Beach sediment alteration by natural processes and human actions: Elba Island, Italy

Beach Sediment Alteration by Natural Processes and Human Actions: Elba Island, Italy

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The surface characteristics and dimensions of many beaches reflect past inputs of sediment due to human activity in tributary drainage basins. Subsequent control of erosion in drainage basins, changes in flow regimes of streams, and construction of shorefront structures have reduced sediment input and eliminated beach area in many coastal segments, leading to calls for artificial beach nourishment. This study evaluates the compatibility of sediments delivered as a result of human activity in terms of the appearance and utility of beaches by comparing sites on Elba Island, Italy. Beach morphology, mineralogy, grain size, and roundness of sediments were determined for five sites where sediments were introduced by artificial nourishment, by erosion of spoils from iron mines, and by stream flow through agricultural or mining lands. Size, sorting, angularity, and color of sediments determine their acceptability by beach users. These characteristics were determined by evaluating the mineralogy and method of delivery of sediment (rivers, bluff erosion, and artificial replenishment) and subsequent modification by wave and human action. Wave energy and time are critical to the reworking of sediments to achieve more natural characteristics, but these constraints can be overcome by more careful selection of the mineral characteristics of fill sediments, prewashing fill sediments to remove silts and clays to reduce turbidity, grading nourished beaches to cycle sediments into the wave and swash zones to cause better rounding of sediments, or raking the beach to create the sandy backbeach that is favored by beach users. *Key Words: beach nourishment, human–land relationships, land use change, mine spoils, recreation, sediment sources, wave action.*

Introduction

Geographic research has extended our understanding of the temporal and spatial scales of human action in shaping landscapes formerly considered natural or little altered (Denevan 1992; Phillips 1997; Cowell and Dyer 2002) and the ways that human-altered nature can be defined and related to culture and environmental issues (Fall, Lines, and Falconer 1998; Eden 2001). It is now difficult to say that the vegetation and landforms in any landscape presently devoid of humans have not been at least partly altered by direct human action on site in the past or by indirect human action off site. One of the principal contributors to human-induced change from off-site activity is alteration of the amount of sediment delivered to streams caused by widespread deforestation for cultivation, grazing, and construction of settlements. Humans have altered coastal sediment budgets in this way for millennia (Walker 1985; Postma 1989; Pranzini 2001). Most of these additions to the coastal sediment budget were unintentional byproducts of human activity and the sequence of events that created many coastal features has been forgotten.

Prior to the nineteenth century, the principal use of beaches was for fishing or launching boats. Beachfront settlements were rare, and direct human impact on landforms and biota was not extensive. A change in emphasis on coastal landforms began about the middle of the nineteenth century, when beaches became foci for recreation and settlement. Shorefront construction eliminated many backbeach and dune environments. These losses were compounded in the twentieth century by reduction in the amount of sediment delivered to the coast by streams as a result of controls on surface erosion and stream discharge through dam construction (Nordstrom 2000). The intensity of use of beaches for recreation and the pace of development of coastal real estate has accelerated in recent decades, placing an increased demand on remaining beach space and an increased economic value on beaches.

Replacing sediment lost from beaches by artificial nourishment is often considered preferable to building static shore-protection structures because nourishment maintains beach space for recreation and for wildlife, while also protecting buildings and human infrastructure (Houston 1991; Hanson et al. 2002). Beach nourishment is, however, a contentious issue in many locations

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because of its perceived high cost, short residence time, and potential effect on biota (Pilkey 1992; Nelson 1993; Lindeman and Snyder 1999; Greene 2002). Nevertheless, nourishment projects continue to increase in number and scope (Nordstrom 2000). Suitable sediment sources for nourishment are finite, and depletion of local deposits often leads to use of more costly or less compatible materials. The most commonly used source materials include natural deposits from offshore, from inland (fluvial and glacial deposits or rock quarries), or dredged materials from navigation projects (Flick 1993). Less commonly used materials include byproducts derived from mining (Bourman 1990), road and tunnel construction (Dzhaoshvili and Papashvili 1993), or building sites (Anthony and Cohen 1995). These sediments initially may be considered unsuitable because of incompatibility with parent beach material, but through time, wave action can rework fill deposits, making beaches more suitable to beach users (Pacini, Pranzini, and Sirito 1997; Cammelli et al. 2004) and potentially overcoming some of the initial objections.

The availability of sediment for future nourishment projects is one of the biggest uncertainties in long-term plans for maintaining beaches (NRC 1995; Hanson et al. 2002). Leidersdorf, Hollar, and Woodell (1994) underscore the importance of utilizing all possible sources of sediment, but use of exotic sediments can turn beaches into engineered artifacts by altering their size, shape, rate of change, surface texture, thermal characteristics, color, and habitat potential from what would occur under natural conditions (Nordstrom 2000). The importance of hydrodynamic compatibility of source materials with native sediments for beach stability and longevity is well documented (Swart 1991), but little is known about the importance of compatibility of source materials with the appearance of a beach and its human use. As more beaches are altered from their natural state, it becomes increasingly important to identify how exotic beach sediment can be effectively utilized. This requires better understanding of how exotic sediment becomes more natural in appearance and accepted and used by stakeholders as a result of abrasion and sorting by wave action or grooming by human actions. This article provides perspective on these aspects of beach naturalization by comparing land use, topography, and sediments at five representative beach sites on the eastern side of Elba Island, Italy (Figure 1), where many beaches were created as byproducts of economic activity over a long history. The sites include locations where (1) mining materials were deposited on the beach for nourishment; (2) mining materials were made available through past mining operations and have been reworked by waves to a more natural appearance; (3) sediment from agricultural lands comprise the beach; and (4) fluvial materials from unmined and uncultivated drainage basins comprise the beach.

Study Area

Elba Island is the westernmost extension of the Northern Apennines (Bortolotti, Pandeli, and Principi 2001). The structure of central and eastern Elba is complex and consists of nine major tectonic units (Bortolotti et al. 2001). Alluvial deposits are composed primarily of poorly cemented or recently reworked gravel, with some local sands and mud. Formations containing iron deposits are restricted to a relatively narrow belt along the eastern coast. They normally occur as iron oxides and form stratiform bodies with some pod-like or vein-like deposits that are associated with siliciclastic rocks or overlying dolomitic formations (Tanelli et al. 2001).

Iron mining played a key role in the evolution of the landscape of Elba, and iron production, along with cultivation and commercial activity, existed from the beginning of written history. Mining appears to have begun in the seventh century BCE. Iron was smelted right on the island when wood was available for processing. When readily available sources of wood became scarce in the third century BCE, the locus for processing moved to the mainland, 16 km to the east (Canestrelli 2001). Evidence for land use changes in the early Middle Ages is sketchy. The island at that time was unsafe due to piracy and experienced a decline in population, so it is likely that mining was limited and revegetation occurred. Mining activity flourished from Cavo to Rio Marina (Figure 1) from the eleventh to the fourteenth centuries CE under the Pisa Republic and again in the sixteenth to eighteenth centuries (Tanelli et al. 2001). Mined materials were often placed directly on the beach before being loaded onto boats. Engravings from the early nineteenth century and a geological map of 1884 show extensive strip mining with resulting bare slopes near Rio Marina, with much of the spoil located on the beach. Major expansion of mining occurred in the late nineteenth century, when mines in the Punta Calamita area were worked. Mining expanded throughout the twentieth century until it ceased in the Cala Seregola and Punta Calamita regions in the 1960s and 1970s; the last iron mine on Elba was shut in 1981 (Tanelli et al. 2001). The amount of iron ore extracted from Elba deposits was over 60 million tons (Tanelli et al. 2001).

Mine waste deposits are locally stratified gravel accumulations, consisting mostly of mineralized host rocks or rejects (frequently limestones) that are still found

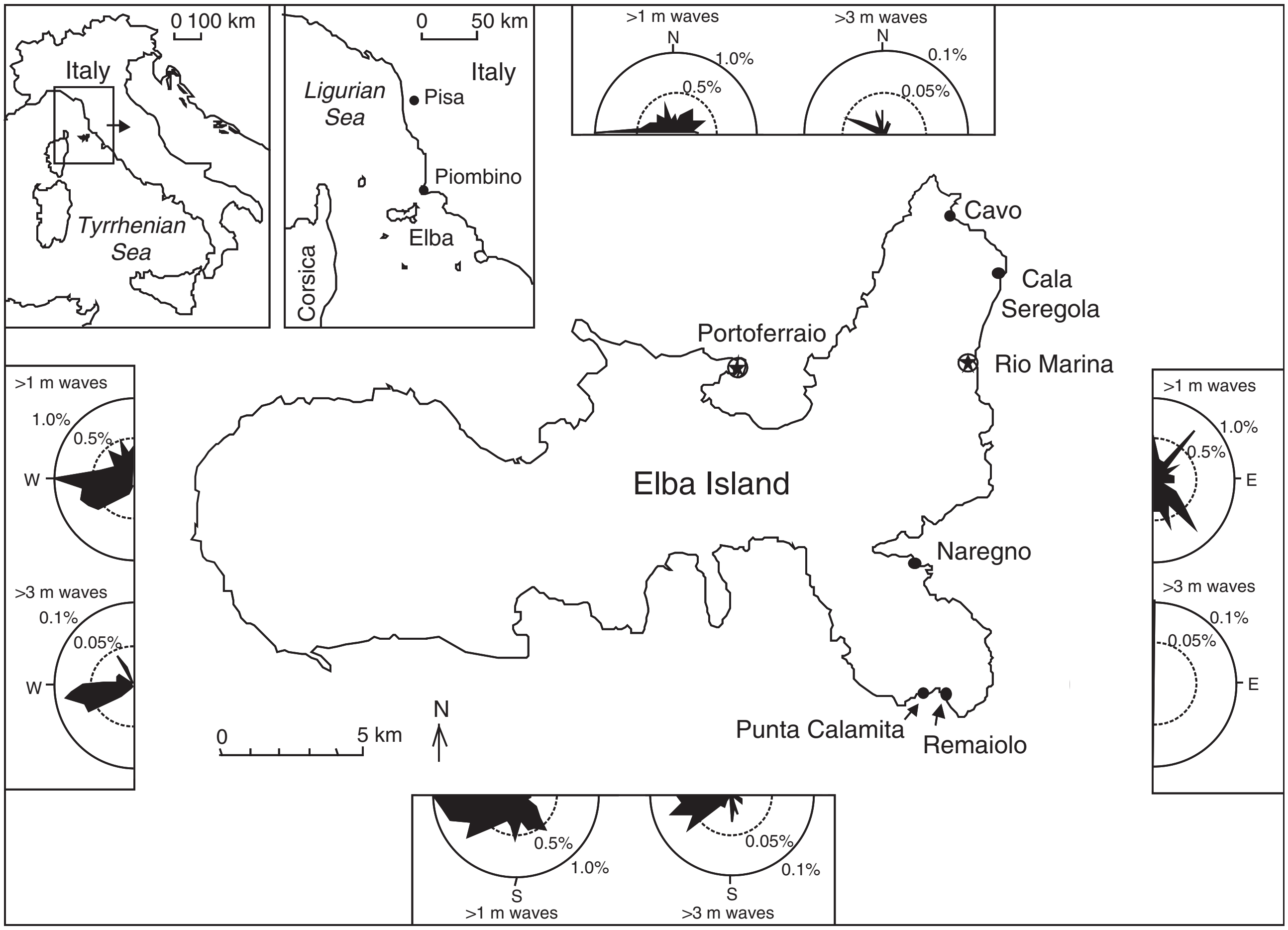

Figure 1. Elba Island, Italy, showing beach study sites. Wave data in insets from a Royal Dutch Meteorological Institute wave climatology for years 1961 to 1990.

within or close to the mining areas and in subaerial and subaqueous fan-like wastes along the coast (Bortolotti et al. 2001). About 10 km^2 of fairly bare surface remains in mined areas because vegetation has been slow to grow due to lack of humus.

Much of the vegetated land in the non-mined areas was converted to agriculture in post-Napoleonic times. By the third quarter of the nineteenth century, most of the land above 300 m elevation was pasture or bare ground; about one-fourth of the island was in vineyards and slightly less than one-tenth in wheat, but much of the soil had already been eroded from agricultural lands (Pullè 1879). The bare ground intensified runoff and soil erosion. Except near Naregno, little land on the eastern part of the island is now devoted to agriculture (Table 1), although much of the landscape throughout the island bears the imprint of former agricultural practices, seen in the large number of abandoned terraced fields. Land cover in drainage basins at Cala Seregola and Punta Calamita (Figure 1) still bears the imprint of mining (Table 1). Much of Elba Island is now forested, restricting the potential for surface runoff. Drainage channels are undersized for the valleys, the channels are vegetated, and delivery of sediment to beaches by streams is minimal.

Tourism has increased in the past three decades, and it now dominates the economy. Beaches all around the island are intensively used in the summer. Visitor counts for 2001 (number of people staying overnight that year) provided by the Provincial Agency for Tourism of the Tuscan Archipelago totaled nearly 3.2 million, with about one-third of the visitors being foreign, mostly from Germany. Before the introduction of the euro, Elba had the second highest rate of foreign currency exchange in Tuscany. The development of the east end of the island occurred later than the west because some of the roads were closed due to mining. Access from the principal port, Portoferraio, was only by unpaved road until recently. The beaches near mining areas were traditionally considered less attractive than other beaches because of the dark

Table 1. Land Use in Drainage Areas in Percent, from a GIS Database in the Province of Leghorn

Land Use	Drainage Area				
	Cavo	Cala Seregola	Naregno	Ramaiolo	Punta Calamita
Urbanized	8	0	11	0	0
Dry or abandoned sown land	9	3	0	2	0
Urbanized agricultural area	0	0	31	0	0
Sown land planted in trees	2	0	17	1	0
Active and abandoned vinyard	3	0	0	0	0
High and low mixed forest	64	20	33	91	0
Fire control lanes	0	0	1	4	0
Open area (herbaceous or shrubs)	4	0	7	0	0
Pasture and grass	3	0	0	1	0
Rock outcrops	5	8	0	0	0
Beach	0	0	0	0	3
Mining area	1	69	0	0	97

color of the iron-rich sediments and the hot surfaces they create in the summer. The quality of the roads on eastern Elba is still worse than on the rest of the island, and there is no evening sunlight on the beach or sunsets over the water to enhance the recreational experience on the beach. However, rental homes and hotels are less expensive and because beach space is at a premium in the summer, beaches on the east side are now intensively used wherever access by motor vehicle is available.

The rugged topography of Elba Island and lack of sedimentary rocks or large streams limit the input of natural sources of sediment and the size and extent of sandy beaches. The beaches owe their origin to runoff from agricultural land, mined land, and mine waste deposits—sources that are no longer available. The demand for additional beach space with the shift to a tourist-based economy has resulted in calls for nourishment by local administrators and stakeholders involved in the tourism industry. The most readily available and least costly sources of unconsolidated materials are the deposits of iron mine waste adjacent to inactive quarries and mineral processing areas. These sediments are a valuable resource, but their characteristics are not always perceived as suitable from the standpoint of aesthetics.

Recent events at a beach nourishment site at Cavo (Figure 2) underscore the difficulties of using mine-waste materials for beach fill. The fill, taken from a nearby deposit of mine spoils, contained fine-grained red, iron-oxide-stained sediments that remained in suspension and discolored the water for months. Fear that these sediments would settle on sea grass (*Posidonia oceanica*) growing offshore caused complaints about potential environmental impact. The mix of dark, iron-rich sediment with lighter-colored limestone and the poor sorting of the gravel, sand, and silts, gave the nourished beach a mottled appearance (Figure 2). Many local stakeholders wanted the fill removed (an operation that could contribute additional fine sediment to the water), and the local engineer who designed the project suggested covering the fill with new, well-rounded, aesthetically pleasing sediments from stream channels on the Italian mainland. These stakeholders were unaware that many of the undeveloped beaches on this part of Elba are composed of sediments that are similar in origin to the recent mine-derived fill but were reworked into more natural-looking forms by wave action over a longer period.

Methodology

Data were gathered to identify (1) how land use influenced delivery of sediment to the beaches; (2) how texture, roundness, mineralogy, and overall appearance of beach sediment differ from source sediment; (3) how

Figure 2. Cavo, June 2002, looking north, showing appearance of beach surface three and a half years after nourishment.

exposure to waves determines the characteristics of beach sediment and topography; and (4) how time causes sediment delivered to the beach to become more natural in appearance.

Background data on changes in land use were obtained from geological and historical reports (Pullè 1879; Bortolotti et al. 2001; Bortolotti, Pandeli, and Principi 2001; Tanelli et al. 2001). Long-term changes were evaluated using an 1884 geologic map at 1:25,000 scale (Liotti 1884) and stereo pairs of air photographs at 1:33,000, 1:13,000, and 1:7,500 scales taken in 1954, 1975, and 1997 available at the offices of the Tuscan government in Florence. Land use and land cover were determined from a GIS database in the province of Leghorn.

We conducted topographic surveys from 7 to 24 June 2002 using a rod-and-transit. Three cross-shore transects were surveyed on each of the five sites. Transects were spaced one-third of the distance along each beach segment between headland boundaries and extended across the shore from wading depths to the backing cliff or human infrastructure. Sediment samples were gathered on the fifteen transects at six common locations, including the surface of the subaqueous beach seaward of the step (where storm waves break), the surface of the step (where normal swash uprush and backwash interact), the surface and at depth on the foreshore in the active swash zone, and the surface and at depth on the storm-worked foreshore above the normal limit of wave reworking.

One surface sample was gathered at each site on the sandy backbeach that is reworked only during large storms. Most of the surface of the storm foreshore and backbeach at Naregno was raked free of pebbles, so, for contrast, the sample was taken in one of the backbeach locations where these pebbles were discarded.

We collected one additional bulk sediment sample to identify the nature of sediment in the principal source landward of the beaches. Sources are the fill materials deposited on the beach at Cavo, the floodplain landward of the beach at Naregno, the local stream channel emptying onto the beach at Remaiolo, and the eroding bluffs of mine waste at Cala Seregola and Punta Calamita.

Surface samples were taken to a depth of 0.05 m or to a depth representing the bottom of the largest surface clasts. Samples at depth on the active and storm foreshores were taken from 0.05 m to 0.2 m below the sediment surface. The surface seaward of the step at Punta Calamita was composed of boulders and cobbles that could not be readily sampled using comparable methods, so visual estimates were made of dominant clast size.

Roundness was visually estimated using criteria provided in Krumbein (1941) that places samples in ten classes varying from 0.1 (least rounded) to 1.0 (spherical). Sediment samples were sieved in a ro-tap machine using 2ϕ intervals in the Wentworth scale that separates size fractions into silts/clays <0.06 mm (4ϕ), fine and very fine sand 0.06 mm to 0.25 mm (4 to 2ϕ), medium and coarse sand 0.25 to 1.0 mm (2 to 0ϕ), very coarse sand and granules 1.0 to 4.0 mm (0 to -2ϕ), small pebbles 4.0 to 16.0 mm (-2 to -4ϕ), large pebbles 16 to 64 mm (-4 to -6ϕ), and cobbles 64 to 256 mm (-6 to -8ϕ). These size intervals are small enough to group sediments that have similar hydrodynamic properties, but they are large enough to summarize the somewhat chaotic distributions found in mixed sand and gravel beaches.

Full grain-size distributions are portrayed here for sediments gathered along the center transects and the backbeach and source samples. Modal grain-size classes were tabulated for all six common sampling points on the fifteen transects (ninety samples), at the five samples on the backbeach, and the five samples in the source areas. Traditional grain-size statistics of mean and sorting can be misleading in polymodal sediments, so the dominant mode is reported as a summarizing measure. More than one size mode is presented if the percentage of particles in the second-most-frequent mode falls within 5 percent of the dominant mode or if the two modes are clearly from different populations (i.e., no sediments are found in one or more of the intervals between two peaks in the distribution).

Deep-water wave data (Figure 1) were extracted from a wave climatology obtained by the Royal Dutch Meteorological Institute and summarized in Aminti (1998). These data are derived from 28,243 in-transit ship observations of wave height (at 0.5 m accuracy) and wave direction for 10-degree sectors made from 1961 to 1990 in four quadrats north, east, south, and west of Elba Island. These data are the only comparative wave data for Elba and are considered useful for formulating general conclusions on between-site differences in potential for wave reworking.

Results

The dominant wind and largest waves approach from the west-southwest (Figure 1). The shorelines at Cavo and Naregno face east, toward the Italian mainland and are the most sheltered from high energy waves. Maximum fetches are <65 km and <45 km at these sites. Waves higher than 1 m height only approached the shore 0.75 percent of the time on this side of the island,

and no waves higher than 3 m occurred during the 30-year wave record depicted in Figure 1. The shoreline at Cala Seregola faces south-southeast and is exposed to a longer fetch. Beaches at Remaiolo and Punta Calamita face south and are exposed to waves generated in the Tyrrhenean Sea across a fetch greater than 500 km. Punta Calamita, unlike Remaiolo, has no confining rock headland to the west, and it is more exposed to the dominant southwesterlies and has the highest wave energies. This site has a rock sill to the east that traps sediment moved alongshore. The other beaches are contained within natural headlands that restrict wave approach to narrow bands and prevent losses by wave-induced longshore transport.

Cavo

The embayment at Cavo (Figure 1) is separated into smaller drift cells by two groins and a marina jetty. The 155-meter-long beach cell investigated here is located between the groins. The shoreline originally fronted Quaternary alluvial sediments supplied from the 500 ha drainage basin of limestone, shale, siltstone, and poorly cemented Quaternary sands. Remnants of the sand-sized sediments that were formerly delivered to the shore remain in the narrow pocket beach trapped against the schist headland to the north (background of Figure 2). Air photos reveal that detached breakwaters were in place in 1954, but there were only a few houses by 1975. A shorefront road was built on the former backbeach after 1975 and was subsequently subject to frequent wave damage. Loss of natural beach led to installation of rip-rap to protect the road, but recognition of the advantages of a recreation beach eventually led to the decision by the municipal government to nourish the beach. In February 1999, the breakwaters were removed and used to construct two groins, and 20,000 m^3 of fill was placed along the shore between the marina and the headland to the north (Figure 2) at a cost of 311,000 euros. The cost was borne by the Tuscan Regional Government (60 percent) and the municipality (40 percent).

The fill was brought by trucks from a spoil pile inland of the beach at Cala Seregola. Sediments consist of limonite, hematite, magnetite, scoria from iron processing, serpentine, sandstone, and limestone. Fine materials in the fill are still suspended during storms, but subsequent evaluations of sea grass beds reveal no permanent damage associated with sedimentation by fill materials (Cinelli 2002). The beach is only lightly used for recreation, in part due to its unattractive appearance and the presence of the sandy pocket beach farther north (background of Figure 2). No renourishment is planned, but the option of covering the sediments with more attractive materials is still under study.

The backbeach is narrow (Figure 3) due to the small volumes of fill used, the truncation of the landward portion of the active beach by a low wall at the shorefront road, and the relatively low wave-energy regime that restricts cross-shore sediment transport. The modal size fraction of sediments on the foreshore and storm foreshore is predominately small pebbles (Figures 3 and 4). Samples taken at depth on the foreshore are similar in mean size to the surface samples there (Figure 4), but there are more fine sediments beneath the active foreshore surface (Figure 3) and the sediments are more angular. The great variability in beach slope below sea level on the three profiles indicates that the dumped sediment had not been reworked into an equilibrium slope three-and-a-half years after the nourishment. Overall slope of the south profile is gentler (Figure 3) and there is a greater percentage of large pebbles on the foreshore and storm foreshore than on the other two transects (Figure 4), indicating less wave reworking of the fill. The gentler profile may be the result of low permeability of the fill due to the presence of silts and clays. The sample taken from the unreworked fill (representing source characteristics) reveals a substantial proportion of these finer sediments (Figure 3) that may cause increased local turbidity during future storms. The source materials are more angular than on the beach, particularly compared to the active foreshore, revealing that the soft iron-rich clasts become quickly rounded by low-energy waves. The sample taken on the surface of the backbeach (1 m seaward of the wall) is 73 percent fine and medium sand. This sand patch appears to be due to wave action rather than aeolian transport because it is relatively coarse and poorly sorted and forms a flat surface rather than an accretional ramp against the low wall. The amount of accretion is small, indicating that modification of the cross-shore gradient by natural processes is evolving slowly due to the limited amount of reworking by the low-energy waves.

Cala Seregola

Cala Seregola (Figure 5) is a 160-meter-long beach enclosed by a shale and siltstone headland to the northeast and a revetment and jetty on the southwest that were built to protect ore handling facilities. The beach is composed of byproducts from mining operations that were deposited at the shore or delivered to it by streams draining the 33.5 ha drainage basin. The history of mining operations is longer at this site than at the others, and there is more sand on the beach and in the

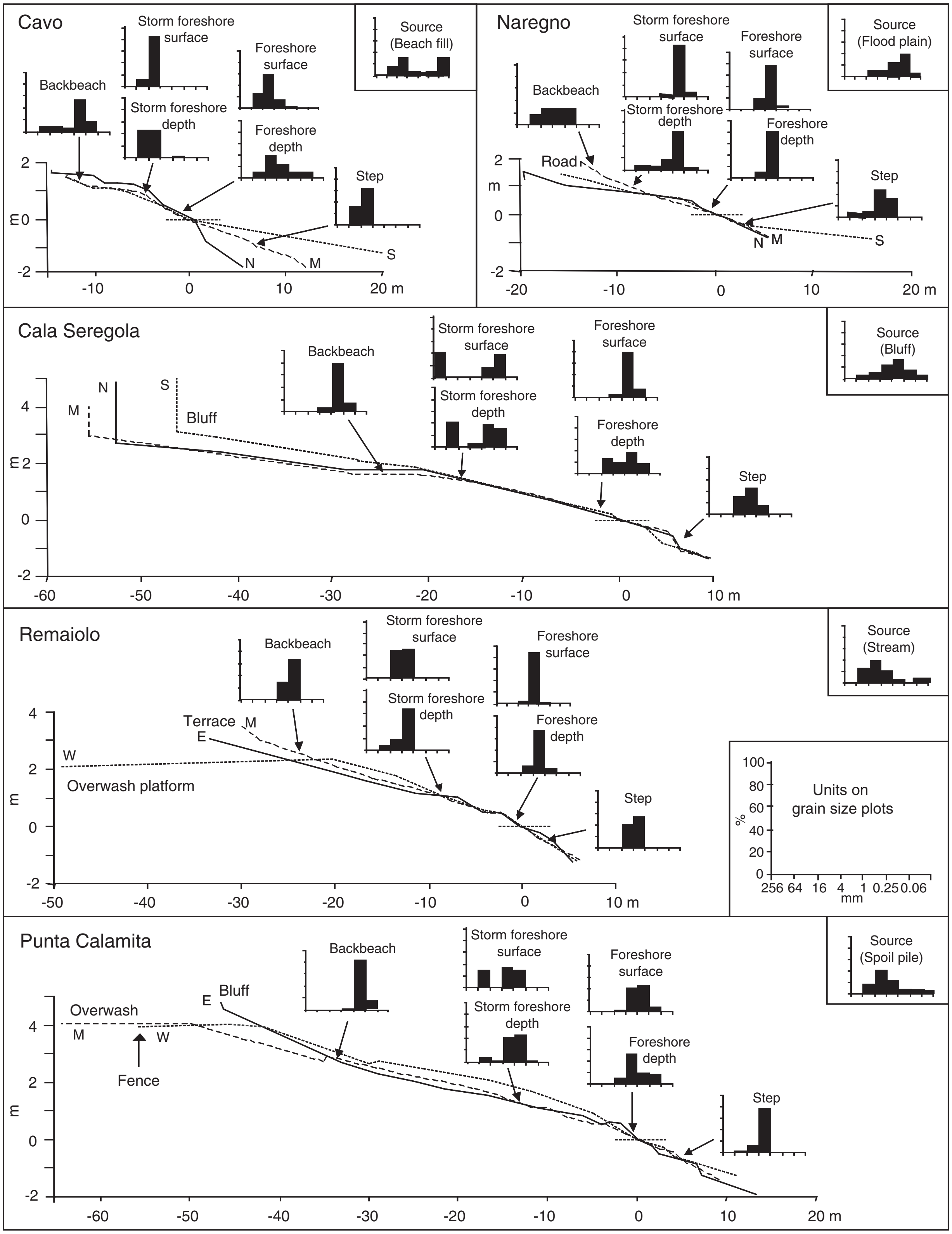

Figure 3. Beach profiles and grain size distributions of sediment samples from center transects and sources. The step sample from the south transect at Cavo is substituted for the missing sample on the center transect. The overwash platform on the West Profile at Punta Calamita is wider than portrayed; the survey was terminated because a fence demarcating private property was encountered.

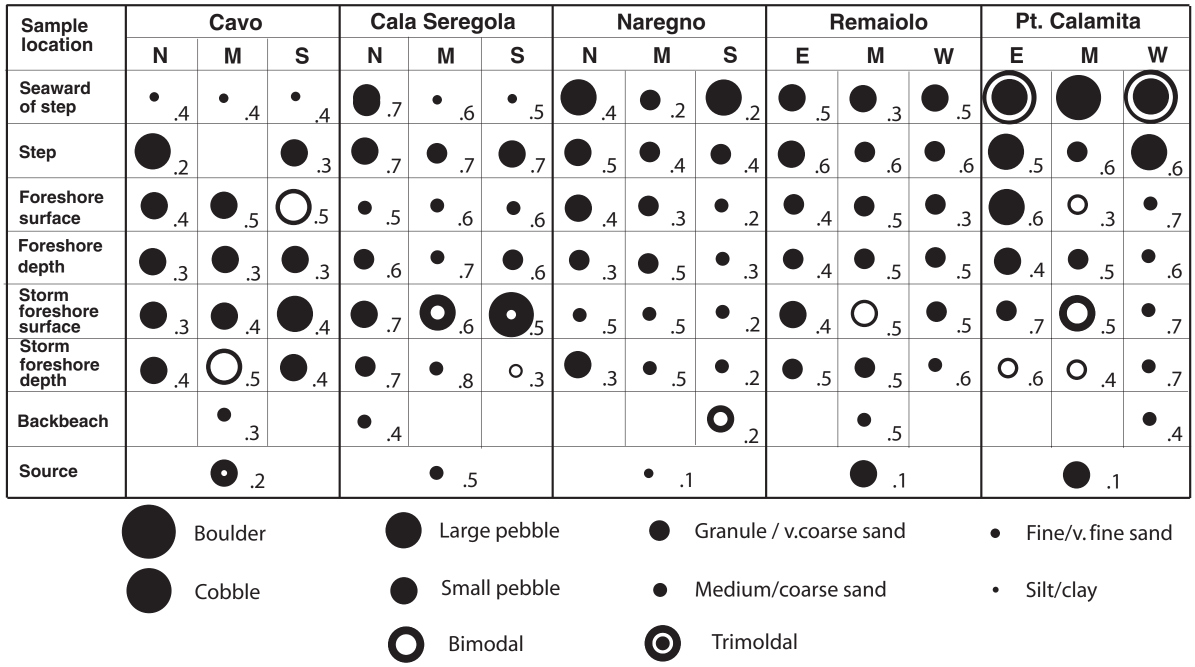

Figure 4. Modal sediment sizes and roundness values (where 0.1 is angular and 1.0 is round). The step sample on the middle line at Cavo is missing due to faulty sampling. Samples seaward of the step at Punta Calamita were estimated visually, and roundness could not be estimated. Upper beach samples were not all on center line, and source sediments were not taken on center line although they are placed in the center of each site for ease of portrayal.

source sediments (Figure 4). Beach materials are limestone, sandstone, schist, and scoria, with a large sand fraction composed of limonite and hematite. The large amount of sand-sized hematite gives the beach a distinctive black color in places. The beach was about the same width in 1954 and 1975, but there was accretion by 1997. There was much less bare ground in the watershed in 1975, implying that there was less runoff and that the source of sediment for the recent accretion was not the drainage basin. The beach is backed by a 1.0 to 3.0 m high bluff cut into a terrace of mine spoils and alluvium that has been graded and used as a parking surface. This terrace is eroded by wave attack during major storms and appears to be the major source of new beach sediments. The backbeach slope is steeper on the south profile, where wave uprush is more truncated by the bluff.

Figure 5. Cala Seregola, June 2002, looking south, showing abandoned ore handling facilities, jetty and revetment, and eroding scarp in the terrace of mine spoils. Waves have organized the surface sediments into distinct zones, with the upper, lighter sandy beach preferred by bathers.

Bluff sediments (and the beach sediments derived from them) are smaller and more rounded than sediments at other sites (Figure 4), implying that they were reworked by waves or running water before being shaped into the flat terrace. The modal size range of the silica sand is medium to coarse (Figure 3), whereas the black sand at comparable beach elevation is fine sand. Beach users prefer the light-colored sand near the berm crest (Figure 5). Better sorting of sediments on the surface of the foreshore than at depth (Figure 3) indicates that wave reworking is confined to the upper layers of the sand matrix.

Naregno

Naregno (Figure 6) is a 490-meter-long beach, enclosed by gneiss and quartzite headlands. Sediments in

Figure 6. Naregno, June 2002, looking southeast, showing the intensive use, low-energy beach, proximity of commercial establishments and trees and shrubs used as landscaping. The shorefront road is just behind the row of trees on the backbeach.

the 250.0 ha drainage basin are composed of these rock types and Quaternary aeolianite and Holocene alluvium. The alluvium just landward of the beach was cultivated farmland until buildings and roads were built (beginning some time between 1954 and 1975). Whatever sediment would be available in the urban and forested drainage basin (Table 1) is now separated from the beach by several hundred meters of buildings and landscaped lots in the resort development. Fluvial runoff is channelized in culverts, and no appreciable amount of sediment is delivered from inland. The dominant beach sediments are gneiss, limestone, and chert, but the sediments show great variety in mineral composition. The relative absence of iron-rich sediments gives the beach a lighter, more pleasing appearance than at Cavo, Cala Seregola, and Punta Calamita.

The shorefront road extends the length of the segment, and the beach has the greatest recreational use of the five sites. The beach at Naregno, as elsewhere throughout Italy, is owned by the state, but most of the beach here is leased to concessionaires who make the backbeach more sandy for tourists by raking gravel from the surface of their plots into the water or into disposal areas on the backbeach in the few publicly managed enclaves. This activity occurs at the beginning of the tourist season and on an as-needed basis thereafter. Removal of gravel from the shore is prohibited, so swash from subsequent storm waves redistributes the gravel, requiring periodic re-raking. On a given day, the texture of the surface sediment exhibits longshore differences related to the amount of effort of individual concessionaires and the location they choose to deposit the unwanted gravel. The division of the beach into small units maintained by individual managers exercising different conceptions of landscape taste results in great variety of types and patterns of vegetation, causing the beach to resemble a garden more than a natural habitat (Figure 6). Most vegetation is ornamental and not typical of beach environments.

The crenulate shape of the bay shore fronting the linear road causes the beach at the middle transect to be narrower and steeper than the two transects closer to the ends of the compartment (Figure 3). The cobbles seaward of the step near the headlands on the north and south sides of the segment (Figure 4) reflect the limited sorting capacity of waves seaward of normal wave breaking and the lack of fresh inputs of sand from streams emptying into the bay. The surface of the raked upper foreshore reveals the sandy texture that is the target of the concessionaires, while the sample taken on the disposal area on the upper beach (Figure 3) indicates the poorly sorted, coarser sediments that would give this beach a different look under natural conditions. The source sample, taken on the floodplain, contains much sand-size material that characterizes the backbeach, but little, if any, of this sediment now reaches the beach via streams.

Remaiolo

Remaiolo (Figure 7) is a 100-meter-long pocket beach enclosed by schist headlands. The beach is formed on alluvium from a 175.4 ha unmined basin with parent rock consisting largely of schist. Beach sediments are mostly quartz, schist, and gneiss and are the least diverse of the five sites. A beach existed here in 1884, and air photos reveal that little change in beach size occurred between 1954 and 1975. Slight erosion occurred by 1997, corresponding to a conspicuous increase in vegetation cover in

Figure 7. Remaiolo, June 2002, looking north, showing the small, unmined drainage basin that has contributed sediments to the small pocket beach.

the drainage basin, which is now largely forested (Figure 7, Table 1).

The beach is steep and narrow where truncated by a terrace in the east and middle segments and wider in the west (Figure 3), where wave overwash deposited sediment in the former stream channel. Beach sediments are relatively coarse, well rounded (Figure 4), and well sorted, even at depth (Figure 3), due to their long residence, the energetic wave regime, and the lack of fresh inputs of sediment due to reforestation inland. Sediments in the stream channel are angular (Figure 4), but little of this sediment now enters the beach compartment. The beach is managed for bathing by a single resort development and is periodically cleaned of litter, but managers have allowed natural vegetation to grow right up to the backbeach (Figure 7).

Punta Calamita

The 370-meter-long beach at Punta Calamita (Figure 8) is bordered by a large pile of mine spoils to the west and a rocky sill to the east. The beach is composed of sediments eroded from the spoil pile by longshore transport or supplied from the backing bluff. No large streams deliver sediment to the beach from the 56.6 ha drainage basin. The 1884 map reveals the beginning of small-scale mining landward of the site and a small beach in the western portion of the compartment. There was no beach in the eastern end of the compartment in 1954 and only a narrow beach in the west. Conspicuous beach accretion occurred between 1954 and 1997. The presence of the scarped, eroding spoil pile on the active beach implies that this was the major source of sediment. The iron deposits inland were covered by crystaline dolomitic limestones and marbles, and beach sediments derived from these cover rocks contribute bright white clasts that contrast greatly with the green schist and gneiss rocks that are the dominant fraction on the beach.

Figure 8. Punta Calamita, June 2002, looking east from the top of the pile of mine tailings, showing the boulders and cobbles near the source and the wide beach created by high-energy waves reworking an ample supply of sediment.

The backbeach in the west and middle segments is a storm overwash deposit composed mostly of iron-rich black sand, with isolated cobbles moved by storm wave swash (Figure 8). The beach to the east is truncated by the bluff and is narrower and steeper (Figure 3). The backbeach is higher than on all other sites because of the greater wave runup associated with higher wave energies. The beach at Punta Calamita is accessible from land only by a long, arduous walk down the bluff, and it is not managed for recreational use. The beach is not raked to remove vegetative litter or gravel. Vegetation consists of natural species, with greater densities near the base of the bluff (Figure 8), where groundwater and debris from mass wasting enhance growing conditions relative to the well-drained beach sand.

Discussion

Hydrologic and geomorphic adjustments of landscapes follow time sequences of successive vegetation cover types that change with changes in the economic use of rural areas; these sequences are usually not continuous in space and not unidirectional (Magilligan and Stamp 1997; Fall, Lines, and Falconer 1998; Mertens and Lambin 2000). The beaches on Elba Island reflect temporal and spatial differences in land use as well, with agriculture and mining resulting in the delivery of sediment to beaches and conversion to a tourist economy resulting in reduction in sediment inputs and truncation of beach profiles.

The volumes of sediment that were delivered directly or indirectly to the beaches on Elba due to mining operations are small compared to some mining sites in Denmark, Australia, Chile, and Namibia, where hundreds of meters of beach accretion has occurred (Bird and Christiansen 1982; Bourman 1990; Paskoff and Petiot 1990; Smith and Mocke 1998). The volumes at Elba are significant in that sediment from mined areas is the primary source at several sites, and the resulting beaches are in great demand for recreation.

The relative size of beaches on Elba is a function of the availability of sediment, wave energy, and human actions. Narrow beach widths and low backbeach elevations at Cavo and Naregno are attributed to the relatively low wave-energy regime and truncation of the landward portion of the profile by human structures. The beaches at Cala Seregola and Punta Calamita are larger, reflecting the greater energy level of the storm waves and lack of cultural features to restrict wave uprush. The high wave energies and large amount of sediment available at Punta Calamita created a wide, high beach that is prevented from attaining its equilibrium width only by the backing bluff.

The characteristics of beach sediments are also a function of wave energy and human actions. Observations of mixed sand and gravel beaches indicate the likelihood of formation of a surface gravel layer over finer sediments (Isla 1993). This generalization applies to the upper storm foreshore of all sites except Naregno, where the operators attempt to remove the gravel, and at Cavo, where portions of the backbeach have not been reworked by either waves or streams and still have fine-grained sediments in the matrix. The lack of reworking is a function of the limited time available since nourishment and of the low wave energy of this east-facing beach.

The abrasion rate of beach sediments depends on pebble characteristics (especially hardness), hydrodynamics (especially wave energy), and exposure (especially the amount of time exposed to transport) (Dornbusch et al. 2002; Cammelli et al. forthcoming). The iron-rich sediments that remain on the active foreshore surface at Cavo are more rounded and better sorted than sediments at depth (Figures 3 and 4), revealing that some sorting and reshaping by waves has occurred in only three and one-half years. The low-energy waves cause little reworking at depth, and buried sediments have remained angular. The sediments at depth on the foreshore at Cala Seregola show greater roundness, presumably from reworking prior to being delivered to the beach, but poor sorting implies little reworking by waves. Beach sediments at Remaiolo are well rounded, despite being composed of resistant quartzose materials that are likely to have been angular when delivered to the beach by the local stream (Figure 3). Rounding of sediments at Remaiolo and better sorting at depth reflects persistent reworking by high wave energies, aided by the long retention time of the beach sediments on the active foreshore between the closely spaced headlands. All sites except Cavo have broad, sandy backbeach surfaces. Elapsed time is critical to naturalization of sediment introduced to the beach, and more sand should accumulate on the backbeach at Cavo through time.

The beaches on Elba Island that are in developed communities (Cavo and Naregno) share a common evolutionary trajectory with beaches in other parts of the world that are in demand for recreation, including (1) supply of sediment to the coast by natural processes; (2) delivery of increased quantities of sediment due to human activities in drainage basins; (3) discovery of the value of the beach for recreation; (4) loss of beach space and restrictions to sediment sources by building facilities too close to the water; (5) recognition of the value of the beach, followed by attempts to overcome the loss of beach width; and (6) conversion of the character of beaches from naturally functioning environments to generic cultural environments (specifically Naregno) by landscape grooming. Some of the natural values and human–nature relationships lost in this conversion process can be recaptured by nourishing beaches with compatible sediment and allowing natural processes to reestablish landforms and biota. The problem of maintaining beach resources on the east side of Elba is less acute than in some coastal locations because the headlands (and groins at Cavo) help retain sediment within compartments.

Stakeholders at Cavo are not unusual in their dissatisfaction with the turbidity and discoloration of nearshore waters, the alien appearance of the beach due to black sand and fine-grained sediment, or the desire to replace the sediment with more aesthetically appealing sand (Chandramohan et al. 1998). The visual impact of turbidity from disposal of mine spoil can seem more threatening than its actual impact on biota (Smith et al. 2002), so the problem may be more perceptual than real. People can become satisfied with a changing landscape, whether it degrades or improves (Dustin and McAvoy 1982; Nordstrom and Mauriello 2001). The stakeholders at Cavo may become accustomed to the new look of the beach as the sediments are eventually reworked to a more compatible size and shape.

Rounding and sorting of disposed mine products is a function of wave reworking that is more effective on high-energy coasts (Bourman 1990; Paskoff and Petiot 1990). Sediments are becoming better sorted at Cavo through elimination of fine-grained material, and they are becoming rounder because of the soft, iron-rich sediments (Figure 4). Marble becomes quickly rounded (Cammelli et al. forthcoming), implying that the marble and soft limestone waste materials in the mine sites near Punta Calamita would make good fill materials for the low-energy east coast sites. The pleasing color of these sediments would be another benefit.

The characteristics of beach sediments at Cala Seregola indicate that source materials that have been previously reworked would accelerate the naturalization process. Prewashing to remove silts and clays prior to emplacing beach fill (to reduce turbidity) or mechanical grading of a nourished beach to cycle sediments into the wave and swash zones (to cause better rounding of sediments) are alternatives used elsewhere (Pacini, Pranzini, and Sirito 1997; Cammelli et al. forthcoming).

These management interventions have potential value for beaches such as Cavo, where wave energies are low and the small amounts of sediment needed make processing economically feasible. Moving gravel from the backbeach to the active swash zone at Naregno is a small-scale, labor-intensive example of this process, although it is not done specifically for this purpose.

Ways may be found to use technology to separate the limestone from the iron-rich sediment in future borrow areas and to use the limestone as fill or surface veneer over sediment with mixed mineral composition. The same types of materials processed during iron production would be used, but the extraction and use of rock types formerly of less interest would be favored.

Conclusions

An ever-increasing reliance will be placed on use of fill materials that differ from the sediment that occurs on eroding beaches, placing greater interest on identifying ways that exotic sediment becomes more acceptable to stakeholders. The sediments made available through past economic activities at Elba have great value as an environmental resource. Many of the materials may appear unsuitable as beach sediments initially, but they will become more natural in appearance through time. Human actions can accelerate the process of converting the fill sediments to a more natural appearance, giving them greater value for recreational use. The acceptability of beach sediment in terms of size, sorting, and angularity is determined by (1) mineralogy; (2) method of sediment delivery by streams, bluff erosion, and artificial nourishment; and (3) subsequent modification by wave reworking and beach grooming. Softer fill materials may be more suitable for nourishment of sites such as Cavo, where wave energies are relatively gentle. Sediments taken from streams near mine sites may be more rounded and better sorted and provide more compatible fill materials than sediments taken from spoil piles. Removal of fines and rounding of sediments used as beach fill can be accelerated by pretreating borrow materials or recycling sediment into the active foreshore after placement. Beach grooming provides a fast way to create a sandy backbeach, and grooming may be required to accommodate users of nourished beaches where wave energies are low. The great value of beaches as recreational resources makes a variety of alternatives practical.

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