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Sediment fingerprinting in New Zealand: a pilot study into the feasibility of the application of the technique

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Abstract Statistically Verified Composite Fingerprinting (SVCF) has been attracting increased attention to identify catchment erosion sources, but to date has not been applied in a New Zealand setting. A pilot study was undertaken to investigate if different catchment land-uses (native forest, exotic forest, and pastoral agriculture) can be discriminated by their geochemical fingerprints. Seven elements were found to discriminate between the three land-use types, and a novel method of data resampling was successfully used to verify the selection of fingerprint properties.

Key words sediment fingerprinting; land-use; erosion; discriminant function analysis; estuary sedimentation

INTRODUCTION

Sediment generated by accelerated erosion of the land surface in New Zealand is often deposited into estuary or harbour environments. Coastal margins have high ecological, recreational, and visual amenity values, and these values are vulnerable to modification (Environment Southland 2007). The key to assessing and mitigating the effects of sediment generation is the identification of erosion sources within the contributing catchment. At the catchment scale, determining these sediment sources is complex due to the variable spatial and temporal nature of sediment delivery (Fox & Papanicolaou, 2008). Most studies have applied indirect (e.g. erosion plots or pins) and/or modelling methods to measure catchment soil erosion. Indirect methods measure sediment movement past a point in the landscape but sediment delivery is a complex combination of mobilisation and redeposition and does not act like a conveyor belt. Catchment sediment delivery processes are still poorly understood, making upscaling difficult as well as providing unreliable data for model calibration (Prosser *et al.*, 2001; Phillips *et al.*, 2007).

The technique of Statistically Verified Composite Fingerprinting (SVCF) seeks to address the complex routing of sediment through a catchment by linking catchment sediment source areas with the sinks (Collins *et al.*, 1997). The SVCF technique is founded on two assumptions. Firstly, that the various source areas (e.g. different land-uses, geological provenances, sub-catchments) can be distinguished on the basis of a range of physical, geochemical and biogenic properties. The use of a number of properties to form the "composite fingerprint" aims to reduce the spurious source–sediment linkage that may occur when using a single property. Due to the complexity of sediment routing and delivery, a single property will rarely prove adequate to discriminate multiple catchment sources (Walling *et al.*, 1999). The second assumption is that the range of selected fingerprint properties can determine the relative importance of various source areas when compared to suspended sediment sink material from a harbour or estuary (Collins & Walling, 2002, 2004).

THE SEDIMENT FINGERPRINTING TECHNIQUE

The SVCF technique involves three stages and the first is to select the properties that will potentially form the composite fingerprint from analysis of soil samples taken from the source areas. The method used is the Kruskal-Wallis H-test. This is the non-parametric equivalent of a one-way ANOVA, but uses the sums of the rankings rather than the raw data to determine significant differences between populations. Hypothesis testing is used to determine if the sums of the ranks are significantly different between source areas (i.e. their *p-value* being below the 5% level of significance).

The second stage is concerned with optimising the number of fingerprint properties selected by the Kruskal-Wallis, and this is achieved by Discriminant Function Analysis (DFA). DFA is also similar to ANOVA in that it examines the ability to predict membership to a group based on the means of the variables. Forward stepwise DFA is used. This is an iterative procedure whereby at each step, each element or property not already in the model is considered separately. The property which results in a model with the best discriminating power, guided by the *F-to-enter* value, is selected and entered into the model. The process begins again with the "new" model as the basis for considering the remaining properties. Forward stepwise DFA does not allow for the possibility of removal of a property entered into the model at an earlier iteration. The smallest combination of properties to form the composite fingerprint is determined by the minimisation of the Wilks' lambda score. The Wilks' lambda is a test statistic used in multivariate analysis of variance to test whether there is a difference between the means of different groups based on a combination of variables (Crichton, 2000; Collins & Walling, 2002).

The third stage uses the results of the analysis of properties of the sediment sink to enter into a multivariate mixing model to estimate the relative contributions of the suspended sediment source areas. The SVCF has been employed in the UK (Walling *et al.*, 2006), Europe (Valentin *et al.*, 2005), Africa (Collins *et al.*, 2001), Australia (Krause *et al.*, 2003) and the US (Miller *et al.*, 2005), but to date has not been used for erosion studies in New Zealand. This paper reports the results of a pilot study undertaken in March 2006 to investigate if different land-use types can be differentiated using geochemical properties by the SVCF technique. The null hypothesis (H_0) is posed that that there will be no significant difference between three land-use types based on their geochemical elements. The paper does not consider the third stage of the SVCF technique.

STUDY AREA AND METHODS

The Whangapoua Harbour (36°49′S, 175°36′E) lies on the east coast of the Coromandel Peninsula on the North Island of New Zealand (Fig. 1). Whangapoua Harbour is 13.7 km^2 and has a contributing catchment of approx. 110 km^2. The catchment is comprised mainly of andesitic rock basement with Holocene alluvium on the lower flood plains. The topography comprises a steep hinterland, where over half the catchment has slopes over 25º, rolling hills and then flood plains and swamps adjacent to the estuary. The Whangapoua Harbour has an annual rainfall of over 1800 mm and the area is known for its frequent, high intensity, localised storms that are often tropical in their origin (Marden *et al.*, 2006). The three main land-use types in the catchment are Rata-Podocarp/Tawa native regrowth forest on the steep upper slopes; predominantly *Pinus radiata* exotic forest on the mid-slopes; and pastoral agriculture (dairy/beef cattle/sheep) on the hills and flood plain areas adjacent to the estuary.

The Waitekuri River subcatchment was used for the pilot study as it provided a representative example of the catchment topography and the associated land-use types. Within each land-use type, three sites were selected. At each site, surface soils (<2 cm), subsurface soils (>20 cm), and streambank material was sampled to represent the main erosion sources (surface, landsliding, streambank). The sampling sites were located close to drainage lines and streams to represent areas that are most likely to erode. For each sampling position, 10 subsamples were collected and bulked in the field so that the 270 subsamples are represented in this study by 27 samples in total. The soil samples were returned to the laboratory, oven dried and dry sieved to recover the <63 μm fraction for geochemical determination by XRF analysis.

RESULTS AND DISCUSSION

The results for 31 candidate elements from XRF analysis were put through the first step of the Kruskal-Wallis *H*-test in the STATISTICA 7.0 software. Seven (Cr, Mg, Ca, Fe, Zn, P and Mn)

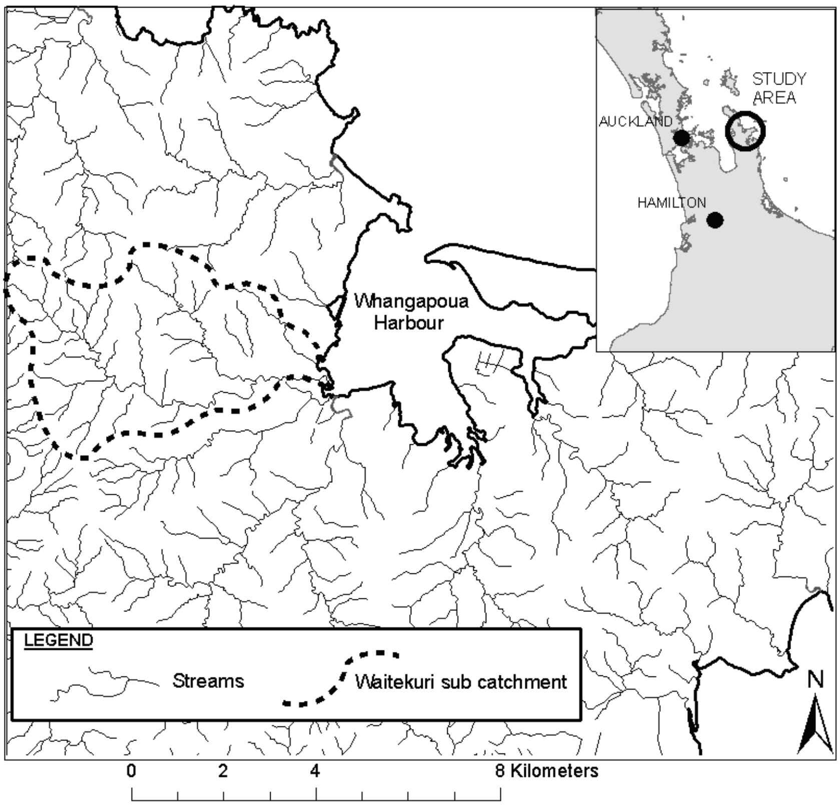

Fig. 1 Location of Whangapoua Harbour and the Waitekuri subcatchment, North Island, New Zealand.

were found to be significantly different between the native forest, exotic forest, and agricultural land-uses. Consequently the null hypothesis is rejected and land-uses can be distinguished by their geochemical elements. The second step is to optimise the composite fingerprint candidates by forward stepwise DFA and minimisation of the Wilks' lambda statistic. In STATISTICA the lowest Wilks' lambda score (0.12050) was achieved with all seven elements. STATISTICA uses a default *F-to-enter* critical value of 1 during stepwise DFA. If this critical value is changed to 3 then only three elements (Mn, Zn, Cr) are selected for the fingerprint. An *F-to-enter* critical value of 3 can be argued as a more realistic value based on a 5% rejection region where df_1 is 2 (k–1) and df_2 is 24 (n–k), as well as in the interest of parsimony and minimisation of errors associated with multiple comparisons. Yet this is at odds with the literature as this results in a larger Wilks' lambda score (0.22762).

An alternative approach is proposed where the results are resampled similar to Bootstrapping (one sample removal) or Jackknifing (portion of samples removed) methods, the difference being that one sample is removed from each land-use group and shall be referred to here as "Jackbooting". In each land-use there are three sites with samples from the surface, subsurface and streambank positions for a total of nine samples per land-use. A macro was written for STATISTICA to sequentially remove one sample from each land-use and run forward stepwise DFA and report the rankings of the remaining 24 samples. This treatment resulted in 729 resampling iterations and the results are summarised graphically in Fig.2.

Figure 2 shows that Mn is ranked the most important element 369 times and third 321 times. Zn is ranked first 351 times and third 52 times, and Cr second 707 times. There is then a clear break between the elements as Ca, P, Fe, and Mg are clustered in the third to fifth ranked positions. This outcome indicates that the optimisation of elements for the composite fingerprint by minimisation of the Wilks' lamba score can be verified by the resampling method of Jackbooting.

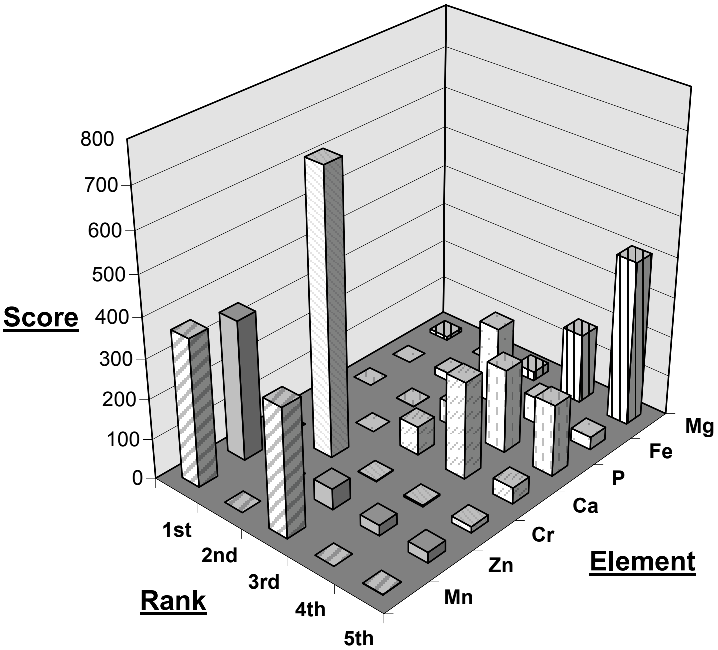

Fig. 2 Results of the Jackbooting resampling method showing the occurrence of rankings from first to fifth for the seven elements.

Seven elements were found to discriminate between the three land-use types ($p < 0.001$), of which three (Mn, Zn, and Cr) were found to be optimal for the composite fingerprint by the Jackbooting technique. The results of this pilot study will guide a further sampling of the Whangapoua Harbour catchment areas. With an increased number of samples collected, it is hoped that not only will the relative importance of land-use to sediment generation be determined, but also the sediment source (i.e. surface, subsurface, and streambank) can be identified.

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