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ABSTRACT

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Economic development of the São Francisco River basin has increased by building seven river dams since the 1950s. Subsequently, strong coastal erosion reaching maximum rates of 98.6 m/year has been recorded at the river mouth, also leading to the destruction of a coastal village. This work combines discharge data with new sediment and hydro-acoustic records, collected in January 2009, to verify the impact of river damming on processes, controlling coastline evolution. Data analysis is focused on discharge evolution, morphology and sediment composition of subaqueous dunes as well as on the impact by tidal currents. Discharge has been strongly regulated since 1986, when the last river dam was implemented. Again, bedform morphology seems to be not affected neither by reduced river-discharge nor by reduced sediment supply. However, migration rates of these dunes, as calculated, are lower due to decreased discharge. At the same time, tidal impact is strengthened at the lowermost part of the river. From this we assume, that the replenishment of sediment at the coast near the river-mouth might be time-delayed, which could support coastal erosion.

ADDITIONAL INDEX WORDS: *River-discharge, grain-size, parametric sediment echo-sounder, side-scan sonar, ADCP.*

INTRODUCTION

Most of large river-dam constructions around the world are intended to overcome the problems of drought and to supply irrigation and power generation, supporting the social and economic development of many countries. The development of the São Francisco River basin (Figure 1), for example, was initiated after the World War II by creating the Commissão do Vale do São Francisco (CVSF). This development is mainly based on water resources and has led to the construction of seven dams as shown in Table 1 (Théry 1978).

The construction of such infrastructures strongly affect the hydrodynamics and thus sedimentary behavior of the rivers, erasing or diminishing the interannual flow variations, particularly the medium floods (Batalla, Gómez, and Kondolf, 2004; Brandt 2000). They reduce the potential volume of the river discharge, a reduction intensified by withdrawal and evaporation (Mugabe, Hodnett, and Senzanje, 2003; Oguntunde *et al.,* 2006). River dams also intercept or disturb the transport capacities of the sediment, either as a suspended load or bedload, downstream toward the river mouth and thus can alter the sediment replenishment of adjacent coastal sites (Chen 2005; Warrick *et al.,* 2009).

River damming, as well as sea-level rise, climate change, and subsidence, has forced many deltaic systems, which originated with high inputs of riverine sediment, to face estuarine conditions and coastal erosion (Dalrymple and Choi 2007; Ericson *et al.,*, 2006; Frihy, Shereet, and El Banna, 2008; Liu *et al.,*, 2010; Ly 1980; Simeoni and Corbau 2009).

The morphology of bedforms, such as subaqueous dunes, mirror the equilibrium of the flow characteristics and intensity, water depth, grain-size, and sediment availability (Bartholdy *et al.,* 2005; Flemming 2000; Gabel 1993; Kleinhans *et al.,* 2002; Parsons *et al.,* 2005; Ten Brinke, Wilbers, and Wesseling, 2009; Tuijnder, Ribberink, and Hulscher, 2009). Many works focus on this interrelationship to verify the environmental conditions (Batalla, Gómez, and Kondolf, 2004; Carle and Hill 2009; Petts and Gurnell 2005; Van Landeghem *et al.,* 2009). Thus, river discharge, among other forcing factors, plays an important role in fluvial systems.

The approach followed in this article is based on analyzing the morphology of bedforms, as well as the sediment and

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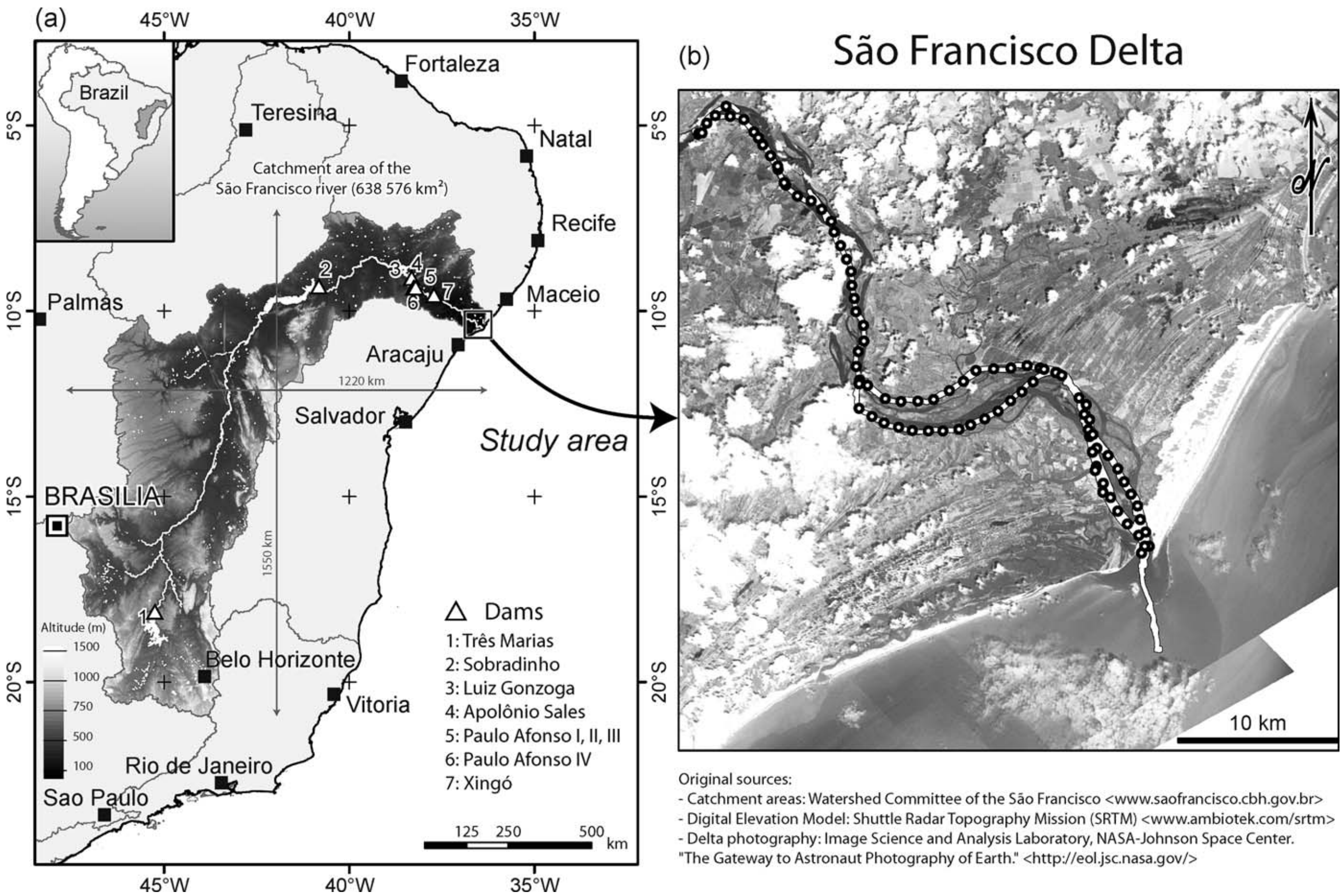

Figure 1. (a) Overview on the São Francisco River basin with its catchment area; (b) satellite photograph of the study area and the locations of the hydroacoustic lines (SSS, SES, ADCP) and grab samples.

Table 1. *General information on the seven dams along the São Francisco River, Brazil. Source: National Water Agency of Brazil (ANA) and Watershed Committee of the São Francisco River (CBHSF).*

Name	Administration*	Longitude	Latitude	Construction Period	Potential Power Generation (Mw)	Reservoir Area (km²)	Useful Volume (km³)	Storage Capacity (km³)	Water discharge control (m³/s)
Três Marias	CEMIG	45°15′36″ W	18°13′12″ S	1957–62	396	1,142	15	21	
Sobradinho	CHESF	40°49′48″ W	9°34′48″ S	June 1973–November 1979	1,050	4,214	28.7	34.1	2,060
Luiz Gonzoga	CHESF	38°19′12″ W	9°5′60″ S	July 1979–June 1988	1,500	835	3.5	10.8	2,060
Apolônio Sales	CHESF	38°12′36″ W	9°21′36″ S	January 1971–April 1977	440	98	0.2	1.2	Weekly regulation
Paulo Afonso I	CHESF	38°16′12″ W	9°22′12″ S	1948–December 1954	180	4.8	9.8	26.0	
Paulo Afonso II				1955–61	480				
Paulo Afonso III				1967–71	864				
Paulo Afonso IV	CHESF	38°16′12″ W	9°22′12″ S	1972–79	2,460	16	29.5	127.5	
Xingó	CHESF	37°47′24″ W	9°38′24″ S	March 1987–December 1994	3,000	60	0.04	3.8	

* CEMIG = Companhia Energética de Minas Gerais; CHESF = Companhia Hidro Elétrica do São Francisco.

hydrodynamics, in the lowermost 40 km of the river by means of hydroacoustic tools to find indications of anthropogenic interferences like river damming.

REGIONAL SETTINGS

The São Francisco River basin is the fourth largest drainage area of Brazil (638,576 km^2) (Figure 1). The river flows 2700 km incising the Atlantic Coastal Ranges and the central Brazilian Plateau (Precambrian–Silurian). Its large dimensions and its S–N orientation lead it to cross three climatic areas: a warm and humid upper sector, with summer rain fall; a warm and humid lower sector, with winter rainfall; and between, a semiarid, middle sector with a negative precipitation to evaporation balance (Knoppers *et al.,* 2006).

The São Francisco River comes out on a vast delta of about 800 km^2 and borders the N–E Atlantic coast of Brazil (Figure 1). Its origin results from the mid-Holocene, sea-level highstand, which reached up to 5 m above the present level 5700 years ago (Martin, Dominguez, and Bittencourt, 2003). A particularly asymmetric configuration of sediment deposits with marine sands in this northern part and fluvial sands in its southern part is governed by interaction between the longshore drift and the discharge of the river (Dominguez 1996; Martin *et al.,* 1996).

In former times, river runoff displayed a strong seasonal variation, with flood events between January and April (up to 12,000 m^3/s), and minimum flow between June and August (1000 m^3/s). Because of the construction of large dams, and particularly since 1986, flood events are rare, and the discharge is kept to an average of about 2000 m^3/s (Bittencourt *et al.,* 2007). The São Francisco delta has been facing severe coastal retreat within the past 10 years, with rates up to 98.6 m/yr between 1986 and 2001 (Bittencourt *et al.,* 2007). The Village of Cabeço, Brazil, which was located directly at the river mouth, was extinguished in a few years, and its lighthouse is now out at sea, several hundreds of meters away from the present coastline (Bittencourt *et al.,* 2007). Whether the series of dams is involved in these changes is still being discussed. If so, the processes and intensities have still not been explained.

METHODS

In this study, acoustic devices with high spatial and temporal resolution were deployed simultaneously during a 2-weeks research cruise on the São Francisco River from 12 January 2009 to 23 January 2009. A 15-m-long fishing boat was used to deploy a dual-frequency (100/500 kHz), side-scan sonar (SSS) of the type 272-TD (EdgeTech, West Wareham, Massachusetts) for the mapping of the riverbed surface. The range was set to 50 m. The layback of the SSS has been corrected. A parametric sediment echo-sounder system (SES-2000, Innomar Technologie GmbH, Rostock, Germany) was used for subbottom profiling. The system emits sound pulses at slightly different frequencies around 100 kHz to generate secondary frequencies between 4 and 15 kHz under high sound pressure. Here, 12 kHz was used with a subbottom penetration of up to 8 m. The system has a vertical resolution of $\geq$6 cm, with an accuracy of, *e.g.,* 100/10 kHz: 2–4 cm $\pm$ 0.02% of the water depth (Wunderlich and Müller 2003).

A motion sensor (MRU-4, Kongsberg Maritime, Konsberg, Norway) was added to compensate for the ship's movement. An Acoustic Doppler Current Profiler (ADCP) of the Workhorse Zedhead type (1200 kHz, Teledyne RDI, La Gaude, France) was deployed to record information on current velocities and directions in a profiling mode. The selected cell-size was set to 25 cm. Geographical positioning was performed with a global positioning system (GPS). The measurements were conducted along longitudinal profiles of the 40-km-long, lowermost river section during a waning moon (full moon to last quarter moon), with tidal ranges oscillating between 2.5 and 0.4 m. The spatial coverage of the analyzed river section was dependent on the channel depths and width. Ground-truthing of the acoustic data was carried out by sampling the riverbed each river kilometer, using a standard Van-Veen grab sampler. Grain-size analyses are based on the dry-sieve method. Here, only the statistical mean, sorting, and kurtosis of 56 samples are reported.

Descriptions of the subaqueous dunes were made, according to the recommended bedform classification scheme of Ashley (1990). The interval (length) between the bedforms was defined as the space separating two consecutive crests. Only dunes with a length >3 m were analyzed. The height of a dune was set as the difference in bed elevation between a consecutive crest and trough. Depth values of the riverbed have not been tide-corrected. Rates of subaqueous-dune migration were derived from the parameter length, height, mean grain size, and water speed, as organized in the equation by Bartholdy *et al.* (2010). Water speed during grab sampling was taken into account for computing the sand-dune migration rates. A depth-related differentiation of the water speed was not distinctive (except for one river section; sample location on 21 January, 19:03 hours); therefore, values for the mean water speed over the water column have been extracted by the software package WinRiver II (Teledyne RDI).

The National Water Agency of Brazil (ANA) provides free online access to time series of water discharge and water-level information between 1977 and 2008, which was used to rebuild an almost-complete discharge data set from 1927 to 2010, and to link that important parameter to our own findings. The measuring station at Propriá, Brazil, was chosen because of its proximity to the river mouth (70 km upstream) and its particularly long time series. Information on tidal-induced water-level variations of tidal gauges provided by the French Hydrographic and Oceanographic Department of the Navy (SHOM) are located at Maceo and Aracaju, Brazil (Figure 1a).

RESULTS

Reconstruction of River Discharge

A significant correlation (n = 376, R^2 = 0.93) exists between the data on water level and the river-discharge data from the Propriá station (Figure 2a). That allowed us to reconstruct the ancient discharge, as shown in Figure 2b. From that, a comparison of the mean-averaged discharge was matched with that of the construction period of the seven dams (Figure 2c), with the following results: The first six dams, including the Sobradinho dam (*cf.* Table 1), did not attenuate flood events

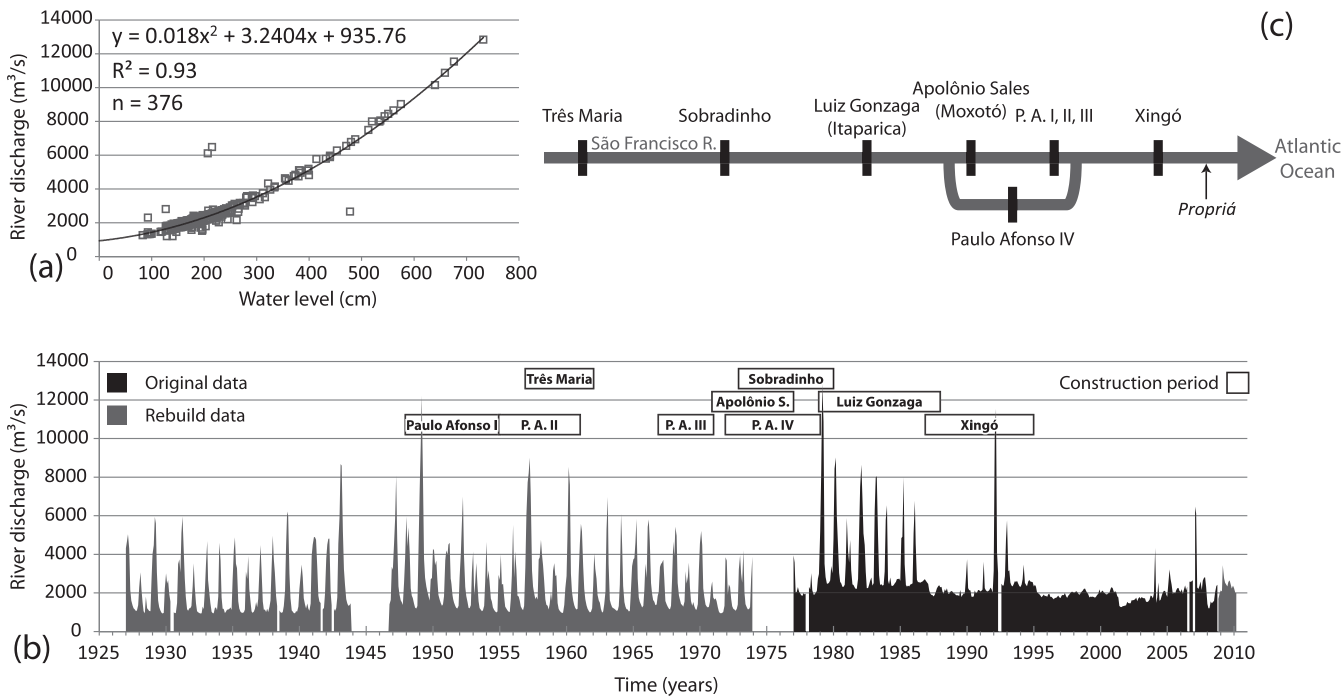

Figure 2. (a) Correlation of river-discharge and water level; data is supported from the ANA. (b) Historical evolution of the monthly mean river discharge of the São Francisco River between 1927 and 2010, combining measured (Propriá station) and reconstructed data. The construction period of each dam is placed, according to the time in relation to the mean flow values. (c). Schematized positions of the seven dams.

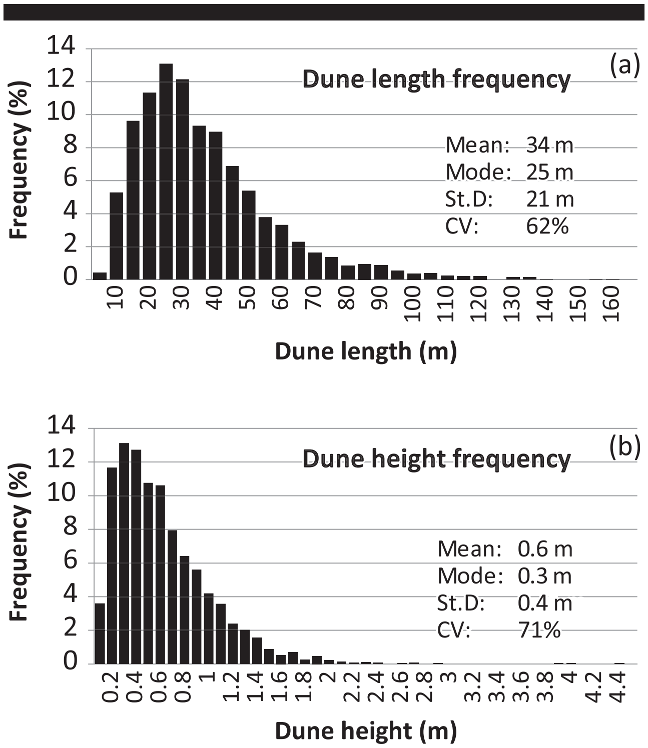

Figure 3. (a) Frequency curve of dune length and (b) dune height, based on 2740 measurements.

but sustained the water flow at a level of about 2000 m³/s. Because of the river damming, the mean water level at the Propriá station increased to about 34 cm. Since the completion of the Xingó dam, flood events have almost ceased (Figure 2a). Seasonally induced variations in river discharge have decreased strongly since March 1987. Only three flood events during winter season with discharge values greater than 6000 m³/s have occurred since March 1987, in comparison to former times, when flood events of the same intensity or stronger occurred in 74% of the wet seasons during the analyzed time frame. The coefficient of variation (CV) of the river discharge equals 67% and 44% before and after March 1987, respectively. From this data, only the Xingó dam seems to have had a strong impact on the river discharge.

Morphology of Subaqueous Dunes and Sandbar Systems

Subaqueous dunes, which occur within the lowermost section of the São Francisco River, display a wide range of sizes (Figures 3a and 3b). The lengths (L) vary from 3 m to several tens of meters, with a maximum length of 165 m. Average dune spacing amounts to 34 m with a CV of 62%. Dune heights (H) reach a maximum of 4.4 m. The average height amounts to 0.6 m, with a CV of 71% (Figure 3b). Overall, the water column of the river section studied reaches a maximum of 20 m, but subaqueous dunes only occur in water depths of up to 14 m.

The geometry of the subaqueous dunes is either two-dimensional (2d) or three-dimensional (3d). The larger ones

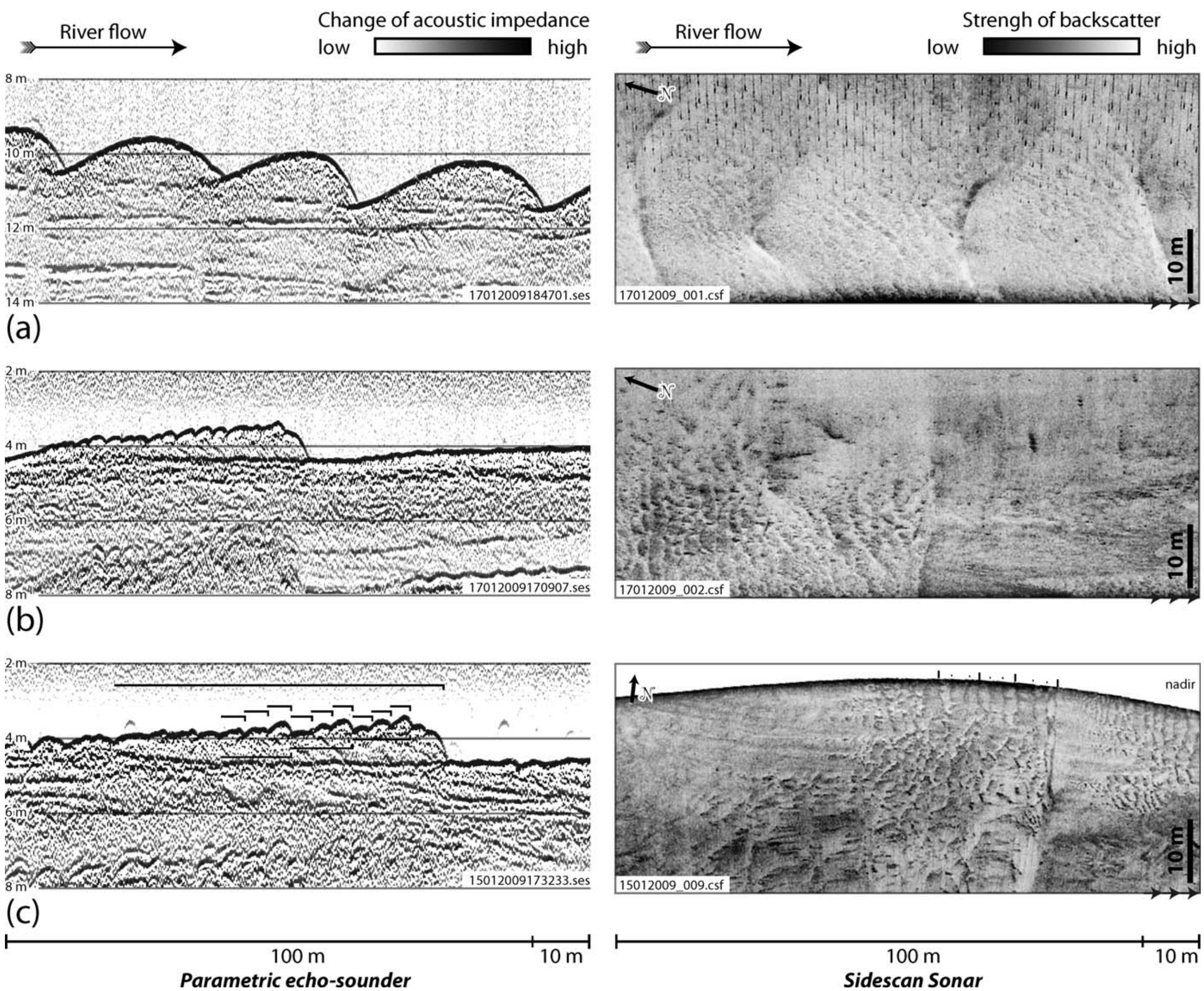

Figure 4. Sections of longitudinal, hydroacoustic profiles (SES, SSS) representing bedform structures of the São Francisco River bed with (a) simple subaqueous dunes, (b) superimposed dunes, and (c) two generations of superimposed dunes. Bedform morphology here is controlled by river discharge.

are mostly superimposed by the smaller ones. Nearly all dunes have an asymmetric shape, either reflecting the river outflow or the orientation of the flood and ebb, respectively (Figures 4a–c and 5a and c). These asymmetries, which are present all along the study area, indicate that both downstream and upstream water currents shape the subaqueous dunes. In some cases, the superimposed dunes reflect different asymmetries, whereas the smaller ones have an inverse orientation to the main dunes (Figure 5c), indicating a polygenic formation. There are also sites with two generations of superimposed dunes (Figure 4c). Subaqueous dunes in the shape of barchans and sand ribbons are rarely found in the study area.

In addition to the subaqueous dunes, there are three pronounced sandbars within the area studied, two inside and one outside the delta (Figures 6a–c). The two internal sandbars are located 1 and 6.5 km upstream the river mouth, respectively (Figures 6a and 6b). These banks are 4 m high. Their internal structure displays cross-stratified and chaotic acoustic reflectors, representing sand dunes. Downstream of the upper sandbar, a big scour mark is displayed in the subsurface (Figure 6b). The most seaward one is located 3.5 km in front of the river mouth (Figure 6c). That bar builds up a 2-m-high bank and displays three sets of internal sediment structures. From the bottom to the top, the first set presents structures in subparallel configuration, with an acoustic reflection of medium amplitude, medium-to-weak continuity, and medium frequency. The second set (foreset) presents complex sigmoid to oblique reflectors of low-to-medium reflection amplitude, weak continuity, and medium frequency, as well as down-lap and top-lap terminations. The third set (topset) covers a top-lap surface with internal parallel oblique to chaotic reflectors.

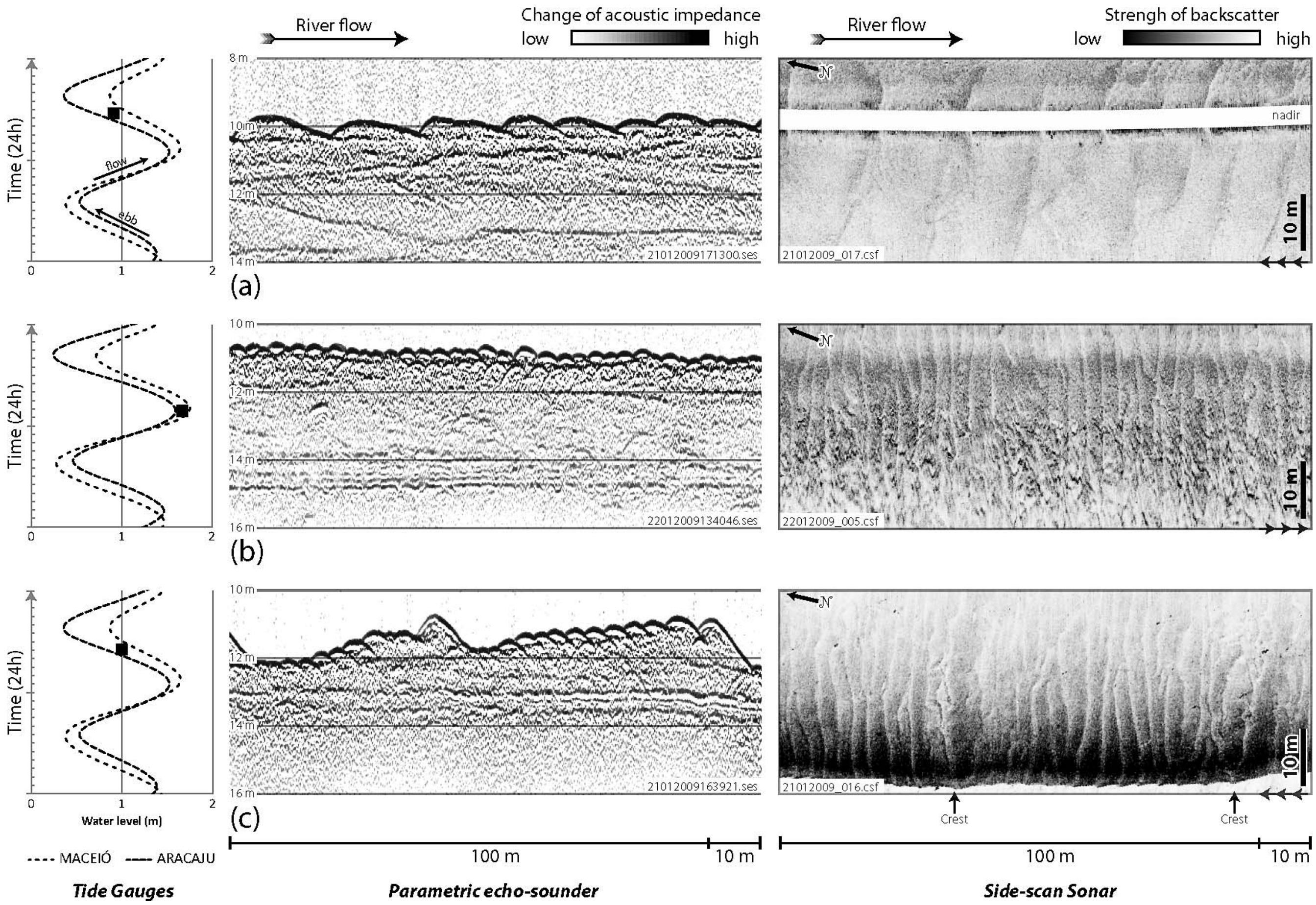

Figure 5. Sections of longitudinal, hydroacoustic profiles (SES, SSS) representing bedform structures of the São Francisco River bed with (a) landward orientated subaqueous dunes, (b) small symmetric dune, and (c) asymmetric superimposed dunes, with different orientation. Tidal information from the gauges in Maceio and Aracaju is added to combine bedform morphology and tidal force.

Grain Size

Grain sizes of the surface sediment range between 0.16 and 0.92 mm (standard deviation [SD]: 0.14 mm), with a statistical mean at 0.41 mm; 82% of the samples reflect fine-to-medium sands, 18% represent the coarse sand class, and 68% of the samples are moderately well sorted, with only 32% being poorly sorted. Kurtosis ranges from 0.66 to 1.62, indicating very leptokurtic to mesokurtic (80%) and platykurtic (20%) grain-size distributions. The overall organic content is low; only a few samples reflect river sections with mud patches.

Seaward-Directed Migration Rates of Subaqueous Dunes

Mean current velocities, which have to be considered for calculations of dune migration rates, were highest within the first 2 days of the grab-sampling period (18–23 January) ranging from 0.2 and 1.0 m/s (Figure 7). Those velocities can be linked to the highest discharge values within that period. Mean current velocities were slightly lower during the days that followed, corresponding to the lower river discharge. Furthermore, velocity values varied in a daily run (Figure 7). Those oscillations were more pronounced in the lowermost part of the river where the tidal impact was enhanced.

Calculated rates of dune migration highlight bedform movement of up to 25 cm/h, with the lowest values of about 5 cm/h, congruent with a decrease in river discharge (Figure 7). On 18 January, the migration rate increased continually over time from 0 to 25 cm/h. Those values reflect the dune migrations at the central part of the river section studied. Again, on 19 January, the migration rates showed an oscillatory evolution over time (Figure 7). Those values were related to the uppermost part of the river section studied. Data from 20 January, which represent a side-lobe of the main river channel, do not indicate any movement (Figure 7). An acceleration of migration rates was seen at 19:17 on 21 January (up to 4.5 cm/h). Migration rates from 23 January seem that there was a decrease from 6 to 0 cm/h over time. These last two data sets represent the lowermost 10 km of the river. Overall, migration rates of the subaqueous dunes seem to change hourly.

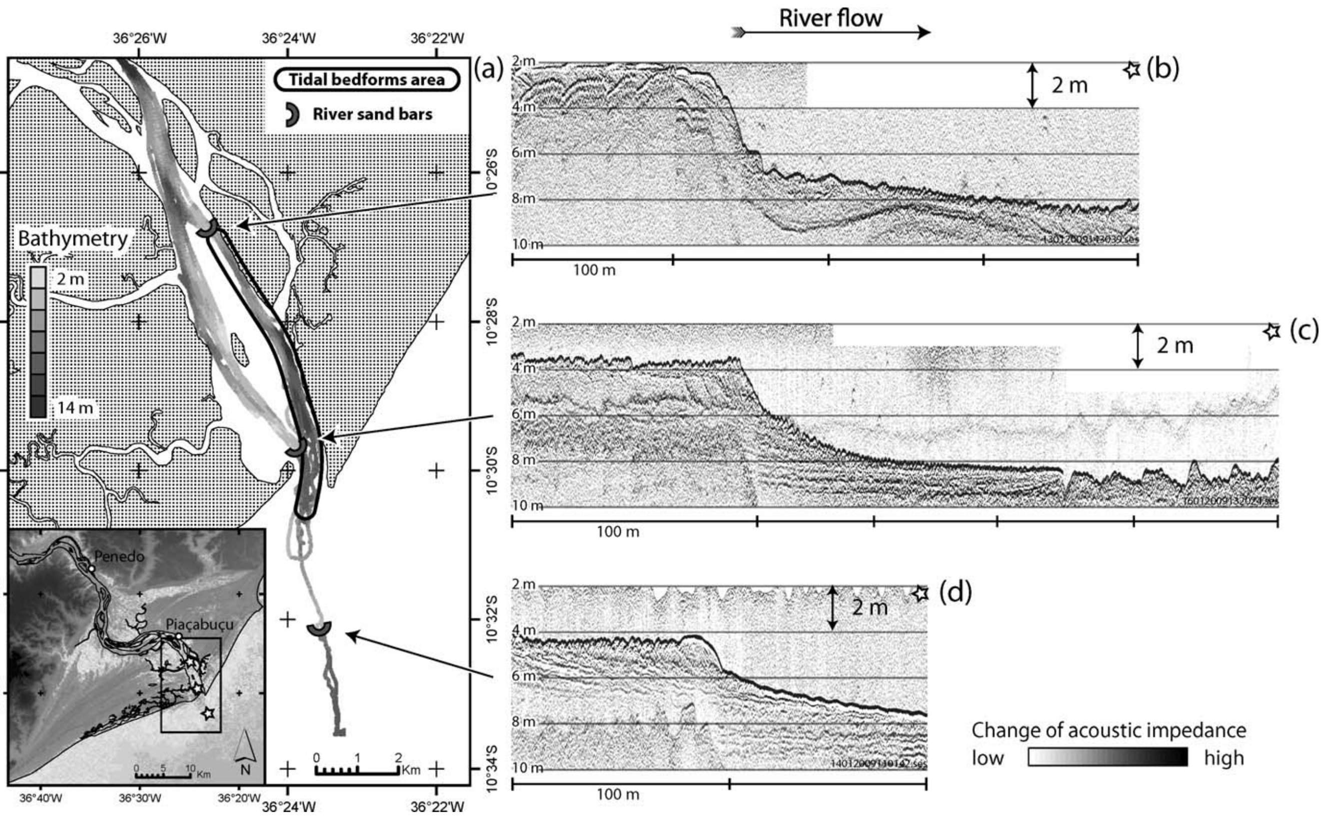

Figure 6. (a) Map of the study area with the location of the channel section reflecting tidal-induced morphology and sandbars; (b) and (c) within the river mouth; and (d) seaward of the river mouth.

DISCUSSION

Impact of River Discharge and Limited Sediment Supply

From 1948 to 1986, when six of the dams were built (Três Maria, Apolônio Sales, Paulo Afonso, Sobradinho, and Luiz Gonzaga) (Table 1), the coast near the São Francisco River mouth was stable or even aggrading (Bittencourt *et al.,* 2007). Since the construction of the Xingó dam, however, severe coastal retreat has been observed. The head of the catchment area provides more than 75% of the river's sediment load (Petts and Gurnell 2005), but the river dams retain up to 99% of that load (Brandt 2000). The Xingó dam is the youngest and most seaward-located in a series of seven dams (Figures 1 and 2c), should not, therefore not the dam that retains the most significant part of the sediment load. However, it seems to be the one that most strongly regulates the river discharge. River discharge is an important parameter in controlling downstream-directed sediment transport, as reported by Allen and Collinson (1974) and Carling *et al.* (2000). Thus, coastal evolution seems to be more affected by a decrease in transport capacity linked to lower river-discharge rates than it is by sediment retention at the dam.

Although river damming takes place, the morphological characteristics of the studied subaqueous dunes do not appear to be unbalanced, *per* data derived from new data sets. Thus, the subaqueous dunes do not seem to be affected by the reduced sediment supply, but, instead, by the reduced river discharge. The H : L ratio was always >0.06, which strongly indicates that subaqueous dunes are not being affected by a sediment deficit (Carling *et al.,* 2000). The great variation in dune sizes is another, similar indication (Tuijnder, Ribberink, and Hulscher, 2009). Barchans and sand ribbons, which could indicate a lack of sediment availability (Kleinhans *et al.,* 2002), are very rare in the investigated area. The uni-modal, positively skewed size distributions of the analyzed subaqueous dunes (Figures 3a and 3b) also conform to the size distributions of other studies (Gabel 1993; van der Mark, Blom, and Hulscher, 2008). However, the steadiness of water flow could be a factor leading to an elongation of the subaqueous dunes, as reported by Carling *et al.* (2000) and as derived by our own data, plotted in Figure 8a. Our values only partially match the data of Jackson (1976) in Flemming (2000), in terms that, under the same water depths, higher wave lengths occurred in the São Francisco River than in other riverine environments.

Considering the composition of the surface sediments of the riverbed, 82% of the statistical mean were in the fine-to-medium sand class, and only 18% reflected the coarser sand fractions. In addition, the analyzed grain-size distributions were very leptokurtic to mesokurtic 80% of the time, which reveals fairly stable river-discharge conditions. These data fit

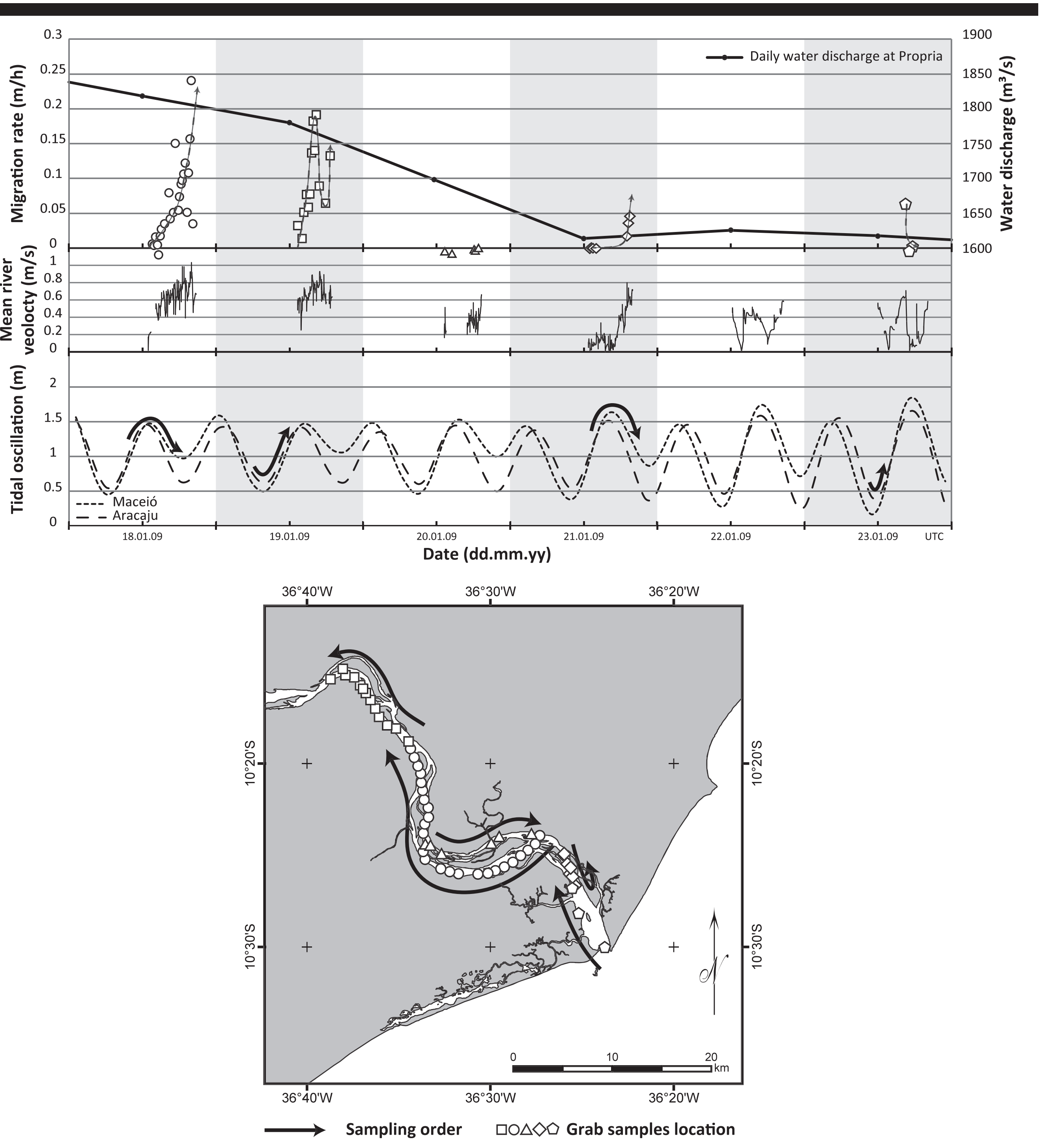

Figure 7. Diagram, showing migration rates of subaqueous dunes in the São Francisco River mouth, representing the time between 18 and 23 January 2009.

well with the ongoing discharge regulations at the Xingó dam. Sediment particles of smaller fractions (clay to very fine sand), which are rarely found, might already be removed, thus leaving in place only the coarser fractions, as reported for other environments with dams (Petts and Gurnell 2005; Stevaux, Martins, and Meurer, 2009; Vericat, Batalla, and Garcia, 2006). Although, the observed bedforms seem to receive sufficient sediment to form stable bodies, the question remains, where does the material originate. There might still be enough sediment in the system downstream of the last dam to be transported seaward as suggested by the presence of the erosional incision of the riverbed downstream from the

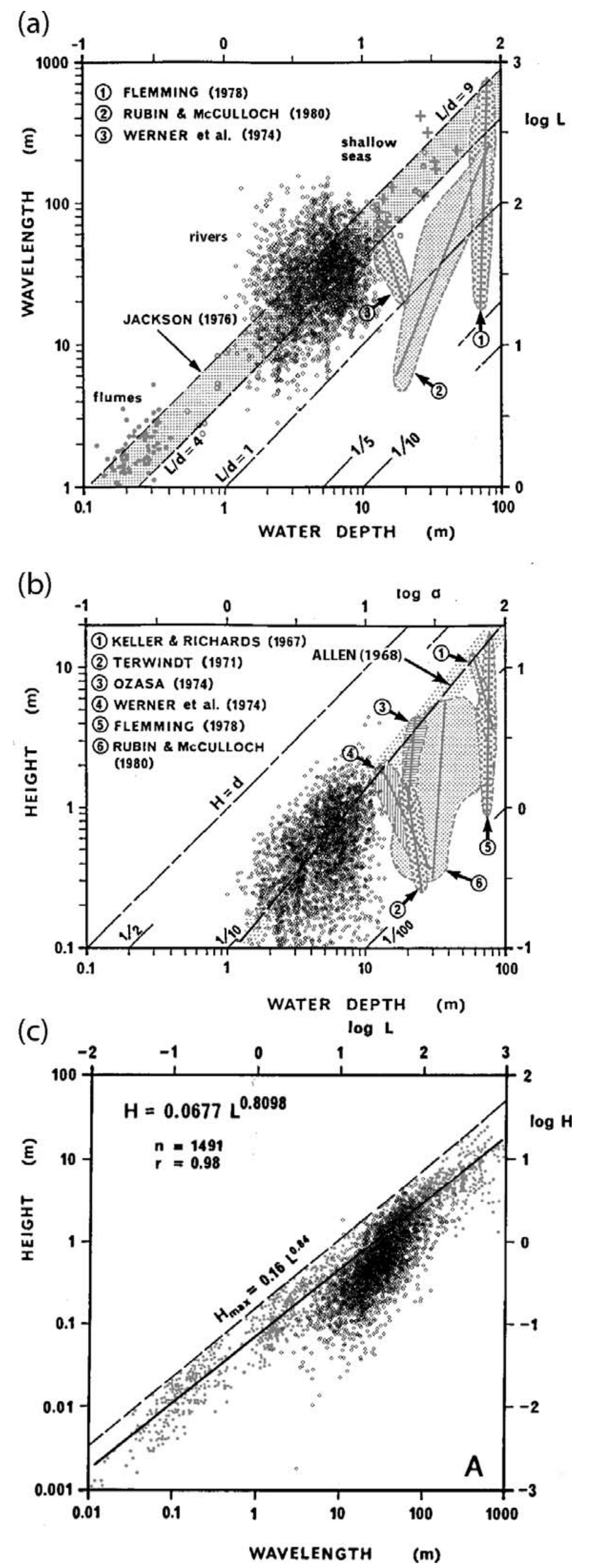

Figure 8. Scatter-plots, displaying dimensions of subaqueous dunes of various data, summarized by Flemming (2000) and added to our own data show (a) wavelength *vs.* water depth, (b) dune height *vs.* water depth, and (c) dune height *vs.* wavelength.

upstream sandbar (Figure 6a), or new sediment might be imported by the tributary located downstream of the dam.

Tidal Influence

Apart from the impact of the river discharge on the morphology of the subaqueous dunes in the São Francisco River, there is also some indication of tidal influence. This can be shown by comparing the data from Allen (1968) reported in Flemming (2000), where the dunes seem to represent different environments, with almost all having lower heights at similar water depth (Figure 8b). During our survey, a maximal tidal range of 2.5 m occurred, changing the water depth and leading to partly higher values. This again fits with Carling *et al.* (2000), who reported that the maximum dune height strongly depended on the water depth. Another indication of tidal influence can be derived from the ratio between dune heights and wave lengths. Smaller dunes seem to be able to respond to changing flow conditions more directly. Importing our data in Figure 8c, where dune heights are plotted against wave lengths, represented by a data collection of Flemming (2000), the smaller dunes of the São Francisco River seem to be slightly flatter. Although the ratio of the longest dunes reaches the maximum limit defined by the power function $H_{\max} = 0.16\,L^{0.84}$, the shortest dunes are below the mean regression line defined by the power function $H = 0.0677\ L^{0.8098}$ (Figure 8c). Observations similar to our findings were made by Francken *et al.* (2004), who announced that small dunes can be easily affected by individual tides.

Asymmetric subaqueous dunes orientated upstream, revealing flood-induced currents, are limited to the first 7.5 km of the eastern branch of the river mouth (Figures 5a, 5c, and 6). The presence of these dunes persist beyond the flood tide, as shown in Figures 5a and c. Again, small dunes, as displayed in Figure 5b, show symmetric shapes under high-slack water, clearly reflecting a direct response to tidal forcing.

The upstream limit of the tidal-induced, asymmetric bedforms coincide with the presence of sandbars, each of which forms an abrupt slope in the riverbed (Figure 6). There is most probably a strong interrelationship among the presence of those sandbar systems, the river flow, and the tidal-flow pattern. The locations of the sandbars and the deeper, eastern branch of the river channel, with the flood-dominated bedforms, indicate a kind of flood ramp, comparable to a throat area of a tidal inlet, as described by Duncan (2005). Based on that finding, the sediment transport does not seem to be unidirectional toward the coast but is more affected by flood tides under the new, constantly low discharge.

Migration Rates of Subaqueous Dunes

Since March 1987, water management at the Xingó dam has erased the flood events and reduced the river discharge by about 30% to around 2000 m^3/s (Bittencourt *et al.,* 2007) (Figure 2b). The migration of subaqueous dunes depends on several factors, including the current velocity (Bartholdy *et al.,* 2010), which correlates with the river flow. During the survey period, the river discharge decreased continuously from 1850 m^3/s to 1600 m^3/s, with a mean current velocity between 0 and 1 m/s (Figure 7). Simultaneous to the decrease in river discharge, the maximum migration rates reduced from 25 to 5 cm/h. Calculated migration rates in the São Francisco are thus lower than those reported in other studies, for example, the 63 cm/h in Bartholdy *et al.* (2010). The migration rates are comparable to, or even higher than, estuarine migration rates, as referenced by Dalrymple and Rhodes (1995). A correlation exists between current velocity and migration rates, which corroborates with observations made by Allen and Collinson (1974) and Carling *et al.* (2000). We noticed a threshold of the mean river velocity that allowed dune migration of ≥ 0.6 m/s.

Migration rates of the subaqueous dunes in the study area also reflect increasing or decreasing trends depending on the tidal phase. Tidal currents act against the river flow at flood tides, whereas tidal currents no longer oppose the river flow at low tides. Almost no water stratification was observed during the sampling period. Thus, the constant increase in migration rates, found on 18 January (Figure 7) can be linked to the corresponding ebb phase. The oscillatory change in migration rates, as observed on 19 January also corresponds well to the tidal phase, with an ebb tide followed by a rising flood tide.

CONCLUSIONS

Although coastal evolution, including the extinction of the Cabeço village, Brazil, might be linked to changes in wave activity, littoral drift sea-level, and/or subsidence, all factors not studied here, this work provides a new indication that river damming has had an impact on the coastal change at the São Francisco River mouth. This can be shown in the data of the river discharge, in the grain-size distribution, and in bedform geometry of the São Francisco River, indicating that the seaward-directed migration of subaqueous dunes is still present but has adapted to the new, low-discharge conditions. In this context, the Xingó dam indeed has the strongest impact. River discharge has been stabilized throughout the year, considerably reducing the sediment-transport capacity. A sediment deficit by dam-induced sediment retention is not, however, reflected in the data. The subaqueous dunes are even slightly longer and higher than observed by others in the literature (for a similar water depth). Thus, the riverbed, seaward of the river dams, still provides enough sediment for the formation of the sand dunes. The ratio H : L is greater than 0.06, and other bedform features, such as grain-size distribution, do not show sediment supply-limited conditions. From the data, we note that tidal impact has now strengthened considerably, especially in the 7.5-km lowermost river section. Indications are that flood-induced currents counteract the downstream migration rates, which might lead to a time delay in sediment supply, supporting coastline instability.

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□ FOREIGN RESUME □

Le développement économique du bassin versant du fleuve São Francisco a été favorisé par la construction de sept barrages hydroélectriques sur le cours du fleuve. Par suite, une forte érosion du trait de côte atteignant un taux maximal de 98,6 m par an a été enregistré à l'embouchure du fleuve, conduisant à la destruction d'un village côtier. Ce travail allie des données de débit, de prélèvements sédimentaires et de nouveaux enregistrements hydroacoustiques collectés en janvier 2009 pour vérifier l'impact d'un barrage sur les processus contrôlant l'évolution du trait de côte. L'analyse des données est concentrée sur l'évolution des débits fluviatiles, la morphologie et la granulométrie du sédiment composant les dunes du fond du fleuve ainsi que l'impact des courants de marée. Les débits fluviatiles ont été fortement régulés depuis 1986 alors que la construction du dernier barrage débutait. La morphologie des dunes fluviatiles ne semble pas être affectée par la rétention sédimentaire des barrages. Cependant, les taux de migration calculés de ces dunes sont plus faibles en raison de l'affaiblissement des débits. Dans le même temps, l'impact de la marée s'est renforcé dans la portion la plus distale du delta. Nous présumons ainsi que l'alimentation sédimentaire du littoral à proximité de l'embouchure fluviale est retardée et donc contribue à l'érosion de cette portion du littoral.