The Effects of Geomorphology and Watershed Land Use on Spawning Habitat

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INTRODUCTION

The distribution and frequency of large geomorphic features in a watershed govern where suitable spawning habit can be found and utilized. The different geomorphic scales each play a vital role in creating habitat as well as in survival of fish eggs. The three spatial scales described below are the catchment scale, the fluvial audit, and the reach scale. Each plays a specific role in determining availability and suitability of habitat. The geomorphology of a river can also help to dissipate the negative effects of land use on the river and on its biology.

GEOMORPHIC SCALES

There are three different spatial scales known as geomorphic scales at which one can view a river system. The largest geomorphic assessment is at the catchment scale. The catchment is usually defined as the area where the stream gets its water from, or the watershed (figure 1).

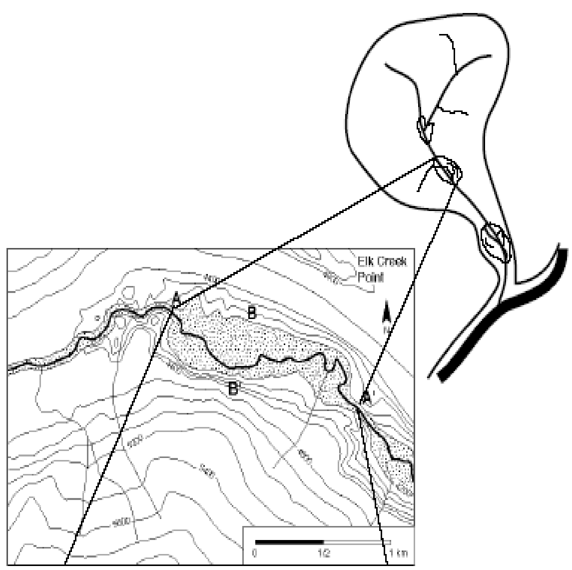

Figure 1. An example of the catchment scale, with a section of stream enhanced. The enhanced section is called a reach, and has many characteristics that govern local habitat, while the catchment governs broad habitat suitability (Baxter and Hauer 2000).

The importance of the catchment scale is to observe how physical habitat diversity and interacts on a large scale with river flow processes. The catchment scale is also used to determine where groundwater enters into the river system by means of hyporheic exchange (Baxter and Hauer 2000). Other physical features described at the catchment scale include the general geologic setting, the orientation and aspect of the vegetation types and the hydrologic flow regime. These features dictate the basic valley types that we observe within the catchment, which in turn greatly affect habitat availability and suitability.

The next smaller geomorphic scale of interest is called the fluvial audit. The fluvial audit provides information about how the river responds to its sediment supply, or the amount of sediment delivered into the river. The sediment budget, or amount of sediment moved through the stream over time, affects the physical properties of the river and aquatic habitat available in the river. Information at the fluvial audit would be used to explain the presence of bars, riffles, and meander bends, and how they relate to the surrounding landscape. This geomorphic scale is important for numerous species of fish, because they can only spawn in certain types of gravel and flow. The processes that operate at the fluvial audit scale generate the greatest stream habitat diversity by distributing different size gravels throughout the stream system. The variety in distribution of gravels is partially responsible for creating the dynamic features in a river that the fish are dependent on for survival. Specifically, these features are also responsible for creating micro flow conditions, such as riffles with intergravel flow, which many species of fish rely on for reproductive success. Figure 2 shows an example of how patches of sediment create geomorphic features (such as bars) that influence microflow conditions and locations of suitable spawning habitat. Information at the fluvial audit can help to reveal areas in the river where optimal habitat conditions exist (Kondolf and Piegay 2003).

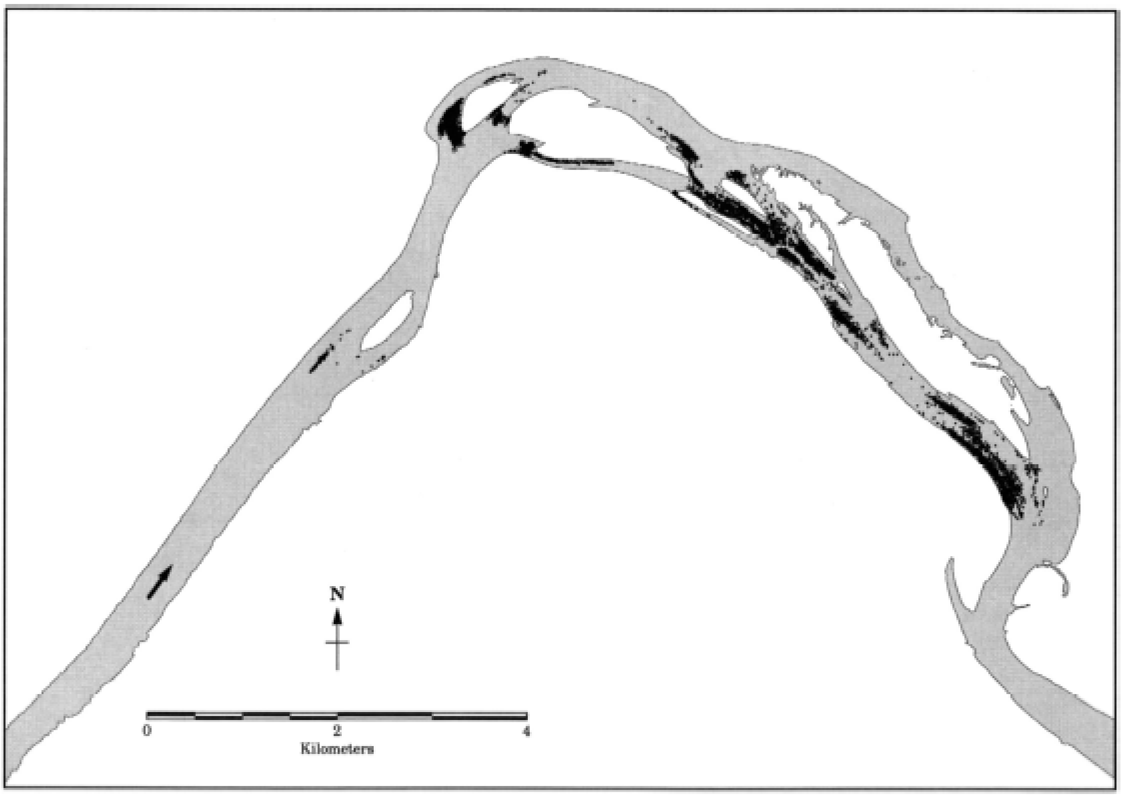

Figure 2. The black areas are individual spawning sites distributed amongst this large geomorphic feature, where differences in channel morphology and flow regime dictate suitable habitat (Geist and Dauble 1998).

Once the fluvial audit has been assessed additional habitat information can be obtained at the reach scale. This is a site specific section of channel that is chosen to be a characteristic section of a river that can be observed throughout the catchment. The reach scale is often used to study certain spawning sites. Figure 1 shows an example of a reach. The reach scale is often the focus for habitat restoration purposes, because the conditions at that scale are easier to quantify than at larger scales. The reach scale gives very detailed information about a specific site. This scale can provide information on the localized sediment transport, which can be used to make estimations about the catchment sediment budget. Studying of the reach scale provides a manageable perspective of optimal habitat conditions and how those conditions interact with the local morphology and local flow regimes. Each of the three scales can be linked together by studying the reach scale extensively and then applying that knowledge throughout the catchment by means of a fluvial audit (Kondolf and Piegay 2003).

SPAWNING HABITAT

The different geomorphologic scales each play a very important role in determining how and where fish spawn. Certain species require different habitats for successful spawning, egg development and emergence as fry. For instance bigger fish can usually spawn in larger sized gravels because they are powerful enough to move them, while smaller fish can't entrain the larger particle sizes (Kondolf 2000). The fish must be physically able to lie on their side and move their tail rapidly up and down to dig their redd. This rapid up and down movement creates a flow that excavates the gravels from the bed and deposits them downstream, leaving a shallow depression in which to deposit eggs. Once the eggs are fertilized and covered they require sufficient amounts of fresh water to keep them alive. The cool flowing water provides two necessities to the developing eggs: it cleans out the metabolic wastes that accumulate in the nest, and it brings dissolved oxygen to the eggs. Once the eggs hatch as Alevin, they reside in the nest until they are large enough (as fry) to make their way out of the bed and into the main channel. Emergence from the gravel can be a problem if fine sediment enters and clogs the interstitial spaces between the gravel in the bed. As a result, high habitat quality is a necessity for successful spawning. (Kondolf 2000).

The size and condition of the sediment required for successful spawning varies depending on the species, there are certain habitat conditions all species require to successfully spawn in a site. The site must have the correct grain size distribution, for egg incubation to take place, and the gravels must be an appropriate size for the fish to move and dig a nest. If the gravels are too big the fish can not move them, but if the gravels sediment is too fine a nest can not be excavated. Kondolf (2000) suggested that spawning fish can not move gravels that have a diameter larger than 10% of their body length. Likewise, if the gravels are excessively compacted, the fish will be unable to move them. The amount of fine sediment in the channel is also important for habitat quality as excess sediment can hinder incubation of the fertilized eggs, and prevent fry from emerging through the gravels into the channel. Increased fine sediment fluxes from changes in watershed land use can bury gravels, suffocating the fry and trapping them in the gravel. Intragravel flow must be adequate enough to keep dissolved oxygen levels high for the fertilized eggs and Alevin. The channel bed permeability can be greatly affected by land use changes in the watershed particularly those that increase the input of fine sediments.

Many habitat conditions must be met in order for fish to choose a spawning site. These conditions are mostly governed by the geomorphology of the reach. However some spawning sites with suitable habitat will not be used by fish. In the Skeena River for example, Chinook salmon spawn in 57 streams, but 87% of the total fish production occurs in only 7 different stream reaches. Similarly, Sockeye salmon spawn in 90 streams, but about 90% of the Sockeye production can be accredited to 13 spawning reaches. Although the reasons for this phenomenon are not entirely clear, the effect of high density spawning may increase the success of egg development and fry emergence (Gottesfeld et al. 2004). Due to high density spawning, there are extreme changes in local bed morphology. Gottesfeld et al (2004) noted that evidence of the redds remained in the channel for more than nine months out of the year. The channel bed morphology did not resemble a typical flood morphology, but rather a bioturbated morphology. If a large flood event did not come through the river system and rearrange the sediments the redds accumulated and the bed morphology was determined by the spawning fish. Gottesfeld et al. (2004) found the bioturbated morphology contributed to the success of spawning and increased the chance of returning finding a spawning site in following years.

HYPORHEIC EXCHANGE

One possible explanation as to why fish choose a very localized spawning site may relate to the interaction of ground water and surface water through the bed. This interaction zone is often referred to as the hyporheic zone. In the hyporheic zone water can either enter the stream channel bed (upwelling), or enter the channel bed from the stream channel (downwelling) (figure 3). Different species of fish have different tolerances for water exchange in the hyporheic zone. Cold water fish like brook trout, sockeye salmon, chum salmon, and rainbow trout all prefer to spawn in areas of up welling, while brown trout prefer to avoid areas of hyporheic exchange (Geist and Dauble 1998). Upwelling water may provide benefits, such as constant temperatures and high dissolved oxygen levels. In glacial rivers upwelling water may be warmer than surface water, which would lead to emergence of the fry at optimal times (Geist and Dauble 1998). High density areas of spawning such as in the Skeena River may be attributed to strong upwelling sites.

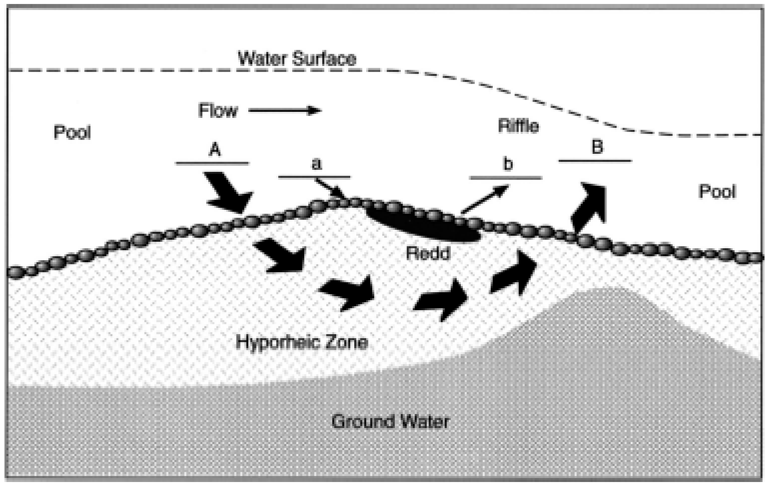

Figure 3. A visual representation of hyporheic flow under a Redd (Geist and Dauble 1998).

Hyporheic exchange is largely determined by the geomorphology of the surrounding landscape. Baxter et al. (1999) found that the amount of groundwater discharge sites in a river was closely related to the frequency of alluvial valleys. They also found out that the presence of knickpoints (steep changes in a river gradient) at the downstream end of valley segments was crucial to directing the hyporheic flow, and in turn directing the location of spawning habitat for certain species of fish. Upwelling and downwelling can also occur in the reach scale of a river. Channel features like woody debris can force downwelling on the upstream side, and an area of upwelling on the downstream of the disturbance (Baxter et al. 1999).

EFFECTS OF LAND USE

Different spatial scales of geomorphology have a profound effect of the spawning habitat of certain fish, as do the localized land uses in the catchment area. Certain land uses that increase fine sediment into the river system can degrade optimal spawning sites. Large scale logging can impact the river from the catchment scale down to the reach scale by introducing fine sediments into the drainage. These fine sediments negatively affect the reproductive success of salmon by altering the channel morphology and filling the interstitial spaced of the gravel. Intensive logging can also lead to water temperature changes within the channel that can negatively affect egg survival rates. In general increases in development within the catchment typically results in a decrease in spawning survival rate. Road density and the number of river crossings throughout a catchment have proven to be viable tools to relate development to declining fish numbers (Baxter et al. 1999). Land use can have a profound impact on the hyporheic zone as well. A drop in the local water table due to excessive pumping, could dewater the channel, decreasing or eliminating hyporeic flow so that a few highly used spawning sites were no longer available. According to Baxter et al (1999), it is hard to quantify the extent of how spawning habitat has been affected by land development, but there is ample evidence it has been impacted. As development continues to alter stream habitat conditions, fish may be forced to rely heavily on less affected conditions, such as temperature of the upwelling ground water, for their continued survival

CONCLUSION

Land use practices not only have an extreme impact upon spawning habitat, but the geomorphology of the surrounding landscape plays a vital role in determining what stream habitat can be used for spawning. Each different geomorphic scale influences spawning habitat quality in a different way [from the catchment scale to the localized reach scale]. Groundwater exchange plays a vital but not well understood role in the selection of spawning habitat. Land use policies must address those different scales and their effects on habitat conditions, or portions of spawning habitat could be rendered useless. The hierarchical approach to viewing and understanding a watershed is a powerful tool for prediction optimal spawning sites as well as interpreting the effects of land use changes on spawning success.

REFERENCES

Baxter C.V. et al. 1999. Management and Conservation of Bull Trout. *Transactions of the American Fisheries Society* Sept: 854-867.

Baxter C.V. and Hauer F.R. 2000. Geomorphology, hyporheic exchange, and selection of spawning habitat by bull trout (*salvelinus confluentus*). *Canadian Journal of Fish and Aquatic Sciences* 57: 1470-1481.

Geist, D.R and Dauble, D.D. 1998. Redd Site Selection and Spawning Habitat used by Fall Chinook Salmon: The importance of Geomorphic Features in Large Rivers. *Environmental Management* 22(5): 655-669.

Gottesfeld, A.S., Tunnicliffe, J.F., and Hassan, M.A. 2004. Spawning Gravel Quality and Salmon Production in British Columbia. Forest-Land-Fish Conference II, April 26-28.

Meyer, C.B. The importance of measuring biotic and abiotic factors in the lower egg pocket to predict coho salmon egg survival. *Journal of Fish Biology* 62: 534-548.

Kondolf G.M. 2000. Assessing Salmonid Spawning Gravel Quality. *American Fisheries Society* 129: 262-281.

Kondolf G.M. and Piegay, H. 2003. Tools in Fluvial Geomorphology. John Wiley & Sons Ltd.