Suspended sediment transport over a dune

R. Kostaschuk
Department of Geography, University of Guelph, Guelph, ON, N1G 2W1, Canada

D. Shugar
Department of Earth Sciences, Simon Fraser University, Burnaby, BC, V5A 1S6, Canada

J.L. Best
Departments of Geology and Geography and Ven Te Chow Hydrosystems Laboratory, University of Illinois at Urbana-Champaign, 1301 W. Green St., Urbana, Illinois 61801, USA

D.R. Parsons
Earth and Biosphere Institute, School of Earth and Environment, University of Leeds, Leeds, West Yorkshire, LS2 9JT, UK

S.N. Lane & R.J. Hardy
Department of Geography, Durham University, Durham, DH1 3LE, UK

O. Orfeo
Centro de Ecología Aplicada del Litoral (CECOAL-CONICET), C.C. 291, 3400, Corrientes, Argentina.

ABSTRACT: Field data from the Rio Paraná, Argentina, are used to examine patterns of suspended sediment transport over a dune. Measurements of three-dimensional velocity are made with an acoustic Doppler profiler (aDcp) and suspended sediment concentration and particle size with a laser in-situ sediment scattering transmissometer (LISST). Topographic forcing of flow over the dune causes higher streamwise velocity and upward vertical velocity over the stoss side and lower streamwise velocity and downward vertical velocity over the lee side. Acoustic backscatter from the aDcp is highest close to the bed, particularly near the top and base of the lee slope. Suspended sediment concentration decreases with height above the bed and is higher over the crest compared to the trough. Suspended sediment size is coarsest near the bed and transport rates are higher over the crest region. About 17% of the suspended-load transported over the crest is deposited on the lee side before it reaches the trough.

1 INTRODUCTON

Dunes are common in sand-bed rivers and estuaries and play an important role in the relationships between boundary layer flow structure and sediment transport (ASCE, 2002). The transport of bed-material load is composed of coarser bed sediment that is transported by traction and saltation as bed-load and in intermittent suspension as suspended bed-material load, herein termed ‘suspended-load’. Despite the dominance of suspended-load in sand-bed rivers (Kostaschuk, 2005), there have been few studies of its potential role in dune processes, morphology and migration, particularly in the field.

Fredsøe (1981) used stability analysis to examine the roles of bed-load and suspended-load on dune morphology. He concluded that bed-load will increase dune height and suspended-load will tend to result in a decrease in height. Numerical simulations and field measurements over estuarine dunes conducted by Johns et al. (1990) showed that sand transport in suspension was more important than bed-load in causing changes to bedform structure. They found that a combination of high flow velocity and fine sand bed-material resulted in a lowering of the dune crest and filling of the trough by deposition from suspension. Flume experiments by Hand and Bartberger (1988) showed that high flow velocities result in a relatively uniform sediment concentration profile with height above the bed. This causes the position of maximum sediment deposition on the lee to shift downstream, resulting in a rounded dune crest and a more symmetrical profile. Field measurements performed by Smith and McLean (1977), Kostaschuk and Villard (1996) and Kostaschuk (2000) suggest that increased sand transport in suspension relative to bed-load was associated with flatter dunes and lower lee slope angles. Amsler and Schreider (1999) used simulated values of the ratio of suspended-load/bed-load and found that higher ratios were associated with a diminishment of dune heights during floods in the Rio Paraná, Argentina. Kostaschuk (2005) extended this approach to several rivers and concluded that deposition of suspended sediment in the trough and on the lee side act to reduce dune height and lower the lee slope angle. Kostaschuk and Best (2005) estimated sediment transport using an acoustic Doppler profiler (aDcp) and a sediment transport model and found that deposition from suspension in the dune trough lowered dune height and made the dune profile more symmetrical in shape.

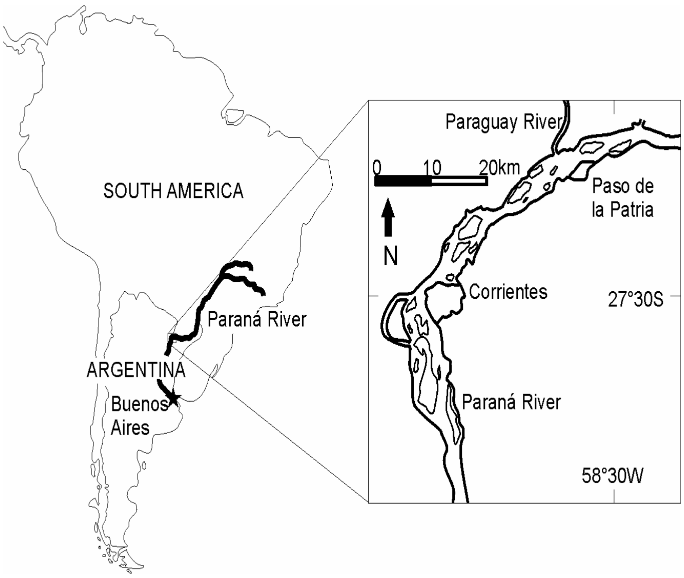

Figure 1. Map of the study area.

The purpose of this study is to use field data from the Río Paraná, near Paso de la Patria (Fig. 1), to examine patterns of suspended sediment transport over a dune and to evaluate the role of deposition from suspension in dune migration. Field data such as these are valuable in avoiding scale issues associated with dune studies in shallow, often narrow, flumes.

2 METHODS

The present study was conducted on the Río Paraná, just upstream of its confluence with the Río Paraguay, NW Argentina (27º30'S, 58º50'W; Fig. 1). The discharge of the Río Paraná during the time of surveying was ~11,000 m^3s^{-1}. At the study site, the Río Paraná is approximately 2.5 km wide and between 5-12 m deep. Flow and sediment transport time series were collected from a small, anchored, survey vessel on March 9th, 2004, while a bathymetric survey was conducted from a second, larger, vessel (Fig. 2). Bathymetry was measured using a RESON™ SeaBat® 8101 multibeam echosounder (MBES), three-dimensional flow velocity was measured with a Teledyne RDInstruments® RíoGrande 600 kHz acoustic Doppler current profiler (aDcp), and suspended sediment concentration and particle size with a Sequoia® Scientific laser in-situ scattering transmissometer (LISST). Transects were also made with the small vessel over the dune field with the aDcp (Fig. 3). Positions for MBES and aDcp surveys were determined with a Leica Differential Global Positioning System (dGPS) in Real Time Kinematic (RTK) mode, which resulted in a relative accuracy of +/- 0.02 m and +/- 0.03 m in the horizontal and vertical positions, respectively.

The smaller launch was anchored over the study dune crest and trough (Fig. 2) and the LISST was lowered a pre-determined depth and data collection was started simultaneously with the aDcp. For the deepest measurements, the LISST was lowered until it was resting on the bed, which resulted in a measurement height of approximately 0.1 m.

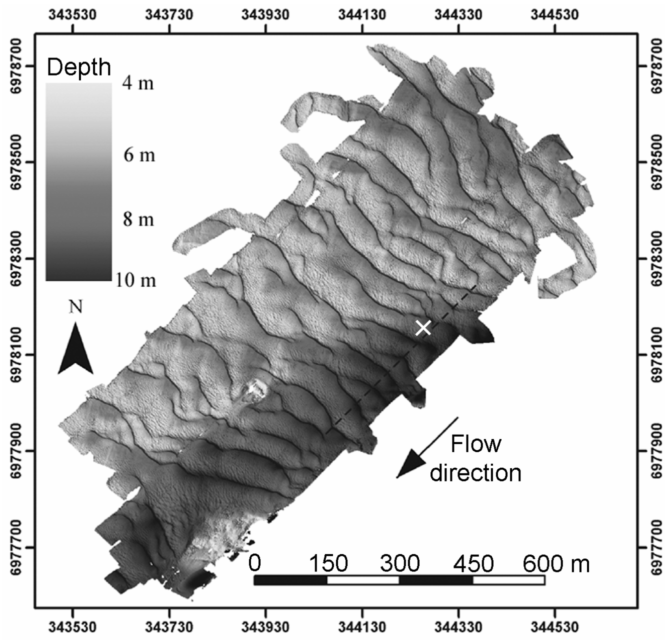

Figure 2. MBES record of dune field. The white X marks the location of the study dune.

3 RESULTS AND DISCUSSION

Dune crests are 'three-dimensional' in shape with sinuous crestlines and dunes range from 1 to 2.5 m in height and have wavelengths between 45 to 85 m (Fig. 2). The study dune is ~55 m long with height ~2.05 m and superimposed bedforms occur on the upper stoss slope (Fig. 3). The lee side angle is 22º on the steepest part of the lee slope.

Streamwise (U) and vertical (W) velocity over the study dune reflect the impact of topographic forcing (e.g., Kostaschuk et al., 2004), with higher U and positive W over the crest area and lower U and negative W over the trough (Fig. 3). Acoustic backscatter (B), obtained from the aDcp, is highest close to the bed, particularly on the crest near the top of the lee slope and in the trough at the base of the lee slope (Fig. 3). There is also a zone of slightly higher backscatter extending above the crest to the flow surface. The acoustic backscatter from the aDcp is strongly correlated (R = 0.92) with suspended sediment concentrations measured with the LISST (Figs. 3 and 5) (Shugar et al., submitted) so it should reflect spatial variations in suspended sediment over the dune. The streamwise velocity profile over the crest shows the 'kinked' log-linear profile typical of flow over dunes

(Kostaschuk et al., 2004) while the profile over the trough decreases logarithmically with height (Fig. 4).

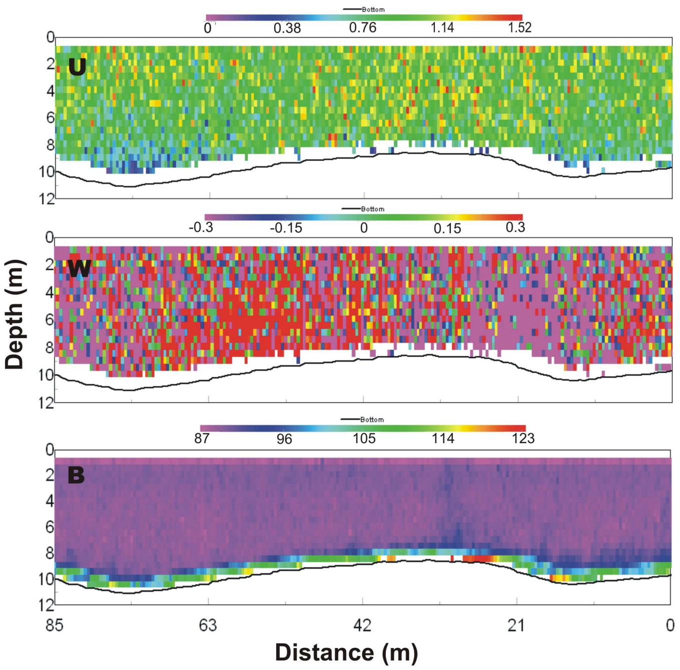

Figure 3. Streamwise velocity (U: m/s), vertical velocity (W: m/s) and acoustic backscatter (B: dB) over the study dune as measured with the aDcp. Flow is from left to right.

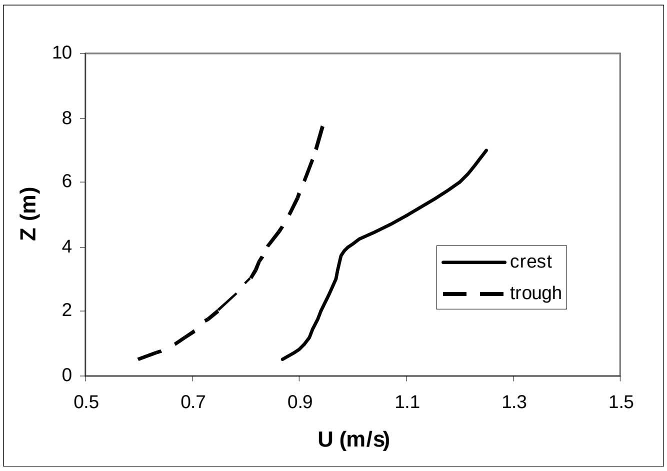

Figure 4. Streamwise velocity (U) based on aDcp time series over the crest and trough.

Figure 5 provides examples of particle size distributions measured with the LISST over the dune crest. Both samples are dominated by sand from 62-250 μm in size, but the measurements near the bed (0.1 m) have higher concentrations in the coarser bins. Both samples also show a second mode >250 μm and the near-surface sample (7 m) shows high concentrations in the 500 μm bin. The coarser mode in the near surface sample is attributed to phytoplankton (see Shugar 2005 for a detailed description of the filtering procedure employed) so these bins (250-500 μm) are not used in the subsequent calculation of 'decontaminated' suspended sediment concentration, particle size and load (Figs. 6-9). This procedure undoubtedly removes some of the coarser fractions of suspended sand from the samples close to the bed and thus underestimates both concentration and particle size in this region.

Suspended sediment concentration (C) over both the crest and trough are highest near the bed and decrease toward the surface (Fig. 6), which is consistent with the aDcp backscatter measurements (Fig. 3). Concentrations are considerably higher near the bed over the crest compared with the same region over the trough. A comparison of particle size distributions over the crest (Fig. 7) with those over the trough (Fig. 8) shows that particle size is coarsest near the bed in both cases. Particle size distributions further above the bed have smaller sizes and are similar in shape.

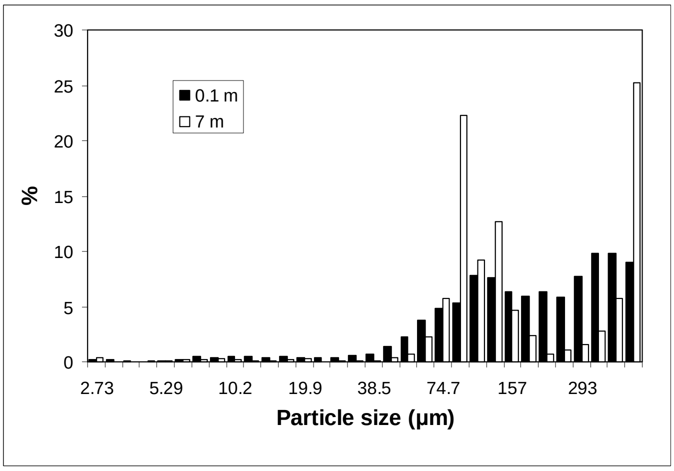

Figure 5. Particle size distributions for 0.1 and 7 m above the bed (Z) at the crest based on LISST data.

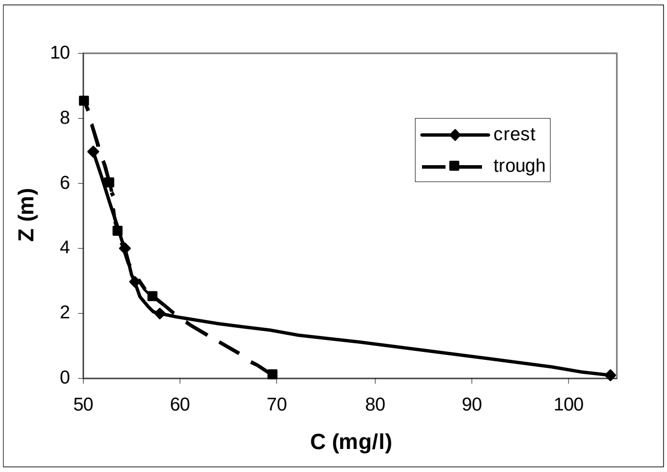

Figure 6. Time-averaged 'decontaminated' suspended sediment concentration (C) with height above the bed (Z) based on LISST data.

Profiles of suspended sediment transport rates per unit channel width (q_s) with height above the bed (Z) (Fig. 9) were calculated from profiles of streamwise velocity (Fig. 4) and concentration (Fig. 6). Transport is higher over the crest compared to the trough at every level. Over the crest, transport is highest near the bed, decreases to 3 m, remains constant to around 5 m then increases toward the surface. This pattern reflects the rapid decrease in concentration with height above the bed and the increase in velocity near the surface. In contrast, transport is lowest near the bed over the trough and gradually increases toward the surface. The trough pattern results from a slower decline in concentration with height above the bed compared to the increase in velocity. Integrating over the full flow depth results in a transport rate of 0.42 kg/s/m over the crest compared to 0.35 kg/s/m over the trough. This indicates that about 17% of the suspended-load transported over the crest is deposited on the lee side before it reaches the trough. Most of this deposited sand originates close to the bed over the crest (Figs. 6 and 9).

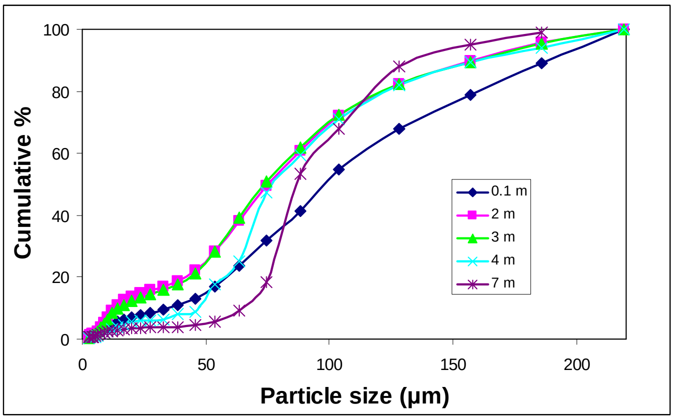

Figure 7. Cumulative % particle size distributions of 'decontaminated' suspended sediment above the crest for heights above the bed (Z) of 0.1 to 7 m based on LISST data.

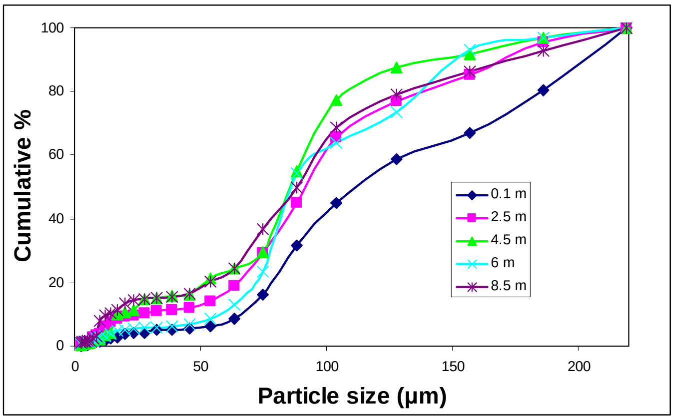

Figure 8. Cumulative % particle size distributions of 'decontaminated' suspended sediment above the trough for heights above the bed (Z) of 0.1 to 8.5 m based on LISST data.

4 SUMMARY

An acoustic Doppler current profiler (aDcp) and laser in-situ sediment scattering transmissometer (LISST) are used to measure velocity and suspended sediment concentration and particle size over a dune in the Río Paraná, Argentina. Topographic forcing by the dune results in accelerated streamwise velocity and upward flow over the crest and decelerated streamwise velocity and downward flow over the trough. Acoustic backscatter from the aDcp and suspended sediment concentration measured with the LISST decrease with height above the bed and are higher over the crest. Suspended sediment particle size is coarsest near the bed. Suspended sediment transport rates are higher over the crest compared to the trough and ~17% of the suspended-load transported over the crest is deposited on the lee side before it reaches the trough. This study thus shows that deposition from suspension in the lee side of dunes contributes to dune migration, and raises significant questions regarding the impact of deposition from suspension on dune morphology. Further research is clearly necessary to determine the controls on dune form and migration with respect to suspension dynamics over these forms.

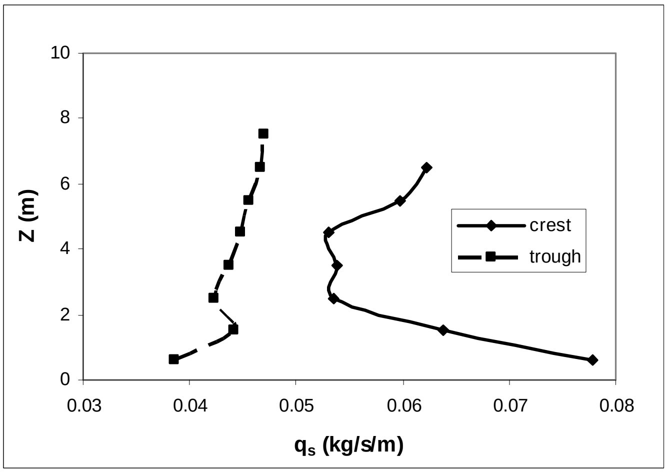

Figure 9. 'Decontaminated' suspended sediment transport rates per unit channel width (q_s) with height above the bed (Z) for the dune crest and trough..

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