4 Discussion

Factors Affecting Direct Damage

Direct damage to greenhouse cultured vallisneria and Eurasian watermilfoil plants in this study was shown to be influenced by interactions between the hydrological treatment conditions, the test plant species, and plant age. These interactions appear in part to be related to the amount of plant biomass and to how that biomass is oriented in the water column during exposure to passing waves.

Under high current velocity treatments, damage to Eurasian watermilfoil and vallisneria appeared to be more dependent on the length of the exposure than on waves. Under these treatments, the 0.25-m/sec ambient current lowered the position of the shoot material in the water column and, thereby, prevented exposure to the full energy of the waves (Figure 12). Consequently, for both species, 8-week-old plants were not damaged significantly more than were 4-week-old plants under the high-current velocity treatment series (T1-T3 and T4-T6) (Figures 7a and 8a).

Under treatment series with either intermediate current velocity (0.10 m/sec) or no current, 8-week-old plants generally received more damage than did 4-week-old plants (Figures 7b-7c and 8b-c). Observations made during these treatment runs suggest that damage was related to the amount of shoot material floating on the water surface prior to initiation of wave exposures. Because 8-week-old plants were longer and had more shoot length and biomass exposed on the water surface than did 4-week-old plants (Figure 3), higher numbers of fragments and biomass losses occurred from 8-week-old plants. Similarly, for between treatment comparisons of fragment losses from the same species and age group, higher losses of fragments and biomass resulted from treatments with no current than from treatments with the intermediate current. These observations suggest that damage from waves may be inversely related to current velocity under conditions where waves and ambient currents are unidirectional.

Results obtained from this study suggest that shoot material entanglement may have contributed to the level of plant damage. Tensile load measurements (Figure 15) recorded at the base of 8-week-old milfoil shoots exposed to waves of different heights under intermediate current velocities increased with wave height. Maximum peak loadings of 150 g (1.5 N) were measured for the 0.3-m wave height exposures and were less than the measured breaking forces for the basal sections (i.e., Zone 1) of both 4-week- and 8-week-old milfoil plants (Figure 4). Since tensile loads should have decreased distally along the shoots, tensile loadings significantly less than this value probably occurred toward the shoot apices and probably did not exceed breaking forces of the upper-shoot sections. However, visual observations during test runs suggest that shoot entanglement may have made plants more susceptible to breakage. During test runs, shoot entanglement probably caused increased loading on some shoot sections while weakening other sections by crimping them at locations of excessive bending. Similar explanations were suggested by Koehl and Wainwright (1977) for observed breakage of giant kelp stipes. These same researchers noted that the tensile load capacity of kelp tissues was often lessened by herbivory.

The fact that entanglement was a major factor determining the amount of direct damage from wave exposures would help explain why Eurasian watermilfoil plants, which have numerous leaf whorls and branches projecting along their shoots, experienced greater damage than did vallisneria plants, whose shoot mass is composed of individual, smooth, ribbon-like leaves. According to Haslam (1978), these and other morphological features of submersed aquatic plant species can be used to explain their riverine distribution patterns. An extension of the findings of this study would suggest that plant species with numerous branches and leaves projecting off the main shoot axis will probably be more susceptible to direct damage from waves than are species with shoot structures that resist entanglement. If this relationship is true, then plants such as *Potamogeton nodosus* and *P. richardsonii* should also be susceptible to direct wave damage due to their branched shoot morphology, even though field-collected plants showed higher breaking force requirements (Figure 16) than did test plants used in this study. However, it must be kept in mind that plant growth forms are usually adaptive to ambient conditions. Plants that successfully grow under high energy conditions similar to test conditions used herein will probably have morphologies more adaptive to resist direct damage than did the greenhouse-cultured plants used in this study.

Ecological Consequences of Direct Damage

The long-term consequences of repeated daily exposure of submersed aquatic plants to navigation-generated waves has previously been documented in several case studies. In European canals, Murphy and Eaton (1983) related the distribution and species richness of submersed aquatic plant communities to a critical frequency of recreational boat traffic. It was noted that direct damage from waves played a significant role in causing differences in plant communities between high traffic and low traffic areas. Similarly, Schloesser and Manny (1982 and 1989) showed that shipping channels in the Detroit and St. Clair Rivers had less diversity of submersed macrophytes than non-shipping channels. Overall abundance of aquatic species was less in shipping channels, and shorter, more narrow-leaved species were more common. These differences were attributed to waves and current reversals resulting from ship passage.

In this study, a given treatment series of exposures to the three wave heights resulted in a total exposure time of 75 min. Bhomik, Demissie, and Guo (1982) determined that daily secondary wave exposures generated by navigation traffic can reach this duration at certain locations in the UMR. Therefore, these results provide a satisfactory first approximation of the potential amount of daily direct damage to submersed aquatic plants in the UMR by navigation-generated secondary waves. In the UMR system, these direct effects will mainly be restricted to plant communities bordering the main river channel. Direct damage from navigation-generated waves will probably not be a widespread occurrence in most backwater sites since they are protected by islands and/or distance from secondary waves generated in the main channel.

In shallow water locations, high wave forces may penetrate to the bottom and heavily damage, or possibly completely uproot, submersed aquatic plants. This and related factors (e.g., upslope sediment characteristics) have been shown (Brewer and Parker 1990; Keddy 1982, 1985; and Wilson and Keddy 1985) to determine the upslope distributions of submersed macrophytes in sites with high wave exposure and may help explain the paucity of submersed plants in the shallow water areas along the main channel borders of the UMR system. Findings from this study suggest that in deeper water sites within the UMR system main channel border, direct damage from waves will be affected by the amount of plant biomass near the surface of the water. For this reason, species with a growth tendency toward canopy formation (e.g., Eurasian watermilfoil) will be more susceptible to damage, and damage should vary seasonally with peak biomass attainment. These findings further suggest that damage from secondary waves will be more extensive in sites with low ambient currents.

For vallisneria, measured biomass losses in this study were very low and illustrate the suitability of this species to occupy high energy areas. It would appear that factors other than fragmentation (e.g., high light attenuation, sediment instability) are responsible for the inability of this species to colonize the main channel border. Results of this study do indicate that vallisneria flowers may be susceptible to direct wave damage. Since little is known about vallisneria seedling ecology in the UMR system (Kimber, Korschgen, van der Valk 1995), the long-term consequences of this type of direct damage are currently not understood.

Other questions concerning the long-term consequences of navigation effects remain unanswered by the results of this study. For example, indirect impacts of shoot breakage may be much more significant than the mere removal of biomass, which in this study never exceeded 30 percent of exposed biomass. In the high turbidity environment of the UMR system, seemingly insignificant losses of shoot material from canopy-forming species such as Eurasian watermilfoil may, in fact, be indirectly detrimental if the plant is prevented from positioning photosynthetic tissues in a favorable light climate at the surface. Likewise, the tendency of higher ambient current velocities to lower the water column positioning of the plants may similarly have negative impacts stemming from reducing light availability. These factors, in addition to direct losses in biomass, may be responsible for the lack of plant establishment at intermediate depths (i.e., depths not influenced by “drawdown” from passing vessels) along the main channel border area.

Finally, though most submersed macrophyte beds in the UMR system are currently located in backwater areas that are not subject to navigation-generated waves, significant damage in backwater areas may be caused by recreational boat traffic, which is capable of generating secondary waves similar to those tested in this study (Bhomik and Soong 1992). If direct damage in these areas is indeed occurring, their impacts may be especially pronounced during this time of aquatic macrophyte recovery from declines that occurred at the beginning of this decade. Currently during this recovery period, Eurasian watermilfoil is colonizing shallow water areas previously occupied by vallisneria (Rogers 1994). The ability of boat waves to produce additional fragments from these milfoil colonies throughout the growing season may increase Eurasian watermilfoil's expansion rate.

Limitations of Present Study

Because the number of treatment conditions and plant species utilized in this study were limited, the results reported herein are not intended to provide comprehensive information on levels of direct damage that will result from increasing navigation traffic in the UMR system. Instead, the primary objective of this study was to provide a first approximation of the amount of direct damage that waves and currents characteristic of those generated by navigation traffic in the UMR system will cause to the submersed aquatic plant communities bordering the main channel border.

Chief among the limitations of this study was the exclusive use of unidirectional waves and currents, a limitation imposed by the test flume capabilities. Based on our observations, it appears that significant damage occurred under conditions which caused shoot entanglement. Therefore, the study was limited by the exclusion of other treatments (e.g., wave direction at an angle to ambient current, current reversals) representative of navigation-generated hydraulic disturbances that likely would cause extensive shoot entanglement. The present study was further limited by the incorporation of a uniform water depth in all treatments. In this study, maximum wave energy in even the highest wave height treatments did not penetrate to the sediment surface. Had water depth been sufficiently shallow to allow penetration of maximum wave forces to the sediment, it is likely that higher levels of damage, perhaps including uprooting, would have occurred. Under these conditions, susceptibility to uprooting would also depend on (1) the stability of the sediments, and (2) to how firmly the plants were anchored in the sediment. Because sediment characteristics would affect both of these factors, utilization of a single sediment type is a further limitation of this study.

An additional major limitation of this study was the use of greenhouse-cultured plants. That plants can morphologically adapt to different hydrological conditions has been documented by Haslam (1978). This study has similarly documented that field-collected milfoil plants were stronger and more resistant to tensile breakage than greenhouse-cultured plants. In this regard, levels of direct damage reported in this study may be different than actual direct damage in the field. Also, the combined effects of inherent field conditions (e.g., epiphytic load, nutrient stress, herbivory, and disease) on plant susceptibility to damage was not evaluated in this study. Finally, the study was designed to investigate acute damage resulting from treatments which represented a “typical” total daily exposure to navigation-generated secondary waves. In this respect, results of this study alone were never intended to be used to predict the effects of navigation-generated hydraulic disturbances on long-term growth processes of submersed aquatic plant communities within the UMR system.