THRESHOLDS FOR MANAGING REGULATED RIVER ECOSYSTEMS[1]

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Abstract. *Fluvial geomorphic processes are the physical underpinnings for determining the structure and function of river ecosystems. Any collective measure of river ecosystem integrity must first incorporate fluvial geomorphic processes that create and maintain a dynamic river morphology and, second, the plant/animal community responses dependent on these processes. We outline a set of nine quantitative physical and biological attributes to assess integrity for alluvial river ecosystems and help select appropriate restoration strategies. Exceedence of physical and biological thresholds is necessary to achieve many of these alluvial attributes. Their identification, quantification, and use as performance criteria in adaptive management monitoring are critical to prescribing annual flow regimes for regulated river systems. We present several physical thresholds related to incipient motion of the channelbed surface, mobilization of alluvial features such as alternate bars, and critical scour depths required by dynamic riparian communities. In summary, we assign an "ecological significance" to all thresholds and establish their relationships with the annual flow regime.*

Key words: river ecosystems, fluvial processes, flow-instream

INTRODUCTION

Fluvial geomorphic processes are the physical underpinnings for determining the structure and function of river ecosystems (Ligon, Dietrich, and Trush 1995). The difficulty in understanding how healthy biological systems function increases with a system's complexity; critical interactions among physical and biological components increase geometrically, obscuring even simple cause-and-effect relationships. River ecosystems are among the most complex, with our prospects of reasonably predicting many cause-and-effect relationships remote in the near future. Therefore, regulated rivers must be managed by mimicking natural geomorphic processes, within contemporary sediment and flow constraints, to the greatest extent possible as the most realistic umbrella strategy for preserving and/or restoring river ecosystem health. For anadromous fisheries in regulated rivers, restoring morphological integrity to the mainstems and tributaries may be the only strategy for reviving instream habitat and fully realizing their potential productivity.

Mimicking natural geomorphic processes includes prescribing sufficient flow magnitudes to encourage morphological adjustment. Such an effort involves identifying, then quantifying, all important threshold processes. The purpose of this paper is to discuss several important thresholds for restoring regulated river ecosystems.

ALLUVIAL RIVER ECOSYSTEM ATTRIBUTES

Any evaluation of river ecosystem integrity, for regulated and unregulated rivers, must first quantitatively recognize the fluvial geomorphic processes that once created and maintained dynamic river morphology, and, second, establish plant/animal dependencies on these processes. Attributes of physical and biological integrity for alluvial river ecosystems can guide a preliminary assessment of river ecosystem integrity and selection of appropriate restoration strategies. Attributes typical of low gradient alluvial river ecosystems are proposed in Table 1.

Given extensive, human-induced influences within many river corridors and watersheds, not all attributes of unregulated alluvial rivers may be feasible or desirable to restore in a given regulated river regardless of effort and funding. For example, pre-dam sediment supply cannot be restored without removing the dam. Furthermore, unregulated rivers with comparable morphologies often no longer exist regionally, making inter-basin comparisons flawed or simply impossible. Instead, quantifying general fluvial geomorphic and riparian processes common to contemporary unregulated alluvial river ecosystems often becomes the only alternative for establishing a baseline for restoration and monitoring of altered alluvial river ecosystems.

Exceeding the physical and biological thresholds is necessary to achieve many morphological responses. Initiation of channelbed mobility (Attribute No.4), scour deeper than the channelbed surface (Attribute No.5), floodplain inundation and deposition (Attribute No.7), and riparian seedling scour (Attribute No.8) are not gradual processes but occur over narrow flow ranges. Their identification, quantification, and use in assessing restoration prescriptions are critical to determining annual flow regimes for regulated river systems.

CHANNELBED THRESHOLDS

Probably the most explored physical threshold for alluvial channels is initial mobilization of the channelbed surface. While the channelbed surface contains a wide range of particle sizes, incipient motion occurs over a narrow range of discharges due to offsetting effects of greater sheltering of smaller particles among more exposed large particles. The

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Table 1.

GENERAL ATTRIBUTES OF ALLUVIAL RIVER ECOSYSTEMS

No.1. *No single segment of channelbed provides optimum habitat for all species. Providing a wide range of physical environments maintains diverse and productive biological communities. Spatial diversity must be incorporated into any investigation designed to identify and evaluate the significance of fluvial processes on river ecosystem function*;

No.2. *Seasonal and annual flow regimes are broadly predictable, but specific flow magnitudes, timing, durations, and frequencies are unpredictable due to natural runoff patterns produced by storms and droughts. This temporal "predictable unpredictability" is the foundation for dynamic river ecosystems*;

No.3. *River reaches export sediment at a rate equal to upstream sediment input. The amount and mode of sediment storage for a given river reach should fluctuate, but maintain a channel morphology in dynamic quasi-equilibrium when averaged over many years*

No.4. *The dominant particle size of alluvial, and many partially-alluvial, channelbed surfaces is significantly mobilized by floods, often labeled the bankfull discharge, once annually as a 30 to 40-year average*;

No.5. *The active channelbed will be periodically scoured deeper than the surface layer by floods exceeding 3 to 5 year annual maximum flood recurrences. These floods, larger than bankfull discharge, are also necessary to deposit finer sediment on the floodplain and lower terraces*

No.6. *The channel will migrate at rates and wavelengths consistent with other rivers in watersheds with similar annual flow regimes, valley slopes and confinement, and sediment supply and caliber (i.e., with regional geomorphic and hydrologic similarity);*

No.7. *Floodplains are inundated once annually (as a long-term average) by common floods exceeding bankfull stage. Lower terraces are inundated less frequently, with their expected inundation frequencies dependent on norms established from regionally similar river channels*

No.8. *Woody riparian plant establishment and mortality are consistent with each species life history strategy, culminating in early successional population structures and species diversities (canopy and understory) characteristic of self-sustaining riparian communities in undisturbed rivers regionally*;

No.9. *Seasonal water quality characteristics, especially water temperature and suspended sediment concentrations, are similar to undisturbed rivers regionally*

D_{84} particle size (the size of the 84 largest particle from a sample of 100) as the threshold particle size is recommended because these larger particles function as the structural framework for the channelbed surface. Therefore, one critical threshold for stream ecosystem restoration is achieving incipient channelbed mobility with frequent (annual), moderate flood flows approaching bankfull discharge (a 1.5 to 2.0 year annual maximum flood peak). Though bankfull discharge is often considered the channel forming or channel maintaining flow, a threshold for incipient channelbed mobility has been documented during flows only 70 percent to 80 percent as deep as bankfull stage.

Another threshold, one achieved by less frequent, higher magnitude floods such as bankfull (and higher), must be satisfied to maintain morphological integrity (see Attribute No. 5). Once an incipient threshold has been exceeded, the river channel must transport mobilized D_{84} framework particles through alternate bar sequences. Without frequently achieving this threshold, river systems would be unable to pass framework particles from one riffle crest, through a pool, and onto the next downstream riffle crest; pools would frequently aggrade and point bars erode. Because we have not observed frequent pool aggradation with coarse particles or point bar erosion, the flow satisfying both thresholds, incipient conditions and transport through alternate bar sequences, may be similar.

By frequently mobilizing the channelbed, upstream bedload supply must be available, generally from tributaries downstream of the dam, or from introduced gravels. To achieve Attribute No.3 riverwide, the entire river must be capable of satisfying physical thresholds, though different segments may do so with different timescales. Thus, Attributes No.3, No.4, and No.5 are too tightly intertwined; stream ecosystem restoration cannot be considered without both.

TWO CALIFORNIA EXAMPLES

On the Tuolumne River below LaGrange Dam, historic aggregate and gold mining activities excavated deep in-channel trenches, creating extremely low gradient reaches that prevent transport of gravels and larger particles. Mainstem ecosystem restoration should eliminate these bedload bottlenecks by targeting both channelbed thresholds in the restoration design. This can be done by first filling in these bedload traps, then redesigning a smaller channel (than the pre-dam dimension) to mobilize and transport bedload with contemporary regulated flow regimes. Bedload supply to downstream reaches would be restored (though not at pre-dam levels), thus improving stream ecosystem integrity throughout the river.

On the mainstem Trinity River below Lewiston Dam, deltas from unregulated tributaries (e.g., Grass Valley Creek and Indian Creek) have aggraded the mainstem as the transport potential of the mainstem has been severely reduced by flood control and trans-basin flow diversion. Aggraded deltas create backwater effects at high flows, decreasing upstream water surface slopes and thus eliminating bedload transport upstream of deltas. Bedload from upstream reaches no longer routes through the river system.

RIPARIAN SEEDLING MORTALITY THRESHOLD

In Northern California rivers, the riparian community quickly encroaches into the mainstem channels once dam closure eliminates high floods. As seedlings grow, their root systems continue to extend downward, generally until saturated conditions are encountered. On the Trinity River, several species of willow seedlings extend roots below the surface layer (defined as the depth of a D_{84} surface particle) after/during their second growing season. By the third or fourth seasons, the roots will extend deeper than the surface layer. If a regulated river can only periodically (every few years) mobilize the surface layer of its alternate bars, riparian seedling survival in the active channel is almost guaranteed. If deeper scour does not occur roughly every 3 to 4 years, seedlings can escape mortality by scouring flows. The magnitude, duration, timing, sequence, and frequency of planned flow releases to achieve a seedling mortality threshold are therefore critical. By accommodating Attributes No.4 and No.5 in a restoration program while considering life history attributes of key woody riparian species, riparian encroachment could be eliminated or greatly reduced.

SUMMARY

Frequently, the response of resource managers to our proposed approach is that pre-dam flow peaks cannot be released (given water contracts, dam limitations, and human encroachment), and therefore mimicking natural processes to accommodate the three thresholds discussed for river ecosystem restoration is unrealistic. While concessions must be made, the natural processes outlined above can be managed without requiring the entire historic flow regime. For example, although pre-dam flow regimes radically impair sediment transport capabilities (Attribute No.3), dams also eliminate bed material supply from the upstream channel. Maintenance flow releases can be recommended that just need to transport the much lower bed material supplied by unregulated downstream tributaries. Even so, bed material introduction may be required immediately below a dam. On other rivers, the post-dam channel morphology can be scaled-down (or be given the opportunity to scale-down on its own), allowing fluvial processes to function as in the larger pre-dam channel but with lower magnitude flows.

REFERENCES

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