SPATIALLY-VARYING MORPHODYNAMICS OVER A SHORE-PARALLEL TRANSGRESSIVE SHOAL, SOUTH-CENTRAL LOUISIANA, U.S.A.

Daijiro Kobashi¹,² and Gregory W. Stone¹

Abstract

Morphodynamics over a shore-parallel sand shoal off south-central Louisiana, USA, have been recognized as complex given the occasional infusion of fine sediments, frequent winter storm passage, and complex shoal bathymetry. Results from field surveys and numerical model studies unveiled spatially-varying morphodynamics; occasional infusion of fine sediments (i.e. fluid mud) created sediment heterogeneity on the shoal; the bottom sediments on the shoal further interacted with storm-induced hydrodynamics. Shallower depths on the western flank of the shoal had high sediment re-suspension, energetic flow velocity, and resultant high sediment transport; the result favored exposure of sandy material on the bottom; the eastern flank of the shoal, located in deeper water, experienced the accumulation of fine sediments. The results had potential implications for some benthic biological variables that spatially change across the shoal. Our results suggest complex bio-physical interaction with uncertainties and further implications for potential future sand mining for restoring rapidly deteriorating Louisiana barrier islands, essential for protecting wetlands along coastal Louisiana.

Key words: hydrodynamics, sediment re-suspension and transport, fluid mud, bio-physical interaction, sand mining, cold fronts, Ship Shoal, Northern Gulf of Mexico

1. Introduction

Physical characteristics of the Louisiana shelf are given due to the study site’s proximity to the Mississippi River and physical forcing, which is not only micro-tidal and low energy in nature, but also the quasi-periodic passages of winter storms and repeated hurricane approaches/landfalls (DiMego et al., 1975; Wright et al., 1997; Keim et al., 2007). Such characteristics create unique physical, morphological and biological processes; however, they commonly exist worldwide, particularly for major river deltas. These geomorphologic, physical and climatic characteristics profoundly affect the Louisiana coastal ecosystem, fishery, and ultimately the coastal communities (Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands and Conservation Authority, 1998; Adger et al., 2005; NRC, 2006; Stone et al. 2009). Some of such unique physical processes off Louisiana have been documented (e.g. Kemp, 1986; Sheremet and Stone, 2003; Sheremet et al., 2005; Kobashi et al., 2007). Whereas, coastal Louisiana has faced unprecedented land loss given natural and anthropogenic impacts, including high land subsidence and occasional hurricane impacts accounting for ~40 square miles of land loss every year (Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands and Conservation Authority, 1998) including loss of Louisiana barrier islands (Penland et al., 2005). In addition, eustatic sea level rise associated with global climate change together with local sea level changes (i.e. relative sea level rise) has a profound effect on low-lying areas such as coastal Louisiana (IPCC, 2007).

In response to growing demand for large volumes of sand to aid in restoring coastal Louisiana (Khalil et al. 2007) and given the prohibitive price tag for restoring the long stretches of delicate barrier islands (Stone et al., 2005), federal and state governments have been seeking potential sand resources for the restoration and have funded numerous environmental studies. This study has been mandated under the

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National Environmental Policy Act (NEPA) to identify potential impacts of sand mining on physical and biological processes and would help make informed decisions before sand extractions are actually conducted (Drucker et al 2004; U.S. Minerals Management Service, 2006). Ship Shoal, the study area is located approximately 20 km off the Isles Dernieres Barrier chain and 50 km southeast of the Atchafalaya River mouth (Figure 1) and is one of the largest sand deposits off Louisiana. The shoal is surrounded by muddy substrate given fine sediment discharge from the Mississippi and Atchafalaya rivers. It has been reported to contain approximately 1.2 billion cubic meters of sand, potentially capable of excavation (Kulp et al, 2001). The current collaborative environmental study had been conducted from 2005 to 2009.

The research project consisted of physical and biological studies; the physical study examined hydrodynamics and bottom boundary layer dynamics associated with winter storms and fluvial fine sediments; whereas, the biological study focused on benthic biological characteristics including blue crabs, based on seasonal field cruises. Such an in-depth integrated approach has little been reported elsewhere. Based on this comprehensive study, spatially-varying morphodynamics have been revealed, their potential influence on benthic habitats has been addressed, and various sand mining recommendations were made (Stone et al, 2009). The purpose of this paper is to discuss such morphodynamics and their potential links to benthic biological processes and the effect of potential future sand mining.

![Figure 1 Location map of study area](image)

2. Methodology

Extensive field surveys and numerical simulations were carried out to examine our objective. In spring 2006 and winter 2008, arrays of oceanographic instruments were deployed on the eastern flank of Ship Shoal and along the middle of the shoal, respectively, to examine morphodynamic characteristics (Figure 1). Three arrays of bottom boundary layer instruments were deployed: two ADV systems on northern and southern edges of the shoal and one PCADP system on the crest of the shoal (i.e. north-south transects).
The PCADP array deployed on the crest was intended for detailed current profile and suspended sediment concentration (SSC) measurements within the bottom boundary layer. Those instrument systems have been widely used to study bottom boundary layer dynamics (Cacchione et al., 2006). The ADV system comprised a downward-looking single-point acoustic Doppler velocimeter, a pressure sensor, and two turbidity sensors; The PCADP system comprised a downward-looking pulse coherent acoustic Doppler profiler, a pressure sensor, and two turbidity sensors. For the 2008 deployment, two Temperature-Salinity sensors and an upward looking ADCP were also installed on the PCADP tripod. Instrument tripods were tethered with oil platforms for secure and easy installation and retrieval, and for robust measurements. Locations of the PCADP arrays and their sensor heights are listed in Table 1. Bottom sediments and water were sampled using a ponar grab during both deployments for OBS (Optical Backscatter Sensor) calibration and grain size analysis. The 2006 and 2008 deployments spanned 45 days and 52 days, respectively.

Table 1 Locations of the PCADP tripods and their sensor heights (SH)

<table>
<thead>
<tr>
<th>Year</th>
<th>System</th>
<th>Instruments</th>
<th>Locations</th>
<th>SH</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>PCADP (SS06_2)</td>
<td>SonTek™ Pulse-Coherent Acoustic Doppler Profiler, D&amp;A™ Optical Backscatter, Druck™ Pressure Sensor</td>
<td>28°53.701'N, 90°41.893'W</td>
<td>116 cm, 30, 61 cm, 116 cm</td>
</tr>
<tr>
<td>2008</td>
<td>PCADP (SS08_2)</td>
<td>SonTek™ Pulse-Coherent Acoustic Doppler Profiler, D&amp;A™ Optical Backscatter, Druck™ Pressure Sensor, RDIT™ ADCP Workhorse 1200 kHz, MicroCat™ TS sensors</td>
<td>90°50.298'W, 28°53.018’N</td>
<td>120 cm, 35, 74 cm, 120 cm, 45 cm, 30, 63 cm</td>
</tr>
</tbody>
</table>

Numerical models, DHI MIKE 21 spectral wave (SW) and MIKE 3 hydrodynamic (HD) models, were implemented in order to examine the spatially varying hydrodynamics and sediment re-suspension and transport. The computational domain covered the entire Ship Shoal area and three near real-time in-situ observing stations, WAVCIS CSI-5, 6, and 15 (Figures 1 and 2) (91.25°W, 28.75°N). The WAVCIS program is a coastal ocean observing system developed and maintained by the Coastal Studies Institute, Louisiana State University, and is well-documented in Zhang (2003). Grids were unstructured triangular and the models solved the wave action equation (for the wave model) and momentum and continuity equations (for hydrodynamics) using a finite volume method (DHI, 2005). Meteorological data were obtained from NOAA North America Regional Reanalyzed wind (NARR) (Mesinger et al., 2006); bathymetry was obtained from NOAA National Geophysical Data Center (Divins and Metzger, 2008) and bathymetric survey results (Kobashi et al., 2009b). Three-dimensional hydrodynamic model was run in barotropic mode to examine wind-induced currents associated with winter storms (i.e. change in water density was ignored). In-situ observational data from field surveys and WAVCIS stations were used to evaluate model performance prior to data interpretation. Results of model validations demonstrated that both wave and hydrodynamic models performed reasonably well except for bottom currents, probably due to inaccuracy of the shoal bathymetry despite its correction (See Kobashi et al., 2009b for a more detailed discussion of model validation).

In order to fully comprehend the shoal hydrodynamics associated with various seasons, five case studies were conducted. Two bathymetries were used: one with the shoal and the other represented a hypothetical situation of complete extraction of the shoal sand. The bathymetry without the shoal was created based on the linear interpolation between northern and southern edges of the shoal. Offshore boundary conditions (i.e. southern boundary) were specified based on Stone and Xu (1996) as listed in Table 2. The larger domain was used for the hydrodynamic model to avoid unrealistic vortex and return flow near the boundary (92.0°W, 28.0°N); however, the same size of the domain area as that of the wave model domain was extracted to analyze circulation over the shoal.
3. Results and discussion

3.1. Sediment heterogeneity on the shoal

Sediments sampled on-site during both 2006 and 2008 deployments were analyzed to estimate the grain size distribution as illustrated in Figure 3. The grain size distribution of the sediments was remarkably different, even for the duration of the deployments. The sediment samples collected when the arrays were deployed in spring 2006 (pre-deployment), were comprised predominantly of clay with a median grain diameter of 1.11 microns (blue bars and lines in Figure 3 top); sediments collected during the retrieval cruise (approximately 2.5 months later) consisted of fine sand with a median diameter of 127 microns (red bars and line in the top figure) (i.e. sediment heterogeneity). In the 2008 deployment, sediments for both pre- and post-deployments were predominantly in the sand range with a median diameter of 153.4 microns during the pre-deployment and 148.8 microns during the post-deployment (Figure 3 bottom). However, the sediments obtained from post-deployments in 2006 and 2008 also contained a small fraction of unconsolidated fluid mud from nearby survey locations. Kobashi et al. (2009a) concluded based on their analyses of in-situ observing data and satellite imagery, that this conspicuous difference in bottom fabric was associated with sediment re-working during winter storms and a pulse of sediment supply in the wake of storms from the Atchafalaya River, located approximately 50 km northwest of Ship Shoal (Figure 1).
3.2. Hydrodynamics and bottom boundary layer characteristics

With the different sediment regimes measured between the 2006 (fluid mud dominant) and 2008 (sand dominant) surveys, results of field surveys conducted in 2006 and 2008 showed a conspicuous difference as to bottom boundary layer characteristics. Table 3 shows a summary of physical parameters in the 2006 and 2008 deployments. Predominant wind and wave direction was from the southeast during both deployments (Table 3); during storms, strong wind stress, directed to the southeast (post-frontal) prevailed. Maximum wind speed attained 22 m/s and 19 m/s during the 2006 and 2008 deployments, respectively. Mean significant wave height was less than 1 m during both deployments; wave height increased as storms approached, exceeding 2 m over the shoal (Table 3), whereas, the wave height on the inshore station was significantly lower than the height over the crest and offshore (55% and 46% for mean and maximum wave heights in the winter 2008, respectively);

Table 3 Summary of physical parameter for the shoal crest (Top: mean value, bottom: maximum value)

<table>
<thead>
<tr>
<th>Year</th>
<th>Wind speed (m/s)</th>
<th>Wind direction (degree)</th>
<th>Mean depth (m)</th>
<th>H_s (m)</th>
<th>T_p (sec)</th>
<th>Wave direction (degree)</th>
<th>Bottom C_sp (m/s)</th>
<th>Bottom C_dp (degree)</th>
<th>U_ort (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>5.9 22.0 166.6</td>
<td>-</td>
<td>13.3</td>
<td>0.58</td>
<td>6.0</td>
<td>129.6</td>
<td>0.02</td>
<td>145.3</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>7.3 19.1 149.8</td>
<td>-</td>
<td>8.2</td>
<td>0.83</td>
<td>6.3</td>
<td>185.3</td>
<td>0.05</td>
<td>180.3</td>
<td>0.22</td>
</tr>
<tr>
<td>2008</td>
<td></td>
<td></td>
<td></td>
<td>2.32</td>
<td>10.2</td>
<td></td>
<td>0.26</td>
<td>-</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.96</td>
<td>16.0</td>
<td></td>
<td>0.30</td>
<td>-</td>
<td>1.38</td>
</tr>
</tbody>
</table>
illustrating the influence of wave dissipation due to shallow topography (not in Table 3). Given the higher wave height and shallower depth, near-bottom wave orbital velocity over the middle shoal was higher than that over the eastern shoal. Mean current velocity near the bottom at both the middle station and the eastern flank of the shoal was minimal (less than 5 cm/s) (Table 3).

Figures 4 and 5 show time series of bottom boundary layer parameters during a winter storm in the 2006 and 2008 deployments. As mentioned by Kobashi et al. (2007) and Kobashi and Stone (2009), in spring 2006, Ship Shoal was exposed to occasional infusions of fine sediments, fluid mud, in the wake of winter storms that accompany cold fronts. This ephemeral accumulation increases in the bed elevation in the wake of the storms. This presence of a thin layer of fluid mud accumulation on the shoal was also corroborated with MODIS satellite images (Kobashi et al., 2007; Kobashi and Stone 2009; Kobashi et al., 2009a). As the next cold front passed the study area, shoal bottom experienced unique sediment dynamics, consisting of four stages: sediment re-suspension, vertical mixing, hindered settling and re-distribution/accumulation (Figure 4) as described below.

![Figure 4](image)

Figure 4 Time series of bottom boundary layer parameters during a winter storm in spring, 2006

Sediment re-suspension occurred when a cold front approached and subsequently the shear stress exceeded the threshold value above which bottom sediments are expected to re-suspend, consistent with increases in bottom SSC (Figure 4f). Sediment transport rates integrated from the bottom to the sensor height, approximately 1 m, were then elevated due to increased high storm-induced currents (not in Figure 4), see details in Kobashi and Stone, 2009) and sediment re-suspension (Figure 4g), resulting in sediment reworking. When the front passed, strong vertical mixing induced by strong positive vertical velocities, shifted SSC maxima positively upward (Figure 4j) lowering the upper and bottom SSCs (Figure 4f) and transport rates (Figure 4g). During the post-frontal phase, the mixed sediment gradually re-settled in the wake of the storm as the wave height and current velocity decreased; however, the upper turbidity
remained high in spite of a reduction in the lower turbidity levels, probably due to hindered settling (Figure 4f). During this time, the sediment transport rates were high (~10 kg/m/s) given the high SSC in spite of weak currents. Despite such high transport rates, a portion of the mixed sediments were re-deposited on the bottom with a reduction in thickness of the fluid mud layer than was apparent during the pre-frontal phase (brown and grey areas in Figure 4i and k) because a portion of the reworked sediments was likely transported outside of the shoal as indicated by high sediment transport rates during the post-frontal phase (Figure 4g). Net fluid mud flux was directed offshore (i.e. southward) during the storm.

During the 2008 deployment, the shoal bottom experienced re-suspension and mixing stages as with the 2006 deployment; however, no such evidence as that for fluid mud bottom was captured except mid-March when fluid mud accumulation seems to occur although this might have been induced by high downwelling currents that forced the fluid mud to accumulated rather than the process mentioned above (not in Figure 5). When the shoal was exposed to sand, as captured by underwater camera images, systematic wave-induced ripples developed. The ripples were likely washed out during strong storms that induced sheet flow conditions. Given a ripple wash-out criterion proposed by Soulsby (1997), the ripples might have been washed out when near-bottom wave orbital velocity exceeded approximately 0.6 m/s over the middle shoal. There were four events during which the orbital velocity exceeded this critical value; it is expected that repeated ripple formation and washout occurred on the shoal when the shoal bottom became dominated by sand. Net sediment flux was directed offshore as with the storm in 2006 discussed previously.

3.3. Spatially-varying hydrodynamics over the shoal: East vs. west

Results of our numerical model studies showed spatially-varying hydrodynamics and bottom boundary layer characteristics. Incoming deep water waves significantly transformed as they propagated over complex coastal bathymetry (Figure 1). Spatial differences in wave transformation were similar for all cases although having differences in magnitude. Wave model results provided similar results as given in Stone and Xu (1996). Significant differences between the model outcomes with and without the shoal were evident. The summary is illustrated in Figure 6. The wave height on the western flank of the shoal was significantly less than that on the eastern shoal (up to 32 percent difference between the east and west). When the shoal existed, the difference was up to 9 percent higher than the difference without the shoal. The spatial difference decreased as the deep water wave height decreased (Figure 6). Wave dissipation between
south and north of the shoal, as a general trend, decreased from the west toward east except during case 1, for which the dissipation was minimum at the western flank, probably due to wave dissipation along the seaward boundary of the western shoal, which was significantly shallower than the middle and eastern flank of the shoal. For case 1, the difference in wave height was approximately 34 percent higher on the middle shoal than the eastern flank of the shoal.

The dissipation in wave height along the western flank of the shoal was approximately 70 percent higher than that on the eastern flank; while, for without the shoal scenario, the difference in the height was significantly smaller. Wave energy dissipation showed similar results and the maximum difference was 52 percent for the bathymetry with shoal and 9 percent for that without the shoal. The above results further influenced sediment re-suspension on the shoal and are discussed further in a later part of this section.

Simulated current fields varied primarily with wind speed and direction; however the current pattern was more associated with the wind direction than the wind speed. Surface currents generally followed the prevailing wind regardless of speed; higher current speed occurred when wind blew parallel to the isobaths (Northeast-southwest). Bottom currents were more variable and strongly influenced by the shoal bathymetry particularly on the western shoal. Both surface and bottom currents were stronger over the shallower portion of the shoal than the surrounding shoal because of flow acceleration due to shoal topography, to satisfy continuity despite increases in bottom friction (cf. Swift, 1985; Snedden et al. 1999). Data indicate that without the shoal, general spatial patterns of both surface and bottom currents were similar. The surface currents on the western portion of the shoal were higher than those on the eastern flank of the shoal; however, the flow acceleration over the shoal was not clearly evident. Modification of the bottom currents with respect to the inner shelf bathymetry was also not evident, though in-situ current velocity showed such modification. The result suggests that neither large-scale nor small-scale sand mining should give rise to abrupt changes in current patterns; however, the large-scale sand mining can change the magnitude of the velocity and therefore the fluxes.

Changes in sediment re-suspension have significant implications for sediment transport and influenced by physical variables and bed characteristics. We estimated sediment re-suspension intensity (RI) from the computed bulk wave parameters defined as wave-induced shear stress subtracted by critical shear stress. Wave shear stress was estimated based on Madsen (1976) and the critical shear stress for sand bottoms (grain diameter coarser than 63 microns were estimated based on Li et al. (1997). The critical stress for sediments finer than 63 microns was chosen as a constant value of 0.15 (N/m) (Kerper, D., personal communication). Results are illustrated in Figure 6.

The RI corresponds to wave height, wave period, and water depth; generally, the higher the wave height and the shallower the depth, the higher the RI. When storms were strong (i.e. cases 1 and 2), the RI was high across the domain, but was higher on the middle and eastern shoal than on the western shoal due...
to wave dissipation on the western shoal. As wave energy decreased, as a general trend, the RI on the shoal decreased from west to east following the change in the shoal bathymetry (Figure 6). For the case 3 scenario (i.e. moderate storms), the RI on the western shoal was twice as high as that on the eastern flank and approximately six times as high as the value outside of the shoal (Figure 6). For case 4 (i.e. weak storm conditions), the RI was positive on the western and middle shoal and was negative on the eastern flank of the shoal and outside of the shoal. For case 5 (i.e. fair weather conditions), the RI was negative across the domain, suggesting that no sediment re-suspension is expected during fair weather conditions, thereby supporting the field survey results as discussed in section 3.2 as well as previous studies (e.g. Wright et al., 1997; Pepper and Stone, 2004; Kobashi et al., 2007; Kobashi and Stone, 2009).

Our results suggest that the deeper eastern portion of the shoal, seems to be suitable for the accumulation of fine-grained sediments occasionally supplied by the Atchafalaya River during storms, typically during spring, even though the eastern flank is farther to the river mouth. On the western and middle portions of the shoal, re-suspension processes outweigh sediment accumulation in spite of its proximity to the river (see Kobashi and Stone, 2009). Results of the RI without the shoal showed that sediment re-suspension was high on the western flank of the shoal during strong storms because of lower wave dissipation rates despite deeper water depth. However, for most of the model results, the RI without shoal was significantly lower than the re-suspension with shoal, particularly when wave energy was moderate (i.e. case 3) to weak (i.e. case 4) (Figure 6). This suggests that large-scale sand excavations from the shoal enhance accumulation of fluid mud supplied from the Atchafalaya River. The result has further potential implications for shoal benthic biological characteristics.

3.4. Potential implication for benthic biological processes and potential future sand mining

The spatial difference in morphodynamics, as discussed in section 3.3 suggests a strong linkage with some benthic biological characteristics and further potential future sand mining. As discussed in the previous sections, changes in water depth and sediment composition play an important role in morphodynamics that affect benthic biological characteristics (Dubois et al., 2009; Grippo et al. 2009). Table 4 summarizes some physical and biological variables that affect water depth on the shoal. When depth changes, some physical variables affect the change including (1) bulk wave parameters, (2) bulk current parameters and (3) sediment suspension and transport (Table 4). Wave dissipation rates decrease as less wave energy reaches the bottom; wave refraction certainly changes as the depth changes, resulting in change in wave convergence and divergence.Current speed decreases as the depth increases. Combined with the changes in waves and currents, sediment re-suspension intensity and sediment transport rates decrease as depth increases.

Table 4 Spatial changes in physical and biological parameters on the shoal

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Ship Shoal</th>
<th>Outside Shoal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>West</td>
<td>Middle</td>
</tr>
<tr>
<td>Depth</td>
<td>Shallower</td>
<td>Higher</td>
</tr>
<tr>
<td>$H_3$</td>
<td>Lower</td>
<td>Higher</td>
</tr>
<tr>
<td>Current speed</td>
<td>Higher</td>
<td>Lower</td>
</tr>
<tr>
<td>Wave dissipation ($\Delta H_3$)</td>
<td>Higher</td>
<td>Lower</td>
</tr>
<tr>
<td>RI</td>
<td>Higher</td>
<td>Lower</td>
</tr>
<tr>
<td>Sediment transport rates</td>
<td>Higher</td>
<td>Lower</td>
</tr>
<tr>
<td>BMA biomass$^1$</td>
<td>Higher, but no spatial changes on the shoal</td>
<td>Lower</td>
</tr>
<tr>
<td>Blue crab biomass$^2$</td>
<td>Higher, but no spatial changes on the shoal</td>
<td>Lower</td>
</tr>
<tr>
<td>Benthic species biodiversity$^3$</td>
<td>Higher, no east-west trend, strong north-south trend</td>
<td>Lower</td>
</tr>
</tbody>
</table>

$^1,^2,^3$Based on $^1$Grippo et al. (2009), $^2$Condrey and Gelpi (2009), and $^3$Dubois et al. (2009)

When depth changes, some benthic biological characteristics may change. Grippo et al. (2009) stated that BMA (Benthic Micro-Algae) serve as a foundation of the Ship Shoal food web. The study concluded that the water depth may be an important factor in BMA abundance and further oxygen levels on the shoal. However, their BMA measurements unexpectedly showed no correlation with water depth. They also
discussed that fluid mud would impact BMA production by reducing light penetration to the bottom. Dubois et al. (2009) discussed that Ship Shoal may act as a local hypoxia refugee during summer, suggesting that BMA may produce substantial oxygen for benthic organisms throughout the year (Dubois et al. 2009; Grippo et al. 2009). Spatial changes in water depth and sediment composition may also affect shoal benthic biodiversity; however, their results did not provide quantitative evidence to prove their hypothesis.

Overall, there still exist substantial scientific uncertainties as to whether and how significant depth changes (i.e. sand mining), sediment size and composition affect shoal bio-physical interactions as well as benthic biological habitats, including how ephemeral fluid mud accumulation affects the habitats. Significant influences of the above impacts are likely affected by abrupt changes in bathymetry. However, Kobashi et al. (2009b) conclude that bathymetric changes associated with proposed sand mining scenarios are relatively small (e.g. restoration of both Whisky and Trinity islands will require a total of 3.7 million cubic meters of sand, which increases the depth by 0.21 m on Ship Shoal Block 88(see Kobashi et al., 2009b for more details) compared to complete excavation of shoal sand (4-6 m). Impacts of physical processes due to small changes in bathymetry are expected to be minimal as discussed by Kobashi et al. (2009b). Our collaborative project concluded that large-scale sand mining that causes abrupt changes in bathymetry would have a profound impact on shoal physical and biological processes and hence was not recommended (Stone et al., 2009). In contrast, small scale sand mining is expected not to cause significant adverse impacts on the processes; however, post-mining monitoring is crucial as substantial scientific uncertainties still exist.

4. Conclusions

In order to examine morphodynamics and further their potential interconnection with benthic biological characteristics over the shoal as a part of an environmental assessment that helps make final decisions on potential future sand mining, field surveys and numerical modeling were conducted; the results led to the following conclusions.

1. Results obtained from bottom boundary layer instruments comprised of high-resolution current profilers, pressure sensors, and turbidity sensors, revealed two contrasting morpho-sedimentary dynamics of the shoal for fluid mud and sand. During spring 2006, the instruments deployed on the deeper eastern flank of the shoal, captured a thin layer of fluid mud accumulation; the fluid mud further underwent re-suspension, vertical mixing, hindered settling and re-distribution during a winter storm. Whereas during winter 2008, instruments were deployed on the shallower middle shoal revealing exposed bottom sediments comprised primarily of fine sand. Thus, resolving sediment dynamics was accomplished by using conventional dynamical solutions.

2. Results obtained from numerical modeling of spectral waves and three dimensional currents, demonstrated spatially-varying hydrodynamics over the shoal. The model results were associated with hydrodynamic forcing and water depth. The magnitude of these hydrodynamic parameters has an east-west trend following changes in bathymetry. Sediment re-suspension intensity (RI) had the highest values on the western flank, decreased gradually toward the east, and became lowest on the eastern flank during moderate and weak storms; the magnitude of the RI has a conspicuous difference between the western flank and eastern flank. The RI without the shoal was much lower than that with the shoal for moderate and weak storms; however, both RIs had similar values for severe and strong storms. The results were consistent with in-situ data, leading to the conclusion that the deeper eastern shoal favored fluid mud accumulation during winter storms.

3. The above spatially-varying morphodynamics further suggest a strong interplay between spatially-varying habitats of benthic organisms on the shoal whose species are likely influenced by size and composition of bottom sediments as well as water depth. Our collaborative benthic biological study suggests how those physical parameters may affect benthic biological habitats; however, no clear evidence on the spatial changes and the relationship between those variables were quantified. As a result, bio-physical interactions on the shoal were not quantified as scientific uncertainties exist although some qualitative interactions were implied. If sand mining is ever to be conducted,
post-mining monitoring is crucial in better understanding the interaction and impacts of the mining on both physical and biological processes.

Acknowledgements

The study was jointly funded by U.S. Minerals Management Service, Dept. of the Interior and Louisiana Department of Natural Resources. Authors thank the CSI Field Support Group for our field deployments. DHI MIKE models were implemented in collaboration with DHI Water and Environment. Biological cruises and data analyses were conducted by our collaborators, Drs. Richard Condrey, John Fleeger and, Stan Dubois and Carey Gelpi and Mark Grippo. Yuliang Chen assisted with cartography. Comments from Dr. Felix Jose and Seyed M. SiadatMousavi are greatly appreciated and helped improve an earlier draft of this paper.

References


Kobashi, D., Stone, G.W., Khalil, S.M., Kerper, D. 2009b. Impacts of Sand Removal from a Shore-Parallel Holocene Transgressive Shoal on Hydrodynamics over the Shoal and Shoreface of Barrier Islands, South-Central Louisiana,
Coastal Dynamics 2009  
Paper No. 108

U.S.A. In: Stone et al. (Eds.), Environmental investigation of the long-term use of Ship Shoal sand resources for large scale beach and coastal restoration in Louisiana, OCS Study MMS 2009-024, 99-126.


Stone, G.W. and Xu, J.P., 1996. Wave climate modeling and evaluation relative to sand mining on Ship Shoal, offshore Louisiana, for coastal and barrier island restoration, MMS OCS Study MMS96-0059. 170p.


