RECENT AND HISTORICAL ENVIRONMENTAL CHANGE IN LAKE DRUMMOND, WITHIN THE GREAT DISMAL SWAMP

David J. Burdige, Ph.D.[2]
Jennifer Slate, Ph.D.[1,3]
Jeremy Hicks (M.S. student)[1]
Melissa Frazier (undergraduate student)[1]
Sean Donalty (undergraduate student)[1]

1. Department of Biological Sciences, Old Dominion University
2. Department of Ocean, Earth and Atmospheric Science, Old Dominion University
3. current address: Department of Biology, Northeastern Illinois University

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Summary

Biological and sedimentological remains indicate that Lake Drummond has been adversely impacted by logging and drainage of the surrounding Great Dismal Swamp. Initial logging and drainage activities by early European settlers increased sediment erosion into the lake, decreasing light transmission through the water. Sponges and diatom communities became dominated by species that require less light. By 1843, sediment erosion had decreased and the sponge and diatom communities had recovered (i.e., there was an increase in sponge species that require more light, as well as an increase in benthic, versus planktonic, diatoms).

In the early 1900s, the digging of drainage canals intensified, causing a renewed increase in sediment erosion into the lake. Sponge and diatom communities once again became dominated by species that require less light. Although sediment erosion has been low since 1965, the sponge and diatom communities have not recovered. At the present time, there is no clear explanation for this most recent lack of recovery of the sponge and diatom communities in the lake.

Although Lake Drummond is part of the Great Dismal Swamp National Wildlife Refuge, there have been few ecological studies to assess water quality. Therefore, we analyzed a sediment core collected in Lake Drummond to infer how the lake has changed since European settlement. Because new sediment is continuously deposited over older sediment, lake sediment contains a chronological record of past water quality conditions.

Our results indicate that the logging of the Great Dismal Swamp that occurred after European settlement greatly decreased the water quality of Lake Drummond. The amount of sediment eroding into the lake increased, ultimately affecting the biotic community. The increase in sediment erosion into the lake can be seen by the increase in the inorganic content of the sediment (Figure 1). Although inorganic sediment was low below 16 cm, it began increasing at 15-16 cm and more than doubled at 14-15 cm. Another peak in inorganic sediment content occurred at 4-5 cm. Inspection under the microscope revealed that these depths had high sand content. Organic sediment content, on the other hand, varied little with depth. Organic sediment is most often produced within a lake, and consists of the remains of organisms such as phytoplankton and zooplankton. Inorganic sediment usually enters a lake via erosion. An increase in inorganic content of lake sediment often occurs after the watershed has been deforested (Engstrom and Wright 1984).

The ^{210}Pb dates indicate that the peaks in inorganic sediment input occurred at times of intense human activity. Because ^{210}Pb has a short half-life, it can be used to date sediments up to about 150 years old (Schelske 1994). We attempted to date older sediments with ^{14}C, but input of dissolved carbon from the surrounding swamp made ^{14}C dating ineffective. Our oldest ^{210}Pb date indicates that 7-8 cm depth dates to 1843 (Table 1). The large input of inorganic sediment that began at 15-16 cm and continued to 11-12 cm would have caused sediment to accumulate more quickly than at higher depths in the core, and this period of sediment erosion into the lake was likely caused by logging and canal-digging by early European settlers. Although Native Americans hunted in the Great Dismal Swamp and cleared small areas for agriculture (Whitehead 1965, Bottoms and Painter 1979), large-scale environmental change began when European settlers began logging and digging canals in the 1770s (Stewart 1979). The second peak in inorganic sediment content, which occurs at 4-5 cm and dates to 1925, appears to be a consequence of increased canal-digging. Most of the 125 miles (200 km) of drainage canals in the swamp were dug in the early 1900s (Levy 2000). Although sand covers large areas of the lake bottom where drainage canals enter the lake (Marshall and Robinson 1979), our data indicates that sand input was even greater during early European settlement and during the early 1900s.

The increased amount of sediment eroding into the lake affected the biotic community. At 15-16 cm depth, the sponge *Anheteromeyenia ryderi*, which requires less light (Harrison 1974), replaced light-positive sponge species *Anheteromeyenia agyrosperma* and *Corymeyenia evertii* (Figure 2). A decrease in benthic (bottom-dwelling) diatoms also indicates decreased light transmission (Figure 3). The sediment input probably also increased the amount of dissolved substances in the lake, increasing water density. At 15-16 cm depth, the proportion of planktonic diatoms increased, especially *Asterionella formosa* and *Aulacoseira herzogii* (Figure 4). Planktonic diatoms, which live within the water column, remain afloat more easily at higher water densities (Lampert and Sommer 1997).

Inorganic sediment decreased above 12 cm depth, indicating that sediment erosion decreased after the initial impact by early Europeans (Figure 1). The sponge and diatom communities also recovered. Sponge species that require more light (*Anheteromeyenia agyrosperma* and *Corymeyenia evertii*) increased in abundance (Figure 2). Benthic diatoms also increased, and planktonic diatoms decreased (Figures 3 and 4). Since the ^{210}Pb date at 7-9 cm is 1843, we know that the recovery began prior to 1843. Low amounts of inorganic sediment and the corresponding recovery of biota remained until 4-5 cm depth, which dates to 1925.

In 1925, the impact of logging and canal-digging became apparent again. The amount of inorganic sediment suddenly doubled at 4-5 cm and the biotic changes seen at the beginning of European colonization occurred once again. *Anheteromeyenia ryderi*, which requires less light, replaced other sponge species (Figure 2). Benthic diatoms decreased and planktonic diatoms increased (Figures 3 and 4). The change in biota remained through the top of the core, even though inorganic sediment had decreased by 1965. This indicates that sediment erosion is no longer high and that another factor is causing the present impact to biota. The low amount of sediment erosion in recent years is not surprising since little logging occurred in the swamp after 1945 and 167 square miles (433 km^2) of the swamp was made a National Wildlife Refuge in 1974 (Ashley 2000, Stutts 2000).

The failure of the biotic community to recover, even though sediment erosion is no longer high, may be due to an increase in nutrients entering the lake. Before the swamp was protected, half of its original 2,000 square miles (5,200 km^2) was drained. The drained areas have been converted to agriculture and suburban development, possibly causing nutrient runoff from the use of fertilizers. In addition, drained swamp sites release more nutrients than flooded swamp sites, because decomposition occurs more quickly once peat is drained (Day and Megonigal 2000). For example, peat that took 3,000 years to accumulate in the Great Dismal Swamp took only 125 years to decompose after drainage (Whitehead and Oaks 1979), so 3000 years of nutrient accumulation were released relatively quickly.

Some evidence exists that nutrient input into Lake Drummond has increased. Cyanobacterial populations have increased, which is a common but undesirable result of increased nutrients (Marshall and Poore 1972, Poore and Marshall 1972, Marshall 1976, Phillips and Marshall 1993). Cyanobacteria produce toxins and are of low food quality for higher organisms. For example, consumption of Cyanobacteria decreases growth and reproduction of zooplankton, an important food source for fish (Lundstedt and Brett 1991). Increased nutrient concentrations can also indirectly lead to anoxia and fish kills, since bacterial consumption of oxygen increases (Lampert and Sommer 1997). Levy (2000) presents anecdotal evidence that the incidence of fish kills in Lake Drummond is increasing.

To determine whether increased nutrient concentrations are the reason for the lack of biotic recovery, we determined the concentrations of organic carbon, total nitrogen, and inorganic and organic phosphorus in this sediment core (analytical procedures described in Aspila et al 1976, and Verardo et al 1990). These results are shown in Fig. 5, and are consistent with a recent increase in nutrient loading to Lake Drummond. At the same time however, these downcore trends could also be interpreted as being the result of organic matter remineralization consuming these particulate nutrients in the sediments (e.g., Berner 1980), coupled with dilution of sediment organic matter with varying amounts of inorganic material (as described above). Unfortunately, with the existing data it is not possible to differentiate between these two possible explanations of the sediment nutrient profiles.

An further examination of the elemental ratios of this surficial organic matter (along with those in all of the organic matter in the upper 20 cm of this sediment core) suggests that Lake Drummond sediment organic matter is largely composed of terrestrial organic matter (vascular plant material), and not that of aquatic organisms living in the lake (Table 2). A simple mass balance calculation using the mean C/N ratios in this table suggests that ~65% of the organic matter in Lake Drummond sediments is terrestrially-derived. A similar calculation is not possible with the C/P ratios since the mean sediment ratio exceeds that of these two possible end-member organic matter sources. Nevertheless, the extreme phosphorus depletion of this sediment organic matter is again more consistent with a terrestrial organic matter source rather than a freshwater algal source.

This apparent constancy in the type of organic matter being deposited in these sediments does not appear to be consistent with a recent increase of nutrient input into Lake Drummond. However, this conclusion must be viewed with some degree of caution given the limited amount of sediment geochemical data presented here. At the same time, if the profiles in Fig. 5 are indicative of a recent increased input of terrestrial organic matter to Lake Drummond, then reduced light levels in the lake from increased levels of dissolved organic matter or suspended particulate organic matter may explain the continued dominance of low light-level sponge and diatom communities. Again, however, more work is needed to critically examine this suggestion. Clearly a better understanding of the cause for the current stress upon the biotic communities of Lake Drummond is required to ensure the health of the lake.

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Table 1. ^{210}Pb dates obtained in the sediment core. Because ^{210}Pb has a relatively short half-life, we were only able to obtain dates for the first 8 cm. The 1965 date was corroborated by high ^{137}Cs activity at 3-4 cm.

Depth (cm)	**^{137}Cs activity (dpm/g)**	**^{210}Pb Date**
0-1		Assumed to be 2001, when core was collected
1-2	0.305	1990.7
2-3	0.342	1983.1
3-4	**3.307**	**1965.0**
4-5	0.237	1924.8
5-6	0.631	1889.1
6-7	0.483	1883.2
7-8	0.767	1843.4

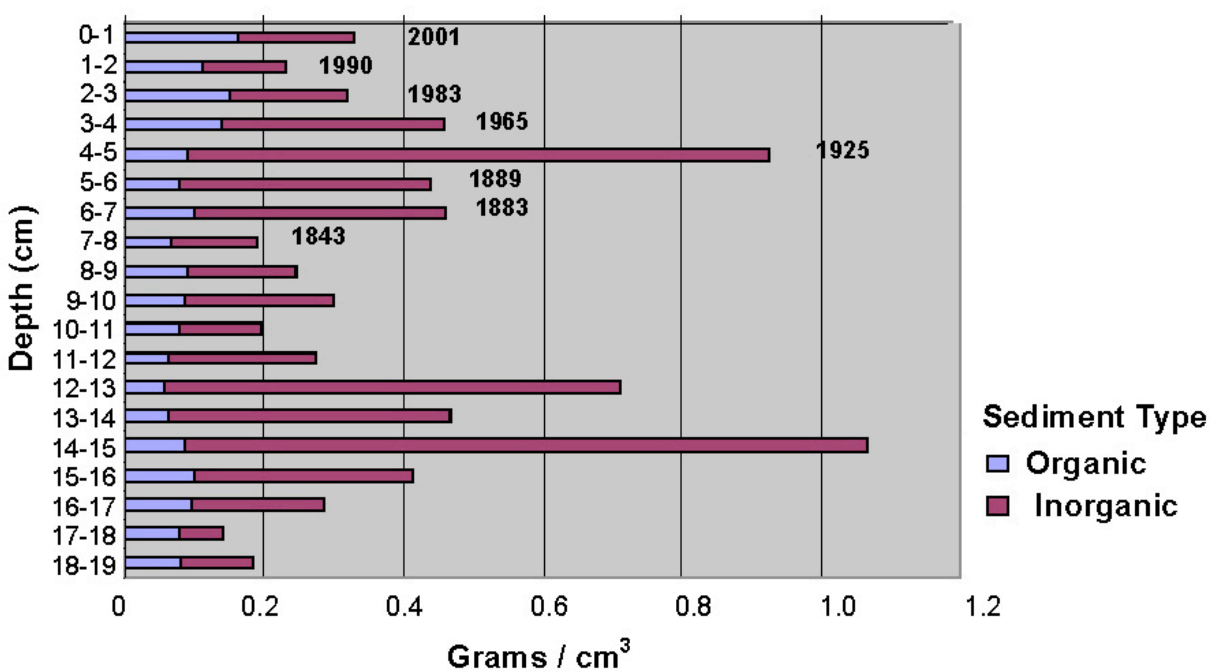

Figure 1. Organic and inorganic sediment content at 1-cm increments throughout the core. The ^{210}Pb dates corresponding to the depth increments are shown to the right of each bar.

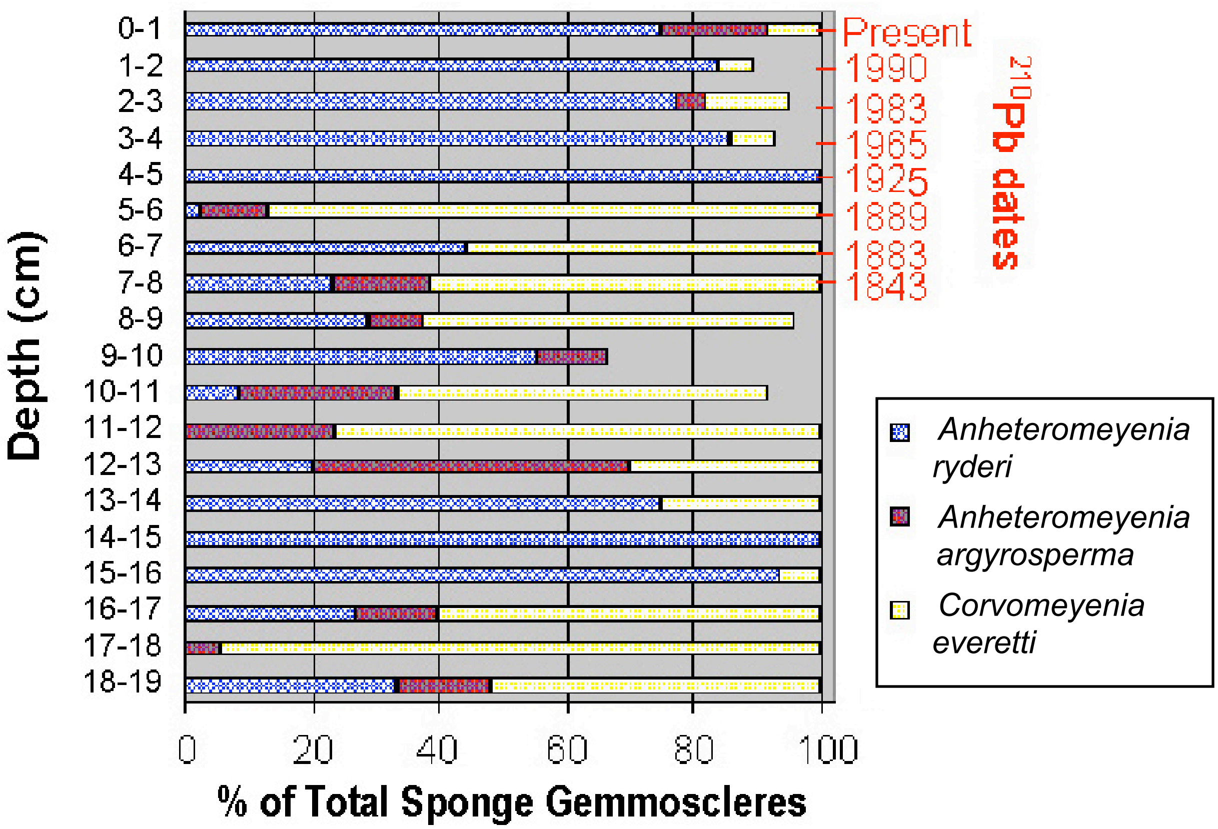

Figure 2. Relative abundance of the three most common species of sponge gemmoscleres found at each depth in the sediment core. *Anheteromeyenia ryderi* requires less light for growth than the other two species.

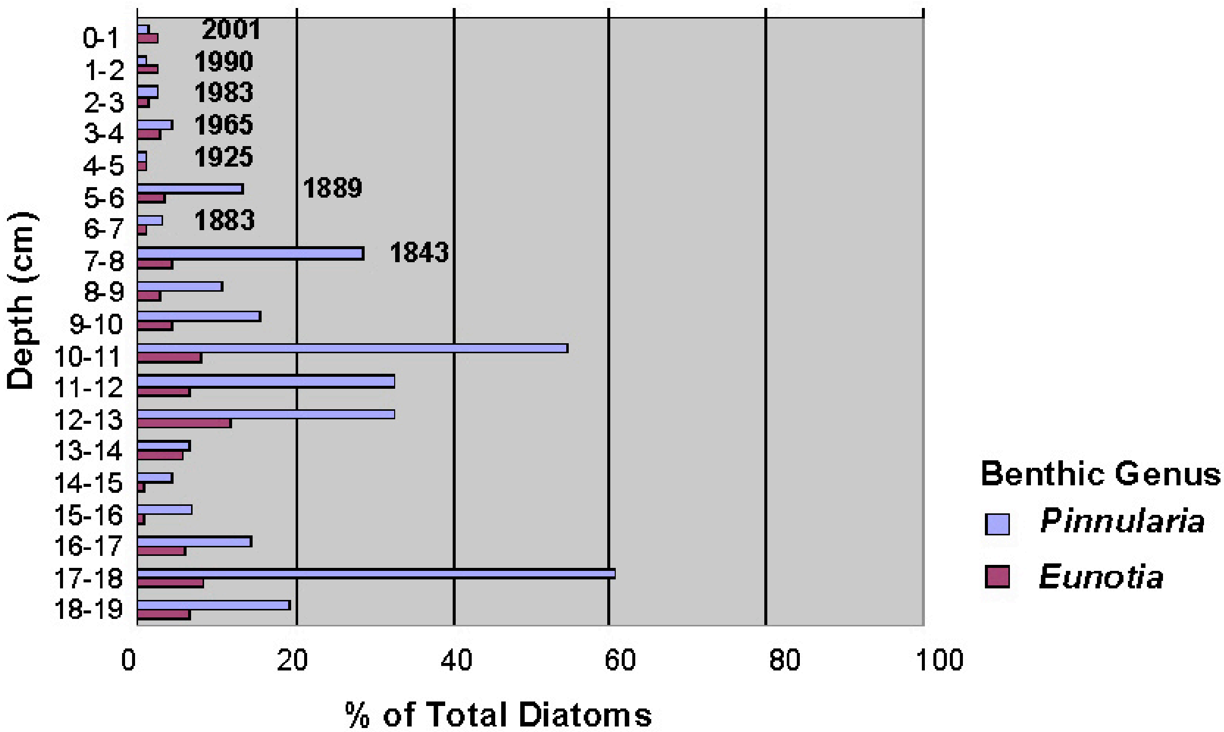

Figure 3. Relative abundance of the benthic diatom genera *Pinnularia* and *Eunotia* (other benthic diatoms were not numerous enough to graph). The ^{210}Pb dates are shown to the right of the group of bars in each depth increment.

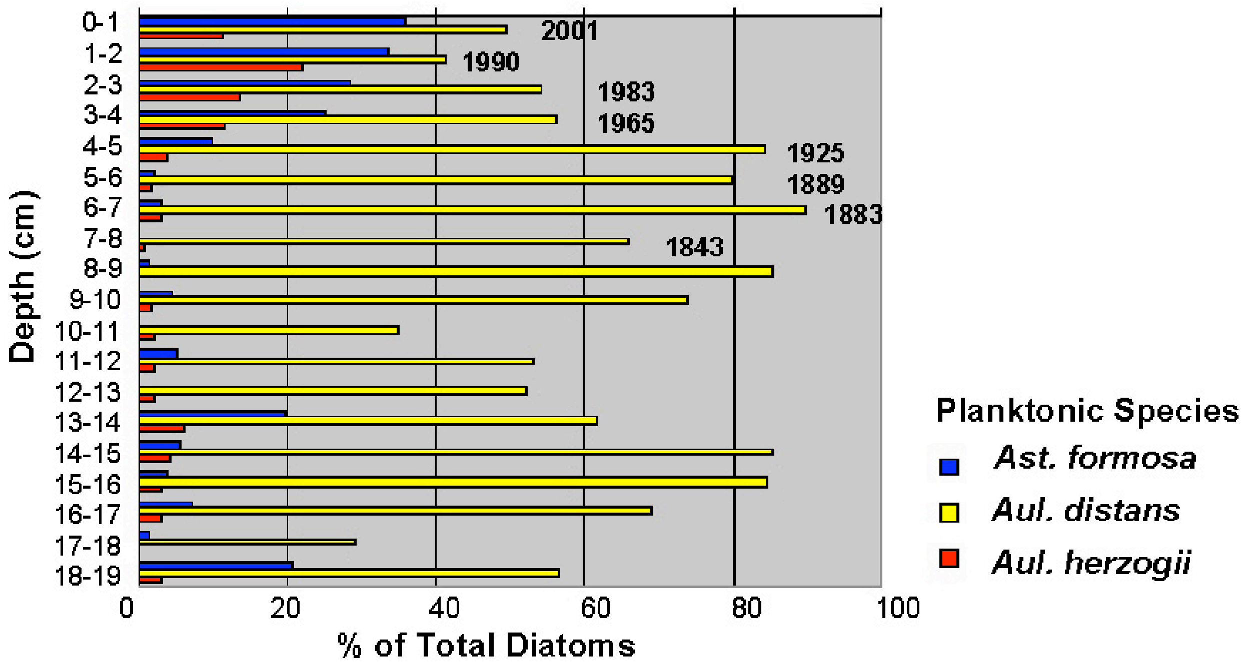

Figure 4. Relative abundance of the planktonic diatom species *Asterionella formosa, Aulacoseira distans*, and *Aulacoseira herzogii* (other planktonic diatoms were not numerous enough to graph). The ^{210}Pb dates are shown to the right of the group of bars in each depth increment.

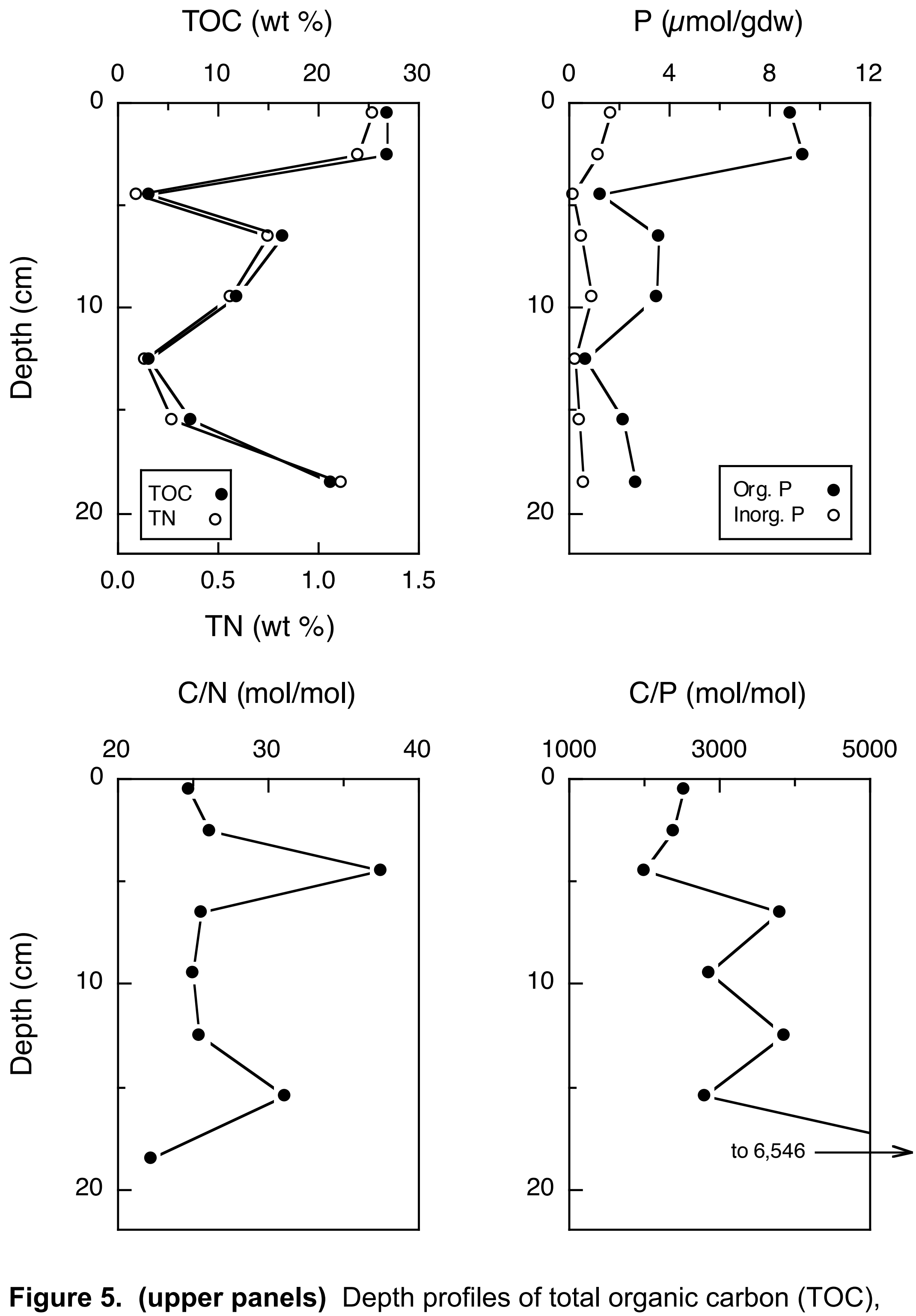

Figure 5. (upper panels) Depth profiles of total organic carbon (TOC), total nitrogen (TN) and inorganic and organic phosphorus in Lake Drummond sediments. **(lower panels)** Depth profiles of the C/N and C/P ratios of the organic matter in Lake Drummond sediments (based on the results above).

Table 2. Elemental ratios in the organic matter in Lake Drummond sediments as compared to potential end-member sources

	C/N (molar)	C/P (molar)
Lake Drummond sediments	27±5	2900±700
Terrestrial (vascular) plants	36 (20-500)	830 (300- >1,300)
Freshwater algae	10 (2-24)	307 (55-1630)

Lake Drummond sediment data is in Fig. 5.
For vascular plants and freshwater algae the values listed are mean values and ranges (in parentheses). Data sources: Sterner and Elser 2002, and Burdige, 2004.

Appendix

Complete List of Diatom Taxa Found in Lake Drummond

Asterionella formosa
Aulacoseira distans
Aulacoseira granulate
Aulacoseira herzogii
Chaetoceros spp. (not found in lake sediments but only in phytoplankton samples)
Cymbella spp.
Diploneis finnica
Eunotia incise
Eunotia indica
Eunotia major
Eunotia monodons var. *bidens*
Eunotia naegelii
Eunotia pectinalis
Eunotia pectinalis var. *ventricosa*
Eunotia serra var. *diadema*
Eunotia soleirolii
Eunotia vanheurckii var. *intermedia*
Frustulia rhomboides
Navicula aerophila
Pinnularia acrosphaeria var. *acrosphaeria*
Pinnularia major
Staurosira contruens
Surirella linearis
Surirella linearis var. *constricta*
Synedra spp.
Tabellaria quadricepta