Atti Soc. tosc. Sci. nat., Mem., Serie A, 116 (2011)
pagg. 11-16, figg. 6; *doi: 10.2424/ASTSN.M.2011.02*

D. Bertoni (*), G. Sarti (*)

GRAIN SIZE CHARACTERIZATION OF MODERN AND ANCIENT DUNES WITHIN A DUNE FIELD ALONG THE PISAN COAST (TUSCANY, ITALY)

Abstract - In this paper, grain size analysis on a large number of samples from a dune field within the Migliarino – San Rossore – Massaciuccoli Regional Park has been carried out in order to define the textural characterization of modern and ancient dune ridges. More than 200 samples along five transects have been collected from the backshore, the active dunes and the steady dunes up to the last recognizable dune ridge. The samples have been dry-sieved and the obtained data have been processed electronically to achieve textural parameters such as mean diameter and sorting. The results showed similar trends of the transects throughout the entire dune field. In particular, the grain size tends to decrease towards the most ancient dune ridges, showing a significant drop at the transition between active and inactive areas. The drastic decrease might be related to a possible variation of River Arno sediment discharge occurred after the XVIII century.

Key words - Coastal dune, grain size analysis, ancient dune ridge, Pisa.

Riassunto - *Caratterizzazione delle granulometrie di dune recenti e antiche all'interno di un campo dunale lungo la costa pisana (Toscana, Italia)*. Nel presente manoscritto sono state effettuate analisi granulometriche su un gran numero di campioni provenienti dal campo dunale situato all'interno del Parco Regionale Migliarino – San Rossore – Massaciuccoli con lo scopo di definire le caratteristiche tessiturali degli allineamenti dunali moderni ed antichi. Più di 200 campioni sono stati raccolti lungo cinque transetti che partono dal backshore e attraversano le dune attive e le dune stabili fino all'ultimo allineamento dunale riconoscibile. I campioni sono stati setacciati per via asciutta e i dati ottenuti sono stati elaborati elettronicamente per ottenere i parametri tessiturali quali diametro medio e classazione. I risultati mostrano tendenze similari per ogni transetto all'interno dell'intero campo dunale. In particolare, la granulometria tende a decrescere verso gli allineamenti dunali più antichi, e mostra un calo significativo in corrispondenza della transizione tra le aree attive ed inattive. La drastica diminuzione potrebbe essere messa in relazione a una possibile variazione della portata solida del fiume Arno accaduta dopo il XVIII secolo.

Parole chiave - Dune costiere, analisi granulometriche, allineamenti dunari antichi, Pisa.

Introduction

Dune systems have always drawn the interest of many disciplines (sedimentology, petrography, geomorphology, biology) due to their naturalistic and economic significance. The vulnerability of this environment has been a major factor towards extensive research on coastal dunes (Clemmensen *et al.*, 1996; Otvos, 2000; Hesp, 2002; Anthony *et al.*, 2006). As a matter of fact, dunes form by the interaction of processes of different nature, such as wind and wave processes, morphodynamic processes, vegetation, human presence. Thus being highly dynamic, dune systems are characterized by an instable equilibrium, where little modifications may cause severe issues. The sense to protect dune environment is felt as a major priority considering that 25% of coastal dune areas has been eroded in Europe since 1900 and 85% of the preserved areas are currently endangered (Muñoz Valles *et al.*, 2011). Recently, also coastal engineering focused on dunes because they are correctly perceived as a primary factor to withstand erosion processes. During periods of decreasing sediment supply, they actually work as a reservoir of sand, which is released to feed the nearshore (Masselink & Hughes, 2003). Therefore, the artificial reconstruction of frontal dunes is considered a viable option to restore a natural, more stable configuration of a beach system (Lemauviel *et al.*, 2005; Levin *et al.*, 2006). The increasing utilization of this technique encouraged the need for an in-depth comprehension of dunes in terms of grain size variability. In addition, there are little data about the textural properties of sediments constituting a dune field as a whole, from modern and active coastal dunes to most ancient and inactive beach ridges (Clemmensen *et al.*, 1996). The aim of this study is to define the grain size characteristics of a dune field located along the coast of Pisa (Tuscany, Italy) in order to evaluate grain size variability through its entire evolution. Moreover, an extensive dataset on coastal dune grain size characterization might be useful to improve and optimize the techniques of artificial dune reconstruction.

Study Area

The area where the fieldwork was carried out belongs to the Pisan coast and is 23 km long (Fig. 1). It nearly coincides with the boundaries of the Migliarino – San Rossore – Massaciuccoli Regional Park, more precisely it is comprised between Torre del Lago Puccini (Lucca) to the north and Tirrenia (Pisa) to the south. The landward limit of the area corresponds to the last

(*) Dipartimento di Scienze della Terra, Università di Pisa; via S. Maria 53, 56126 Pisa, Italy. Tel. +39 050 2215734. Fax: +39 050 2215800. E-mail: sarti@dst.unipi.it

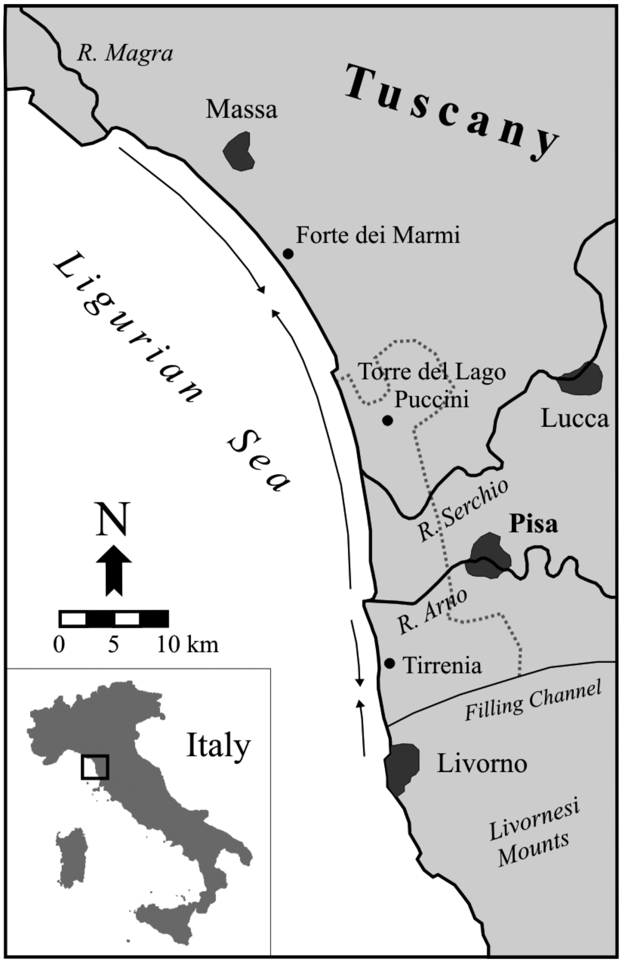

Fig. 1 - Map of the area where the fieldwork was carried out. The thin black arrows represent the direction of littoral drift. The dotted line marks the boundary of the Migliarino – San Rossore – Massaciuccoli Regional Park.

recognizable coastal dune ridge system, which is generally 1-3 km away from the coastline. The high grade of preservation of the entire dune field is related to its belonging to the Regional Park. Local authorities prevented the area from uncontrolled anthropization: man-made structures are rare and whatever human intervention is minimum.

The conservation of the natural characteristics of the area makes it a suitable place for the definition of dune sediment textural properties. This huge dune field formed during the continuous progradation of the River Arno delta in the last 2000 years. Its evolution underwent an abrupt acceleration in the early XVII century due to the artificial cut of the River Arno course (1606). The orientation of the mouth was switched from SW to NW because river floods generally coincided with the most powerful storms, which in the area typically came from the southwest (Pranzini, 2001). The simultaneous nature of these events caused recurrent severe inundations in the inland because strong incoming waves obstructed the natural river flow into the sea. Therefore, the cut determined an increase in River Arno sediment discharge and, as a consequence, an enhanced progradation rate of the dune field. The dune system experienced a rapid growth for as much as three centuries, but a reversal of trend was recorded in the middle XIX century (Aminti *et al.*, 2000; Pranzini, 2001; Bowman & Pranzini, 2003). The River Arno discharge began to decrease, preventing the beaches from natural nourishment. The Pisan coast was then struck by violent erosion processes, which caused a recorded retreat of 1 km on the right side of the River Arno delta and 300 m on the left side (Fig. 1). The different erosion of either sides of the delta was due to a lack of protection structures on the right side, whereas the centre of Marina di Pisa, located on the left side, was protected with groynes and breakwaters after first erosive events (Bini *et al.*, 2008). The retreat of the area belonging to the Regional Park was not impeded until recently, when a series of breakwaters and groynes were built to contain the erosion.

Methodology

The accurate sedimentologic characterization of the dune field was achieved by grain size analysis performed on a large amount of samples. The samples were collected in the summer of 2006 along five transects normal to the coastline. The transects were traced out before the fieldwork along significant features of the area, such as river mouths and courses. In detail from north to south, the five transects are (Fig. 2): 1) Vecchiano (VE), located downdrift of the River Serchio mouth; 2) Fiume Serchio (FS), located updrift of the River Serchio mouth; 3) Fiume Morto Vecchio (FMV), traced along the River Morto Vecchio course; 4) Strada del Filo (FI), located north of the River Arno mouth; 5) via della Bigattiera (BG), located south of the River Arno mouth. Each transect began at the coastline (the so called «active zones») and cut off at the oldest recognizable dune ridge (the so called «inactive zones»).

The dune field was subdivided into three main zones (Fig. 3) in accordance with the classification of Sarti *et al.* (2008), modified from Hellemaa (1998): 1) *frontal dunes*, which are currently subjected to physical processes and are covered with typical psammophile vegetation; 2) *semi-mobile dunes*, which still might experience erosion and accretion processes and are characterized by shrubbery; 3) *steady dunes*, which are no more subjected to the processes that previously led to their formation; they are fixed and characterized by arboreous vegetation.

The samples were collected at any significant positions along the transects. They were taken from the surface in absence of a clearly formed soil (beach, frontal dunes and semi-mobile dunes); where an evident soil was present (steady dunes), they were collected by means of an auger that enabled to drill up to a depth of 30-70 cm. A total of 226 samples of about 500 g were collected from the dune field. In particular, the beachface, the

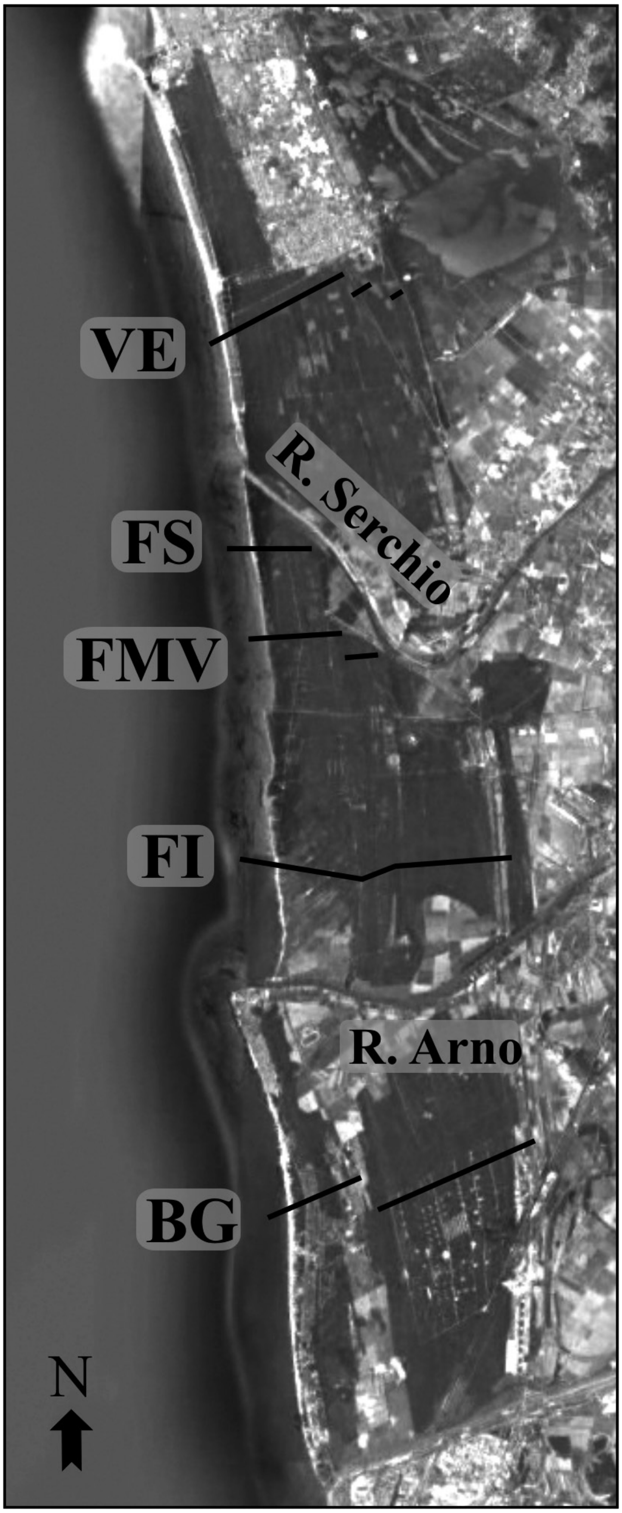

Fig. 2 - The aerial image shows a detail of the Migliarino – San Rossore – Massaciuccoli Regional Park. The black lines point out the position of the five transects along which the samples were collected.

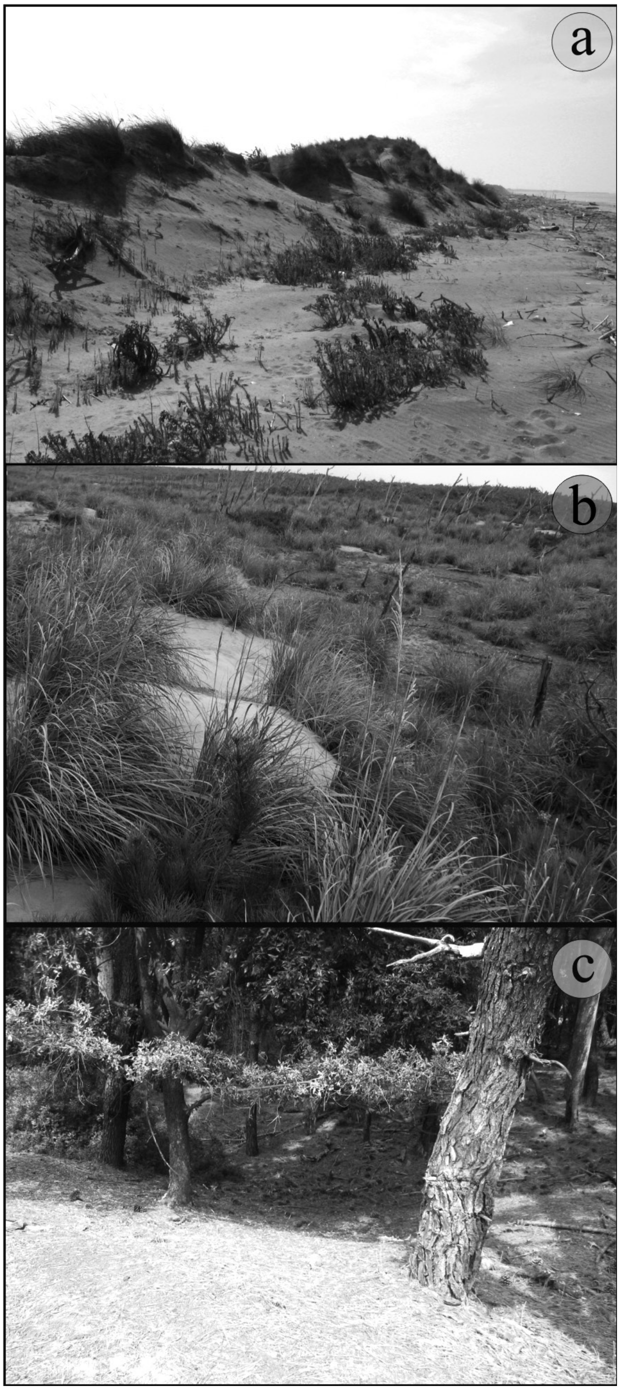

Fig. 3 - Pictures of the three main types of dunes sampled during the fieldwork: a) frontal dune; b) semi-mobile dune; c) steady dune.

fair-weather berm, the storm berm and the backshore were sampled on the backshore; the stoss-side toe, the crest and the lee-side toe were sampled on the frontal dunes; the crest and the interdune areas were sampled on the semi-mobile and the steady dunes. In the oldest sector of the dune field, which is defined by the steady dunes, the most recognizable and preserved dune ridges were sampled. Before the grain size analysis, each sample was dried in an electric oven to eliminate exceeding moisture (120°C) and then reduced to about 100 g, which is the minimum amount of sediment required for grain size analysis procedure still representative of the entire sample. The samples were dry-sieved for 10 minutes using a series of sieves with mesh interval of 0,5 phi, where phi corresponds to

$phi = - \log_2 D_{mm}$,

where D_{mm} is the diameter of the grains expressed in millimeters. The last sieve is characterized by the finest mesh (63 μm). The resulting data were then processed by an application of Excel, which provides Folk and Ward (1957) main parameters like Mean (Mz) and Sorting (σ).

Results and Discussion

Grain size analysis performed on samples that were collected from five transects within the Migliarino – San Rossore – Massaciuccoli Regional Park provided for an in-depth characterization of sediment textural properties. The results showed a trending decrease in grain size towards the most ancient dune ridges (Fig. 4): sediments from the beach and the frontal dunes are characterized by a mean diameter of about 1,5-2,0 phi; then the grain size diminishes to about 2,2 phi in the semi-mobile dune zone, reducing furthermore in the steady dune area (2,4 phi), where it reaches the finest value of about 2,7 phi.

In addition, the grain size drops off sharply at the transition between active and inactive areas, i.e. at the limit between semi-mobile and steady dunes. Sediments from the active portion of the dune field show a mean diameter of about 1,6-1,8 phi as opposed to 2,3-2,7 phi for the inactive portion. The drop is noteworthy considering that the grain size shifts from medium sand to fine sand in a comparatively brief span of time: the first dune ridge belonging to the steady dune area dates back to the XVIII century, whereas the semi-mobile dunes formed right after. The resulting grain size variation might be credited to a possible modification of the River Arno sediment discharge, occurred after the XVIII century at the very least. The change in land use (mountain reforestation, land reclamation) during the XIX century together with river bed quarrying and dam construction, which ultimately led to first erosion processes in the area due to the drastic decrease of River Arno sediment discharge (Aminti *et al.*, 2000; Pranzini, 2001; Cammelli *et al.*, 2004), might explain the alteration of the main sediment source of the Pisan coast. The increase of mean grain size of frontal and semi-mobile dunes may be indirectly related also to the erosion of the River Arno delta. Among the first protection schemes set up to slow down the erosion processes, a long pier was built on the right side of the mouth. The pier forced the river's flow to unload the finer sediments further offshore, where no wave processes could push them back towards the coast. Thus, only the coarse fraction of sediments could have reached the beach, causing what turned out to be a relative increase of mean grain size.

Since the grain size of the inactive portion of the dune field does not change significantly, the FI transect is tagged as the reference (Fig. 2). Unfortunately, FS and FMV transects cut off before the sixth dune ridge, so it is not possible to appreciate their previous evolution. In any case, FS and FMV trends overlap nicely with that of FI transect (Fig. 4). The finest grain size (about 3,0 phi) of the whole dune field is recorded along the most ancient dune ridges of the BG transect, which is located south of the River Arno mouth. Being the only transect south of the delta, the considerable difference in mean grain size might be ascribed to a different dis-

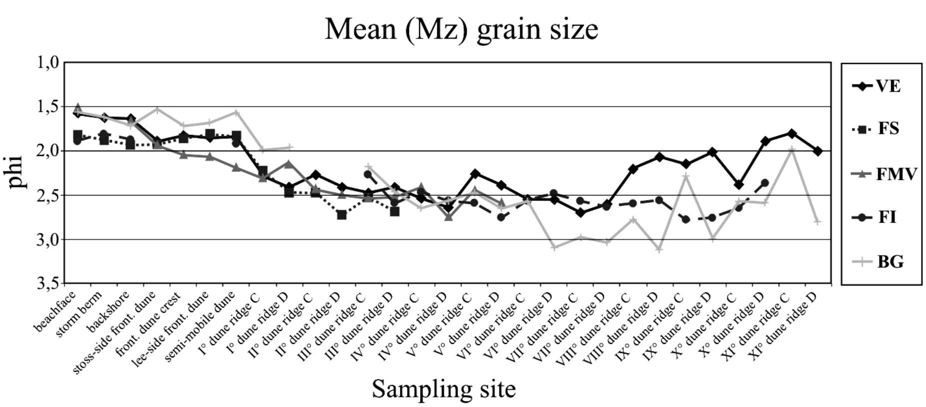

Fig. 4 - Plot of the Mean (Mz) resulting from the grain size analysis of the samples taken from the five transects. Letters «C» and «D» beside the samples collected from the dune ridge area define crest and interdune samples respectively.

persion of sediments in this sector of the coast. Coarser grains might have been preferably transported northwards, even though present beach sediments display the opposite trend. The plot in Figure 4 also highlights the coarser mean diameter of sediments collected from the ancient dune ridges of VE transect (between 1,8 and 2,2 phi), which is located north of River Serchio mouth (Fig. 2). Even though River Serchio sediment discharge is subordinate to that of River Arno, the proximity of River Serchio mouth might contribute to the grain size of the area explaining the resulting different mean diameter. Present beach sediments seem to confirm this trend.

Another remarkable trend inferred from the plot of Figure 4 is the different grain size of samples taken from the crest of the steady dunes (C) and samples collected from the interdune areas (D). Barring few exceptions, C samples are coarser than the corresponding D samples throughout the entire dune field. The difference is slight (about 0,3 phi), but it is not negligible. This trend can be explained by wind processes wiping out mainly the crest of the dunes rather than the interdune areas. Wind action produces a selection of the finer sediments, which eventually determines their displacement towards the depressed zones, where they cannot be further removed (Reineck & Singh, 1973). The Sorting diagram emphasizes this discrepancy (Fig. 5): the weaker sorting of interdune samples confirms that more fine particles are present in those samples, in turn reducing their mean grain size.

As a matter of fact, beach and frontal dune sediments are generally well sorted, since few or no silt is present in those samples. The plot sand vs silt further verifies the aforementioned trends (Fig. 6): in particular, it stresses the higher percentage of fine fraction in samples taken from the ancient portion of BG transect relative to samples collected from the same portion of the remaining transects.

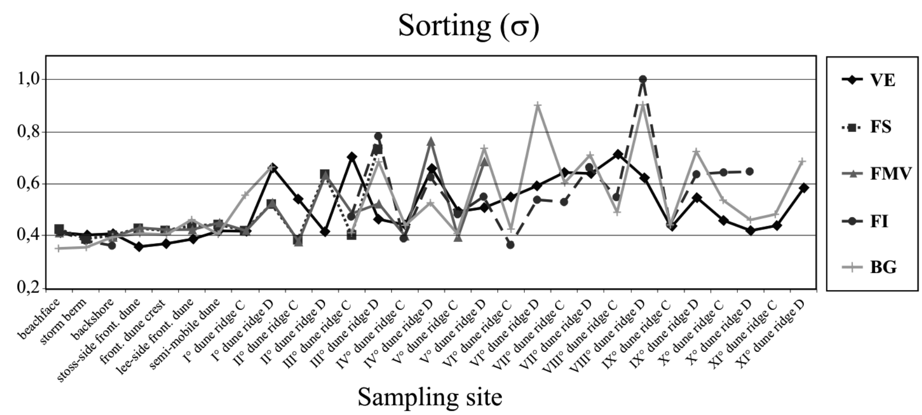

Fig. 5 - Plot of the Sorting (σ) resulting from the grain size analysis of the samples taken from the five transects. Letters «C» and «D» beside the samples collected from the dune ridge area define crest and interdune samples respectively.

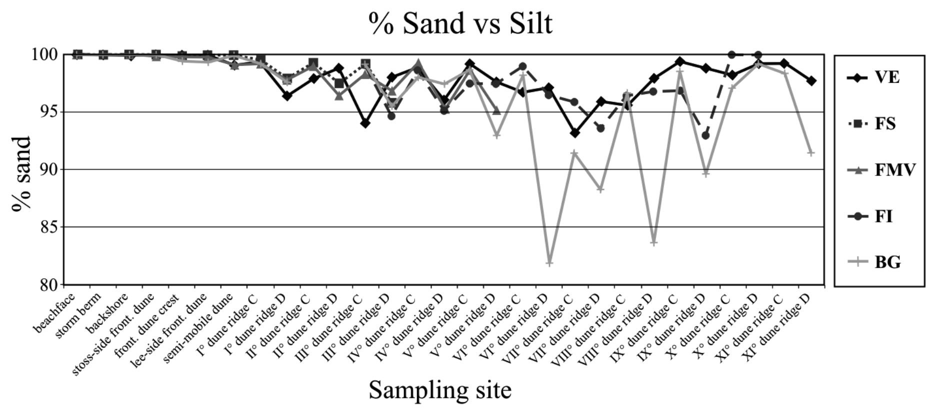

Fig. 6 - Plot of the Sand vs Silt percentage resulting from the grain size analysis of the samples taken from the five transects. Letters «C» and «D» beside the samples collected from the dune ridge area define crest and interdune samples respectively.

Conclusions

Grain size analysis performed on a large number of samples collected from a dune field within the Migliarino – San Rossore – Massaciuccoli Regional Park pointed out few remarks about its textural characterization:

1. the grain size tends to decrease towards the most ancient dune ridges; a distinct drop (from about 1,7 phi to 2,5 phi) occurs at the transition between active zones (beach, frontal dunes and semi-mobile dunes) and inactive zones (steady dunes), which corresponds to the XVIII century;
2. samples (C) that were collected from the crest of the steady dunes show a coarser grain size rather than samples (D) that were taken from the interdune areas of the inactive zones;
3. both Mean and Sorting plots show a definite overlap between the transects up to the second dune ridge, which is the point where more ancient dune ridges are characterized by the finest grain size. This trend is also confirmed by the sand vs silt plot, proving that the silt fraction increases beyond the second dune ridge;
4. the mean diameter of ancient dune ridges of VE and BG transects diverges from the typical trend.

In conclusion, the definite decrease in grain size at the transition between active and inactive zones is likely related to a variation in River Arno sediment discharge occurred after the XVIII century. The finer mean grain size of samples taken from the most ancient dune ridges of the transect that is located south of the River Arno mouth might have been related to a weaker southward distribution of sediments along the coast; similarly, the impulse of River Serchio sediment discharge might have affected the most ancient dune ridges of the transect located north of its mouth, causing a slight increase in mean grain size. Additional studies, such as petrographic and geochemical analyses, might help define the trend highlighted by sediment textural properties investigation.

Acknowledgements

The Provincia di Pisa funded the present research in form of a grant to Dr. Giovanni Sarti. We are thankful to Drs. Lorenzo Ciulli and Serena Giacomelli for their significance support during the fieldwork and the laboratory analysis. Comments by Dr. Adriano Ribolini led to improvements of the manuscript.

(ms. pres. il 25 ottobre 2011; ult. bozze il 30 luglio 2012)

References

Aminti P., Cipriani L.E., Pranzini E., 2000. «Back to the beach»: converting seawalls into gravel beaches. Proceedings of the First International Soft Shore Protection Conference, Patras, Greece, pp. 187-196.

Anthony E.J., Vanhee S., Ruz M.H., 2006. Short-term beach-dune sand budgets on the north sea coast of France: sand supply from shoreface to dunes, and the role of wind and fetch. *Geomorphology* 81: 316-329.

Bini M., Casarosa N., Ribolini A., 2008. L'evoluzione diacronica della linea di riva del litorale pisano (1938-2004) sulla base del confronto di immagini aeree georeferenziate. *Atti Soc. Tosc. Sci. Nat., Mem., Serie A* 113: 1-12.

Bowman D., Pranzini E., 2003. Reversed responses within a segmented detached breakwater, the Tuscany coast Italy – A case study. *Coast. Eng.* 49: 263-274.

Cammelli C., Jackson N.L., Nordstrom K.F., Pranzini E., 2004. Assessment of a gravel nourishment project fronting a seawall at Marina di Pisa, Italy. *J. Coastal Res.* SI 39: 770-775.

Clemmensen L.B., Andreasen F., Nielsen S.T., Sten, E., 1996. The late Holocene dunefield at Vejers, Denmark: characteristics, sand budget and depositional dynamics. *Geomorphology* 17: 79-98.

Folk R.L., Ward, W.C., 1957. Brazos River bar: a study in the significance of grain size parameters. *J. Sediment. Petrol.* 27: 3-26.

Hellemaa P., 1998. The development of coastal dunes and their vegetation in Finland. *Fennia* 176: 1-157.

Hesp P., 2002. Foredunes and blowouts: initiation, geomorphology and dynamics. *Geomorphology* 48: 245-268.

Lemauviel S., Rozé F., Clement, B., 2005. A study of the dynamics of the seed banks in a complex dune system, with the aim of restoration. *J. Coastal Res.* 21: 991-999.

Levin N., Kidron G.J., Ben-Dor, E., 2006. The spatial and temporal variability of sand erosion across a stabilizing coastal dune field. *Sedimentology* 53: 697-715.

Masselink G., Hughes M.G., 2003. Introduction to coastal processes & geomorphology. Arnold, London (UK), 354 pp.

Muñoz Valles S., Gallego Fernandez J.B., Dellafiore C.M., 2011. Dune vulnerability in relation to tourism pressure in Central Gulf of Cadiz (SW Spain), a case study. *J. Coastal Res.* 27: 243-251.

Otvos E.G., 2000. Beach ridges – definitions and significance. *Geomorphology* 32: 83-108.

Pranzini E., 2001. Updrift river mouth migration on cuspate deltas: two examples from the coast of Tuscany (Italy). *Geomorphology* 38: 125-132.

Reineck H.E., Singh I.B., 1973. Depositional sedimentary environments. Springer-Verlag, Berlin (Germany), 440 pp.

Sarti, G., Bertoni, D., Ciulli, L., Consoloni, I., Giacomelli S., 2008. A threefold research aimed at the reconstruction of an artificial dune (Migliarino – San Rossore – Massaciuccoli National Park, Pisa, Tuscany, Italy): preliminary data. GeoSed Congress 2008, Bari, Italy, pp. 117.