



High frequency data reveal state dependant hyporheic processes: implications for hydroecological studies



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For further information see: Malcolm, I.A. Soulsby, C. and Youngson, A.F. (2006) High frequency logging technologies reveal state dependant hyporheic process dynamics: implications for hydroecological studies *Hydrological Processes* 20 615-622

Introduction

Salmonids deposit their eggs in open gravel structures - known as redds - to depths of up to 300mm in the hyporheic zone. The period between spawning and emergence accounts for a high but variable proportion of lifetime mortality and is strongly influenced by the delivery of oxygen. Understanding the controls on hyporheic oxygen concentrations and critical DO concentrations is essential for managing salmon populations.

Recent studies have shown that the discharge of chemically reduced (low DO) groundwater can adversely affect embryo survival and performance. Previous field-based studies of embryo survival and hyporheic DO have employed low frequency sampling strategies due to logistical problems inherent with sampling the hyporheic environment. However, recent advances in sensor technology, combined with traditional hydrometric techniques, have made it possible to characterise the variability of GW-SW interactions and assess the impact on hyporheic DO at fine spatial and temporal scales.

This poster presents data collected using this new technology to assess the variability of dissolved oxygen at fine temporal scales in the hyporheic zone of salmon spawning gravels in an upland stream. Our specific objectives are to: (i) characterise the temporal and spatial variability of dissolved oxygen concentrations in an artificial salmon redd; (ii) assess the influence of GW-SW interactions in determining this variability and (iii) evaluate the contribution that continuous water quality data can make in improving our understanding of hyporheic dynamics and ecological response.



Plate 1 Aanderaa™ DO Optode with analogue converter

Methods

In December 2004 (spawning time) an artificial redd containing two Aanderaa™ optodes (Plate 1) was constructed at a known spawning location on the Girnock Burn. Aanderaa™ 3830 optodes with 0-5V analogue converters were wired to a Campbell CR23X datalogger such that DO (% Sat.) and temperature were measured in surface water and at 150 and 300mm depth in the hyporheic zone (the artificial redd) at 1 minute intervals, with average data stored every 15 minutes.

Local GW-SW interactions were assessed using hydraulic head data obtained from piezometers at depths of 38 and 70cm using Eijkelkamp™ Diver pressure transducers with integrated loggers and thermistors. The direction of water movement was inferred using the difference in head between piezometers such that a positive value indicated upwelling, while a negative value indicated downwelling.

Results

Figure 1 shows the temporal variability of stream and hyporheic DO (150 and 300mm) between 08 December 2003 and 19 January 2005. Changes in DO are plotted relative to discharge and hydraulic gradient (see methods). Increasingly positive (streamward) hydraulic gradients were observed as the frequency and magnitude of hydrological events increased, consistent with increased water table elevation in response to groundwater recharge. DO concentrations in stream and hyporheic water were initially similar. However, following catchment re-wetting, the deeper hyporheic optode (300mm) began to exhibit marked low DO episodes.

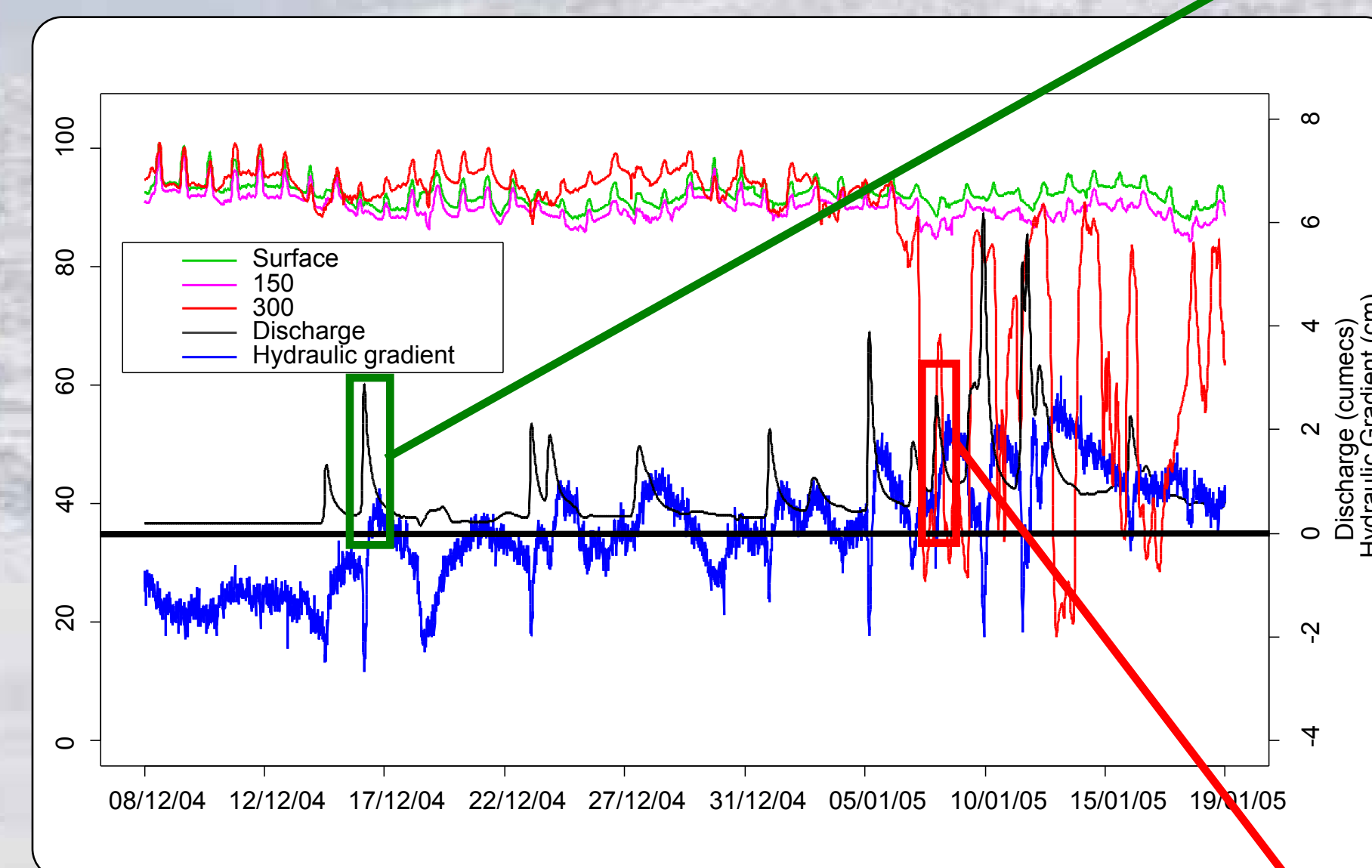


Figure 1. DO concentrations in surface and hyporheic water (150 and 300mm) relative to discharge and hydraulic gradient. Streamward gradients are indicated where hydraulic gradient exceeds 0 (solid line)

In general event based responses in hydraulic gradient followed a consistent pattern. At the event peak hydraulic gradient became increasingly negative as stream water was driven into the bed. On the recession limb increasingly positive hydraulic gradients were established. Changes in hydraulic gradient were thought to result from changes in the relative difference between stream stage and riparian water table elevation.

Although patterns of hydraulic gradient were consistent among events, the magnitude of gradients and changes in hyporheic water quality were variable. Prior to the 6th January, small event-based occurrences of positive hydraulic gradient were not associated with changes in hyporheic DO levels; as shown in Figure 2. However, following catchment re-wetting and the establishment of increasingly positive hydraulic gradients, events of similar magnitude were associated with rapidly changing hyporheic DO concentrations. This is shown in Figure 3 where low DO concentrations associated with the recession limb of a previous event, rapidly increased in response to increasing stream stage and negative hydraulic gradients, before declining on the recession limb as positive gradients were re-established.

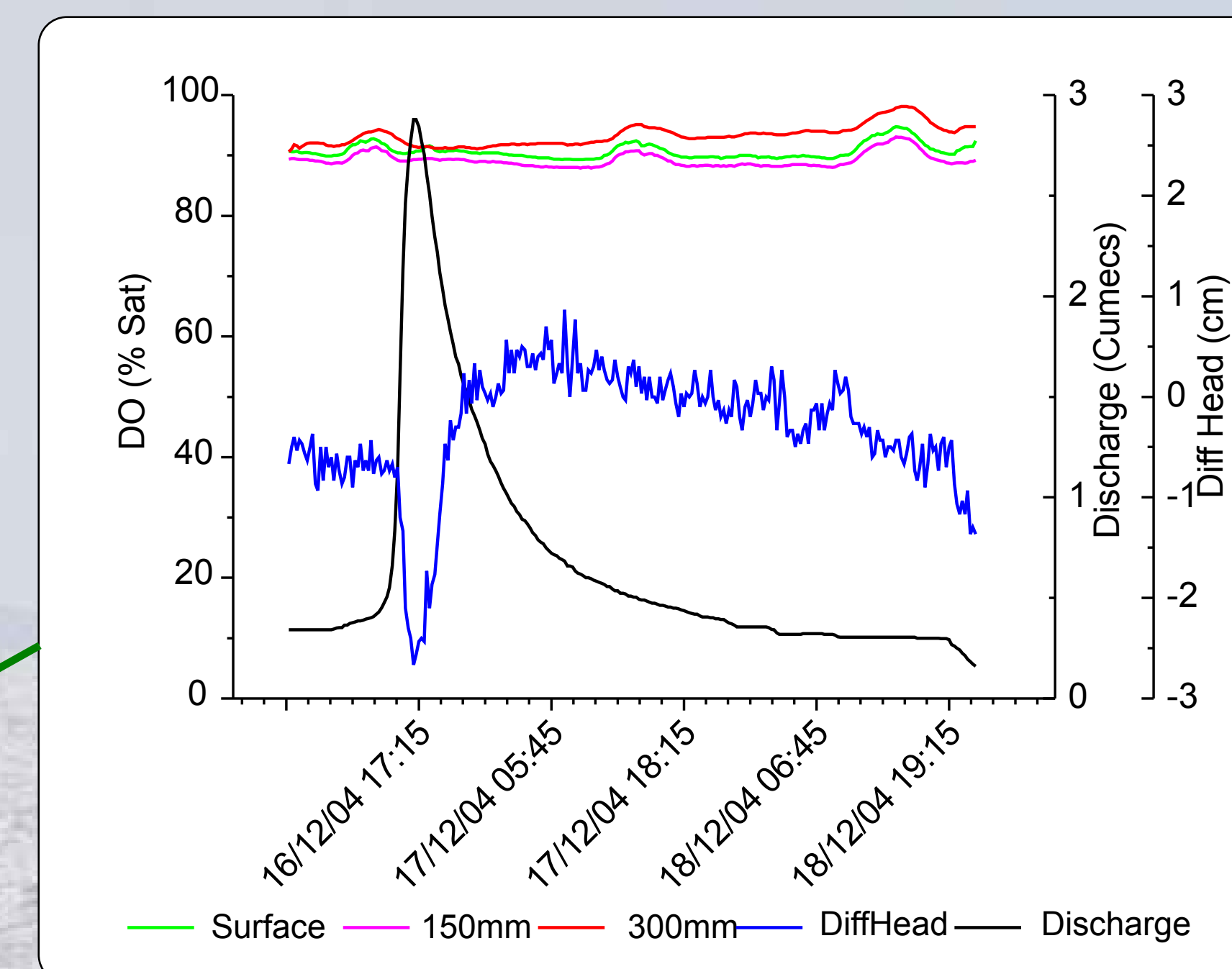


Figure 2. Event based variability in stream and hyporheic DO relative to discharge and hydraulic gradient (Difference in head between 38 and 70cm) prior to catchment re-wetting

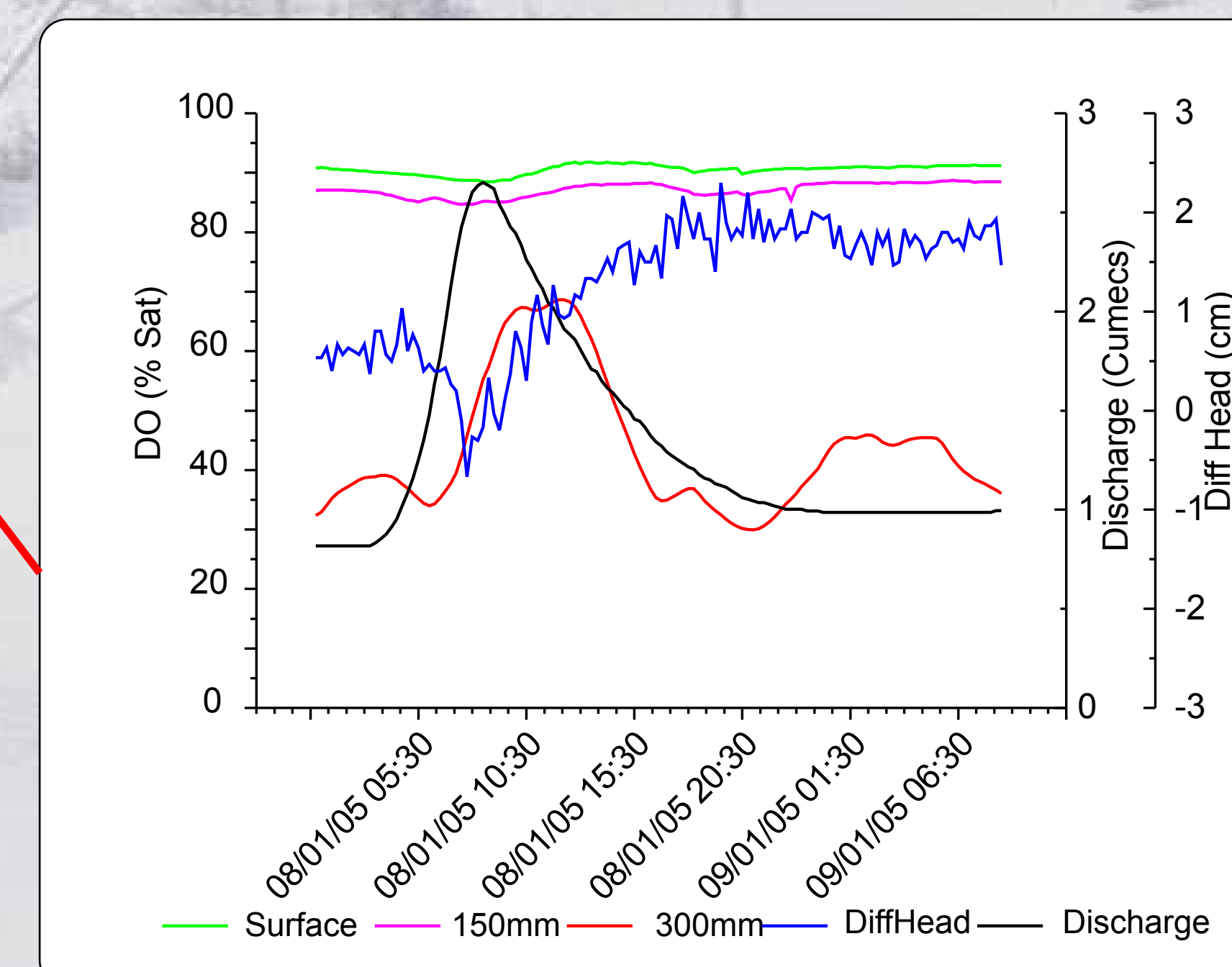


Figure 3. Event based variability in stream and hyporheic DO relative to discharge and hydraulic gradient (Difference in head between 38 and 70cm) following catchment re-wetting

Implications

Previous hydro-ecological studies of the hyporheic zone have failed to identify the nature and significance of the frequency and magnitude of changes in hyporheic processes, including changes in GW-SW interactions and water quality. This has resulted in widely varying sampling strategies that are generally of much lower resolution than is required to characterise the hyporheic environment. Table 1 shows the frequency of hyporheic sampling employed in previous studies of salmon spawning habitat. Typical sampling strategies include weekly, fortnightly, monthly or in some cases only single samples.

Study	Sampling frequency
Youngson <i>et al.</i> , (2005)	Fortnightly
Groves and Chandler (2005)	Monthly
Malcolm <i>et al.</i> , (2004)	Weekly
Bowen M.D and Nelson S.M.(2003)	1-3 Monthly (3 Occasions over 5 months)
Malcolm <i>et al.</i> , (2003a)	Weekly (with more frequent event based monitoring)
Niepagenkemper and Meyer (2002)	Monthly / Bi-monthly
Ingendahl (2001)	Fortnightly
Peterson and Quinn (1996)	Weekly - Fortnightly
Rubin and Glimsater (1996)	Approx. Fortnightly
Curry and Noakes (1995)	Single sample, 24 hours after samplers deployed
Curry <i>et al.</i> , (1995)	Monthly - Bi-monthly (strategic to developmental stage of embryos)
Sowden and Power (1985)	Approx. Monthly

Table 1. Frequency of hyporheic oxygen sampling in previous studies of salmon spawning habitat. Where sampling frequency has not been explicitly stated, it is derived from figures or sample numbers in a specified period

The sampling frequencies employed in previous studies (Table 1) are long in comparison to the hydrochemical response times identified in this study, and risk missing biologically important low DO episodes. Figure 4 uses the continuous hyporheic water quality data (300mm) collected in this study to demonstrate the effect of traditional sampling strategies using 100 random repeat samples. Such sampling misses much of the variability and extremes in hyporheic DO. We conclude therefore that any biological inferences made on the basis of low resolution sampling have the potential to be highly misleading.

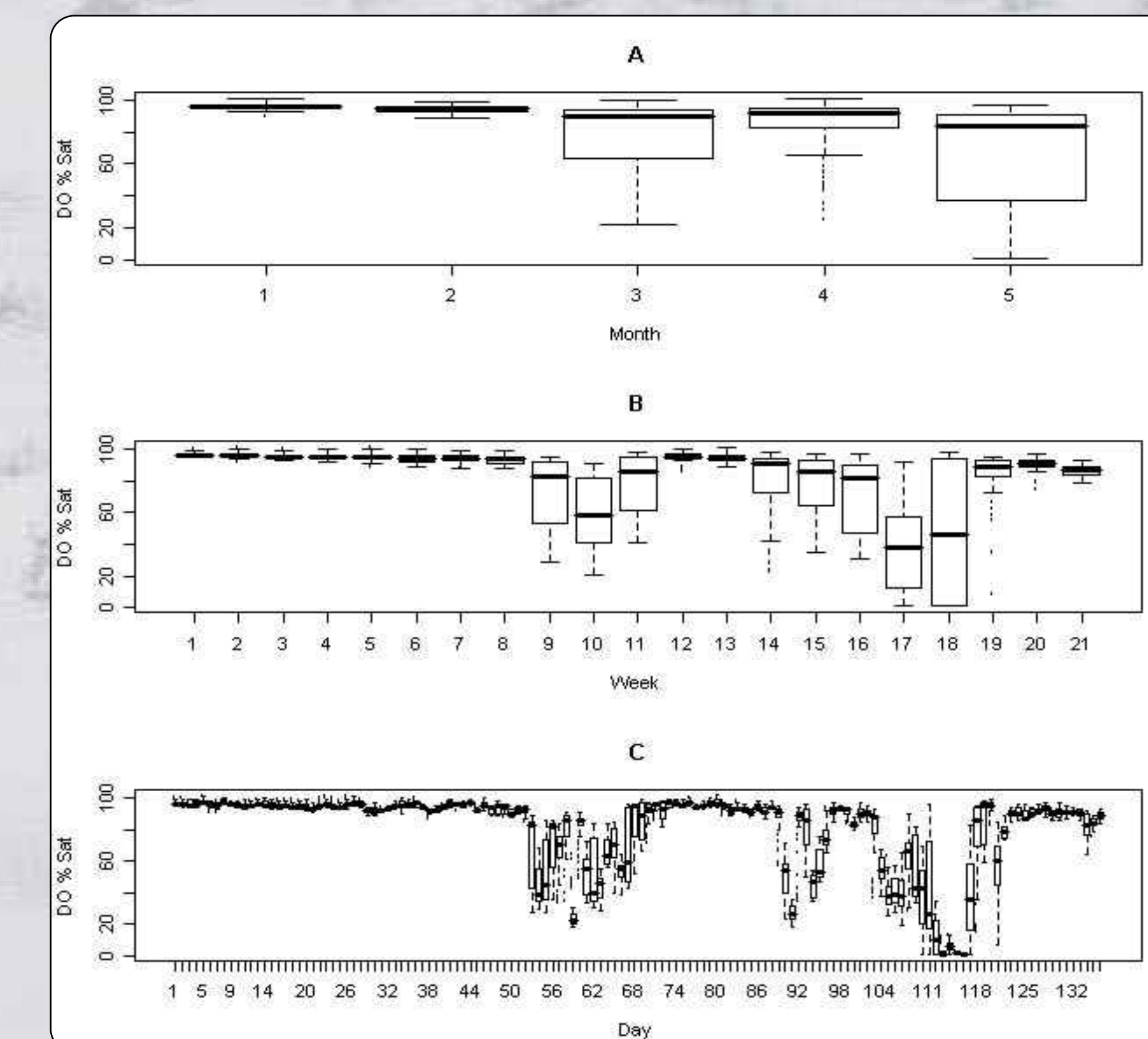


Figure 4. The effect of sampling frequency on observed hyporheic DO concentrations

Summary

- Hyporheic oxygen levels were measured in an artificial redd
- Optical-chemical sensors revealed rapidly changing hyporheic DO concentrations
- Hyporheic DO varied depending on local GW-SW interactions
- Similar hydrological events revealed variable hyporheic responses depending on antecedent conditions (state-dependant)
- Previous studies have underestimated hyporheic dynamics
- There is a need to re-assess the biological interpretations of previous water quality studies of the hyporheic zone

