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Sediment budget for salmonid spawning habitat rehabilitation in a regulated river

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Abstract

Bed elevation, feature adjustments, and spawning use were monitored at three Chinook salmon (*Oncorhynchus tschawytscha*) spawning habitat rehabilitation sites to measure project longevity in a regulated river. Sites enhanced with 649–1323 m^3 of gravel lost from 3–20% of remaining gravel volume annually during controlled flows of 8–70 m^3/s and 2.6–4.6% of placed material during a short-duration (19 days) release of 57 m^3/s. The oldest site lost ~50% of enhancement volume over 4 years. Of the mechanisms monitored, gravel deflation was the greatest contributor to volumetric reductions, followed by hydraulic scour. Spawning, local scour around placed features, and oversteepened slopes contributed to volumetric changes. As sites matured, volumetric reductions decreased. Sites captured as much large woody debris as was lost. While complexity is an extremely important aspect of ecological function, artificial production of highly diverse and complex habitat features may lead to limited longevity without natural rejuvenation.

Keywords: Salmonid; Spawning habitat; Rehabilitation; Restoration; Morphometric budgets; Digital elevation model differencing

1. Introduction

A sediment budget quantifies sediment fluxes and storage in a designated area over a specific time period. Budgets can be performed for whole basins (Dietrich et al., 1982; Reid and Dunne, 1996) or individual channel reaches (Fuller et al., 2003). The morphometric sediment budget approach quantifies erosion and deposition volumetrically by differencing observed topographic changes (Brasington et al., 2003; Lane and Chandler, 2003). Morphometric sediment budgets largely reflect changes from bedload transport (Fuller et al., 2003). In regulated rivers, bedload is rarely transported past large dams, hence virtually eliminating the (volumetric) input term of the sediment budget from upstream (Vaithiyanathan et al., 1992). In these areas, sediment-starved flow may erode the channel bed and banks, producing channel incision, bed material coarsening, and gravel loss (Waldichuk, 1993; Gilvear and Bradley, 1997; Kondolf, 1997; Shields et al., 2000). Such changes typically result in habitat modifications for numerous aquatic organisms, including anadromous salmonids (Osmundson et al., 2002).

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Sediment budgets provide a record of relative channel stability and thus a means of assessing physical habitat change. For instance, because of declining salmonid populations (Yoshiyama et al., 1998), coarse sediment and physical structures [such as large woody debris (LWD), boulder complexes, and groins] are being added to streams to augment deficiencies, create meandering channels, and enhance spawning riffles (Scheeler, 1990; Chapman, 1995). Reviews of such spawning habitat rehabilitation (SHR) projects are detailed elsewhere (e.g., Kondolf, 2000; Wheaton et al., 2004c). While SHR projects appear to attract spawning fish and may increase embryo survival and fry production (Merz and Setka, 2004; Merz et al., 2004), numerous failures have also been documented (Frissell and Nawa, 1992; Avery, 1996). Expectations of stability are one of the greatest inadequacies associated with SHR (Wheaton et al., 2004c). Even with low flows, without further sediment input, natural and placed gravels eventually scour (Paintal, 1971). While the placement of structures (such as boulders and woody debris) is designed to improve habitat for fish, it can also accelerate scour locally (Kuhnle et al., 2002). For placed gravel, scour has been viewed as a failure (Kondolf et al., 1996); whereas the failure may not be scour itself, but rather the expectation that it should stay there. A site-scale sediment budget to estimate residence times of placed gravels and requirements for habitat maintenance might produce more reasonable expectations.

In this study, sediment budgets were used to track the fate of gravel, boulders, and LWD placed according to complex SHR designs and to identify mechanisms controlling project longevity. Site-scale (i.e. ~10^1 channel widths) sediment budgets were calculated for three spawning bed enhancement projects in a low-slope regulated river impacted by in-stream mining. Sediment input (from construction), change in storage, and gravel loss were measured volumetrically at each site and compared with process-based analyses of compaction, slope failure, and entrainment potential to assess specific mechanisms of morphological change after gravel placement. This study is significant for its insight into the relative roles of mechanisms for gravel-bed change under low flow, low-slope conditions, with lessons for future gravel placement design and monitoring strategies.

1.1. Site-scale sediment budget

A volumetric sediment budget for an SHR project on a regulated river at the typical site-scale of ~10^1 to 10^2 channel widths should account for all gravel sources and losses associated with project implementation and subsequent changes (Fig. 1). Because SHR projects involve gravel placement in a generally gravel-deficient setting, we emphasize the volumetric loss components.

1.1.1. Sources for gravel placement

Gravel for SHR is typically purchased from floodplain quarries or in-channel mining sources (Kondolf, 2000). In California, the cost for each metric ton of concrete-grade aggregate ranges from USD 7–20 at the mine, plus USD 0.06–0.10 km^{-1} for site transportation. On the Mokelumne River, cost for in-basin river gravel (including triple-washing and transport) was USD 22.90 m^{-3} total. The cost for gravel placement equipment and labor was an additional USD 0.47 m^{-3}. As gravel is sold by weight, some volumetric change may be due to overestimates in mass to volume conversions.

1.1.2. Fluvial sediment recruitment

Fluvial sediment recruitment refers to the local sediment supply via fluvial erosion of upstream sources. Localized bank sloughing, tributaries, and upstream augmentation are potential sediment sources. Hydraulic structures are often intended to encourage gravel deposition (FISRWG, 1998). Depending on trap efficiency, reservoirs may pass sand at a reduced rate (Brune, 1953), detrimentally affecting developing salmonid embryos within the substrate (Kondolf, 1997). However, sand does not comprise a significant volumetric component of the sediment budget for a placement project.

1.1.3. Gravel losses before placement: operational losses

Depending on how gravel is imported to a site, staged at the site, and positioned in the stream, some material is lost prior to placement (Fig. 1). The larger the site and number of staging areas used, the greater the gravel loss from floodplain and channel bank imbedding. Overhandling during construction can cause gravel breakage and spawnable-material loss. Misconfiguration and loss from spillage during transport and placement may further decrease final volume. Unforeseen problems, such as loose banks or pools too deep to operate equipment, may require operators to use a gravel portion to create access.

1.1.4. Gravel losses after placement: fluvial erosion

The volume of the final configuration can be deflated by several mechanisms. Hydraulic drag and lift forces are foremost in conventional thinking (Paintal, 1971). Particle entrainment is generally assumed to be estimated by shear stress (Nelson et al., 2000). Lacking direct