LARGE RIVER BED SEDIMENT CHARACTERIZATION WITH LOW-COST SIDESCAN SONAR: CASE STUDIES FROM TWO SETTINGS IN THE COLORADO (ARIZONA) AND PENOBSCOT (MAINE) RIVERS

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Mapping subaqueous riverbed sediment grain size across channels and in nearshore areas typically used by fish and benthic invertebrates is difficult where and when the water flow is too swift or deep to wade yet impractical to access with large boats and instruments. Fluvial characteristics can further constrain sampling options, particularly where flow depth, water column turbidity or channel bottom structure prohibit use of aerial or bottom deployed imaging platforms.

Sidescan sonar returns that image swaths of the bed from a vessel have the potential to meet the technical shortfall confronting bed sediment change detection in large rivers. Inexpensive, easy to use sonar devices designed to be mounted to small durable vessels are commercially available. They are lightweight and have low power demands, providing opportunities for use in a large range of rivers by one or two personnel. The modern sidescan transducers are low profile and require minimal draft, making them suitable for imaging in very shallow water. Swath mapping using these devices has the potential to rapidly map bed sediments, structural features and large woody debris, with minimal logistics and cost. Coupled with a GPS or other type of vessel tracking, they can produce geo-referenced images of the acoustic returns and relate spatial variations in the signal ('bed texture') to the grain size of the bed surface sediments and structural changes (Figure 1).

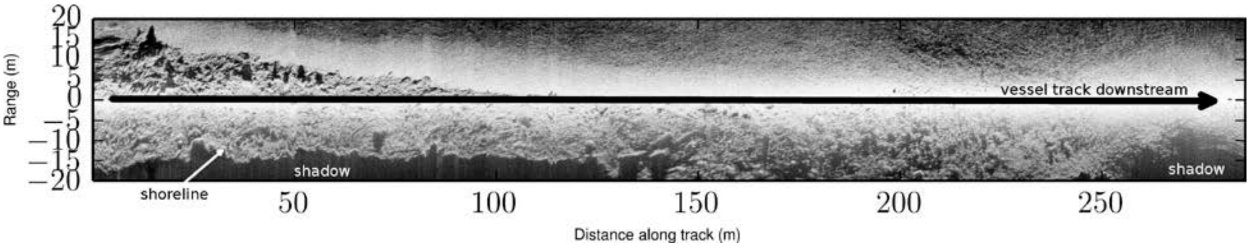

Figure 1 An example merged (port and starboard) sidescan sonar echogram. The transducer sends out a high-frequency (typically several hundreds of kHz) acoustic beam perpendicular to the vessel heading on either side (positive ranges are port and negative ranges are starboard) and records the amplitude of the returning echoes from a wide swath. One ping constitutes the simultaneous acquisition of data from the two sidescan beams at an instant, returning a swath composed of pixels whose intensity relates to the echo strength, determined by the acoustic impedance and reflection at those locations. A small strip of the bed is imaged with each ping,

building an echogram that provides near continuous coverage as the vessel moves slowly along-track (up or downstream).

The typical spatial resolution (pixel size) of a sonar signal return varies from decimeters to meters depending on range and acoustic parameters. The acoustic texture relates to morphological form roughness rather than the grain-scale roughness. The strength of the returned echo is a function of the bed sediment composition. A harder surface with greater acoustic impedance, such as bedrock and cobbles, will return more acoustic energy than a softer bed such as sand. The predictable relation between the sonar signal, acoustic texture and substrate properties provides a basis to distinguish dominant grain sizes and structures of a sedimentary environment (Figure 2).

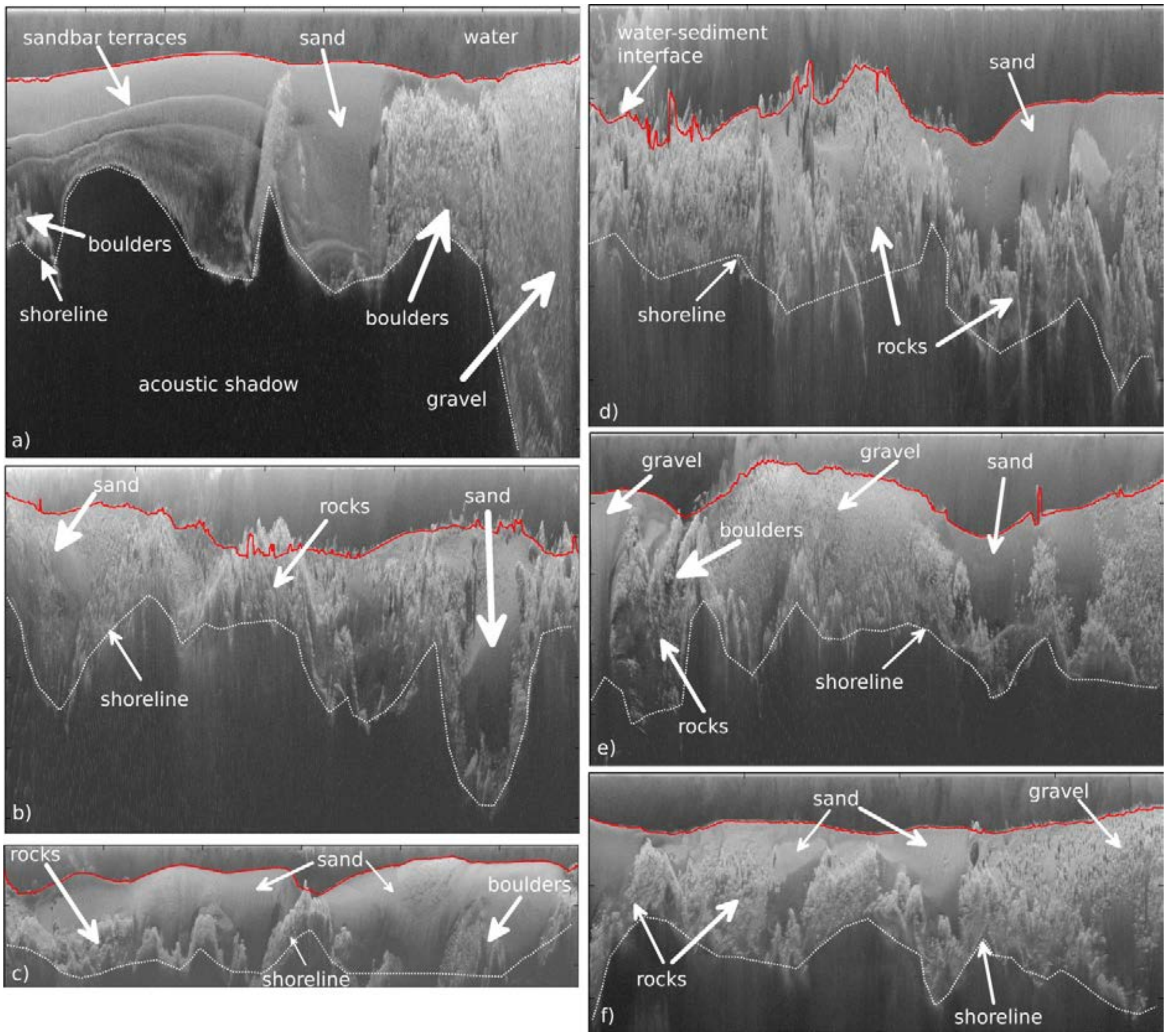

Figure 2 Examples of raw starboard sidescan sonar echograms (left to right, upstream to downstrean) collected with a Humminbird® instrument. The top of each image is the water column, and the bottom the acoustic shadow caused by the shoreline. Some sediment types have been identified. The label ‘rocks’ refers to bedrock outcrops. The line delimiting the water and the bed has been detected automatically. The challenge is to develop an automated means to

classify, in a robust manner, sediments that can be recognized by a trained eye. ®, Any use of trade, product, or names is for descriptive purposes only and does not imply endorsement by the U.S. government.

Here we discuss considerations in the use of sidescan sonar for riverbed sediment classification using examples from two large rivers, the Colorado River below Glen Canyon Dam in Arizona and the Upper Penobscot River in northern Maine (Figure 3). These case studies represent two fluvial systems that differ in recent history, physiography, sediment transport, and fluvial morphologies. The bed of the Colorado River in Glen Canyon National Recreation Area is predominantly graveled with extensive mats of submerged vegetation, and ephemeral surficial sand deposits exist below major tributaries. The bed is imaged periodically to assess the importance of substrate type and variability on rainbow trout spawning and juvenile rearing habitats and controls on aquatic invertebrate population dynamics. The Colorado River bed further below the dam in Grand Canyon National Park is highly dynamic. Tributary inputs of sand, gravel and boulders are spatially variable, and hydraulics of individual pools and eddies vary considerably in space and in response to varying dam operations, including experimental controlled flood releases to rebuild eroding sandbars. The bed encompasses the full range of non-cohesive sediments, deposited in complicated spatial patterns. The mobile portion of the Penobscot River is generally more uniform, and consists predominantly of embedded gravels interspersed between bedrock outcrops with small isolated sand patches in sections with modest or low gradients. Patches of large cobbles, boulders and bedrock outcrops are present in the lower reaches of the river near locations of two recent dam removal projects but are of limited extent below the "head of tide" on the river. Aggregations of coarse materials often correspond to locations with abrupt bed elevation drops in the Upper Penobscot River.

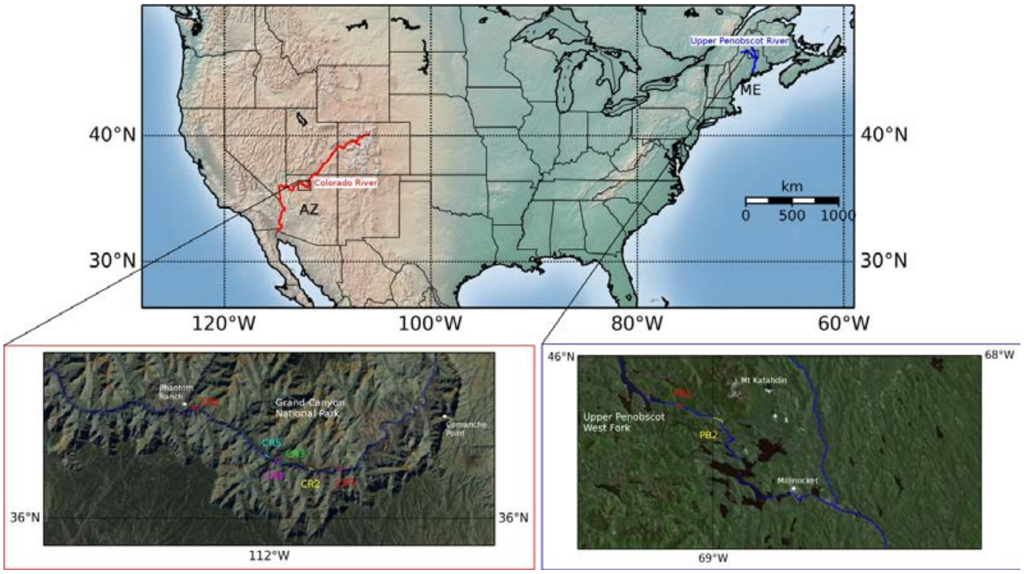

Figure 3 Location of the Colorado and Penobscot Rivers an d some sampling reaches (inset). The sites that will be discussed in this presentation are PB1 and PB2 on the Penobscot and CB1 through 6 on the Colorado.

First, we discuss data collection 'best practices' based on experience in varied environments. Second, we relate uncertainties in instrument positioning and boat attitude (heading and pitch) to sidescan bed-sediment texture measurements. Third, we present methods to relate raw echoes to backscatter amplitudes (in dB Watts) and acoustic impedances by correcting for transmission, spreading and absorption losses, the sonar footprint and instrumental factors such as time-varying transducer power. Fourth, we discuss the merits (and some pitfalls) of likely approaches to automated bed-sediment classification from sidescan imagery, such as textural classification based on machine learning and spectral signal decomposition. Finally, we present a promising spectral technique for automated sediment classification from sidescan echograms (Figure 4). The recursive application of the wavelet transform over small overlapping windows of the echogram provides a robust measure of variation in wavelengths of alternating patterns of strong and weak echoes. The greater this variation, the more textured the echogram and the coarser the substrate. The method provides an objective quantification of textures in physical units (length), for the purpose of riverbed sediment classification. We will evaluate this method using data from all contrasting case study sites.

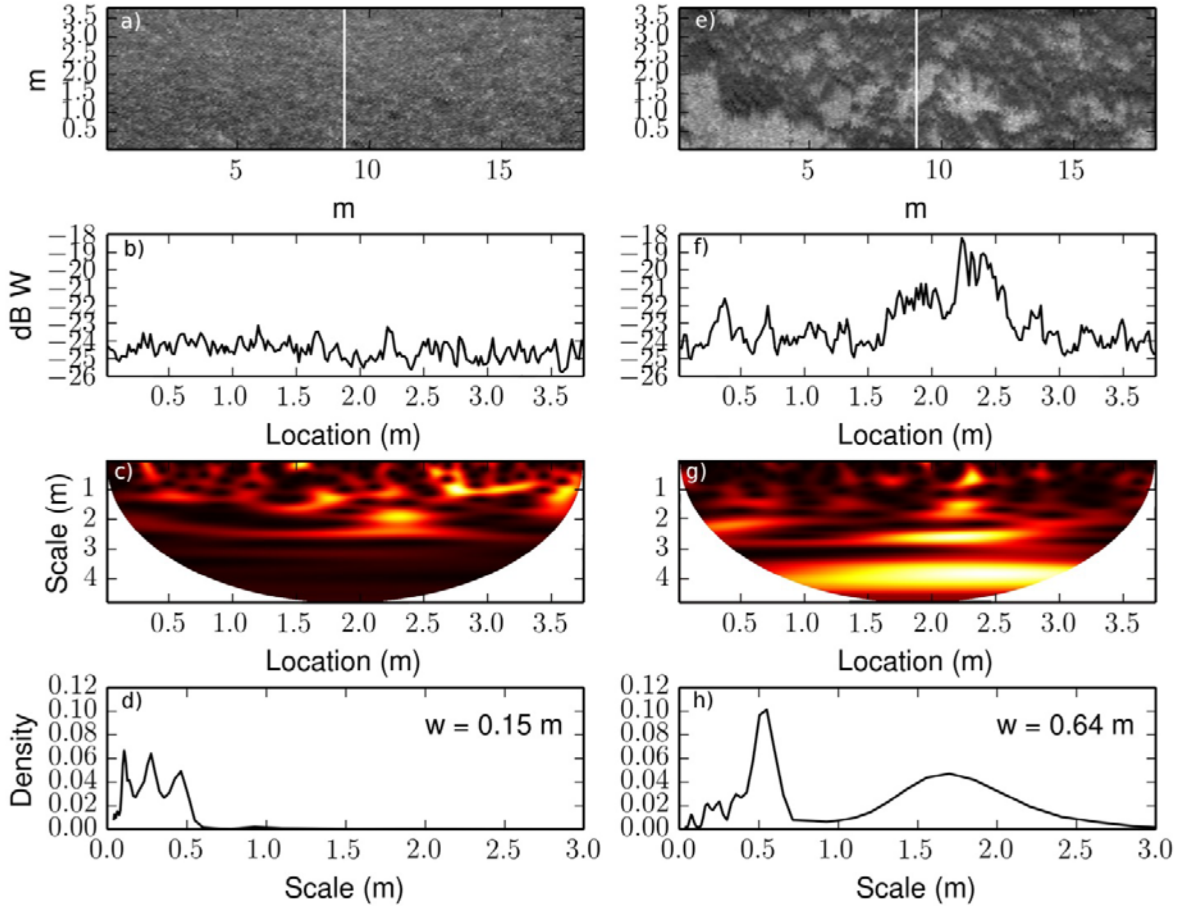

Figure 4 Example analysis of a small patch of homogeneous echogram texture: (a) a 200 x 200 pixel (~4 x 17m) window showing the textural signature from small well-sorted gravel at site in PB1 (Figure 3); (b) the trace through the white line in (a); (c) the continuous wavelet transform

of the data in (b) showing areas of high spectral power in lighter shades and low spectral power in darker shades; and (d) the normalized autospectral variance derived from (c) which shows spectral energy in a narrow band of scales. Panels e) through h) are the same for a 200 x 200 pixel (~4 x 17m) window showing the textural signature from small boulders at the same site. These different signatures for different substrate types are used to classify sediments in an objective and fully automated fashion.