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Alteration of Sediment Porewater Associated with a Eurasian Watermilfoil Invasion

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ABSTRACT

Competitive advantages possessed by invasive species encourage aggressive growth that ultimately results in loss of native species diversity and richness. Eurasian watermilfoil, *Myriophyllum spicatum* L., is a non-native invasive macrophyte that has altered native species composition on several trophic levels. In this study, we examined changes in the nitrogen and phosphorus porewater content within sediments underlying areas dominated by *M. spicatum* and adjacent sediments supporting native macrophytes. Total dissolved phosphorus (TDP) concentrations were significantly greater early in the growing season in porewater underlying an *M. spicatum* canopy and declined more rapidly early in the growing season under areas dominated by *M. spicatum* than under native macrophytes. Rapid, early season uptake of TDP may provide a competitive advantage for *M. spicatum*. Throughout the growing season, total dissolved nitrogen (TDN) concentrations were on average 2 to 3 times greater in porewater from the native macrophyte areas than the *M. spicatum* dominated areas. A horizontal transect showed similar TDN profiles within 10 m of the *M. spicatum* bed center. Profiles of TDN at the edge and in the native area were significantly different from all other samples. We demonstrated that in Lake George, an oligotrophic lake, *M. spicatum* influences porewater TDP on a seasonal basis, while porewater TDN concentrations appear to be altered on a longer time scale. The increased microbial activity associated with macrophyte biomass and the possible strengthened nitrification-denitrification coupling may help explain the TDP and TDN profiles, respectively.

Key words: Myriophyllum spicatum, nitrogen, phosphorus, porewater.

INTRODUCTION

Eurasian watermilfoil, *Myriophyllum spicatum* L., has been a nuisance plant throughout North America for more than four decades, taking over lakes and rivers, out-competing native macrophyte populations, and costing millions of dollars each year in attempts to control its aggressive nature (Eiswerth et al. 2000, Madsen 2005). Once established, asexual reproduction allows for rapid production of dense growth (Madsen et al. 1988). *Myriophyllum spicatum* growth can dominate an area in a matter of a few years, thereby limiting research on the invasion process and determining possible limitations to its growth and expansion (Aiken et al. 1979). *Myriophyllum spicatum* was first discovered in Lake George, a large, deep-water oligotrophic lake in the southeast portion of the Adirondack Mountains, in 1985 (Madsen et al. 1988). Initial studies in Lake George by Madsen et al. (1988) have shown that given the right conditions, *Myriophyllum spicatum* can nearly triple the area of lake bottom inhabited in a single growing season. The slow spread of this generally aggressive species in Lake George, however, has allowed studies to continue for more than 20 years that compare localized *M. spicatum*-dominated areas to the surrounding native macrophyte habitats.

While there is consensus that nitrogen and phosphorus are both essential nutrients and primarily acquired from sediments under natural conditions (Nichols and Keeney 1976, Best and Mantai 1978, Carignan and Kalff 1980), studies have shown that under eutrophic and hypereutrophic conditions nitrogen and phosphorus assimilated into plant tissue has come from foliar uptake (Bristow and Whitecombe 1971, Nichols and Keeney 1976, Denny 1980, Carignan 1982). While beneficial, this mechanism for obtaining nutrients is not the most efficient due to poor translocation of nutrients from the shoot downward to the rest of the plant (Nichols and Keeney 1976).

Nutrient enrichment studies have been used to determine limiting nutrients in aquatic macrophytes but have had contradicting results. Anderson and Kalff (1986) found supplemental nitrogen significantly increased the growth of *M. spicatum* (25% greater dry weight) two consecutive years, while supplemental phosphorus had no significant effect on the plant's growth. Wakeman and Les (1994) demonstrated how a sediment ammonia threshold facilitated growth of several macrophyte species. Carr (1998) demonstrated that macrophyte biomass increased with sediment phosphorus in a river system and then substantiated the experiment with an artificial stream experiment that revealed biomass enhancement with phosphorus additions, while nitrogen was only a secondary limiting nutrient. Rattray et al. (1991) found that increased growth in eutrophic sediments resulted in luxuriant uptake of phosphorus while nitrogen uptake was unaffected. Best and Mantai (1978) showed that while nitrogen can be growth limiting, there is a synergistic relationship between nitrogen and phosphorus, and nitrogen limitations may vary considerably depending on the concentration of phosphorus present.

The purpose of this experiment was to determine the sediment porewater nitrogen and phosphorus changes in both an established *M. spicatum* bed and the surrounding native macrophyte area over a single growing season.

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MATERIALS AND METHODS

Lake George is a large oligotrophic lake located on the southeast margin of the Adirondack Mountains of New York State. The study site was located at the mouth of Northwest Bay Brook, the largest subcatchment of the lake at 72.8 km^2 (Shuster 1994). The Northwest Bay location was one of the initial sites in which *M. spicatum* was found in Lake George in the mid 1980s. The *M. spicatum* bed is located in 2.5 to 3.5 m of water and covers an area of 1800 m^2. The sediment consists of a flocculent, organic matter with little sand.

The experiment was designed to determine if porewater nutrients varied between the *M. spicatum*-dominated areas and the native macrophyte-dominated areas during the growing season. Each month, one porewater sampler was placed in the center of the *M. spicatum* bed and another was placed in the native macrophyte dominated area at the same depth and distance from the shore. At the end of July, samplers were placed in a linear fashion from the center of the bed radiating to the native area to determine if horizontal differences were present. The porewater profiles were compared statistically by a paired t-test; if incomplete profiles were being tested, its compliment was truncated to accommodate the analysis. The monthly profile changes were also analyzed by the paired t-test.

Sediment porewater was collected utilizing "peepers" constructed of 1.27 cm lexan with one chamber every 2 cm to a depth of 30 cm (Hesslein 1976). Each chamber was able to hold approximately 20 ml of deionized water. A 0.2-µm pore size polysulfone membrane was held in place by a 0.313-cm sheet of lexan with complimentary chambers to the 1.27-cm sheet. The entire apparatus was held together with nylon screws. Peepers were deployed for a minimum of 2 weeks to allow complete equilibration of porewater nutrients. Upon retrieval, samples were separated and frozen prior to analysis. After thawing, samples were syringe-filtered (0.2-µm polysulfone membrane) to assure only dissolved constituents were analyzed.

Total dissolved phosphorus (TDP) was determined using the persulfate + molybdate method (Modified Standard Methods 4500-P; Clesceri et al. 1989). Total dissolved nitrogen (TDN) was analyzed via ion chromatography using a Lachat QuikChem Model 8000 Ion Chromatograph following persulfate oxidation (Modified Standard Methods 4500-NO_3 B/ 4110 B; Clesceri et al. 1989). Duplicate analyses were conducted on every 10^{th} sample to ensure the error associated with these measurements was less than 10%, while spikes were only conducted on reference samples due to the limited quantity of sample.

RESULTS AND DISCUSSION

While the total dissolved phosphorus (TDP) concentrations within sediments dominated by either *M. spicatum* or native macrophytes decreased over the growing season, the *M. spicatum* porewater TDP decrease was more dramatic and occurred earlier in the season than the native profile decline ($P < 0.01$). On average, the TDP concentration in the *M. spicatum* bed exceeded that of the native area by 2.5 times in early July but by only a fraction in early August (Figure 1). Significant differences were observed between the *M. spicatum* bed profile and the native macrophyte profile in June ($p < 0.01$) but not in August. In one month the TDP within the *M. spicatum* bed decreased by more than half its original concentration, while the native area TDP concentration decreased 20%. From August to September, the native area TDP porewater concentration fell by half, while the *M. spicatum* porewater TDP concentration decreased only 30% (Figure 1). Again the September *M. spicatum* and native macrophyte porewater profiles were significantly different ($p < 0.05$). All the *M. spicatum* profiles were significantly different from one another. However, only the September profile for the native macrophyte-dominated areas differed significantly from the June and August profiles. Early and rapid TDP uptake by *M. spicatum* could impart a competitive advantage that enables *M. spicatum* to dramatically alter habitats, eventually outcompeting native macrophyte populations in a localized area or whole water body.

While TDP concentrations decreased over the growing season in both the *M. spicatum* bed and the native macrophyte-dominated areas, TDN concentrations demonstrated very different patterns, both between sites and through the growing season. The TDN concentrations in the *M. spicatum* bed rarely exceeded 1000 ppb, while the TDN concentrations in the native macrophyte area were often two to three times greater than the *M. spicatum* bed and even approached 6000 ppb at depth early in the growing season (Figure 2). While the TDN profiles did not change significantly over the growing season for either the *M.* spicatum or the native macrophyte-dominated areas, the two sites were significantly different from each other throughout the growing season, during June and August ($p < 0.05$) and September ($p < 0.01$). Both TDN profiles demonstrated two different patterns vertically in the sediment. In the upper top 20 cm portion in the *M. spicatum* bed and the top 10 cm in the native area, there was a decrease of TDN in August with a rebound in September. In Lake George, *M. spicatum* roots have been found to depths of 24 cm, while native macrophytes root zones were seldom observed below 14 cm (C. Boylen pers. observ.). The root zone observed in these areas helps explain the exploitation of nitrogen in this region. Carignan (1985) documented exchangeable ammonium differences in this region between colonized sediments of *M. spicatum* and uncolonized sediments. Below this portion of the sediment there was no consistent trend between the two profiles. In the *M. spicatum* bed, there was little change or a slight increase as the growing season progressed. In the native porewater profile, two more patterns arise between 10 to 20 cm and 20 to 30 cm; between 10 and 20 cm there was an increase in concentration during the growing season, often doubling the initial TDN concentrations measured. In the bottom third of the profile, the September TDN concentrations were the lowest measured during the summer of 2006.

The large deviation in TDN between the *M. spicatum* bed and the native macrophyte area implies long-term sediment chemistry changes as a result of *M. spicatum* uptake and utilization (horizontal trend in Figure 3). These samples taken between July and August show that within 10 m of the *M. spicatum* bed center, the TDN concentrations were similar within the root zone of both sites, while greater variation was

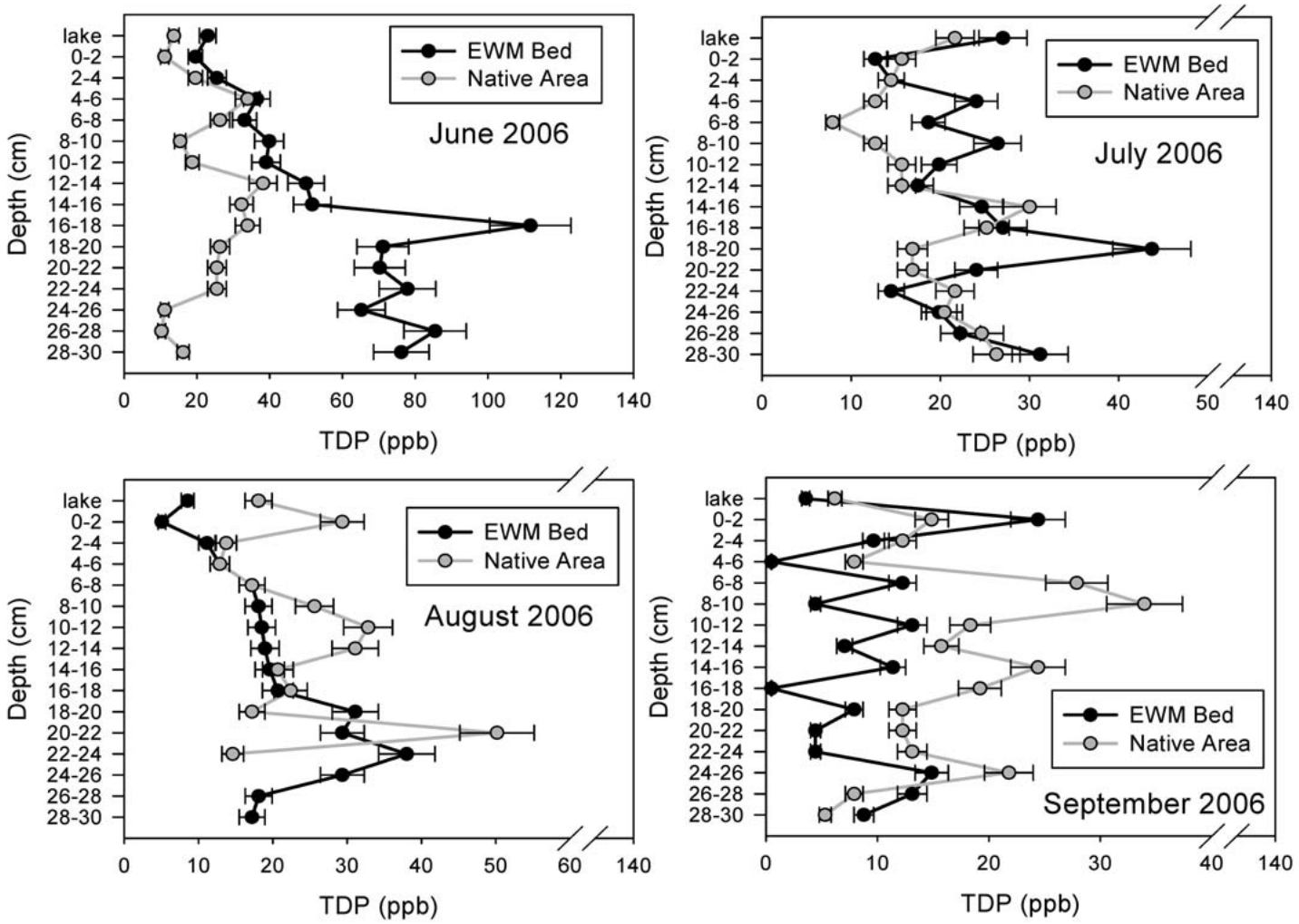

Figure 1. Total dissolved porewater phosphorus (ppb) profiles in Northwest Bay 2006. June and September profiles are significantly different from all other profiles ($p < 0.01$) using a 2-tailed paired t-test. The profiles were drawn by connecting the points determined by individual analyses at each of the depth intervals specified on the y-axes. The error associated with this analysis is on the order of 10% based on QA/QC (see Materials and Methods).

seen as depth increased. The 15-m site, near the edge of the *M. spicatum* bed, generally had a higher TDN concentration. Ten meters into the native macrophyte area, the TDN concentration increased substantially and approached 6000 ppb. Statistically, TDN porewater profiles were not different within 10 m of the *M. spicatum* bed center, but all profiles were significantly different from the native sample 10 m from the *M. spicatum* bed ($p < 0.01$). The TDN profile at 15 m near the edge of the two areas was significantly different from the center, 10 m, and native profiles ($p < 0.01$), as well as, the 5-m profile ($p < 0.05$).

This study has shown that the influence of rooted macrophyte growth is more pronounced in the TDP profiles, both in concentration and depth. Furthermore, *M. spicatum* may be taking up nutrients earlier in the growing season than the native macrophytes. Although the root zones vary between *M. spicatum* and the native macrophytes, all species influence the TDN concentrations only during peak growth. The TDN within the root zones rebound to initial concentrations in the *M. spicatum* bed and exceed initial concentrations in the root zone of the native macrophyte area. To observe large differences in the TDN profiles between both areas, a longer time scale is needed to observe the effect of *M. spicatum*, possibly due to the coupling of nitrification and denitrification within the *M. spicatum*-dominated sediments. Karjalainen et al. (2001) found that oxygen release from root systems supported aerobic mineralization and may enhance the loss of nitrogen through strengthened nitrification-denitrification coupling. Caffrey and Kemp (1992) determined that the nitrogen cycle may be stimulated by enhancing nitrification through root oxygen release, denitrification through root exudation of organics, or both. By this means, the TDN in the porewater associated with a *M. spicatum* bed may diminish over time.

Microbial activity may also be responsible for the higher TDP porewater concentration observed in the *M. spicatum*-dominated areas early in the growing season. While *M. spicatum* does over-winter in Lake George, it does not appear to initiate new growth until mid- to late June, depending on spring conditions. The increased bacterial counts associated

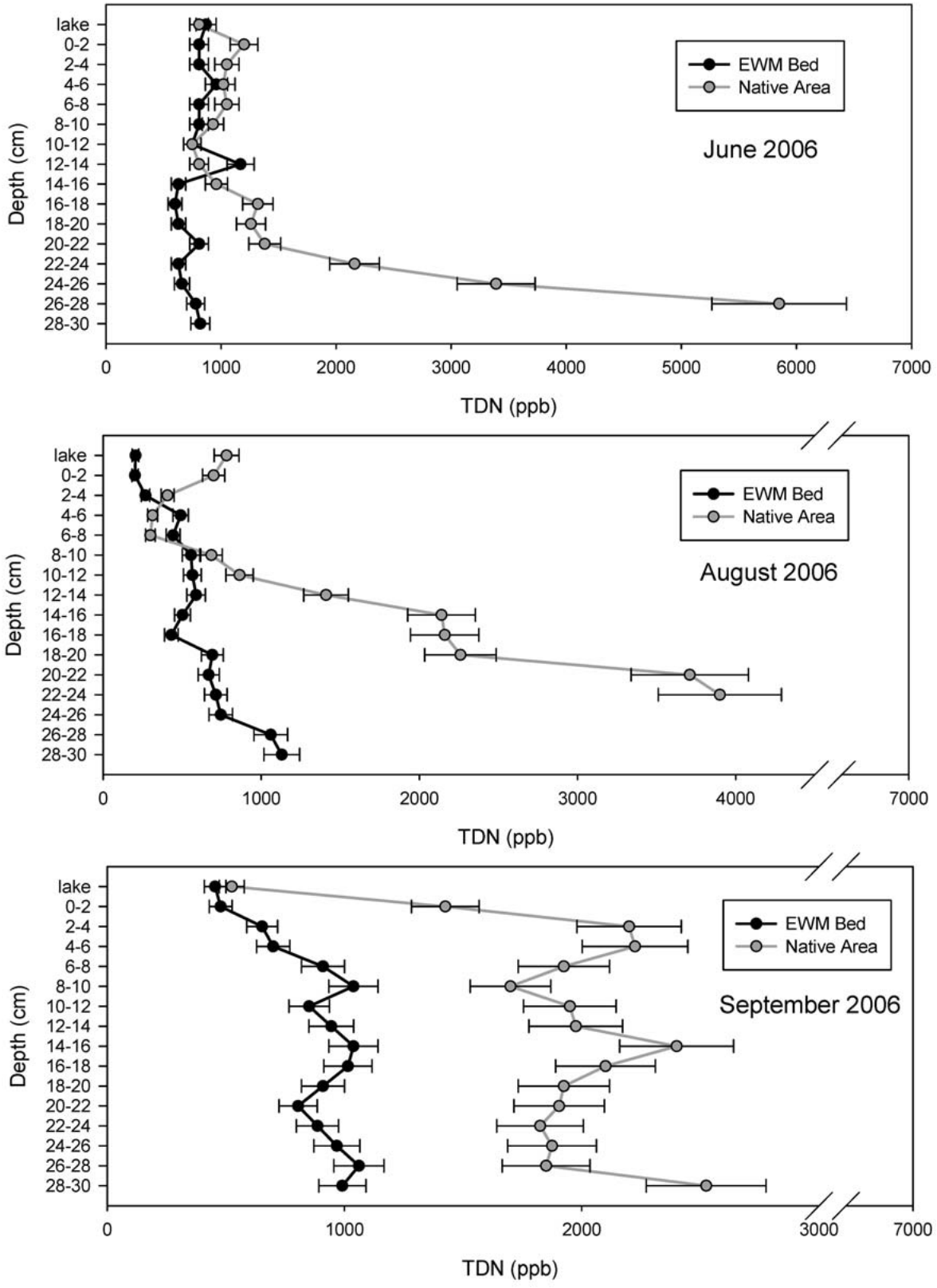

Figure 2. Total dissolved porewater nitrogen (ppb) profiles in Northwest Bay 2006. The June profile is significantly different between sites ($p < 0.05$); August and September profiles are both significantly different between sites ($p < 0.01$) using a 2-tailed paired t-test. The profiles were drawn by connecting the points determined by individual analyses at each of the depth intervals specified on the y-axes. The error associated with this analysis is on the order of 10% based on QA/QC (see Materials and Methods).

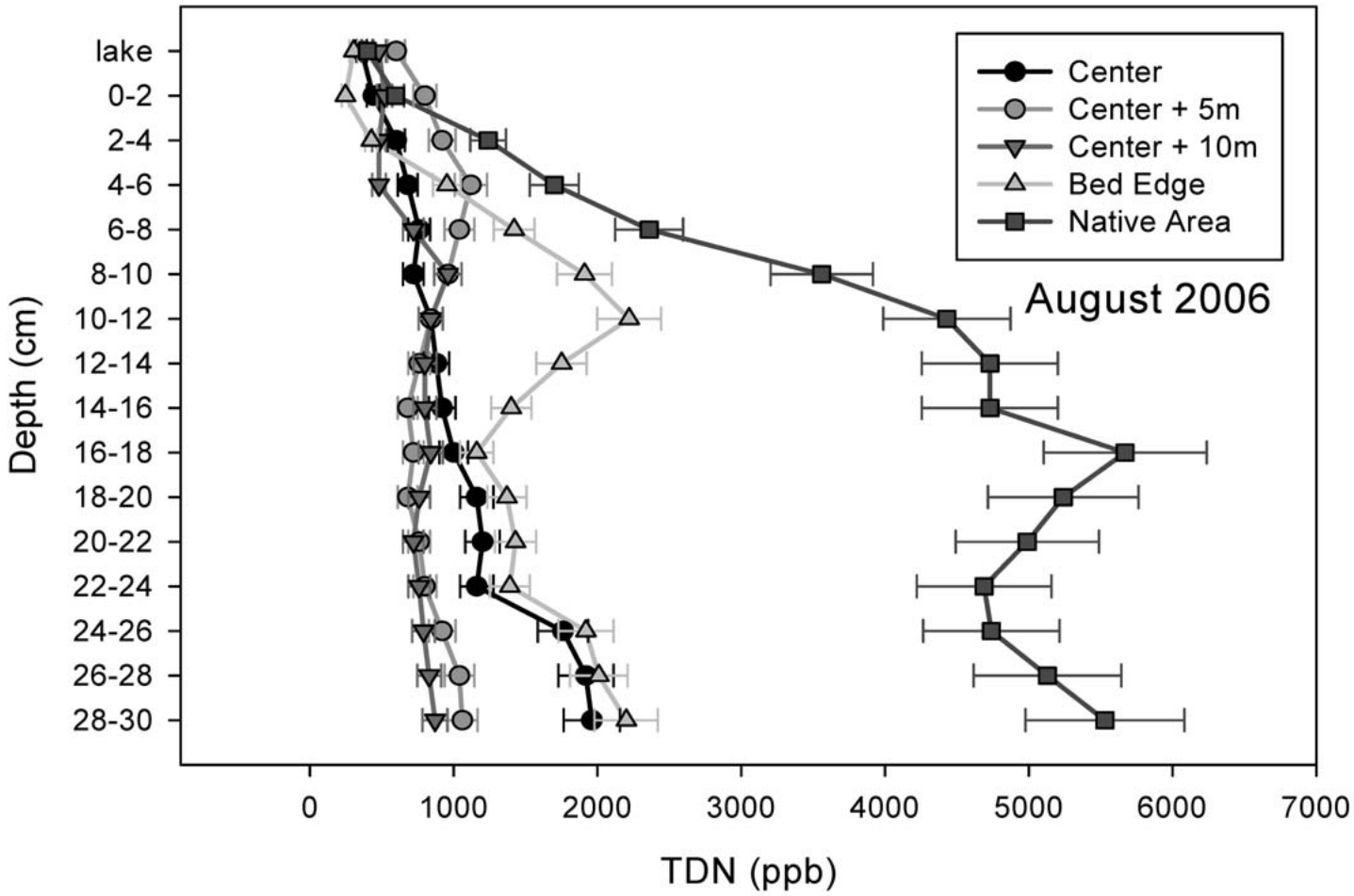

Figure 3. Total dissolved porewater nitrogen (ppb) profiles along a transect from the Eurasian watermilfoil bed center to the native macrophyte-dominated area. The center and 10-m profile are significantly different ($p < 0.05$), as are the edge and native profiles, from all other profiles ($p < 0.01$) using a 2-tailed paired t-test. The profiles were drawn by connecting the points determined by individual analyses at each of the depth intervals specified on the y-axes. The error associated with this analysis is on the order of 10% based on QA/QC (see Materials and Methods).

with submersed macrophytes (Duarte et al. 1988) may allow a build-up of TDP prior to initiating new growth. Other processes complicating the understanding of nutrient dynamics associated with macrophytes are benthic invertebrates, which Cronin et al. (2006) found to increase with the presence of macrophytes, the thickness of the benthic boundary layer, and groundwater advection.

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