Nitinat Lake – A British Columbia Tidal Lake

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The Pacific Coast of British Columbia has a large number of unusual lakes. One group of lakes is notable in that they have major marine influences. Ten to 15 thousand years ago, during the last glaciation, most of British Columbia was covered by a vast ice sheet, thousands of meters thick. As the climate warmed and the ice sheet melted, the present mountainous landscape emerged, shaped by ice movement with many narrow valleys sloping to the pacific coast. Many of these glacial trenches became marine inlets – many with the classic fjörd morphometry with a shallow sill at the mouth of the fjörd. As the ice melted and the weight of the ice was removed, the land area began to rise in elevation – a process called isostatic rebound. Consequently, the outlets of many of the ocean inlets rose above sea level and the coastal fjörds were cut off from the sea and gradually the seawater was replaced with inflowing fresh water and the coastal inlets evolved into lakes. Many coastal lakes at low elevations have had complete replacement by fresh water (e.g., Kennedy presently at 12 meters above sea level, Hobiton at 5 meters ASL, but with their deepest depths well below sea level). Other lakes such as Sakinaw and Powell are completely cut off from the sea with the lake surface above sea level but are strongly stratified meromictic lakes with a surface layer of fresh water and the depths of the lake occupied by 10,000-year-old sea water that has been slowly replaced by fresh water (Williams et al. 1961; Northcote and Johnson 1964).

Nitinat Lake is a long, narrow, and strongly salt-stratified fjörd-lake located on the west coast of Vancouver Island, British Columbia (see Figures 1 and 2). It is at sea level, connected to the ocean by a 3-km long natural channel,



Figure 1. Nitinat Lake showing the lake outlet and the Pacific ocean at the bottom of the photo.



Figure 2. Nitinat Lake aerial view down the lake

only 2.5m deep at low normal tides that limits exchange between the 205m-deep lake and the Pacific Ocean. It has inputs of saltwater at high tidal elevations at its narrow southern ocean outlet and freshwater inputs from its terrestrial watershed at the north end of the lake. This unusual situation results in very unusual physical stratification as well as resulting unconventional chemical and biological features. The unusual stratification with a thin freshwater surface layer over a mostly seawater volume was first reported by Northcote et al. 1964 and a number of studies of this unusual lake have followed. Its location on the west coast of Vancouver Island is subject to high rainfall – 3000-4000 mm per year (Lamont 2005) and the area is geographically a temperate rainforest and heavily forested (Figure 3).

Nitinat Lake and the surrounding region are an important part of the Vancouver Island economy. Tourism is important to the region, with the close proximity of Pacific Rim National Park and Carmanah Valley, while the lake itself is an internationally known destination for windsurfing and kite-boarding due to the strong and regular wind that blows from down the valley along the lake axis, as well as being well known for recreational fishermen (Figure 4). Furthermore, a number of important salmon runs access spawning grounds through Nitinat Lake, and the Canadian Department of Fisheries and Oceans operates the largest hatchery for pacific salmon in the country on the Nitinat River, which is the major tributary to the lake (Lamont et al. 2004).

Nitinat Lake is important as a major producer of salmon – primarily of chum salmon (*Onchorynchus keta*). Prior to about 1925 returns of fish were about 350,000 per year but numbers declined up to the 1980s due to overfishing and habitat damage (Fedorenko et al. 1979). Recent salmon returns have improved as a result of better management. The lake contains several other large salmon runs and at the head of the lake is the largest salmon hatchery in Canada, rearing over 40 million fry annually.

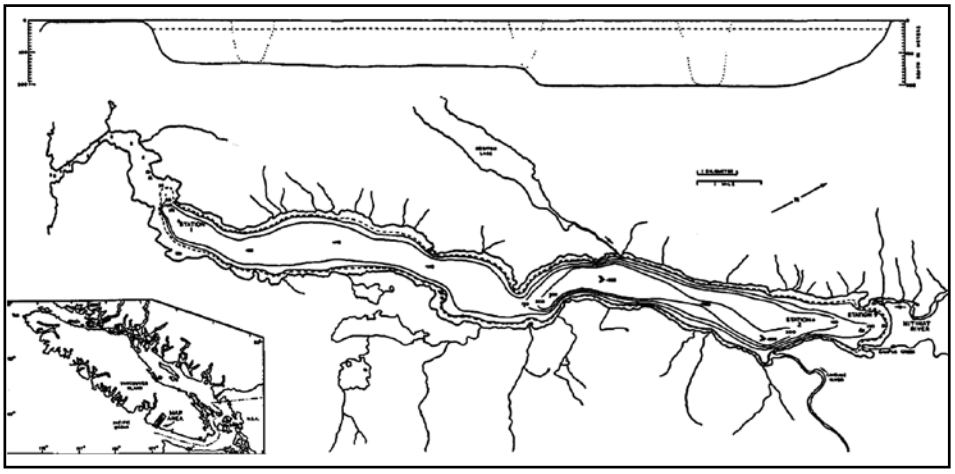

Figure 3. Location map/bathymetric/side profile of Nitinat Lake, Vancover Island, British Columbia. Longitudinal profile and depth contours in meters. Source: Northcote et al., Figure 1.

Physical Characteristics

Nitinat lake is 23 km long, 1.2 km wide with a surface area of 27.6 km^2 The tidal influence is minor with a tidal range of 8 to 45 cm. The depths below 20-30 meters are permanently anoxic and contain high concentrations of hydrogen sulfide. The thermocline and halocline (a strong, vertical salinity gradient) occur in the upper 10 meters (typically between 5-10 meters depending on the time of year) with a strongly stratified brackish surface layer and the deeper waters maintaining temperature and salinity fairly constant at 10°C and 31 ppt salinity (Fedorenko et al. 1979). The watershed receives relatively heavy precipitation, typically between 250 and 350 cm per year. Almost all of the rainfall is in the October through March period typical of BC coastal lakes. Snow is rare and the relatively mild maritime-influenced climate precludes any ice cover on the lakes in this area (Nordin et al. 2004).

Upwelling events where the thin fresh and brackish surface water layer is disturbed have been observed on the lake by both the Ditidaht First Nation of the area and the Nitinat Fish Hatchery employees, and have resulted in



Figure 4. Wind surfing on Nitinat Lake.

significant fish kills in the lake. Upwelling events are usually localized and are often detected by smell ("rotten egg") or by sight (surface waters turn a "brown color") (Shortreed et al. 1987). The record of events is incomplete as there has never been continuous monitoring of the lake, but does provide a starting point for examining conditions that lead to upwelling events (Lamont et al. 2004).

Due to the remote location, it is likely that many upwelling events were not documented, but several dates have been recorded: July and October 1970, October 1972, November 1987, March 2002 and March 2003. The upwelling events in the 1970s resulted in the evacuation of the village of Malachan for several days due to the strong sulfide smell and the 2002 and 2003 events were significant enough to have been reported in newspaper stories. These upwelling events are particularly significant for fisheries as they result in the mortality of hundreds of thousands of salmon.

Strong winds blowing parallel to the long axis of the lake are thought to be a primary factor leading to upwelling events (Ozretich 1975). These winds impart a shear stress onto the lake surface that "pushes" the surface layer toward one end of the lake. If sufficient sustained winds are present during times of weak stratification, it is possible that upwelling of anoxic water will occur at the upwind end of the lake. On Nitinat Lake, an upwelling event due to wind shear is most likely to occur in the late fall after a dry summer. The upwelling event of October 1972 was probably caused by this combination of weak stratification and strong NE winds (Ozretich 1975).

There are several motivating factors for further study of wind-induced upwelling on Nitinat Lake. First, the density stratification is weakest in the late fall, which coincides with the time that spawning fish are returning to the lake (Ozretich 1975). Second, upwelling is most likely to occur at the northern end of the lake, since anoxic water is shallower at the north end of the lake than the south (Broenkow, 1969). This is unfortunate due to the fact fish pens used by the Nitinat River Hatchery are located at the north end of the lake (Lamont et al. 2004).

Water Chemistry Patterns

The initial survey by Richards et al. (1965) reported accumulations of ammonia, carbonates, phosphate silicates, and sulfides in the deep water of the lake that they attributed both oxidation and fermentation processes in the decomposition of planktonic organisms. Methane in the deeper waters indicates anaerobic fermentation. The chemical processes in the lake are of interest to contemporary researchers (Pawlowicz et al. 2007) to provide insight into the basic physical and microbiological / biochemical processes in the water column that maintain stable anoxia for most of the time except during turnover. Understanding of the complex chemistry in *meromictic lakes* (lakes where the deepest water does not mix with surface water) is still being examined (Perry and Petersen 1993). Environments such as Nitinat Lake are stable natural models for the emerging use of man-made pit lakes receiving mine wastewater where the aim is to precipitate metals by sulfate reduction cheaply and over long periods of time (Boehrer and Schultze 2006).

Aquatic Biology

Northcote et al. (1964) sampled the phytoplankton and reported that the species were all brackish and marine species. The zooplankton observed were also almost entirely brackish or marine but a few freshwater taxa were reported from the east end of the lake near the Nitinat River inflow. The benthic plant community was marine to brackish, the two dominant species being the seaweeds *Fucus* and *Pylaiella*. Animal benthos was also marine or estuarine in nature. The fish community sampled included marine species (herring, seaperch, flounder, and sculpins) as well as salmonids (coho, chinook, chum, and sockeye salmon, steelhead, and cutthroat trout).

Summary

Of major concern from an economic and ecological perspective is the instability of the stratification of the lake. In times of low freshwater input, the wind energy input can be sufficient to destratify the lake and bring the anoxic deeper water to the surface with its high concentration of hydrogen sulfide.

Upwelling events of anoxic water are potentially catastrophic for fish hatchery operations such as fish harvesting and juvenile releases, highlighting the need to better understand the physical mechanisms that lead to upwelling (Lamont et al. 2004).

Scientific interest in the lake is focused on the complex water chemistry of the deeper waters as well as the physics of the density stratification as well as the microbial community that exists in these unusual environments (Pawlowicz et al. 2007).

Nitinat Lake has a dual personality. For windsurfers and fisherman, it is a wilderness lake in a pacific coast rainforest with extraordinary aesthetic potential. For scientists it represents a lake of unusual and interesting physical, chemical, and biological characteristics as a rare hybrid of a lake and a fjörd – perhaps thought of as the confused child of the Pacific Ocean and the coastal rainforest.

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Rick Nordin is a mostly retired limnologist who has worked for more than 40 years on a variety of lakes in British Columbia as a government scientist and researcher and teacher at the University of Victoria. He is a former NALMS board member and was the local committee chair for the 2004 NALMS conference in Victoria, BC (where attendees were surprised to find an umbrella in their registration kits – but soon discovered why).

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