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Impacts of climate and river flooding on the hydro-ecology of a floodplain basin, Peace-Athabasca Delta, Canada since A.D. 1700

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Abstract

Multi-proxy paleolimnological analyses on lake sediment cores from "Spruce Island Lake" (58° 50.82′ N, 111° 28.84′ W), a perched basin in the northern Peace sector of the Peace-Athabasca Delta (PAD), Canada, give insights into the relative roles of flow regulation of the Peace River and climatic variability on the basin hydro-ecology. Results indicate substantial variability in basin hydro-ecology over the past 300 years ranging from seasonal to periodic desiccation in the 1700s to markedly wetter conditions during the early 1800s to early 1900s. The reconstruction is consistent with (1) dry climatic conditions that defined the peak of the Little Ice Age and subsequent amelioration evident in conventional ring-width and isotopic analyses of tree-ring records located hydrologically and climatically upstream of the PAD, and (2) Peace River flood history inferred from sub-annual magnetic susceptibility measurements from another lake sediment record in the Peace sector of the PAD. Although regulation of the Peace River for hydroelectric power generation since 1968 has long been considered a major stressor of the PAD ecosystem leading to reduced frequency of ice-jam and open-water flooding and an extended period of drying, our results show that current hydro-ecological status is not unprecedented as both wetter and drier conditions have persisted for decades in the recent past under natural climatic variability. Furthermore, paleolimnological evidence from Spruce Island Lake indicates that recently observed dryness is part of a longer trend which began some 20–40 years prior to Peace River regulation.

Keywords: Paleohydrology; Paleoecology; Multi-proxy study; Climate change; Water balance; Lake sediments; Stable isotopes; Diatoms; Plant macrofossils; Peace-Athabasca Delta

Introduction

The Peace-Athabasca Delta (PAD), situated at the confluence of the Peace and Athabasca rivers at the western end of Lake Athabasca in northern Alberta, Canada, is one of the world's largest freshwater deltas. Numerous shallow basins characterize the PAD and support bountiful wildlife, including migratory waterfowl and a large population of North American bison. The PAD has been designated a Ramsar site (International Ramsar Convention on Wetlands) and is part of Canada's largest national park, Wood Buffalo National Park.

We are conducting extensive multidisciplinary research to gain better understanding of the past and present hydrology, ecology, and climate of the PAD (Wolfe et al., 2002). This manuscript is one of several from a comprehensive, multidisciplinary, three-year research program reported in Hall et al. (2004), which included multi-proxy paleolimnological reconstructions spanning the past few hundred years from several basins in the PAD. The aim of our research is to assess the impacts of both natural and anthropogenic factors, ranging from climatic variability and change to the influence of river flow regulation resulting

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from hydroelectric power generation at the headwaters of the Peace River since 1968. The latter is of particular interest because of the possibility that alteration of Peace River discharge may be affecting the frequency and magnitude of spring ice-jam flooding, which is considered to play an important role in the water balance of many basins that are perched above and disconnected from the complex channel network in the PAD (e.g., Prowse and Lalonde, 1996; Prowse and Conly, 1998, 2000). Concerns became particularly acute in the early 1990s as an extended dry period that followed a major flood in 1974 had resulted in extremely low water levels in many perched basins, which provide important wildlife habitat (Prowse and Conly, 1998). Although many environmental studies have been conducted in the PAD over the past 35 years to address ecological impacts of low water levels (PADPG, 1973; PADIC, 1987; PADTS, 1996; Gummer et al., 2000), absence of long-term hydrological and ecological records has limited the ability to objectively evaluate the importance of anthropogenic versus natural climatic forcing in regulating hydro-ecological conditions of the PAD.

Our paleoenvironmental studies have included multi-century reconstructions of regional climatic variability near the headwaters of the Athabasca River (located climatically and hydrologically upstream from the PAD) and Peace River flood history in the northern part of the PAD (Hall et al., 2004; Wolfe et al., 2005a). The climate records, which consist of quantitative reconstruction of changes in temperature and relative humidity, were developed from carbon and oxygen isotope analyses of a composite tree-ring chronology. These records clearly depict cold and very dry conditions during the 1700s corresponding to the peak of the Little Ice Age. Subsequent warming and moistening occurred until the early part of the 20th century, followed by progressive drying. Reconstruction of flood history, inferred from exceptionally high-resolution (sub-annual) magnetic susceptibility measurements on a sediment core from an oxbow lake adjacent to a major flood distributary of the Peace River, shows close correspondence with the isotope-based climate records. In particular, the dry 1700s were characterized by extremely low flood frequency.

Here, we focus on a sub-decadal, 300-year, multi-proxy hydro-ecological record from a perched (i.e., closed-drainage) basin informally named "Spruce Island Lake." Located in the relict fluvial-deltaic landscape of the northern Peace sector of the PAD, it is distant from major flood distributaries of the Peace River and outside the effect of all but the most extreme floods. Hence, Spruce Island Lake was expected to be very sensitive to former arid conditions that occurred during the Little Ice Age. The paleohydrological record is based on quantitative reconstruction of lake water balance derived from analysis of cellulose oxygen isotope composition constrained by investigations of modern isotope hydrology. Organic carbon and nitrogen content, diatom assemblages, and plant macrofossils, the latter two techniques founded on a delta-wide surface-sediment assessment of biological proxy indicators (Hall et al., 2004), are used to further refine paleohydrological inferences as well as provide information pertaining to related ecological changes. We compare the Spruce Island Lake paleolimnological record with likely major hydro-ecological drivers, namely regional climatic variability and Peace River flood history (Hall et al., 2004; Wolfe et al., 2005a), to address the following research questions: (1) Have hydro-ecological conditions in Spruce Island Lake since 1968 varied beyond the range of natural variation during the past 300 years? (2) Is there evidence that flow regulation of the Peace River has caused significant changes in hydro-ecological conditions in Spruce Island Lake? (3) How is hydro-ecological variability at Spruce Island Lake related to natural climatic variability and Peace River flood history?

Our study demonstrates that profound changes in hydro-ecological conditions are clearly a natural feature of this ecosystem, independent of human influence or intervention. Such temporal insight is critical for understanding the hydro-ecological evolution of the PAD, anticipating future hydro-ecological trajectories under continuing climatic variability as well as the likelihood of increasing demand for hydroelectric power and consumptive water use (e.g., Athabasca tar sands oil extraction), and developing effective and appropriate water resource management strategies.

Study area

Climatic and hydrological setting of the Peace-Athabasca Delta

The Peace-Athabasca Delta (Fig. 1) is centered at approximately 59° N 112° W within the subhumid mid-boreal ecoclimatic region (Ecoregions Working Group, 1989) and is characterized by long, cold winters and relatively short, warm summers. Based on 1971–2000 climate normals (Environment Canada weather station at Fort Chipewyan, Alberta), mean annual air temperature is −1.9°C, mean January air temperature is −23.2°C and mean July air temperature is 16.7°C. Precipitation averages 391.7 mm annually, with about 59% falling as rain during the May–September period. Mean annual lake evaporation calculated from class-A pan measurements at Fort Smith, NWT, 145 km to the north, is 525 mm (AES, 1993).

Under normal flow conditions, Lake Athabasca, a major inland waterbody in western Canada, drains northwards via the Rivière des Rochers, Revillon Coupé and Chenal des Quatre Fourches to the Peace River where they join to form the Slave River which enters Great Slave Lake to the north (Fig. 1). During high-water events on the Peace River, accentuated by ice-jam conditions near the confluence of the Peace and Slave rivers, water can flow southwards from the Peace River through these channels and cause overland flooding of the northern Peace sector of the PAD. Periodic ice-jam flooding is thought to be important for maintaining