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Field Experiment with dye tracing and an acoustic Doppler current profiler in Kootenay Lake, B.C.

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by P.F.Hamblin, C.L,Stevens and G.A.Lawrence

MANAGEMENT PERSPECTIVE

Kootenay Lake, British Columbia's largest lake, has undergone dramatic shifts from over-enriched in the early 1970s to undernurished in the 1990s. Coincident with these water quality changes there has been a rapid decline in the economically important sports fishery; in particular, the Kookanee salmon and the Gerard rainbow trout. In response to the near critical level of these fish stocks a four-year program of artificial fertilization has been proposed by B.C. Environment.

This paper was prepared at the invitation of the convenors of the Upper Columbia River Basin Workshop who asked for a summary of the main findings to date of the physical component of Kootenay Lake fertilization study, June 1992. Briefly, we make recommendations on the most efficient methods of nutrient dispersal in the North Arm of Kootenay Lake should the four-year enhancement study prove that fertilizer release on a continuing basis is warranted.

FIELD EXPERIMENTS WITH DYE TRACING AND AN ACOUSTIC DOPPLER CURRENT PROFILER IN KOOTENAY LAKE, B.C.

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ABSTRACT

Understanding mixing of the surface waters of lakes is essential for the efficient introduction of nutrients to the photic zone as might be required to augment primary productivity for the purposes of the restoration of a sports fishery. Herein, we describe a field study of the tracing of patches of dye in the near surface layer of Kootenay Lake and the background environmental data responsible for the mixing. On the basis of our study we recommend that fertilizer be introduced in major inflowing river plumes and near promontories that accelerate flow and promote enhanced mixing.

INTRODUCTION

Public concern for declining sports fishery stocks in Kootenay Lake, B.C., particularly Kokanee salmon but also an impending decline of Gerrard stock of rainbow trout, has motivated the enhancement of productivity by the addition of artificial fertilizers to the surface water during the growing season. In order to optimize the use of these fertilizers it is necessary to quantify the mixing rates of the surface waters of the lake. In an on-going experiment the British Columbia Ministry of Environment's fertilization programme injects nutrients into the near surface waters from a barge travelling down the north arm of the lake. In the event that this four-year artificial enhancement experiment proves successful, the results from the present study could be applied to determine which introduction site to use in the long term. Some results of our study have been previously reported. Stevens et al.(1994) have focussed on the analysis of dye releases into a major inflowing river while Hamblin et al.(1994) have described one of the open lake experiments in some detail.

EXPERIMENTAL DETAILS AND DATA ANALYSIS

Kootenay Lake is a long(110)km, narrow(average width 3km), deep(100m),steep sided fjord-like lake. It is part of the Columbia River system and has its major inflows and outflows regulated by hydroelectric storage reservoirs. In other B.C. lakes where fertilizer addition has been of concern dye has been first released to determine the optimal method of dispersal, for example, the surface injections of dye described by Lawrence et al.(1994). Here, we follow a similar approach and also measure the background variables which are considered to influence mixing. In eight experiments at a number of locations during June 1992 we released up to 30Kg of Rhodamine WT dye in a vertical column over the upper 10m of the lake or into the inflowing Duncan River(Fig.1). The dye patch was monitored by a sensitive profiling or tow-yoing fluorometer for periods up to six hours after release. These observed mixing rates could then be compared with the background environmental conditions as determined by a suite of instruments

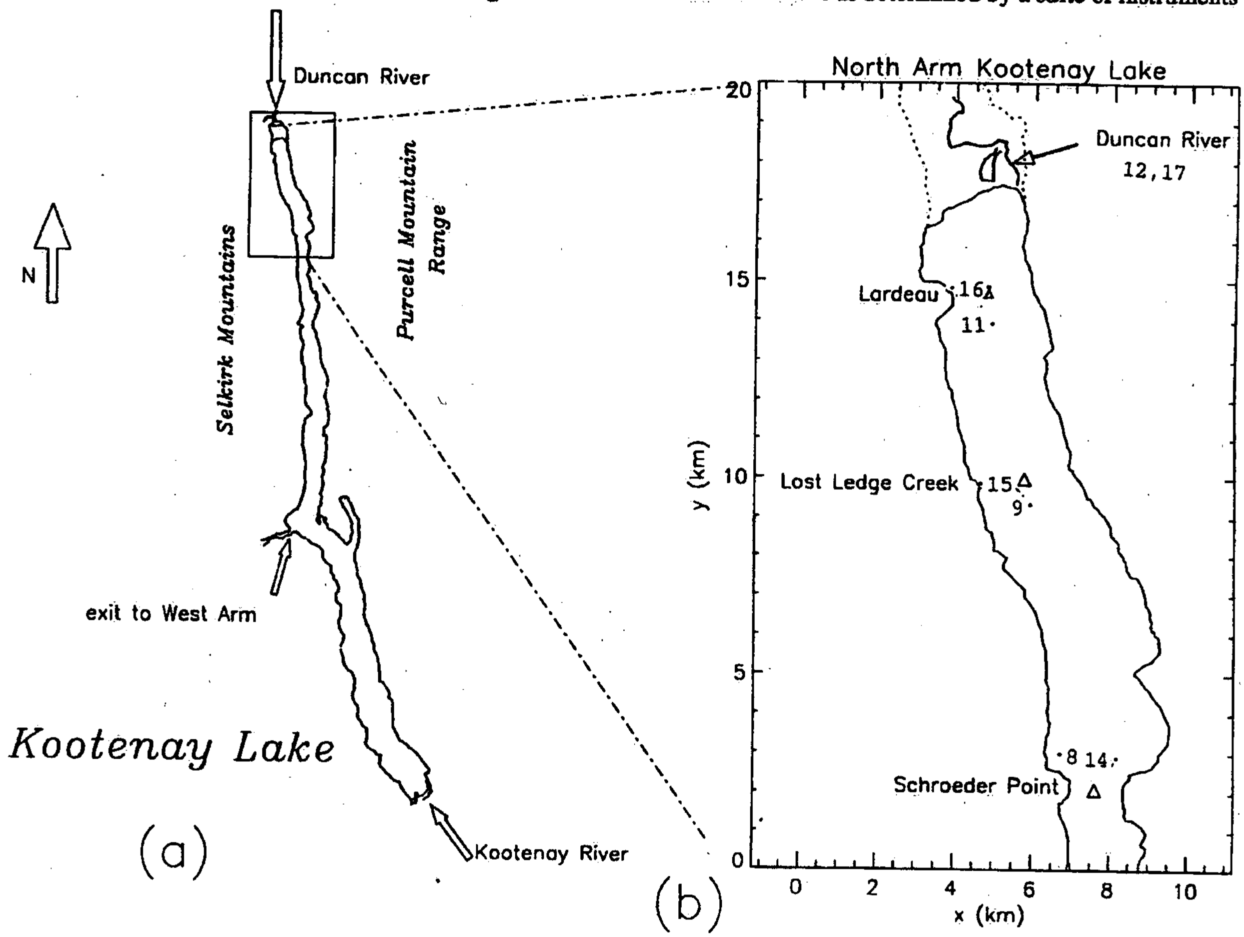

Figure 1 (a) Kootenay Lake shoreline; (b) study location in north arm. The triangles indicate the positions of the thermistor chains. The meteorological buoy was at the Lost Ledge Creek triangle. The numbers indicate location and date in June 1992 of the dye releases

including a conductivity-temperature-depth profiler(CTD), an acoustic doppler current profiler(ADCP), a meteorological station and three thermistor chains each recording 1-min temperatures at ten depths. Background hydrological and meteorological conditions are provided in Fig.2 during the study period.

DISCUSSION

On the two occasions when dye was released into the Duncan River the dye tracings showed that it did not plunge to the bottom or below the photic zone as it entered the lake as feared but remained as a coherent gradually spreading plume at an intermediate depth evident in Fig.3. However, there are some interesting differences between the two days; on June 17 despite nearly the same inflow(Fig. 2) and nearly the same release point in the Duncan River the dye entered the lake as a series of patches instead of a continuous slug, the inflow was significantly colder causing the inflowing plume to insert into the water column at a deeper depth and typical dilution rates were of the order of 30 times smaller than the shallower inflow. These dilution rates are deduced from the rate of change of dye concentration. Nonetheless, both experiments demonstrate that most nutrients injected into the Duncan River would be introduced to the open waters of the lake. However, some of the nutrients could be pooled in the delta region

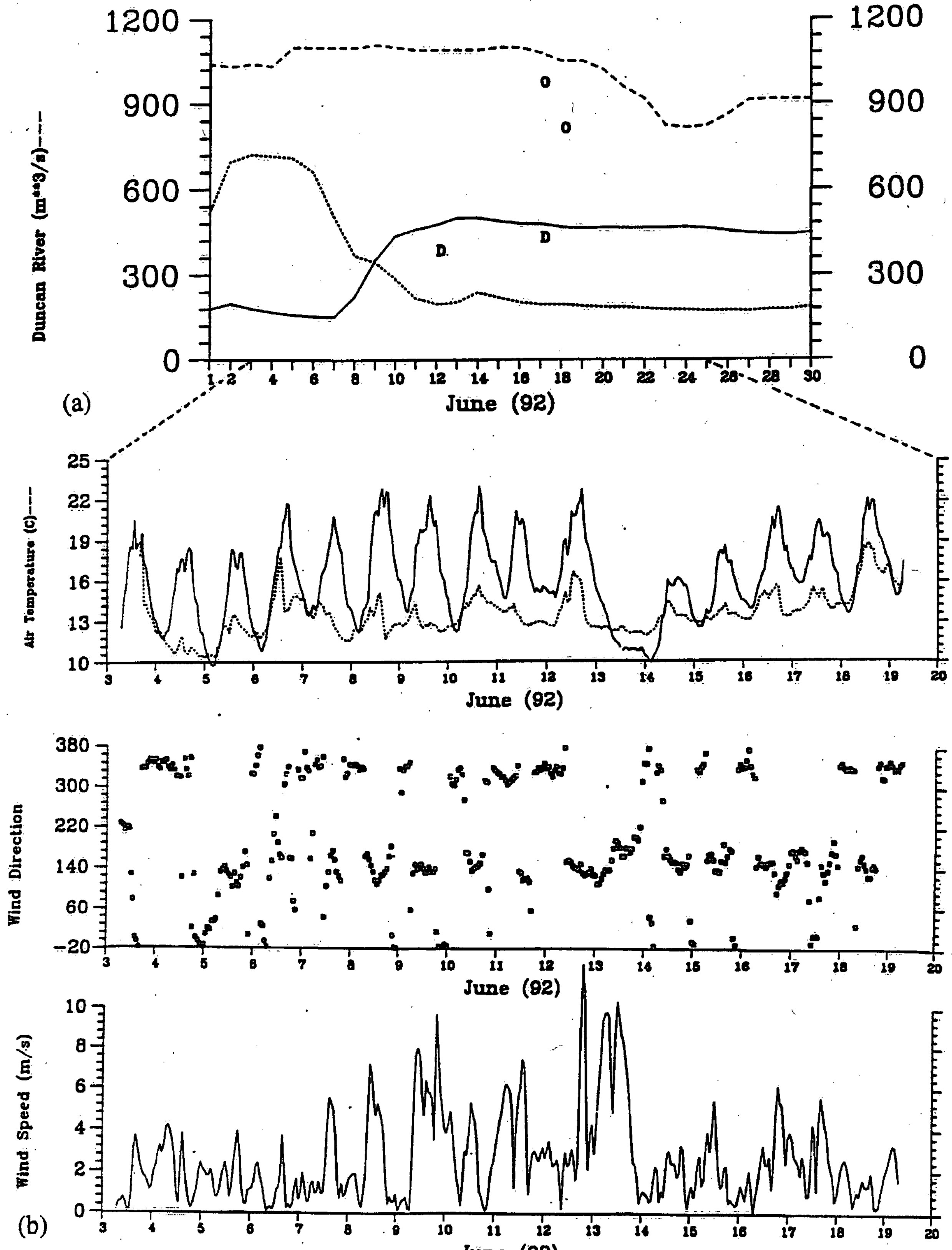

Figure 2 (a) Daily discharges in m³/s of major inflows and the outflow of Kootenay Lake for June,1992. (b) Surface meteorological data during the experimental period.

unless care is taken to inject into the main river plume entering the lake. The ADCP data near the shore indicated several distributaries and flow in agreement with the dye patterns. This, as well as the differences between the behaviour of the dye for the two days illustrate the complexity of the river delta as a site to inject fertilizer.OffshoreADCP gave evidence(Fig.4) of the river-induced flows at depths of around 18m on June 12 and around 22m on June 17 also trending in the same direction as the dye. Interestingly, the current vectors indicated eddies formed on one side of the main river inflow which could play a role in spreading of nutrients. Both the dye and the current profiler data suggest that the Duncan River plume plunges to a depth range from 15 to 25 m, maintains its distinct identity over distances of several kilometres and trends gradually across the lake to the western shoreline.

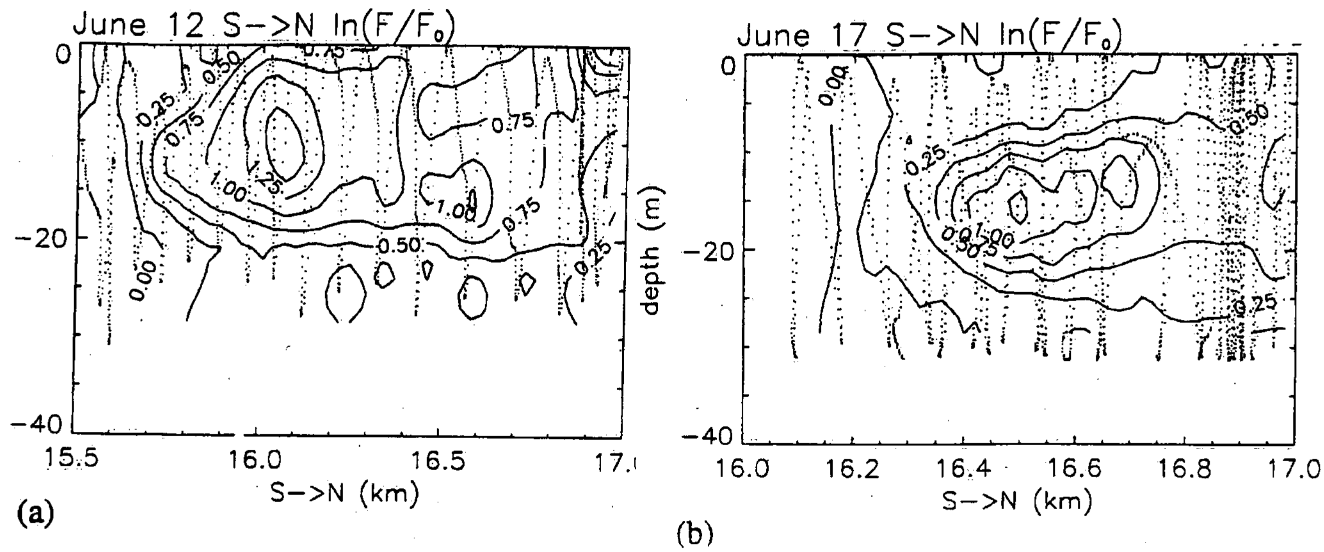

Figure 3 Contours of dye concentration in logarithmic units as a function of depth and distance along a north-south line for (a) June 12, (b) June 17. The Duncan River inflow is on the right hand side.

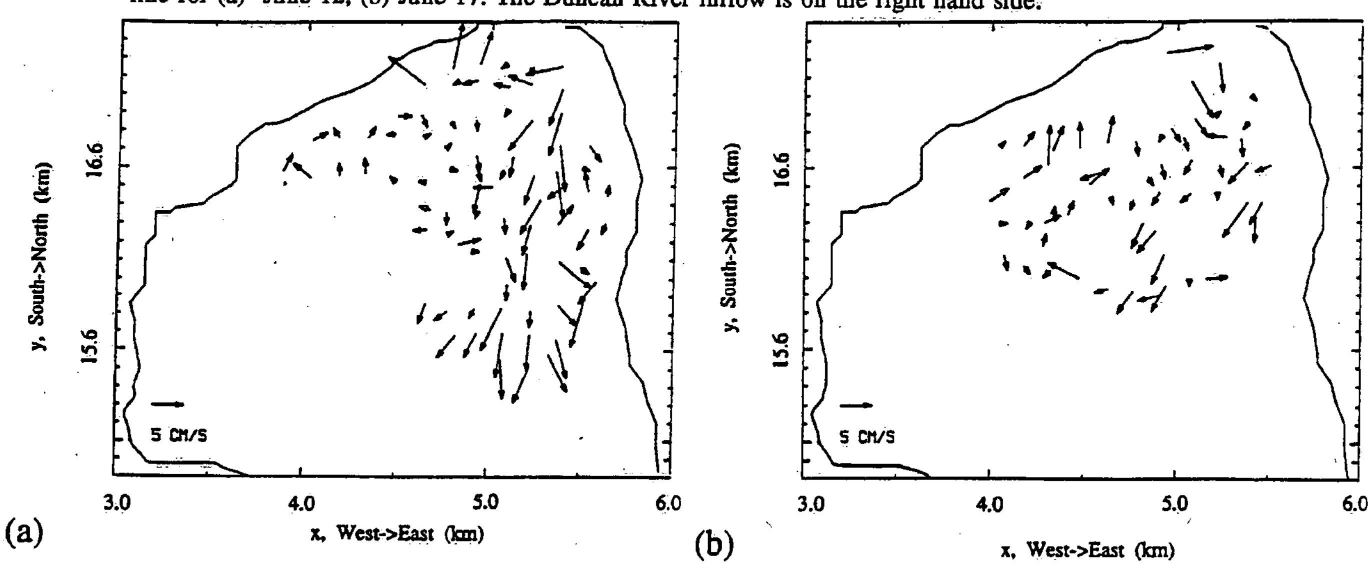

Figure 4 Vectors representing velocity differences in cm/s between the depths of 16 to 20m for (a) June 12 and (b) from 21 to 25m for June 17.

The six other experiments performed in the open lake water away from the direct influence of the river inflow revealed a range of mixing strengths depending mainly on the wind speed but also on the stratification and current shear. In the experiment on June 16 near Lardeau and several kilometres from the river mouth, the wind driven surface flow and the river flow appear to have combined. The dye plume, unlike other experiments, spread out transversely to the direction of the wind and moved at a substantial velocity against the wind.

The experiment of June 14, the day following a major storm(Fig.2), took place under light winds, yet the travel of the dye and its spreading were among the most complex of all the experiments. This is attributed to basin scale internal waves or seiches set up by the storm and by the eddies shed by the narrows at Schroeder Creek. A day later, on June 15, the experiment at Lost Ledge Creek showed little displacement of the dye patch and that dilutions were weakest of all the experiments. June 8 has received the most complete analysis to date(Hamblin et al.,1994). The mixing rates deduced from this experiment are larger than those typical of other lakes and even for coastal ocean values. This vigorous mixing was attributed the fortuitous coincidence of vertical current shear associated with internal seiches and that caused by surface wind forcing both being focussed by the headlands at the Schroeder Creek narrows. As well, ADCP data in the vicinity of the Lardeau headland on another occasion showed that a large eddy was shed by the headland. Likely, such eddies are also shed at Schroeder Creek leading to enhanced mixing. On a subsequent day in the absence of any significant wind, residual motions from the previous days winds and internal waves generated substantial mixing also.

For the June 8 experiment Hamblin et al.(1994) have shown how ADCP data and CTD profiles can be combined to predict likely occurrences of mixing and that under these strong mixing conditions that the thermistor chain data may indicate that mixing is occurring.

PRACTICAL IMPLICATIONS AND CONCLUSIONS

With regards to riverine injection of nutrients the ADCP data indicate low flow regions where the fertilizer might remain at high concentrations for long periods of time. Once the nutrients reach the open lake strong diurnal winds and basin scale internal waves create shears sufficient to generate turbulent mixing that would cause high concentrations to be quickly dispersed especially around headlands. In the case of shore-based injection, locations near promontories and at basin narrows are the obvious preferred sites. Acoustic doppler current profiles are a useful complement to underway CTD profiles during dye tracing experiments. Combined, they permit the identification of likely zones of enhanced mixing.

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