (i.e. cutting plant stems in the top 1-2 cm sediment layer) has been used effectively to maintain openings in dense milfoil beds for several months (Cooke et al. 1990), but the method was accompanied by a reduction in water quality. Dredging also has been shown to be effective in controlling milfoil (Newroth 1979), but undoubtedly at a greater cost. Direct uprooting of milfoil plants has met with limited success (Nicholson 1981). Hand harvesting of milfoil is an effective means of controlling milfoil growth at low density levels[8],but is not practical for large applications.

Assessments of Fish Removal:

An estimated 891 total fish or 0.06 fish kg^{-1} dry weight of plants were removed during the entire operation. The close-cut harvester removed 231 fish at a rate of 36 fish ha^{-1}, while the conventional harvester removed 660 fish at a rate of 2254 fish ha^{-1}. Mikol (1985) estimated 2226-7420 fish ha^{-1} were removed by conventional harvesting of plant beds dominated by Eurasian watermilfoil. Our estimate for the rate of fish removed by conventional harvesting lies within those values. Close-cut harvesting removed fish at a much lower rate.

Fish species captured did not differ substantially between the two harvesting methods. Bluegill, yellow perch (*Perca flavescens*), and blackchin shiner (*Notropis heterodon*) made up 63%, 10%, and 7% respectively, of all species removed. The remaining 20% were distributed across centrarchids, percids, and cyprinids.

The average size of fish captured by the conventional cutter (65 mm) was greater than the average size (34 mm) taken with the close-cut harvester. Small fish dominated the catch, regardless of machine type (Figure 5). The size of fish

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[7] Madsen, J. D., J. W. Sutherland, and L. W. Eichler. 1989. Hand harvesting Eurasian watermilfoil in Lake George. Rensselaer Fresh Water Institute Report #89-8, Rensselaer Polytechnic Institute, Troy, NY. December 1989. 29 pp.

[8] Madsen, J. D., J. W. Sutherland, and L. W. Eichler. 1989. Hand harvesting Eurasian watermilfoil in Lake George. Rensselaer Fresh Water Institute Report #89-8, Rensselaer Polytechnic Institute, Troy, NY. December, 1989. 29 pp.

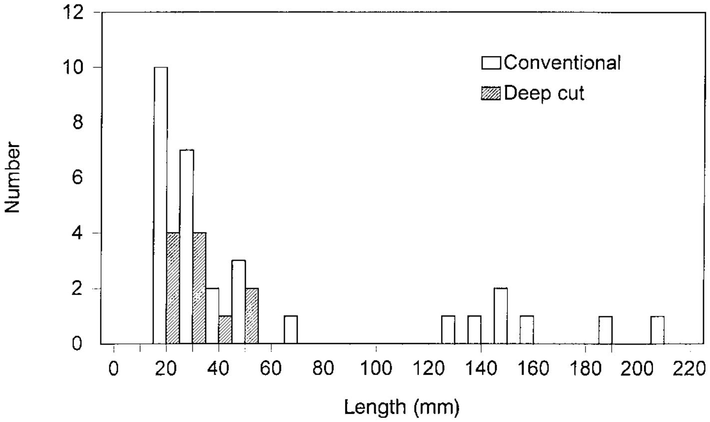

Figure 5. Number of fish by length class as removed by the two methods of plant harvesting. Data represent the number of fish found in the subsamples (i.e. tubs of plants surveyed).

ranged from 20-50 mm using the close-cut harvester, while fish from the conventional harvester ranged from 20-210 mm. Wile (1978) documented a similar range in size (12-190 mm) for conventional clearcutting of large areas in dense (300-400 g m^{-2}) plant beds.

The modified close-cut harvester appeared to have less impact on fish communities than the conventional harvester. The differences in mortality and size distribution of fish removed between the two machines may be related to basic differences in operating procedures. A lag time exists between cutting and removing plants using the modified close-cut harvester, giving fish time to flee; whereas the conventional harvester immediately picks up plants as it cuts, trapping fish between the pickup conveyor and approaching uncut beds thus, restricting escape. An alternative explanation for the observed differences in fish mortality between the two machines may be associated with differing fish densities according to habitat. The conventional harvester generally was used in shallow water (< 2 m) and areas where plant densities were too thick (dry wt biomass > 1000 g m^{-2}) for the close-cut harvester to operate; whereas the close-cut harvester was used at water depths ranging from 1.5 m to 4.5 m and where plant densities were lower. Additionally, fish size distribution in the catch is probably influenced by depth of cuts, rather than by cutting pattern or plant density.

Other Management Considerations:

The cost of modifying a conventional harvester by replacing the cutter bar, adding a hydraulic boom, and installing a depth finding unit was estimated at $10,000 (Wilson and Carpenter 1997). The close-cut harvester created channel length at a rate of 854 m hr^{-1}, which corresponded to plant removal rates of 0.15 ha hr^{-1} by area and 354 kg hr^{-1} by dry wt biomass. Staffing requirements exceeded that of a conventional harvesting operation due to the addition of one individual to monitor water depth and control the depth of the cutting bar. Operating time included stopping to periodically clean vegetation that accumulated on the cutting bar arm. Although we employed a second conventional harvester to pick up and remove cut plants, the close-cut harvester also could be used to pick up plants with its standard front mounted cutting bar and conveyor ramp. However, such an operation would be much slower due to the necessity of more frequent trips to shore to offload plants. Direct comparisons between close-cut harvesting rates and the conventional harvesting rates might be misleading because differences in plant densities and channel lengths resulted in a disproportionate amount of operating time required to maneuver the conventional harvester. And, while the rates of removal of the close-cut harvester fall at the lower end of the ranges of conventional harvester removal rates reported in the literature[9](Koegel et al. 1977, Livermore and Koegel 1979), such comparisons are not entirely valid because the close-cut harvester was not designed to compete with conventional harvesters. Rather, the close-cut harvester was designed to create narrower channels (to take advantage of self-shading aspects of milfoil) and to remove more than just the upper 2 m of plant stems) thus, achieving a long-lasting cut with a one time effort.

We conclude that a close-cut plant harvester is an effective tool to create edge habitat in dense beds of Eurasian watermilfoil that may persist for several years in deep water habitats. Furthermore, another study involving the close-cut harvester (see Olson et al. 1998) suggests that close cutting of channels, even when limited to shallow water, can produce a pulsed, positive response in growth rates and size structures of littoral zone fishes, which can carry through the lifetime of the individual fish. The close-cut harvester may be an effective management alternative to standard mechanical harvesting techniques (i.e. clear-cutting) by creating additional fish edge habitat while providing access through dense beds of milfoil for anglers and other recreational users.

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