Estimation of Optimal Beach Profile Sample Intervals

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ABSTRACT


Although alternatives abound, some types of research in applied coastal geomorphology require repetitive monitoring of beach profile transects with elevations recorded at fixed intervals. Where the primary purpose of survey profiles is to estimate beach volumes and sediment budgets, only a reasonable approximation of the beach surface or a reliable estimate of mean elevation is necessary. In such cases field time may be minimized with no cost in accuracy by using wider spacing of sample intervals than is usually the case. The semivariance function is proposed as a method for choosing optimal profile sample intervals, and its use for that purpose is illustrated. Semivariance functions reveal spatial dependencies in survey data which typically provide estimates of optimal sample intervals and justification for less intensive surveys.

ADDITIONAL INDEX WORDS: Beach profile, beach survey, coastal geomorphology, sample intervals, semivariance function.

INTRODUCTION

One of the most common methods of measuring coastal topography is the survey profile. There are several techniques; all involve determining elevations relative to a datum along a linear transect (OWENS, 1982). With care and a trained eye, accurate surveys are possible with break-of-slope methods, where elevations are recorded at visually-determined slope discontinuities. Often, however, concern with statistical methods or efforts to reduce operator variance demand that survey profile elevations be taken at constant, fixed intervals. This may also be the case if fixed stakes are used to monitor change.

Time-series monitoring of dynamic geomorphic systems such as beaches can require repetitive monitoring of survey transects. This can be tedious and expensive, so it is desirable to determine the minimum number of elevation readings that must be taken along a profile to achieve a given accuracy. If the first profiles in a monitoring program are taken at short, frequent intervals, this data can be analyzed to determine whether longer intervals may be utilized without sacrificing significant information. The purpose of this paper is to illustrate the use of the semivariance function for estimating optimal beach profile sample intervals. This function is derived from geostatistics, a body of applied statistics devoted to spatial interpolation, determination of spatial sampling schemes, and related problems. The method is especially applicable where beach profiles are monitored primarily to estimate local sediment volume changes. An example is given from monitoring of a beach nourishment project at Sandy Hook, New Jersey.

THE SEMIVARIANCE FUNCTION

The semivariance function is a central concept of geostatistics and the theory of regionalized variables (MATHERON, 1971). Geostatistics may be thought of as the application of the statistical foundations of time series analysis to spatial data (RIPLEY, 1981). A brief explanation of semivariance is presented below, but interested readers should refer to one of the reference works on geostatistics and geomathematics (AGTERBERG, 1974, for example).

Generally, the semivariance function and related techniques such as kriging are used to estimate
The semivariance function reveals the range of distance over which elevations are spatially dependent, the expected elevation difference between surveyed points a given interval apart, and the nature of spatial dependence in the data. The beach surveyor wants to know how much the sampling interval may be lengthened without a significant loss of information. If profiles are taken to estimate sediment volumes, for example, the desired information is the longest sampling interval which will yield a reliable curve representing the beach surface or a reliable estimate of mean elevation.

The semivariance had been defined as half the expected squared distance between points a given distance apart. It is also equivalent to the variance of a sample consisting of only those surveyed points this given distance apart. This property can be exploited to determine optimal sampling distance.

In the beginning of a monitoring program at least one set of profiles should be surveyed at frequent intervals of, say, one to five meters. Semivariance functions can be computed based on this information. The semivariance at each lag up to a distance representing 20 percent of the total profile length can be compared to the total sample variance. Any sample interval less than the distance represented by the lag where the semivariance approaches the total variance may be used without a significant loss of information to generate a reliable estimate of mean beach elevation. If the original sample interval were one meter and the semivariance was found to approach the total variance at lag $h = 10$, then beach volume estimates based on surveys at 10 m intervals would have comparable reliability to estimates based on surveys at 1 m intervals.

This critical interval can be determined directly from the semivariance, or estimated from the semivariogram. The point at which a semivariogram levels off (termed the “sill”) usually occurs at a semivariance value roughly equal to the total variance in the data, since this value is asymptotically approached by most semivariograms. When semivariance functions are known, the required number of samples needed to generate a mean value within some tolerable variance of $s^2_{\text{max}}$ is given by McBRATNEY and WEBSTER (1983)

$$t = 2(s^2_{\text{max}})/w$$

APPLICATION TO BEACH PROFILES

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where $w$ is the ratio of the semivariance to the associated lag. For relatively flat or smooth beach profiles this approach often yields extremely low values. When the number of samples indicated by (4) is too small to plot a reasonable profile curve (this is not uncommon), there are two options. First, the $s^2_{\text{max}}$ value could be decreased. Second, a simple examination of semivariance functions and semivariograms gives an idea of a range of acceptable alternative sampling intervals.

**EXAMPLE**

Seven profile lines established at Sandy Hook, New Jersey were surveyed using a dumpy level and metric stadia rod at five-meter intervals from the backbarrier to wading depths. During the course of the beach monitoring, the profiling scheme was altered in some cases so that elevations were recorded at break-of-slope across the static back beach and at regular intervals shoreward in the active, mobile portion of the beach.

Autocorrelation functions were computed for profiles surveyed in December, 1982, and semivariances were computed from these using equation 3. Semivariograms for three profiles are shown in Figure 1.

The semivariograms show spatial dependence in elevation data through at least seven survey intervals (35 m), and as many as nine intervals. This means that the per-observation variance even over seven to nine lags is less than the total variance in the data. Roughly one-seventh the sampling effort could have produced beach volume estimates of comparable accuracy and a fixed interval considerably longer than five meters could be appropriate.

The procedure was repeated for the same profiles in June, 1983 after the majority of the beach had been smoothed by bulldozing (Figure 2). Although the June semivariances are about a third of the December values and the profiles themselves differ greatly, the pattern of spatial dependence is remarkably stable.

The analysis indicates future monitoring of the Sandy Hook beach could be carried out with 30 to 40 meter intervals with little or no sacrifice of precision. To test this, cross-sectional areas above the mean sea level datum were computed for a number of profiles based on both five-meter and 30-meter data point spacings. Agreement was very close, and cross-sectional area estimates based on 30-meter intervals fell within the confidence limits for estimates based on the more intensive sampling. Calculated values for six profiles are shown in Table 1.

**DISCUSSION**

Although alternatives abound (OWENS, 1982; GOUDIE, 1981; NORDSTROM, 1979), repetitive monitoring of fixed-interval beach profiles is often necessary. Often only a reliable estimate of total volume is required, or detail is needed only in a limited zone. In such cases typical 1-10 meter sampling intervals may represent unnecessary effort. However, use of a fixed interval longer than five or 10 meters may require theoretical or empirical
justification for funding agencies, reviewers, or other research consumers. The semivariance function may provide that justification in many instances. In the case of Sandy Hook beach, semivariance functions showed that beach volumes could be estimated as reliably with 30-meter as with five-meter sample intervals. With seven backbarrier-to-foreshore transects, such a reduction was found to reduce field time for a two-man crew by about three hours per visit. Other savings are possible in data reduction, computer time, etc.

Beach profile monitoring for the purpose of estimating volumetric changes and determining sediment budgets is a much different matter than surveys designed to record details of shoreline processes. In the latter case identification of particular morphologies or features is important, some portions of the profile are more important than others, and detailed transects are needed if profiling is the chosen method of data collection. In the former case only the specification of a representative profile curve or a reasonably accurate determination of mean elevation is necessary.

A mixed profiling strategy may be appropriate in some studies. Separate sampling intervals or methods may be used, for example, in relatively static back-beach or controlled beach areas, and in more active foreshore and nearshore zones.

CONCLUSIONS

Repetitive survey profiling can be tedious. It may be possible to minimize field time without sacrificing accuracy by using longer, less frequent sample intervals than is usually the case. Semivariance functions based on profiles taken at frequent intervals reveal spatial dependencies in the data which provide justification for less intensive surveying. The semivariance can be used to identify the optimal sample spacing.

LITERATURE CITED


PHOTO 12. Coconut palms (*Cocos nucifera*) on the north coast of Trinidad, West Indies. Growth conditions for coastal groves are ideally met on sandy coasts throughout the tropics. Coconuts are widely distributed by currents and deposited on beaches by waves.

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