Late-Quaternary Environmental Change in the Sierra Nevada: A 19,000-Year Sedimentary Organic Matter Record From Swamp Lake, Yosemite NP, California

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Introduction

Swamp Lake is a small, remote mid-elevation lake (1564 m) in the northeastern corner of Yosemite National Park in the Sierras Nevada of California (Fig. 1). Thanks to its position near the low-elevation southernmost Wisconsin-age glaciation, Fig. 2, the lake is thought to have been ice-free prior to 17,000 yr BP. Thus, the continuous, 18,000-year sedimentary record from Swamp Lake - among the longest and most complete yet recovered in the Sierra — provides a rare opportunity to examine relationships among climate variability, drought, and ecosystem response over the time frame spanning deglaciation and the entire Holocene, including several periods in which the Sierra Nevada is thought to have been warmer and wetter than the present. Laminated sediments in the upper half of the record (to 540 cm, ~10 kyr BP, Fig. 3) provide the potential for high-resolution reconstruction of Sierra Nevada paleoclimates through the Holocene.

Lake sedimentary organic matter (SOM) preserves palaeoenvironmental information in a variety of elementary, isotopic, molecular, and microbial indicators. In this study we utilize carbon and nitrogen elemental abundances (TOC, TN, CN) and isotopic compositions (δ13C, δ15N) of bulk organic matter, along with measurements of biogenic silica (BSi) and diatom assemblages to reconstruct lake productivity, organic matter sources, and plant and algal community composition in relation to climatic variables (see Table 1, below).

Table 1: Palaeoenvironmental Proxies

<table>
<thead>
<tr>
<th>Proxy</th>
<th>Description</th>
<th>Use</th>
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<tbody>
<tr>
<td>TOC</td>
<td>Mass of organic matter, reflecting lake productivity, allochthonous OM input, and degree of degradation</td>
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<tr>
<td>TN</td>
<td>Usually tracks TOC divergence indicative of changes in source OM or selective OM decomposition</td>
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<tr>
<td>δ13C VS, δ15N</td>
<td>Indicators of organic matter source (phytoplankton vs. land plants)</td>
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<tr>
<td>δ13C SOM, δ15N SOM</td>
<td>Indicators of organic matter source, lake productivity, carbon source (C3 vs. C4), and growth rate, respectively</td>
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<tr>
<td>BSi</td>
<td>Algal vs. plant OM contribution, S source, lake productivity/maturity ratio</td>
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<tr>
<td>Diatom assemblage structure</td>
<td>Indicator of diatom (and chrysophyte) productivity</td>
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Results

Late Glacial (18.5 - 16.4 ky B.P.)

(1) Proxy variability dominated by productivity changes of cladoceran (copepod) taxa including Diaphanosoma and Ceriodaphnia, with low organic deposition.

(2) Long-term increases in TOC and TN consistent with increasing lake productivity and subsequent contribution to the Swamp Lake basin.

(3) 3D3C generally anti-correlated with other proxies (TOC, BSI, 415N, CN).

Early Holocene (11.6 - 6.5 ky B.P.)

(4) CO2 content and lake productivity (peak BSI) continues Bolling-Alley and, interrupted by a presumed merotrophic input ~14 ky B.P.

(5) Younger Dryas characterized by high, low CTM accumulation, and an increase in diatom index (Fragilariopsis sp), indicating cold, nutrient-poor water, short growing season, and/or windy conditions.

(6) Continued long-term increase in lake productivity (peak BSI) continues Holocene recovery, and a shift toward terrestrial and/or macrophytic-derived OM.

(7) Paleotemperature proxies to show modern relationships (CN, δ13C, δ15N), indicating no significant shift in the North American monsoon system.

(8) After ~10 ky BP, terrestrial input events begin to be seen in the sedimentary record of plant OM (CN, δ13C, δ15N).

Middle Holocene (8.1 - 3.5 ky B.P.)

(9) Peat interval at 8.1-5.6 ky B.P. appears as a major peak in the CN, δ13C, and δ15N records, a low in BSI, and a decline and rapid reversal in TOC ~ consistent with a collapse in algae population and a shift toward terrestrial and/or macrophytic-derived OM.

(10) Event coincides with a 2°C decline and partial recovery in the N. California margin SST record of Bunder et al (2003), but may also be related to volcanic eruptions or lake level changes.

(11) Middle Holocene is characterized by higher TOC and BSI values (and lower δ13C and δ15N) than previous intervals, as well as distinct 198-199 year cyclicity in the proxy results.

Late Holocene (3.5 ky B.P. - present)

(12) At ~3.1 ky B.P., a shift toward higher TOC, BSI, and lower δ13C and δ15N baseline values, coincident with a period of warmer SSTs off northern California.

(13) Continued centennial-scale variability in the proxy results.

(14) Large amplitude cycle during medieval period and Little Ice Age (1000 - 1300) YBP (see below)

(15) Major regime shift over the past 150 years, possibly reflecting anthropogenic alteration of the lake system.

Analysis

Organic Matter Sources — Fig. 8 (right)

Variations in CN and δ15N values can be explained largely by varying proportions of OM inputs from algal, terrestrial plants, and aquatic macrophytes, with algal and macrophyte sources dominating.

Nasa: Late glacial (18.5 - 15.5 ky B.P.) sediments fall outside the mixing triangle and show a negative relationship between CN and δ15N. This may reflect a different set of OM sources and/or a shift in the carbon chemistry of the lake system.

Late Holocene Record — Fig. 9 (left)

Maxima in the CN and δ15N records, along with higher abundances of the cold-water diatom Fragilariopsis menardii in TOC and BSI, occur during known cold intervals in the Sierra Nevada at 500 - 150 yr BP (the Little Ice Age) and ~1000 yr BP.

Minima in the CN and δ15N records and high values of TOC and BSI are observed in the warm Sierra neotradal period (~950 - 550 yr BP), which broadly corresponds to a mid-century peak in warm EPSO frequency and a generally negative PDO index.

The relationship between OM proxies and known Sierra Nevada droughts is less clear - there is some evidence for higher CN and δ15N values (greater plant/macrophyte input in a shallower lake).

Key Findings

- The Swamp Lake record traces the post-glacial development of a mid-elevation Sierra Nevada lake system, and indicates that relatively stable sedimentary conditions have prevailed over the past 10,000 years.

- Declined centennial-scale cycles in the TOC, TN, CN, δ13C, δ15N, and BSI records over the Holocene reflect alternating periods of increased algal ... plant contribution to the total OM pool. Based on a comparison with the well-known, recent climate record, these oscillations most closely match cycles in regional temperature. The Swamp Lake SOM record may thus reflect a unique, high-resolution reconstruction of Holocene temperature in the Sierra Nevada.

- The link between regional temperature and OM proxies in Swamp Lake may be direct — e.g., effects on lake productivity via phytoplankton growth rates or changes in the growing season — or may be mediated, with features such as wind speed or precipitation in the recent record on OM accumulation and degradation.

- Potential links to paleoceanographic conditions off California, and to larger Pacific basin processes such as EPSO and PDO, will require further investigation.

References


