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Multiple isotope and pollen evidence for natural and human-induced environmental changes at White Lake, New Jersey

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Natural and human-induced environmental changes have been widely recognized from lake sediment records. However, few studies have carried out multiple-proxy investigations of anthropogenic effects in contrast to the Holocene environmental context. Here we present sedimentary lithology, fossil pollen, organic C:N ratio, and isotopic compositions of organic matter (OM) and carbonate in sediment cores from White Lake, New Jersey, USA to understand natural- and human-induced terrestrial and lacustrine environmental changes.

The chronologies were controlled by five AMS ^{14}C dates for a long core covering the last 14 ka and by two ^{14}C dates and ^{210}Pb measurements for short cores covering the last 600 years. Sediments in the long core show lithologic changes from silty clay before 14 ka, through carbonate-rich marl at 14-11 ka, to gyttja after 11 ka (with large fluctuations of carbonate and OM between 11 and 5 ka). Stable isotopes of sedimentary OM show large negative shifts from -26.2 to -39.7‰ in $\delta^{13}C$ and from +3.7 to -0.8‰ in $\delta^{15}N$ from >14 to 11 ka, with a corresponding increase in C:N ratios from 12 to 21, probably due to the increasing chemoautotrophic microbial production and possibly due to enhanced input of terrestrial OM with decreasing C and N isotopic compositions corresponding with the vegetation change from herbs to spruce and further to pine-spruce trees from 16 to 11 ka. $\delta^{13}C$ and $\delta^{15}N$ are maintained at very low values of -35‰ and -3‰, respectively, during the Holocene, suggesting sustained contribution of microbial biomass since the late glacial period.

Ambrosia and other herb pollen percentages from the short cores increase rapidly in 1760 AD and then decrease in 1930 AD, corresponding with agricultural activities with the European settlement and the abandonment of agricultural lands in the region, respectively. The lithology changes from gyttja to marl in ca. 1760 and becomes laminated sediment since 1895 AD. Also, the sediment accumulation rates show a 30-fold increase from 1760 to 1930 AD, followed by a sharp decrease afterwards to pre-European settlement level. Similarly, OM show large positive shifts of 7.5‰ in $\delta^{13}C$ and 5.8‰ in $\delta^{15}N$ from 1760 to 1930 AD with a rapid increase at 1820 AD. All these changes around 1800 AD were likely caused by (1) elevated inputs of terrestrial OM and other detrital materials as a result of land disturbance and erosion and (2) subsequent decreasing microbial production due to the chemical environmental change of water column. Eutrophication likely played a less important role here because $\delta^{13}C$ of calcite show no increase trend. During the last 70 years, $\delta^{13}C$ values of both OM and calcite decreased for >3.7‰, suggesting recovery from landscape disturbance and lake eutrophication. However, $\delta^{15}N$ of OM continued to increase for 1.5‰, probably caused by addition of ^{15}N-enriched sources from industrial pollutants.

The multiple-proxy comparison indicates that anthropogenic effect is larger than any other natural effects on terrestrial and aquatic environments in the Holocene. The differentiation of terrestrial and aquatic processes using multiple proxies provided more constrained explanation for the causes of human-induced aquatic environmental changes. Combined isotopic evidence of OM and calcite demonstrated that the large positive human-induced isotopic shifts of OM in White Lake around 1820 AD was caused by decreasing microbial production and elevated terrestrial input other than the more common interpretations of eutrophication and productivity used for other lake records, implying that terrestrial input is more direct and efficient than eutrophication in influencing aquatic environments. This effect is also shown by increasing $\delta^{15}N$ of OM after 1930 AD, when aquatic productivity recovered rapidly from the human-induced eutrophication, whereas the lake still accepted N loading from industrial pollutants, leading to a new aquatic status after recovery from eutrophication.