Groundwater-Surface Water Interactions in Riparian Ecosystems: Implications for Hyporheic Zones and Salmon Embryo Survival

Introduction

In early winter, salmon (Salmo salar) and sea trout (Salmo trutta) lay their eggs in depressions that they excavate in streambed gravels. These nests are typically between 10 and 30 centimetres deep. Burial in gravel protects the eggs from disturbance or predation during incubation. Eggs depend on a supply of well-oxygenated water for survival and development. However, the water found beneath the streambed often contains low oxygen concentrations and in some cases eggs die as a result.

What factors determine streambed water quality?

A typical stream catchment in Scotland contains in excess of a year’s annual precipitation due to storage below the surface of the landscape. This so-called groundwater drains through soils and rocks towards streams. Transit times, for rainfall falling on the catchment to leaving as stream flow, range from near instantaneous during heavy rainfall events, to years or even decades for long-residence groundwater.

After prolonged contact with soils and rocks, groundwater becomes chemically different from stream water. It contains more dissolved minerals (indicated by high alkalinity) and less oxygen than surface water. In general terms, groundwater is detrimental to fish embryo survival. Groundwater and surface water mix beneath the streambed in the hyporheic zone. Hyporheic water is made up of complex mixtures of groundwater and surface water that are of similar variable quality. Because the hyporheic zone is where salmonids make their nests, and hyporheic water bathes the developing eggs, it is important that scientists be able to understand the processes governing groundwater intrusion. This way it will be possible to identify locations affected by groundwater that are likely to be unfavourable for egg development.

What are the implications for salmon management?

In the Girnock Burn the barriers that caused groundwater upwelling also reduced stream gradient causing spawning gravels to accumulate. Thus, the two short reaches of stream that were strongly affected by groundwater attracted about 40% of all the spawning that occurred in the Girnock Burn. Therefore, despite its limited spatial extent, groundwater upwelling has a disproportionate effect on salmon spawning success in the stream as a whole.

Where low DO groundwater has sufficient impact on egg survival to reduce fry recruitment, surface water incubators could be used to rear eggs and mitigate against the effects of low hyporheic oxygen.

Figure 1. Map of the Girnock Burn, Aberdeenshire showing monitoring locations.

Figure 2. Spatial variability of stream (      ) and hyporheic (     ) water quality in the Girnock Burn, Aberdeenshire showing DO and alkalinity. Red sites are groundwater dominated and green sites surface water dominated.

What causes groundwater upwelling?

The two sites showing strong groundwater upwelling were located immediately upstream of valley constrictions caused by ancient deposits of glacial debris. These impede groundwater flowing down the valley, forcing it laterally towards the stream channel where it upwells into the hyporheic zone.

How does water quality affect salmon embryos?

At sites where there was a strong influence of groundwater, salmon egg survival was low. At sites dominated by surface water, or at sites with intermediate characteristics, egg survival was generally good. Even here, however, a range of sub-lethal effects was observed. These included delayed hatching and reduced body size (Plate 1). The severity of these effects was related to hyporheic oxygen concentrations.

<table>
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<tr>
<th>Site</th>
<th>DO (mg/l)</th>
<th>Alkalinity (mg/l)</th>
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<tbody>
<tr>
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<td>0</td>
<td>0</td>
</tr>
<tr>
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<td>10</td>
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</tr>
<tr>
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<tr>
<td>5</td>
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<td>80</td>
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Summary

- Hyporheic water quality varied across a set of 15 sites investigated in the Girnock Burn, Aberdeenshire;
- Hyporheic conditions varied according to the relative influence of groundwater and surface water;
- Valley constriction caused by post-glacial features favoured both groundwater upwelling and salmon spawning due to the accumulation of suitable spawning gravel;
- Because of this dual effect, the impact of groundwater upwelling on salmon embryo survival in the stream as a whole was disproportionately large.