

A RAPID COMPATIBILITY ANALYSIS OF POTENTIAL OFFSHORE SAND SOURCES FOR BEACHES OF THE SANTA BARBARA LITTORAL CELL

Neomi Mustain[1], Gary Griggs[1], Patrick L. Barnard[2]

1. Department of Earth and Planetary Sciences, University of California, Santa Cruz, 1156 High Street, Santa Cruz, CA 95060, USA. nmustain@pmc.ucsc.edu, griggs@pmc.ucsc.edu
2. United States Geological Survey, Pacific Science Center, 400 Natural Bridges Drive, Santa Cruz, CA 95060, USA. pbarnard@usgs.gov

Abstract: The beaches of the Santa Barbara Littoral Cell, which are narrow as a result of either natural and/or anthropogenic factors, may benefit from nourishment. Sand compatibility is fundamental to beach nourishment success and grain size is the parameter often used to evaluate equivalence. Only after understanding which sand sizes naturally compose beaches in a specific cell, especially the smallest size that remains on the beach, can the potential compatibility of source areas, such as offshore borrow sites, be accurately assessed. This study examines sediments on the beach and in the nearshore (5-20m depth) for the entire Santa Barbara Littoral Cell east of Point Conception. A digital bed sediment camera, the Eyeball©, and spatial autocorrelation technique were used to determine sediment grain size. Here we report on whether nearshore sediments are comparable and compatible with beach sands of the Santa Barbara Littoral Cell.

INTRODUCTION

Beaches are extremely important in California: they provide a large recreational area for an ever increasing tourist and coastal population, they offer invaluable protection to bluffs, cliffs and back beach development from direct wave attack, and they provide unique habitats supporting many diverse species. In addition, the beaches of California benefit not only the economy of local communities and the state, but also the entire United States (King 2002; King and Symes 2003). Most of the beaches of the eastern Santa Barbara Littoral Cell (from Point Conception to Point Mugu) are naturally narrow (Flick 1993; Wiegel 1994). Although beach widths fluctuate in response to seasonal and climatic cycles (e.g. PDO, ENSO), there is data suggesting that the beaches of this cell are also narrowing in response to human activities (Runyan and Griggs 2003; Willis and Griggs 2003; Revell and Griggs 2006). Because the beaches of California are a valuable natural resource, it is important to consider approaches to expand the existing beaches to a healthy width that will allow the surrounding coastal communities to maintain beaches that are safe and appealing for recreation, suitable for existing biological diversity, and are economically productive.

One possible way to widen a beach is through nourishment, or the addition of sediment to the beach. For a nourishment project to be successful, however, suitable sediment-sand with a grain size equivalent to or slightly coarser than sand found naturally on the beach-must be used (National Research Council 1995; Dean 2002; U.S. Army Corps of Engineers 2002). In this study we have surveyed the Santa Barbara Littoral Cell beaches and nearshore inner shelf to inventory natural grain size distributions and determine whether suitable material for nourishment exists offshore. Traditional methods of grain size analysis require considerable time to process samples, whether through sieving or settling. As an alternative, we used a relatively new method, the USGS-developed digital bed sediment Eyeball© camera and autocorrelation algorithms, to rapidly collect and process over 400 sediment samples (Rubin 2004; 2006). The speed and efficiency of both the collection process and the grain size determination technique have allowed for an unprecedented amount of data to be gathered quickly (within a summer) for the study area, thus allowing us to quickly assess the broad compatibility of inner shelf and onshore sediments throughout a very large area-about 149 km (~93 miles) of coastline.

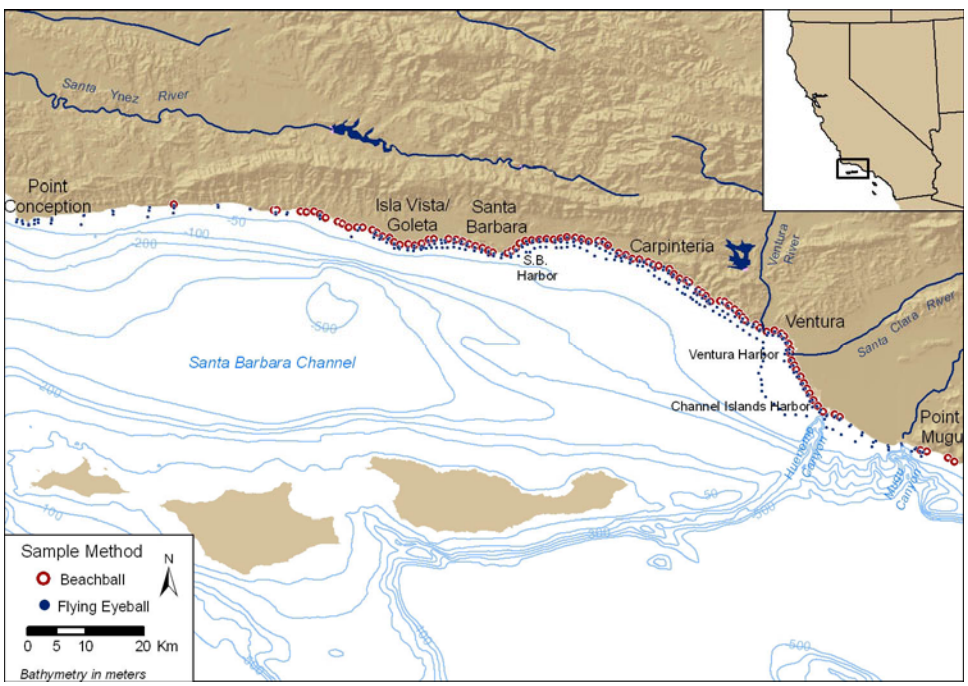

Fig. 1. The Santa Barbara Littoral Cell (from Point Conception to Point Mugu), with beach (Beachball) and nearshore (Flying Eyeball) sampling locations.

BACKGROUND

The Santa Barbara Littoral Cell, east of Point Conception, extends 149 km southeast, terminating at the Hueneme and Mugu Submarine Canyons (Fig. 1). In the west, the majority of the south facing coastline consists of thin, narrow beaches backed by vertical sedimentary cliffs. South of the Ventura River, the coast opens up into a large, populated alluvial plain, fronted by wider beaches and coastal dunes. Sediment is supplied to the cell from north of Point Conception, coastal cliffs and small coastal streams along the northern Santa Barbara Channel, and two large rivers (the Ventura and Santa Clara) in the eastern portion of the cell (Patsch and Griggs 2005). Sediment is transported through the cell primarily by longshore currents, which flow dominantly from west to east due to the common oblique wave approach. Although waves drive the longshore current, the wave climate is generally mild along most of the south-facing coast. This is a result of the coastal orientation which limits wave exposure: waves must enter the Channel directly from the west, bend around Point Conception from the north, or pass between the Channel Islands from the south. From Isla Vista to the Mugu Naval Air Base human development dominates the coast. In addition to building coastal protection structures directly on the beach, people have also extensively developed atop coastal dunes, bluffs and reclaimed wetland areas.

Nourishment may be a solution to the problem of narrow beaches, although many concerns still exist (Griggs 2006; Patsch and Griggs 2006). One issue along this coast is that a very large volume of sediment would be needed for a successful project, as the rates of littoral drift are very high throughout the cell; rates are estimated to be ~300,000 yds^3/yr at the Santa Barbara Harbor, ~600,000 yds^3/yr at the Ventura Harbor and ~1,000,000 yds^3/yr at the Channel Islands Harbor (Patsch and Griggs 2005). As a result of the large volume of sediment needed for nourishment, offshore sediment sources, as opposed to inland sources, may be the more economical option (Patsch and Griggs 2006). When initially locating a suitable offshore source, or potential borrow area, sediment characteristics, environmental impacts and dredging feasibility, both technological and economical, must be considered (National Research Council 1995; McLellan and Hopman 2000; Dean 2002).

Sediment characteristics, such as grain size, sorting, and thickness, in the potential borrow area are very important. Sediment that is too fine-grained is not suitable nourishment material: fine sediment will not remain on the beach, is undesirable by the user population and may also store contaminants (National Research Council 1995). Previously, the sand-silt cutoff diameter, 0.0625 mm, has been used to determine what could be placed on the beach. However, recent studies have shown that on some of California's high-energy beaches very fine-grained sand, or in some cases, even fine-grained sand, is not stable (Limber et al. in press). As a result d_{10}, or the finest 10% of a sample's sediment distribution, has been used to define the littoral cutoff diameter (LCD), or the smallest size of grains that are present or stable on any particular beach (Best and Griggs 1991; Runyan and Griggs 2003; Limber et al. in press).

Offshore California, there is generally a gradation from coarser to finer sediments moving offshore and typically coarser sediments (consistent with a transgressive shoreline) in the subsurface. Processes that operate along the coast-wind, wave and current driven-control the ultimate site of sediment deposition. Coarse sediments can be deposited in high-energy environments, while fine sediments are kept in suspension until they are transported into calmer environments where they can settle out. The California coast is dominated by very fine sands and mud; however, the Offshore Surficial Geology Map of California also indicates that there may be medium and coarse sands, suitable deposits for beach nourishment, offshore (Welday and Williams 1975). Deposits of coarse sediment may be found in localized, present-day high-energy environments, or as relict beach or channel deposits trapped within tectonically controlled structural highs and lows which were deposited when sea level was lower (Welday and Williams 1975; Fischer 1983).

Recently, the USGS has compiled data on seafloor sediment characteristics, including surficial grain size from cores, into a comprehensive database, usSEABED (Reid et al. 2006). Some nearshore cores reported in usSEABED are inconsistent with the Offshore Surficial Geology Map of California: instead of coarse and medium-grained sand, cores contain very fine sand or silt (Welday and Williams 1975; Reid et al. 2006). While these differences may represent natural changes within a dynamic environment, the change may alternately result from limitations of the Welday and Williams map. The Offshore Surficial Geology Map was compiled from various sources which were collected between 1855 and 1975. Currently there is no detailed information about data density, data quality or the original data collection methods or classification schemes. In addition, fine sands and very fine sands were mapped together as one unit, and if the specific class of sand was undefined in the original data set, it was mapped as medium sand by Welday and Williams. The present study will rework and update this surface sediment map for the innershelf.

Previous studies have surveyed the continental shelf, with geophysical profiling and coring, to assess offshore sand sources in various locations of the Santa Barbara Littoral Cell (Noble Consultants 1989). This study takes a different approach to locate additional suitable sand deposits; we examine and map mean surface grain size over a wide area of the inner shelf using the Eyeball© camera and spatial autocorrelation algorithm. The major shortcoming of this method is that only surface grain size is captured. However, this bias can be limited by testing Eyeball© images with grab samples that penetrate several centimeters beneath the surface. The major advantages of this method are the extensive amount of area that can be covered as a result of the speed of the collection method, the number of samples that can be processed as a result of the rapid grain size determination method, and that samples can be taken in very shallow depths-as shallow and close to shore as small coastal research vessels can safely transit.

METHODS

The field survey was designed to collect samples along a cross-shore profile, from the beach and the nearshore at 5, 10 and 20 m water depth, with transects spaced at least every kilometer alongshore, throughout the entire Santa Barbara Littoral Cell (Fig. 1). To compare seasonal grain size variations, beach samples were also collected in March and October (winter and summer samples) at Isla Vista/Goleta, Carpinteria, and Ventura at a higher spatial resolution.

Two different Eyeball© camera systems were used to collect digital samples. Swash samples were collected with the Beachball© camera, a 5-megapixel digital camera encased in a waterproof housing (Rubin 2006). To sample the beach, the camera is placed flush against the sediment, which is illuminated by a ring of LED lights. Camera settings such as aperture, shutter speed, zoom, focus, and pixel resolution of the image are held constant. Nearshore samples were collected with the underwater Eyeball© version, the Flying Eyeball©, which is a video camera illuminated by LED lights encased in a wrecking ball (Rubin 2006). Live video is reviewed on deck while the instrument is repeatedly raised and lowered to the seafloor to collect digital video samples. The clearest frames of video are then captured as still images and processed for grain size. For both systems, multiple images are taken at each location and later averaged into one grain size result.

Images are processed by running a Matlab© script that uses a spatial autocorrelation algorithm developed by Rubin (2004). This algorithm determines the correlation (as measured by pixel intensities) between a pixel and subsequent pixels at increasing distances. Grain size of an image is then interpolated by comparing the spatial autocorrelation result to a calibration matrix. The calibration matrix contains spatial autocorrelation results of calibrated sample images and was produced by imaging ¼ phi interval sieved sediment collected from throughout the study area with the same equipment and camera settings as used in the field. The calculated calibration matrices are valid only for sediment of similar size, shape and mineralogy as the sediment initially sieved and imaged. Figure 2 shows the mean grain size determined from the autocorrelation method compared to mean grain size from both processing samples in a settling tube (Fig. 2b) and from point counting, or calculating the mean of an image by hand-measuring the size of 100 grains in the image (Fig. 2a).

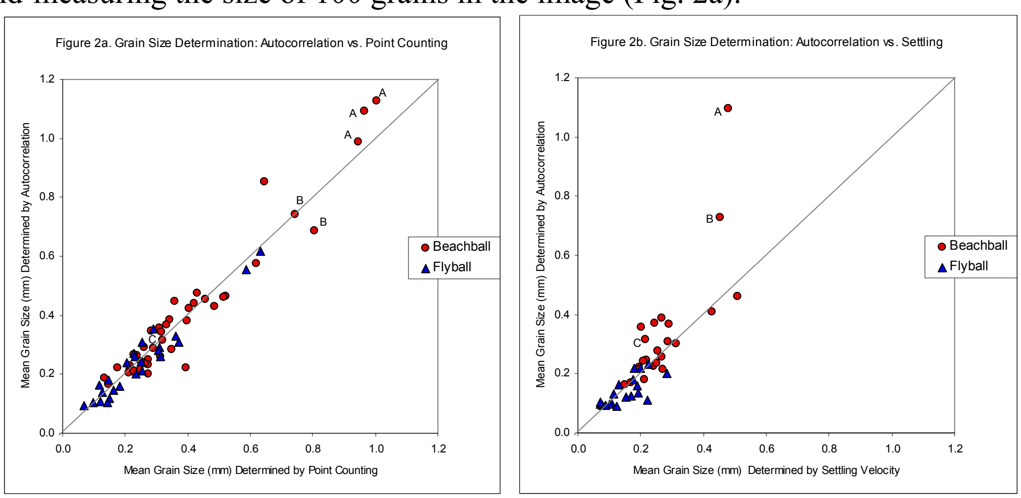

Fig. 2. Mean grain size of Eyeball© images: autocorrelation method compared to point counting of images (2a) and settling velocity of grab samples (2b). Samples A, B, and C are labeled in both 2a and 2b.

On the beach, there is a potential bias for sampling coarser surficial sediments (Fig. 2b). This may occur if fine sediments have been winnowed away or if a coarsening-upward sequence has developed. Beach samples that fall off the 1:1 line of correlation in Figure 2b may be a result of either of these two processes. However, the autocorrelation method is still valid-samples off the 1:1 line in 2b, appear near the 1:1 line in 2a-since point counting determines whether the algorithm accurately determines grain size of the image. In the nearshore, there is a potential bias for surface sediments to be finer than the immediate subsurface layer (Fig. 2). Consistent with rising sea level, this may be a result of recent fine sediment deposition. Alternately, fine sediments could have been winnowed or washed while bringing the grab sampler to the surface, resulting in grab samples appearing coarser than they actually were.

The autocorrelation method, especially when using the Flying Eyeball©, is limited by pixel resolution: once grains become very small (as small as or smaller than two or three pixels) clusters or flocs of small grains begin to look (in terms of correlation) like larger grains. As a result, when nearshore grain size is less than 0.09 or 0.10 mm, the ability to accurately determine grain size by the autocorrelation method is diminished. However, this is not a significant problem for this study because the aim of offshore sampling is to determine if beach compatible material exists, and from the following conclusions, an acceptable grain size cutoff for the Santa Barbara Littoral Cell beaches is 0.125 mm, making the Flying Eyeball© results adequate and this study applicable.

RESULTS

The mean grain size of 93 swash zone samples from throughout the Santa Barbara Littoral Cell ranged from 0.15 mm to 0.43 mm (fine to medium sand; Fig. 3). The mean of one sample just north of the Port Hueneme Harbor was 0.60 mm, or coarse sand. The average of all (94) samples was 0.27 mm. Grab samples were well sorted: in most cases, 80% of a sample's grain size was distributed across only one phi interval. The finest sediment on the beach (d_{10}) varied from location to location, but followed the mean well (when the mean increased so did d_{10}). Very fine-grained sand did not remain on the beach in any significant amount anywhere throughout the cell (Fig. 3). Mean grain sizes of summer swash samples were smaller than winter swash samples throughout the beaches of Isla Vista/Goleta, Carpinteria, and Ventura. Grain size in the southeast decreased seasonally more than in the northwest: Ventura beaches seasonally fined an average of 0.15 mm, Carpinteria beaches fined an average of 0.08 mm, while Isla Vista/Goleta beaches fined an average of only 0.05 mm.

Throughout the cell, 319 nearshore locations were examined, although some areas were cobble or bedrock reefs, which did not allow for grain size determination. Mean grain size was determined for about 100 samples at each water depth (5, 10, and 20 m). Grain size fined moving from the beach offshore (Fig. 4). Only 2% of all samples were medium

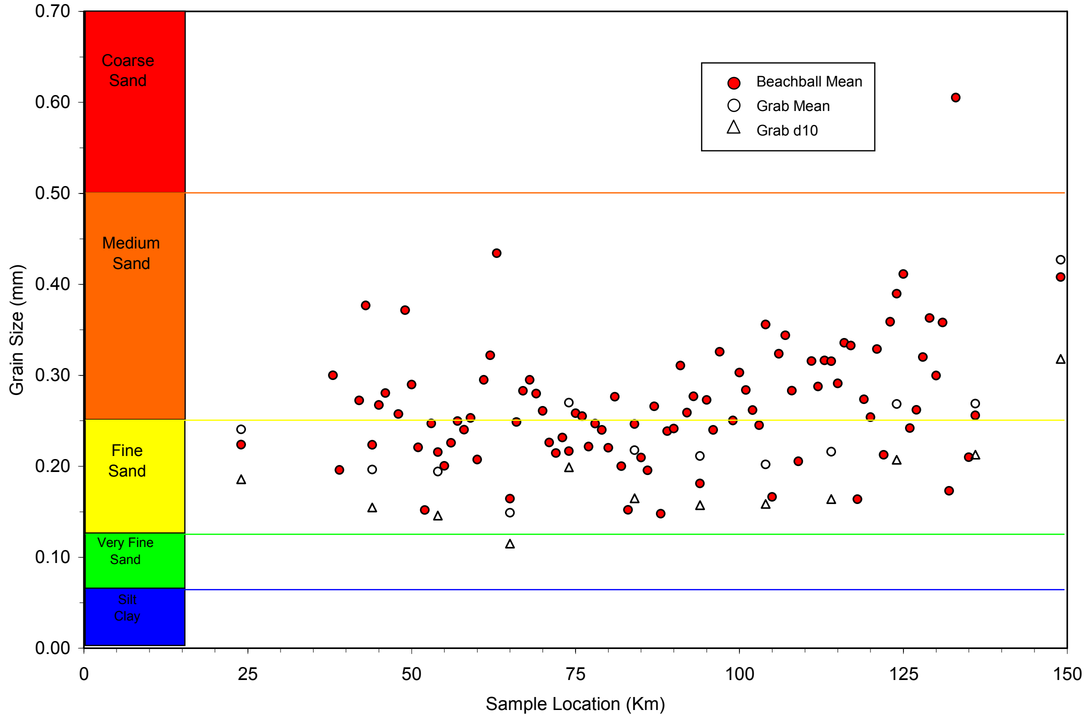

Fig. 3. Mean grain size and d_{10} of beach samples.
Horizontal axis is distance east of Pt. Conception.

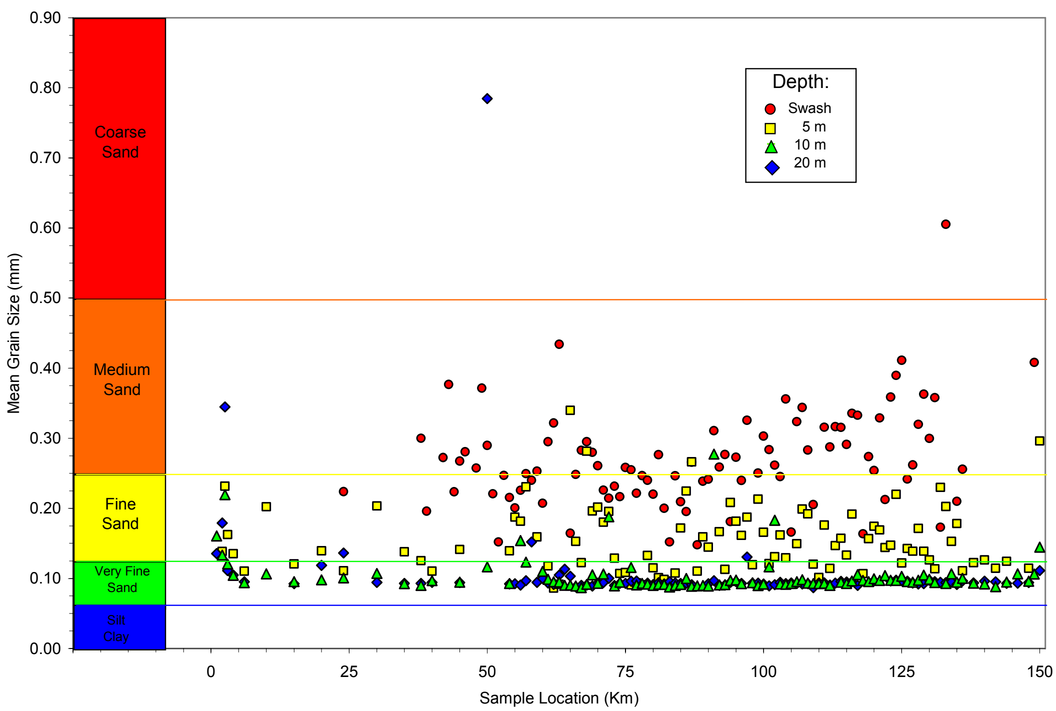

Fig. 4. Mean grain size of beach and nearshore samples.
Horizontal axis is distance east of Pt. Conception.

sand, 24% were fine sand and 74% were very fine sand or smaller. The coarsest samples were found in shallow depths: 82% of all samples coarser than very fine sand were located in 5 m water depth. Only 5% of all Flying Eyeball© (15 samples) found in 10 or 20 m water depth were coarser than very fine sand. Some of these coarser, deep samples were located near major headlands, such as Point Conception and Point Mugu, near offshore reefs, such as west of Coal Oil Point in Isla Vista and Sand Point in Carpinteria, or offshore rivers and streams, such as Gaviota Creek and Rincon Creek. Samples coarser than very fine sand not located near headlands, were likely to be fine sand (75%) rather than medium or coarse sand (25%).

DISCUSSION

The majority of Santa Barbara Littoral Cell beach sediment is fine to medium-grained sand (Fig. 5). When the cell is divided based on physical setting by the Ventura River (location #117), beach sand in the western portion of the study area is finer grained than in the eastern portion. This is likely a result of regional differences in both sediment inputs and coastal processes. For example, if the Ventura and Santa Clara rivers in the southeast deliver a coarse load, and if the fine-grained bluffs of the west contribute fine sediments to the beach, than the resulting beach grain size could be a result of sediment source grain size. Differences in wave energy and nearshore current velocities are also important in determining what sediment grain sizes compose the beach. Coarser beaches in the east are more exposed to high wave energy as compared to finer beaches in the west/central, which are more sheltered from the dominant wave energy. (Beaches at the westernmost end of the Channel would also be exposed to greater wave energies and may also be comparatively coarser, but these beaches were not sampled.) Seasonal alongshore variation, as measured by the magnitude of grain size change, may be a result of alongshore differences in both sources and processes acting on each particular beach.

Summer grain size distributions represent the finest sediment that remains on the beach. An examination of the grain size distribution of summer grab samples indicates that nowhere in the cell does the sand/silt break define what grain sizes compose the beach. Runyan and Griggs (2003) previously determined that the average Santa Barbara LCD was about 0.125 mm. However, results from this study indicate that a single value cannot accurately define what remains on the beaches throughout the entire cell. When nourishing a beach, the appropriate cutoff diameter, specific to that beach, should be used. In general terms, when assessing potential offshore sources for the cell, the boundary between fine sand and very fine sand (i.e. 0.125 mm), can be used as a general LCD because this value will not underestimate what will remain on the beach. However, in some cases-possibly more in the eastern portion of the study area-this value may be an extreme overestimation.

As expected, finer sediments are found offshore. Coarser sediments are not transported into deeper waters since they are not easily kept in suspension; instead they settle nearshore. Overall, the coarsest offshore sediments exist in an extremely narrow zone close to shore, probably within the depth of closure. These fine and medium-grained sands are likely an active part of the littoral drift system and anchor the submarine beach

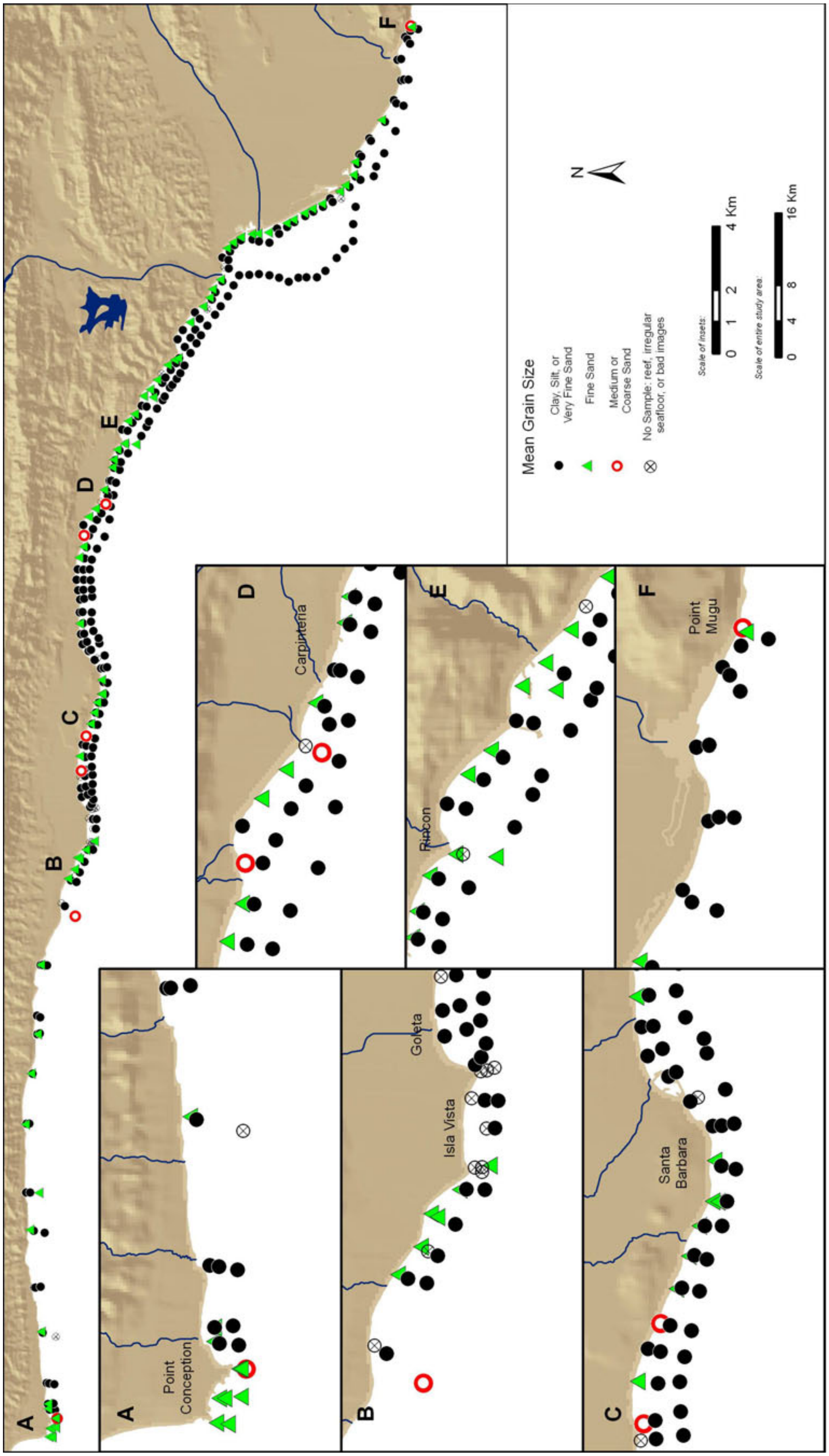

Fig. 5. Mean grain size of nearshore (5, 10, 20 m) Flying Eyeball Samples, eastern Santa Barbara Littoral Cell.

profile. As a result these coarser, shallow sediments should only be considered sources for beach nourishment with a thorough evaluation of the coastal impact. This includes sediment within 5 m and other deeper areas affected by higher energy.

The coarsest offshore sediments deeper than 5 m are found at only a few locations throughout the cell (Fig. 6 and 7). Coarser sediments are commonly found near major headlands, such as Point Conception and Point Mugu, as a result of the steeper nearshore slopes and/or higher energy environment. As a result of additional energy focused onto the headland and because these sediments are located close to shore, within ¾ of a km at Point Conception, these deep, coarser sediments may still be part of the active littoral drift system, within the depth of closure. However, more information is needed. If it is confirmed that these deposits are part of the active littoral system, then they should not be dredged. However, if they are not, then thickness of the deposit and the economics of dredging these areas should be evaluated-keeping in mind that these sediments are located far from populated beaches needing nourishment.

If Point Conception is not considered too far to serve as a potential borrow area, then one other site should be examined: an offshore geology map indicates a large sand deposit just offshore of Point Conception (Greene and Kennedy 1989). The sediment here could be a final sink for the Santa Maria Littoral Cell (a debated cell extending from the Santa Maria River to Point Conception), or if there is a single continuous cell around the point, then this deposit could be a partial sink within the Santa Barbara Littoral Cell (Patsch and Griggs 2005). Either way the deposit is likely to have accumulated as a result of the longshore current deflecting sediments offshore as it encounters the headland. Further investigation of the area is recommended; both sediment thickness and grain size data should be obtained.

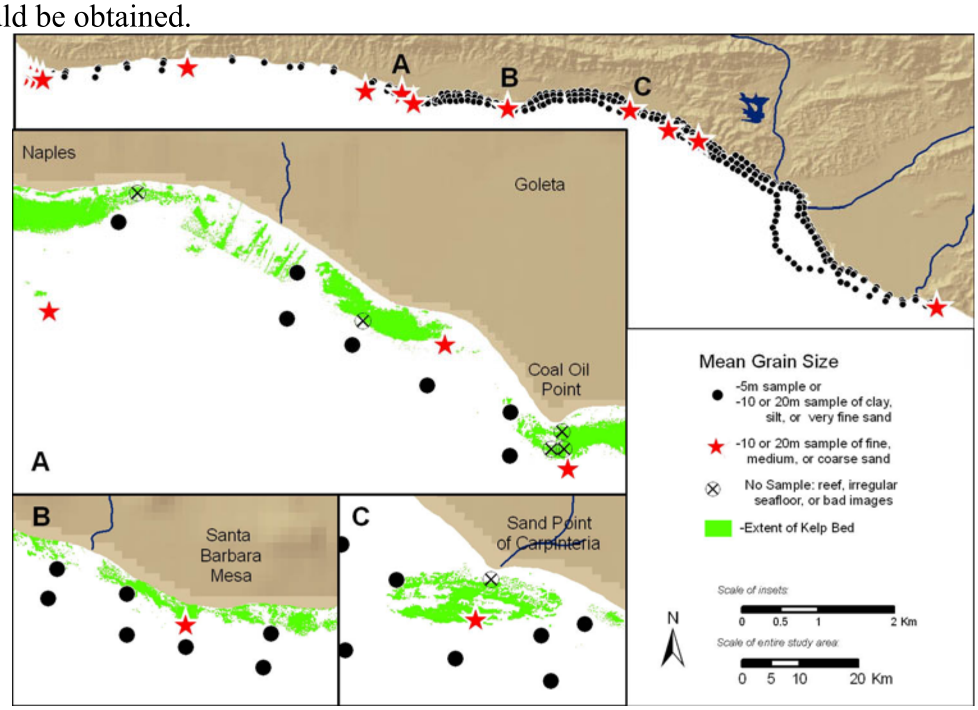

Fig. 6. Coarser samples in 10 and 20m water depth (locations starred). Insets show coarser samples and proximity to kelp beds.

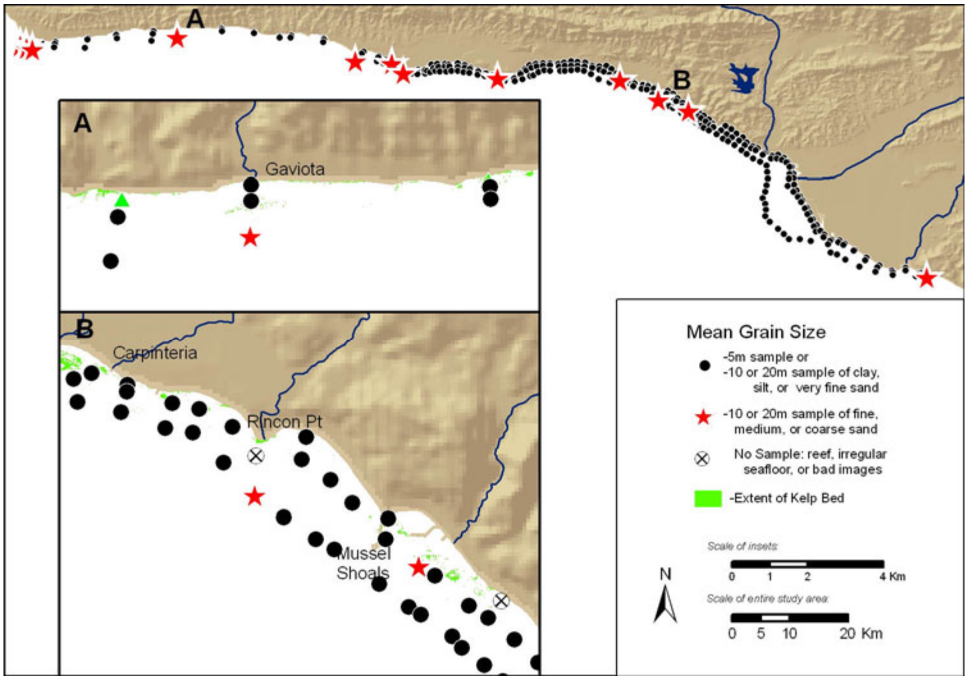

Fig. 7. Coarser samples in 10 and 20m water depth (locations starred). Insets show coarser samples and proximity to kelp beds and streams.

Sample locations of coarser sediment found deeper than 5 m, were examined with respect to distance from kelp beds, a proxy for exposed bedrock outcrops on the seafloor (Fischer 1983; California Department of Fish and Game 2006). Sediments found near rocky reefs are likely to be composed of coarser broken reef fragments which have accumulated in reef pockets. These deposits are presumably very thin and therefore not viable for dredging. The samples west of Coal Oil Point and offshore of Sand Point in Carpinteria are in very close proximity to the mapped kelp beds (Fig. 6). In addition it was noted in the cruise field notes that the Flying Eyeball© had to be navigated through kelp to reach the seafloor at these locations. As a result, these coarser deposits are most likely only thin deposits within reef pockets and are therefore not considered suitable borrow areas for beach nourishment. For a few locations, south of Coal Oil Point, Naples, and the Santa Barbara Mesa, it is not clear whether coarser samples are related to the nearby reefs (Fig. 6). All three of these samples were in close proximity to kelp; however, the isopach maps of Fischer et al (1983) indicate that the unconsolidated sediment is at least 4 m thick at each of these locations.

Coarser samples deeper than 5 m are sometimes found offshore rivers and streams (Fig. 7). If these deposits are not relict beaches, than they may be associated with the stream as either part of a paleostream deposit or as a result of a more recent hyperpycnal flow (Fischer 1983; Warrick and Milliman 2003). If the deposit is related to an old stream channel from an earlier sea level, it would be expected to contain coarser sands and gravels, which may or may not be suitable for nourishment. Grain parameters such as shape and roundness, and characteristics such as sorting and layering of grain sizes within the deposit, should be thoroughly examined to determine if sediments are compatible with the beach. In addition, it should be confirmed whether sediment thickness is sufficient in these areas. The isopach maps of Fischer et al (1983) indicate adequately thick unconsolidated sediments at Gaviota, Rincon Point, and Mussel Shoals. However, while these samples are not located within the present-day kelp cover, they are located within the historic kelp extent as mapped by Fischer et al. (1983).

In addition, because the Flying Eyeball© only samples surface sediments and coarser deposits may exist beneath the surface, it is recommended that complete grain size distribution be obtained offshore Goleta, the Santa Barbara Mesa and Harbor, and the Ventura/Oxnard area (Fig. 8). However, since greater wave energy is received in the eastern portion of the study area, if compatible sediments are found at 10 m water depth in the Ventura/Oxnard area, it needs to be determined whether these sediments reside within the depth of closure before a borrow area is considered.

It is difficult to evaluate how well the results of this study compare to the offshore surficial deposits map, since an overwhelming 98% of the offshore samples observed were very fine sand or fine sand which was mapped as one unit by Welday and Williams (1975). However, some of the smaller pockets of medium and coarse sand delineated by Welday and Williams were found in this study to be composed of fine sand or very fine sand. It is not known however, if this is a result of the original data collection and processing methods, the mapping scheme of Welday and Williams (for example, undefined sand was mapped as medium sand), or as a result of sampling only the very surface with the Eyeball©. Alternately, the observed change may be legitimate and simply the consequence of sediment transport and deposition in a dynamic environment for over 100 years.

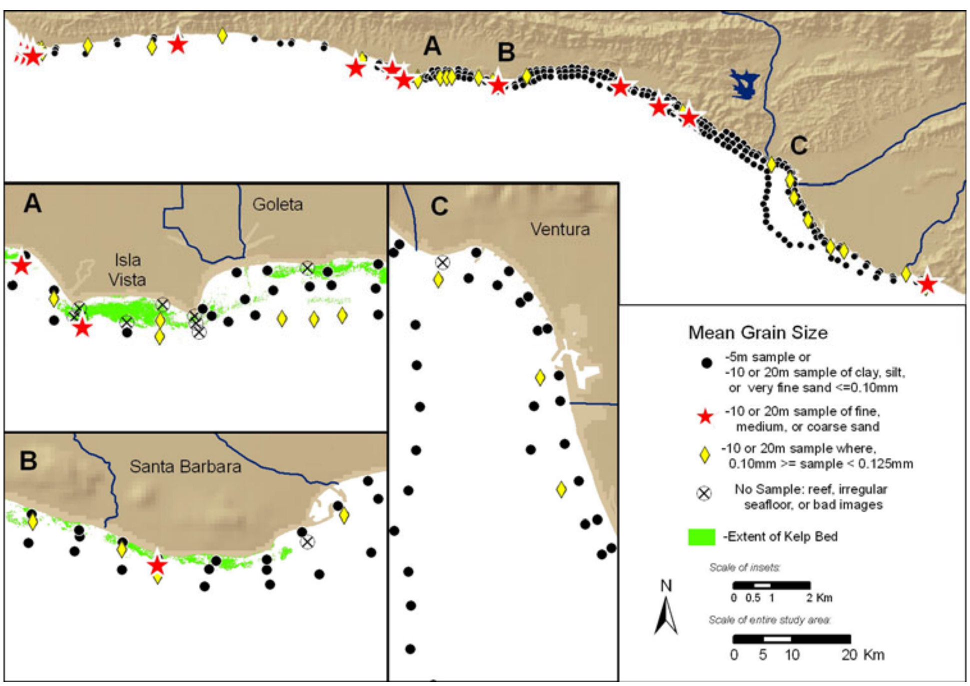

Fig. 8. Coarser samples in 10 and 20m water depth (locations starred), and 10 and 20m very fine sand samples >= 0.10mm.

CONCLUSION

The Eyeball© cameras provide a rapid way to determine the grain size of many surface sediments throughout a very large beach and offshore area. Overall, compatibility is poor between beach and nearshore surface sediments in the Santa Barbara Littoral Cell. The coarsest offshore sediments are found at 5 m, most likely within the depth of closure. Some coarser deposits exist deeper, for example at Naples, Coal Oil Point, the Santa Barbara Mesa, and Rincon Point, but it is unclear whether they are part of a thick deposit of suitable nourishment material, or simply a thin, coarser deposit within reef pockets. Further grain size analysis of cores is recommended to resolve this question. In addition, cores should also be taken at Goleta, the Santa Barbara Harbor, and the Ventura/Oxnard area; surface sediments at these locations were not coarser than very fine sand, but complete grain size distribution should be completed as they showed more promising results of coarser surface sediments and sufficient sediment thickness than most other locations.

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