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# Morphodynamic evolution of a microtidal barrier; the role of overwash: Bevano, Nothern Adriatic Sea


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**ABSTRACT**

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This study discusses the morphological changes of the Bevano "microtidal barrier" and the washover dynamics and evolution in response to several storm surges recorded during one year between September 2008 and September 2009. This barrier corresponds to the old Bevano river spit (characterised by a northward migration) which was abandoned after the relocation of the river mouth some 600 m to the south of the previous inlet position. The first overwash event was recorded in this barrier just after one of the highest surges recorded in the last 100 years (01 December 2008) with a high tide level of 1.59 m above MSL and surge of 0.97 m, combined with an offshore significant wave height of 1.45 m (measured in Venice). Seven separate washover fans were identified together with severe damages to fences and dune vegetation. The washover fans had different dimensions, the most important one being around 18 m wide, and generating a ~ 9 m landward migration of the back-barrier limit. The study area was therefore subjected to a series of storm-surges during the study period with surge values fluctuating between 0.6 m and 0.8 m. The ovewash processes and particularly the exceptional surge of 01 December 2008 was the instigator of initial morphological changes which then facilitated successive morphological changes caused by the subsequent storm surges and, as a result, generating the complete change of the morphologic configuration of the microtidal setting.



**ADDITIONAL INDEX WORDS:** *beach profiles, washover sedimentation, erosion*


## INTRODUCTION

Coastal overwash occurs when surge level combined with an important wave run-up height exceeds the dune crest height. The overwash deposits (washovers) results from the water flow and sediment generated by the overwash providing a record of the intensity of the storm and/or past intense storms. Overwash typically occurs during tropical storms, hurricanes and cyclones, causing a hazard to coastal communities and infrastructures (Donnelly, 2007). Overwash depositis in coastal sediment provided the basis for constructing prehistoric records of intense hurricanes strikes (Liu and Fearn, 1993, 2000; Donnelly *et al.,* 2001) and intense storms (Donnelly *et al.,* 2004).

Several factors control the intensity and the frequency of overwash and associated morphologies. The response of beaches, barrier beaches or spits depends on marine conditions (Fisher *et al.,* 1974), beach topography (Leatherman, 1976; Donnellly, 2007), nearshore bathymetry (Ritchie and Penland, 1988), the orientation of the coast relative to the storm (Fletcher *et al.,* 1995), dune morphology (Donnelly and Sallenger, 2007), beach volume (Matias et al., 2009), dune vegetation (Donnelly, 2007) and engineering structures (Hayden and Dolan, 1977). Overwash morphologies have been characterised based on the spatial extent and shape of washovers as viewed from the air (Price, 1947; Pierce, 1970) and the categorisation of cross-shore profile response to overwash into 7 types was realised by Donnelly *et al.,* (2004) in the base of a study of o set of more than 110 cross-shore profiles. The occurrence of overwash is predicted based in the maximum elevation of wave run-up on the beach and dune crest level by the model developed by Sallenger (2000) and tested usefully by Wetzell *et al.,* (2007) and Matias *et al.,* (2009).

If overwash typically occurs in open coasts when the occurrence of hurricanes, cyclones and intense storms is important, it occurs also on closed seas and naturally protected areas and can generated a complete change or instigate a mutation of the site initial morphological configuration.

The purpose of this study is to associate the overwash, including cross-shore profile morphologic changes and hydrodynamic forcing, with the morphologic evolution of a managed old river spit into a microtidal sand barrier.

## STUDY AREA

The Bevano beach is a small microtidal shore facing the Adriatic Sea located south of Ravenna, in the Emilia-Romagna region, northern Italy. This beach corresponds to the old Bevano river spit which was abandoned after the relocation of the river mouth some 600 m to the south of the previous inlet position (Figure 1). The old river mouth was cut off from the Adriatic by massive sand dumping and the sediments on the newly created beach were fixed by aeolian fences and vegetation.

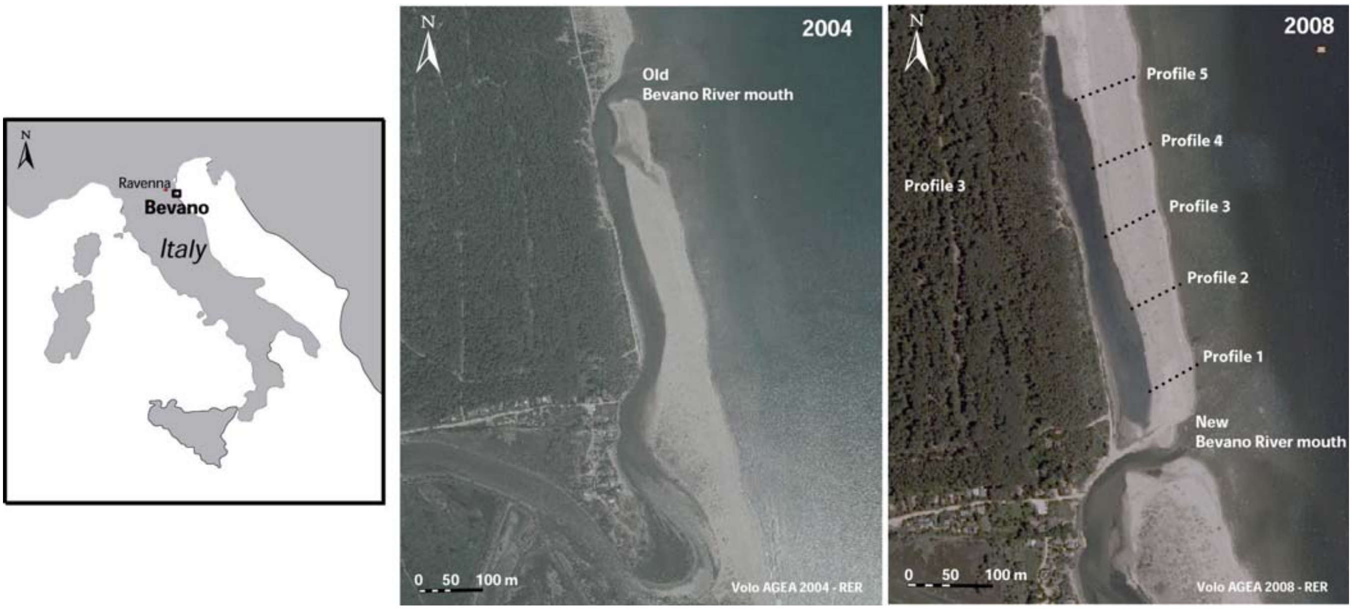


Figure 1. Location of the study area and the state of Bevano beach before (2004) and after (2008) the relocation of the river mouth. Notice the position of surveyed profiles

The old mouth of Bevano river had complex dynamics resulting from the interaction between alongshore sediment transport and tidally controlled fluxes in the channel's outlet. The northward migration of the old river mouth generated an important risk from flooding to inland areas below sea-level, with several damage to the pine forest growing behind the dune closer to the river course. The migration rate of the old river mouth and spit measured using aerial photos from 1943-1998 was around 21 m/yr between 1982 and 1996 before increasing more than three time between 1996 and 1998 (70 m/yr) (Ciavola *et al.,* 2005). Between 1998 and 2002 the migration rate was around 80 m/yr and reach up to 100 m/yr between 2002 and 2005 before the relocation of the river mouth (Figure 2). This 600 m long featureless beach looks like a sand barrier: it is backed by the abandoned channel of the Bevano River and is one of the lowest dune systems of the region (around 1 m height). The tidal regime in the Northern Adriatic is strongly asymmetric, showing both diurnal and semi-diurnal components and the tidal excursion in this area is low and the maximum spring tide range is about 0.8 m. The wave climate is usually of low energy, with significant wave heights less than 0.5 m, mainly from the East (65% of occurrences) (Gambolati *et al.*, 1998). Two different storm directions prevail: the Scirocco from SE and the Bora from NE. The strongest storms come from the NE, while the most frequent events, but with lower energy, come from the SE. The most intense storm events originate from Bora and Scirocco winds with similar intensity; waves may reach 3.5 m every year and rise to 6 m every 100 years. The Bevano barrier beach is characterised by remarkably heterogeneous sand, the median diameter (D50) of which ranges from 1.6 Phi on the upper beach to 3.2 Phi in the lower part of the beach. The nearshore bathymetry of the Bevano barrier highlights a system of double bars connected with the submerged delta of the river mouth (Armaroli and Ciavola.,*in press*).

## METHODS

The Bevano barrier was surveyed for one year from December 2008 to December 2009 in order to study the morphodynamic of this "microtidal barrier" under different hydrodynamic conditions including several storm surges recorded between September 2008 and September 2009. Five cross-shore transects were surveyed once a month using a high resolution DGPS (Figure 1). More frequent surveys were realised just before and after predicted the highest surges. Offshore wave parameters (mean significant wave height Hs, wave period Tp) over the survey time-span were obtained from hourly recordings by the ARPA SIMC Buoy of Cesenatico (20 km to the south of the site) and wind speed and direction were recorded at the national tide gauge of Porto Corsini (9 Km to the north of the site). Additional water levels measurements were obtained using a tide gauge deployed temporarily just inside the inlet. These confirmed negligible tidal delays between Ravenna and the Bevano.

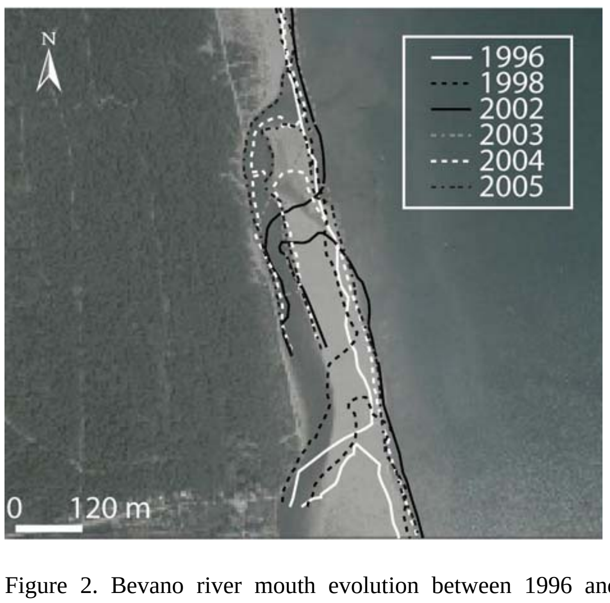


Figure 2. Bevano river mouth evolution between 1996 and 2005 (Base photo – Volo AGEA 2004 – RER)

## RESULTS

**Hydrodynamics**

An event summary of offshore wave heights and tide conditions during the surveys (from October 2008 to April 2009) is shown in Figure 3. The tidal curve is very asymmetric reflecting the strongly asymmetrical tidal regime in the Northern Adriatic Sea with both diurnal and semi-diurnal components. Several high water levels corresponding to significant surges were recorded between October 2008 and April 2009 with surges values fluctuating between 0.6 m and 0.8 m. During the survey period, one of the highest water levels of the last 100 years in this region was recorded with a high tide level of 0.93 m above MSL combined with an offshore significant wave height of 1.45 m (black arrow in Figure 3)

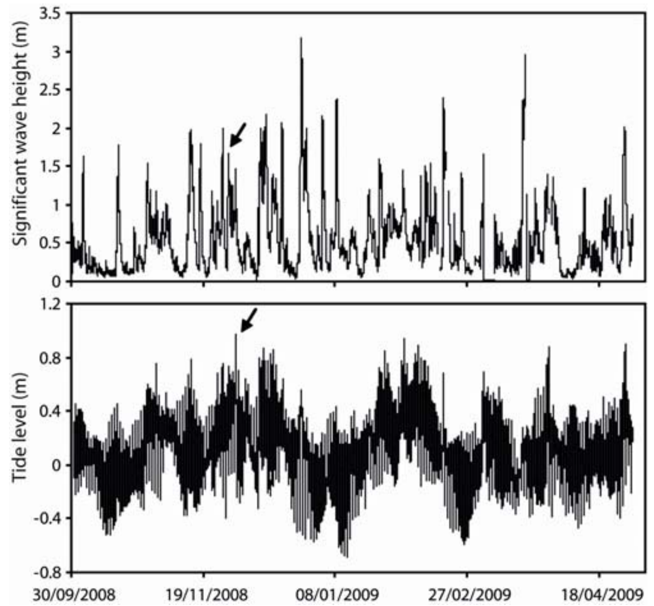


Figure 3. Offshore significant wave height (upper panel) and water level (lower panel). The arrow indicates the event of 01 Dec

During most of the survey period, offshore significant wave height was less than 2m (90%) and only 5 storm events (with significant wave height up to 2 m) were recorded. There is a clear seasonality in the wave climate, with more energetic events normally between September and February caused by "Bora" or "Scirocco" winds. The most important storm was recorded in the end of December during neap tide (26 December 2008) with Hs reached up to 3.18 m and only with a surge of 0.2 m. No clear relationship between high energy events (important Hs) and surges was observed during the survey. The occurrence of surges is more related to wind and atmospheric conditions than to wave intensity action and therefore the recorded breaking wave heights at the nearshore or intertidal zones of the study area had much lower wave energy than those recorded at the offshore location (Sedrati *et al.,* 2009).

**Morphology**

Cross-shore profiles of the Bevano barrier highlights a significant morphologic difference between the northern parte of the area, the southern limit and the middle of the barrier (Figure 4). The dune crest is much higher in the north and in the south than at the center of the barrier where the dune crest never exceeds

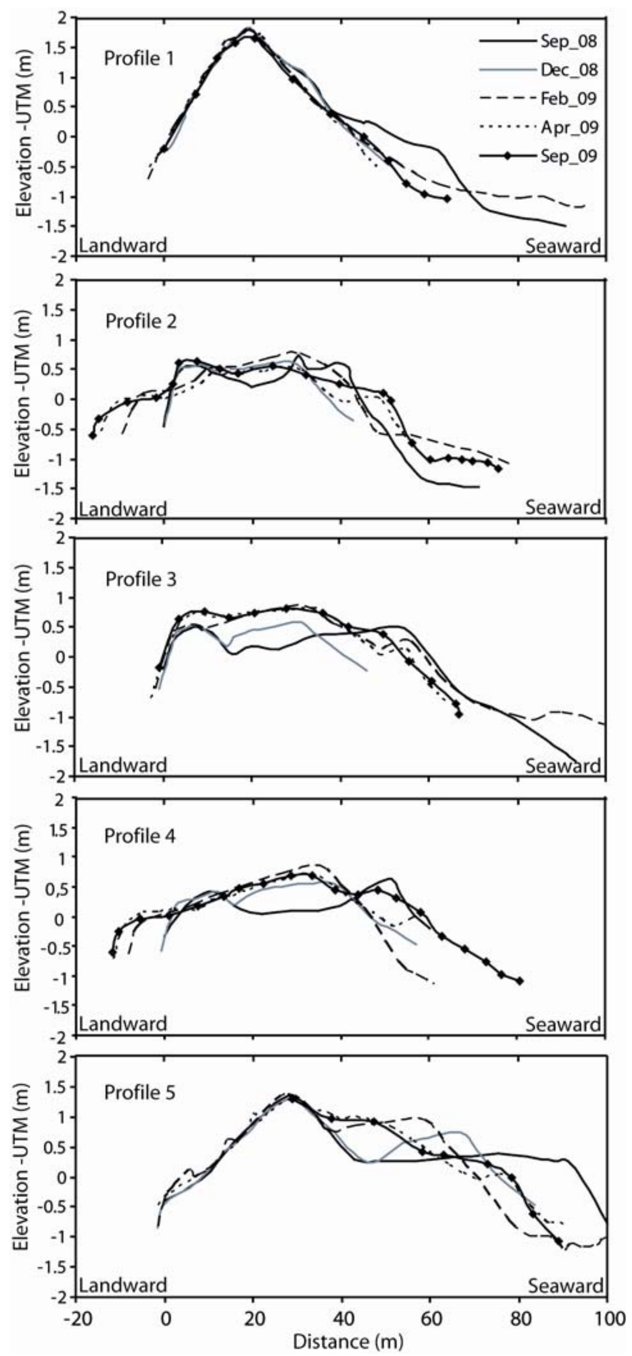


Figure 4. Examples of the evolution of surveyed profiles

of height and sand volume of the lower dune crest of the Bevano beach caused the entire barrier to be inundated during the high tide of the first recorded overwash event of the 1st December 2008. Seven separate washover fans were distinguished together with severe damages to fences and dune vegetation. The washover fans had different dimensions, the most important one being around 18 m wide, and generating a ~ 9 m landward migration of the northern back-barrier limit. The surveyed cross-shore profiles highlights both barrier rollover processes (Profiles 3, 4 and 5) and dune destruction (Profile 2). The storm surges occurred between

December and February caused important wave run-up and water level set-up on the upper beach. New washover fans were developed during this period (actually 11 washover fans, Figure 5) and the previously developed washover fans continued their landward migration (~ 10 m) with the most important one is now at few meters from the landward side of the old river channel, threatening to form a lake. The other washover fans that were originally less developed merged into a single large washover terrace. The cross-shore profiles of this period show a significant accretion in the Bevano dune crest. This confirms an important sediment supply in the area during this period. More important surges occurred between February and March 2009 and caused more overwash sedimentation along the study area and the landward migration of the washover fans (Figure 5). A heterogeneous evolution of the upper beach can be observed in the surveyed profiles from February to September, profiles 4 and 5 shows a significant accretion of the upper beach when the rest of the profiles were eroded or still stable. Furthermore, another significant surge of 0.6 m was recorded in April 2009, this surge occurred during the low tide (neap tide condition) causing a weak erosion of the upper beach by the action of the wave set-up and a formation of an ephemeral berm.

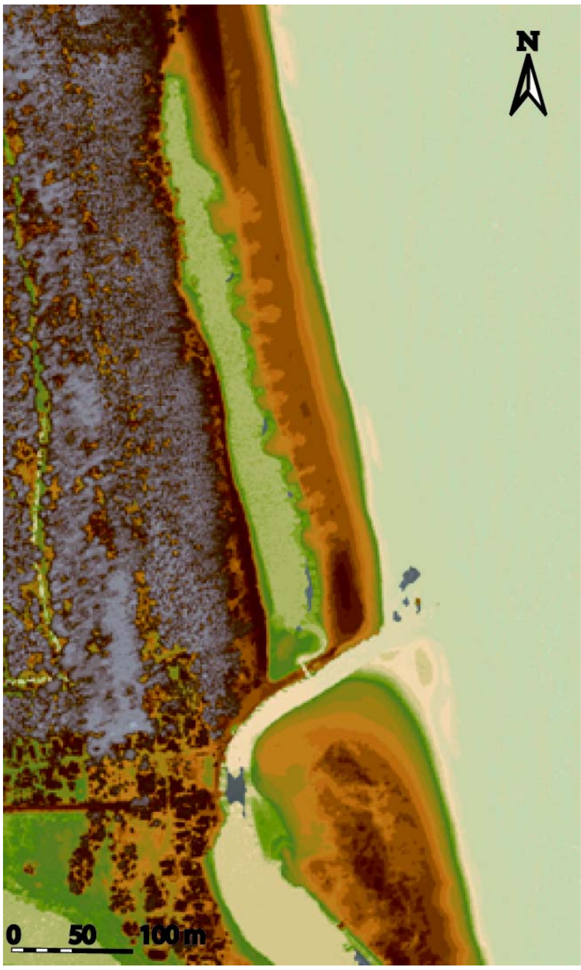


Figure 5. Recent Lidar survey of the Bevano barrier (February 2009) showing the washover fans.

## DISCUSSION

The evolution of the Bevano river mouth was studied over a time-span of 62 years (1943 – 2005) using aerial photos (Ciavola *et al.*, 2005, Gardelli, *et al.*, 2007). The evolution of the Bevano spit shoreline and mouth morphology corresponded to an important northward migration of the spit with an absence of significant ovewashes. However, the exceptional surge of 1 December 2009 was the instigator of initial morphological changes (formation of seven washover fans) which then facilitated successive morphological changes caused by the subsequent storm surges and, as a result, generating the complete change of the morphologic configuration of the barrier's setting (Figure 5).

Variable meteorological and marine conditions determined the occurrence of overwash in the study area. It was assumed that the peaks of offshore wave height were not coincident with the main overwash events. A possible explanation is that large wave heights do not necessarily lead to large run-up heights. Recorded overwash events were mostly seen during the winter months with low wave energy and a spring tidal range. This implies that overwash occurs when a water level and run-up height threshold is exceeded.

A significant aspect highlighted by the monthly surveys is the absence of a clear trend of morphological change and sediment budget in the upper beach notwithstanding a clear seasonal energy pattern. Furthermore, the impact of the recorded surges on the beach morphodynamic was clearly irregular. Thus it may be related to the presence and migration processes of nearshore rhythmic bars which cause significant wave attenuation. The nearshore rhythmic bars as well as some intertidal and swash bars observed along the Bevano barrier show landward migration under low energy conditions and can protect the dune foot. However, during high energy events, the intertidal bars can be eroded and the eroded sediment may enhance overwash sedimentation under large wave run-up and swash processes. The cross-shore profile response to the overwash event can be categorized into two types (1) barrier disintegration and (2) barrier rollover relative to the dune crest height. However, the central profiles (profiles 2, 3 and 4) of the study area show an irregular response to overwash events (particularly the overwash events between December and February) despite the morphological similarities (dune width and height and beach face slope). This is related to the run-up overwash flows which erodes sediment from the higher beach crest and rear dune slope (especially at the northern and southern limits) and deposits sediment on the back barrier slope due to the combined effects of lateral spreading, friction and infiltration (Donnelly, 2007). The higher washover sedimentation in the study area is related with lower washover crest elevation and higher lateral rear dune slope that aids the lateral sediment flows and consequently the size of washover fans. Those that were originally less developed merged into a larger washover terrace (Figure 5). The factor that controlled most the overwash sedimentation in the Bevano barrier is the regenerated beach volume and additional sediment supply from the intertidal bars and the submerged delta of the inlet (the sediment balance of the barrier, including the washover sediment, is positive). Furthermore, the scarce vegetation cover of the dune system may facilitate wave run-up flow and accelerate the washover sedimentation processes. At comparable low-lying barriers (with similar crest elevation), the berm width and beach volume seemed to be more important in limiting overwash (Matias *et al.*, 2008). The back barrier (abandoned channel of the Bevano River) silted-up significantly during the overwash events because the washover sediments were deposited in shallow water threatening to completely infill the back-barrier lagoon in the future. Again, the back-barrier water level must also play an important role in controlling the water table and influencing the friction and infiltration.

## CONCLUSIONS

Overwash processes seems to be the major cause controlling the evolution of the Bevano microtidal barrier after the relocation of the old river mouth and the fixation of the spit. The occurrence of overwash processes in this area is more related to the surge level (during spring high tide) than to the storm energy and duration. However, a storm will impact the morphology of the beach face by the modification of the beach slope (favoring or not wave run-up) and determined the sediment supply which will be involved in the overwash mechanisms under wave run-up flows. Furthermore, the irregular nearshore topography (mobility of the nearshore double bar system) and the connection with the submerged delta of the inlet induces variation in breaking waves characteristics and also in tidal excursion and by consequent hence differences in overwash processes. At this type of low-lying barrier, the vegetation and human development also affect significantly the type of overwash response.

The inlet management plan was realised by local authorities to stop the lateral erosion of the dune area and the forest. The intervention was also justified by the fact that the river has lost efficiency, therefore under flood conditions, coupled with storm surges, flooding of agricultural land is observed. With the current rate of washover fans sedimentation and landward migration associated to the increasing infill processes of the back-barrier (as confirmed by recent survey) the barrier will disappear in few years and it is urgent to plan a new management project for this barrier (e.g. dune nourishment and planting of new vegetation).

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