High riverine transport of particulate organic carbon in New Zealand: potential significance of soil erosion to carbon accounting

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Abstract

Tectonically active small island nations contribute a disproportionate amount of sediment to the world's oceans. For such nations, particulate organic carbon (POC) export associated with riverine sediment load can also be important compared with C fluxes reported under the United Nations Framework Convention on Climate Change (UNFCCC) and accounted for under the Kyoto Protocol. We quantified the total riverine export of particulate organic carbon (POC) from New Zealand's landscape to the ocean. New Zealand comprises 0.1% of global land area, 0.2% of the world's CO_2 emissions, and 1% of global riverine sediment flux. POC export was estimated at 3±1 Mt C yr^{-1} (10±3 tC km^{-2} yr^{-1}). The total riverine POC yield represents a movement of C equivalent to approximately one third of New Zealand's total fossil fuel emissions. Since elevated rates of erosion are associated with non-forested landcover, reforestation may contribute to changes in riverine POC fluxes.

Key Words

Soil erosion, soil organic matter (SOM), particulate organic carbon (POC), New Zealand.

Introduction

Tectonically active regions throughout the Pacific Rim and Oceania have disproportionately large riverine C export rates, contributing 17–35% of the global sediment and POC flux to the oceans from only 3% of global land area (Lyons et al., 2002). Particularly large POC fluxes are known to occur in tectonically active catchments on soft or highly fractured rocks and are enhanced by the frequency of large storms such as tropical cyclones (Kao et al., 2003, Gomez et al., 2003). Although there is no mechanism to account for riverine C flux under Article 3.3 of the Kyoto Protocol during the first commitment period, POC fluxes could become important under stricter accounting regimes because erosion responds to land-use change and management (Blaschke et al., 2000), and can represent an important net C flux (Tate et al., 2000, Stallard, 1998).

To improve the understanding of POC flux, we examined the riverine carbon export within New Zealand, a small island nation (268 000 km^2) located at the intersection of the Indian-Australian and Pacific tectonic plates. Our aim was to quantify current riverine carbon export throughout the entire nation, and highlight regions that contribute the majority of soil-derived carbon to the ocean.

Methods

Stream Monitoring

Samples were collected for 1 year at monthly time intervals for DOC, POC, and total suspended sediment (TSS) concentrations from 44 NIWA water quality stations within New Zealand (Smith et al., 1996). These stations have a 12-year record of monthly water-quality measurements, and the network of stations provide spatial coverage of the entire country. In addition to the routine monitoring, high-flow sampling was also performed within the Manawatu, Waipaoa, and Motueka catchments in order to capture the relationship between POC and TSS as discharge increases. Although our high-flow dataset was limited within the Manawatu and Motueka catchments, frequent high flows resulted in adequate coverage over a range of TSS values. Furthermore, the Waipaoa dataset was supplemented by TSS-POC concentrations over the last 6 years as part of another programme.

For each of these stations, 20-year discharge and daily TSS records (Hicks et al., 2000) were used to estimate POC annual fluxes. POC fluxes were estimated by developing relationships between %C, TSS, turbidity, and total organic nitrogen. These relationships were then applied to the 20-year TSS records to estimate annual POC flux. At 14 of the stations, daily TSS records were not available. Annual POC fluxes at these stations were estimated by developing station-based surrogate relationships between POC and total organic nitrogen and turbidity. POC fluxes from these sites were low from each of the 14 stations, but inclusion into the spatial model allowed for a better coverage across the nation.

POC spatial model

The POC spatial model was built using POC fluxes from the 44 stations and 3 other stations within the East Cape region (Waiapu, Uawa and Mangatu) (Gomez et al., 2003). Models with several functional forms (Table 1) were applied to the dataset to obtain a statistical relationship suitable for scaling the variability observed across 47 stations to produce a national estimate. For the best fit, a power-law model (Model 2.1 in Table 1) was applied that used mean annual rainfall (MAR) as the primary variable, and an adjustment included for regions containing highly erodible rock types. Inclusion of this geomorphological variable was required to capture the high POC fluxes within the East Cape region of New Zealand, where large gully systems provide sediment and organic carbon to the river network.

Table 1. Empirical models used to extrapolate $\log_{10}$(POC) from 47 river stations to the national scale. Y_{POC} represents the POC yield (t C ha^{-1} y^{-1}), MAR is mean annual rainfall, slope is obtained from a 25 m digital elevation model (DEM), α_ι and β are regression parameters, and ET_{731} and ET_{732} represent the proportion of area in landsliding and earthflow/gully susceptible terrains, respectively. Models 3.1 and 3.2 differ in using %C in TSS and TON/Turbidity, respectively, as surrogate variables for estimating the yield at the station.

Model	Yield	Approach
2.1	POC	$\log_{10} Y_{POC} = \beta + \alpha_1 \log_{10}(MAR) + \alpha_2 \log_{10}(slope) + \alpha_3 (ET_{731} + ET_{732})$
3.1	POC	$Y_{POC} = \beta + \alpha_1 (MAR) + \alpha_2 (ET_{731} + ET_{732}) + \alpha_3 (ET_{731} + ET_{732}) \times (MAR)$
3.2	POC	$Y_{POC} = \beta + \alpha_1 (MAR) + \alpha_2 (ET_{731} + ET_{732}) + \alpha_3 (ET_{731} + ET_{732}) \times (MAR)$
4.1	POC	$Y_{POC} = (\alpha_1 + \alpha_2 (ET_{731} + ET_{732})) \times MAR^{1.7}$
5.1	POC	$Y_{POC} = (\alpha_1 + \alpha_2 (ET_{731} + ET_{732})) \times MAR^{\alpha_3}$
6.1	POC	$Y_{POC} = (\alpha_1 + \alpha_2 ET_{731} + \alpha_3 ET_{732}) \times MAR^{1.7}$

Results

Model 2.1 (Table 1) produced the median estimate of models with good statistical fitting (see Table 2). We therefore quote values produced by model 2.1 as median estimates. We estimate average annual national POC yield as 10.4 tC km^{-2} yr^{-1} on the North Island and 7.7 tC km^{-2} yr^{-1} on the South Island, based on model 2.1 described in Table 2. The estimates for individual locations range over 4 orders of magnitude, from less than 0.1 tC km^{-2} yr^{-1} in portions of the South Island's Canterbury Plains to over 1200 tC km^{-2} yr^{1} in gully dominated systems in the North Island's East Cape Region.

Table 2. Parameter values for POC regression model 2.1 used to produce the median spatial extrapolation of data from 47 river stations to national-scale. Symbols are as in Table 1.

$$\log_{10} Y_{POC} = \beta + \alpha_1 \log_{10}(MAR) + \alpha_2 \log_{10}(slope) + \alpha_3 (ET_{731} + ET_{732})$$

Explanatory variable	**Coefficient**	**t value**	**Pr (>|t|)**
β	10.0	7.2	8×10^{-9}
α_1	2.05	7.3	7×10^{-9}
α_2	1.20	2.4	0.02
α_3	1.05	4.9	2×10^{-5}

Multiple R^2: 0.85, Adjusted R^2: 0.84

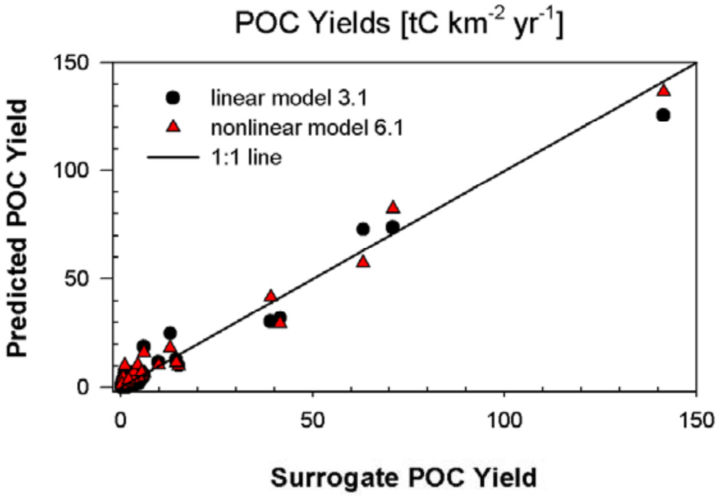

Figure 1. Comparison between POC yields calculated from measured data (based on surrogates) and predicted from model 3.1 and model 6.1 (as shown in Table 1).

Taking the sum of model 2.1 across the entire area of New Zealand, we estimate national POC export via rivers and streams to the ocean as 2.7 Mt C yr^{-1}. This figure represents only the export via rivers to the ocean and does not include terrestrial sedimentation (Stallard, 1998). Figure 1 shows the variability in two of the different models used to produce national estimates. Based on the variability in the results achieved by different methods of scaling riverine data to produce a national sum for each model shown in Table 1, an uncertainty of approximately 1 Mt C yr^{-1} can be estimated.

New Zealand's largest POC yields correspond with high sediment yields, and occur in specific geographic regions where either soft or fractured geology, and/or high uplift rates combine with high intensity precipitation. This observation has been reported previously (Lyons et al., 2002, Gomez et al., 2003), but these new results enhance the detail and certainty of understanding at the national scale. Elevated erosion rates occur under non-forested land uses in steep hill country on soft or fractured rock types (Page et al., 2004, Blaschke et al., 2000), suggesting that these areas should be evaluated for potential impacts of erosion on soil C accounting and the potential for soil C management through reducing erosion.

Conclusion

Budgets for POC transported to the ocean by New Zealand's rivers strongly suggest that riverine C fluxes may be important net C fluxes in tectonically active regions of the Pacific Rim and Oceania. New Zealand's average annual POC flux to the ocean is 2.7±1 Mt C yr^{-1}. Although this value can not be translated into a net effect on atmospheric CO_2 due the unknown fraction of POC that is permanently buried on the seafloor, this movement of C is equivalent to approximately one third of New Zealand's fossil fuel CO_2 emissions. Moreover, the total movement of C related to erosion and riverine transport is larger, as this estimate does not include terrestrial sedimentation (Stallard, 1998) or dissolved organic or inorganic carbon transport. The magnitude of these fluxes, and the potential response of erosion to land-use change and management (Blaschke et al., 2000), suggest that accounting for riverine C fluxes may improve the accuracy and reliability of C inventories that include soil C. Further research will be required to improve the availability of POC data from extreme events, to link changes in POC fluxes to land use and land-use change, and to determine whether riverine C is sequestered upon burial or oxidized.

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