Towards a national assessment of erosion-related soil carbon losses in New Zealand

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Abstract

New Zealand currently intends to ratify the Kyoto Protocol. Anticipating the future need for New Zealand to report on sources and sinks of carbon (C), which may include erosion-related losses, a preliminary estimate of soil C delivered to oceans was made at the national scale. Using estimates of C concentrations delivered to rivers by different erosion processes and estimates of sediment yields for New Zealand rivers, the potential transfer of C to the ocean by erosion was estimated to be in the range of 3-11 Mt C y^{-1}. A national-scale programme has subsequently been established to reduce this large uncertainty in the effect of erosion on the national C budget. Nationally, we need to know how much eroded soil C is sequestered annually in land and marine environments and lost annually to the atmosphere as CO_2, as well as what proportion of these fluxes is anthropogenic. Physically based models for simulating the erosion, transport, deposition, and decomposition of soil C in the landscape, as influenced by land cover, are currently being calibrated in catchment systems. Catchments selected for calibration have well-constrained sediment budgets. Measurements of C flows in riverine environments, and C partitioned between storage in sediments and loss as CO_2 are being conducted. Preliminary results from this programme suggest that C transfer to the ocean environment, especially those related to anthropogenic erosion, will be at the lower end of the 3-11 Mt C y^{-1} range, but that there may be significant C stored in sediments and soils, or lost as CO_2 in the terrestrial environments. The ability of soils and vegetation to regenerate C on eroded sites strongly supports the application of soil conservation practices that have always been traditionally applied to sustain the life supporting capacity of our terrestrial ecosystems. Globally, soil conservation practices now have an added value in enhancing the ability of our land systems to mitigate rising concentrations of atmospheric CO_2...

Key words: New Zealand, Carbon, Erosion, Mass balance, Sediment budget, Soil Conservation

Deforestation and erosion related C transfers

Compared with most countries New Zealand (comprising 50% of lowland steeplands) has had a very brief agricultural history, which includes extensive deforestation and establishment of pastoral agriculture between 1860-1920. This initiated a period of dramatic landscape transformation throughout most of New Zealand (Page and Trustrum, 1999). Many landscapes are naturally prone to erosion but this rapid land-use change led to marked increases in erosion and sedimentation rates. In the erodible North Island soft-rock hill country a century of increased anthropogenic erosion increased sedimentation rates by over an order of magnitude (Page and Trustrum, 1997). In some areas afforestation and reafforestation have reversed this trend but recovery of the landscape is long-term, and will require many centuries of soil reformation (Trustrum and DeRose, 1988). In the meantime the degraded landscape continues to redistribute the products of this erosion, including nutrients and C (Page et al., 2000). Trustrum (1999) used a sediment budget of the 2200 km^2 Waipaoa River basin to demonstrate that the high rates of anthropogenic erosion were also likely to lead to significant erosion-related C transfers and possible losses. The study also showed that because the largest proportion of soil C is usually stored in the upper soil horizons there is an inverse relationship between the quantity of sediment generated by different erosion processes and the amount of C eroded from hillslopes.

A national perspective and research approach

New Zealand is a signatory to the Kyoto Protocol. In anticipating the need to include potential carbon transfers and losses from erosion in full C accounting beyond the initial Kyoto commitment period, Tate et al. (2000) used a sediment budgeting approach to estimate soil C delivered to oceans at the national scale. The potential loss of soil C to the oceans was estimated to be somewhere in the range of 3-11 Mt C y^{-1}. No attempt was made to isolate the human-induced proportion of this figure, but this range is on the order of New Zealand's fossil fuel emissions (8.3 Tg C y^{-1} MfE 2001). The estimates of C concentrations delivered to rivers by different erosion processes, were based on sediment budgets from a limited number of erosion terrains. Scaling up to the national level was constrained by estimates of river sediment yields.

Current efforts to reduce uncertainties include the establishment of a national-scale programme in 2001 that is using a combination of empirical and processed-based approaches to quantify the amount of anthropogenic C transferred to the oceans and lakes, the amount lost to the atmosphere as CO_2 by biogeochemical processes during transport in streams and deposition, and the amount of C sequestered in fluvial sediments and revegetated eroded land (Figure 1). This two-year project should allow New Zealand to include potential C losses from erosion in reports on C storage nationally, to the required level of precision by 2008 and contribute to full C accounting beyond the initial commitment period. Formal negotiations for the second commitment period of the Kyoto Protocol, which are likely to include soil C changes from land-use practices, will begin as early as 2005.
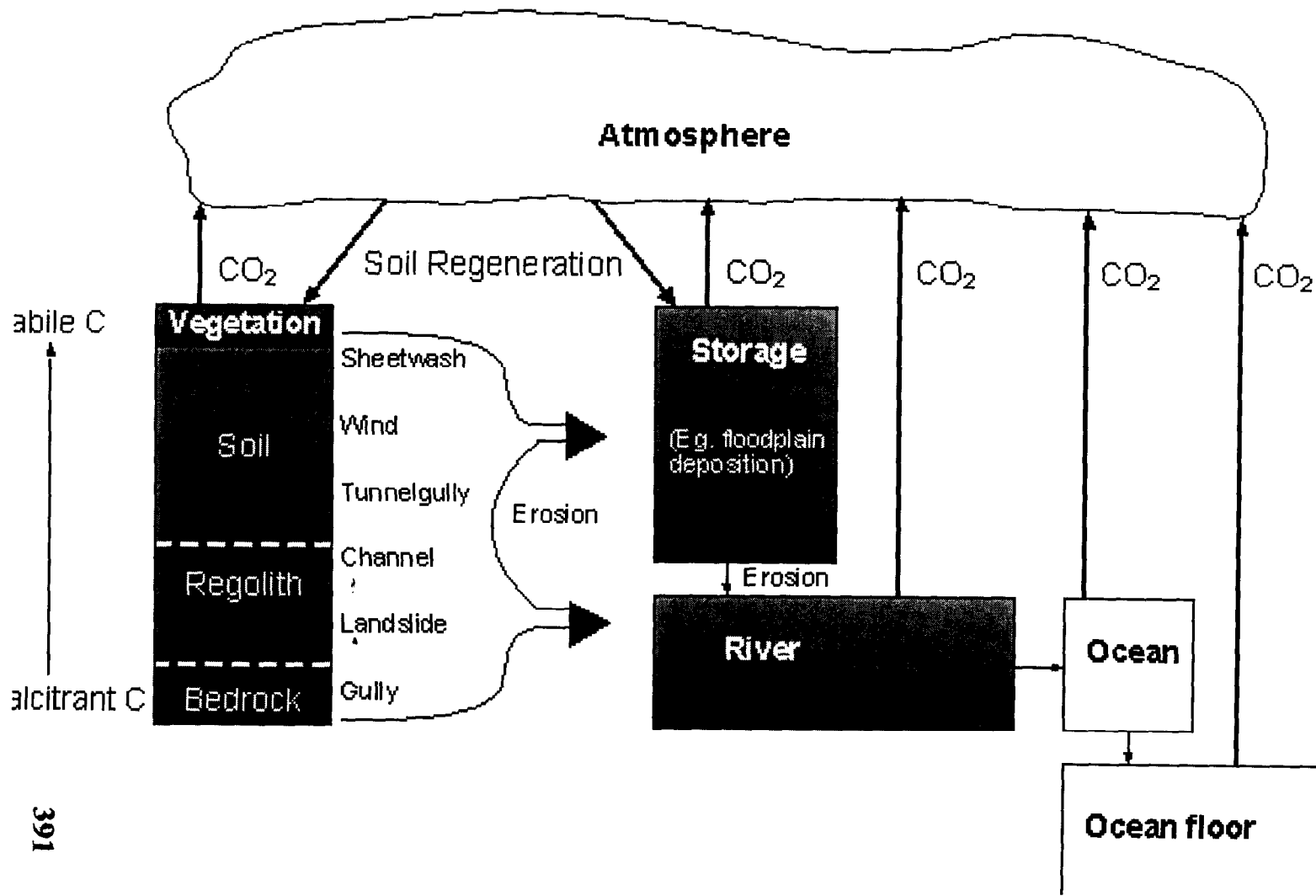
Figure 1: Mass balance approach being used to assess how much eroded C is sequestered annually in land and marine environments and lost annually to the atmosphere as CO_2. This study is focussed on reporting on potential sources and sinks of erosion-related C in the terrestrial environment. The size of arrows indicating CO_2 fluxes are not related to their magnitude.

Carbon sources and sinks and C feedbacks in terrestrial ecosystems
The erosion-related C transfers represented in Figure 1 show a number of potential sources and sinks of erosion-related C, and feedback mechanisms for C regeneration. The figure also provides the conceptual framework for applying a mass balance approach (Jacinthe and Lal, 2001) to measure erosion-related C transfers, including the differential removal of labile C versus recalcitrant C by different erosion processes, and testing hypotheses about the extent to which erosion may lead to overall net C losses from the terrestrial system. A central hypothesis being tested is whether erosion could possibly establish a "dynamic C equilibrium" where erosion results in an overall C sink, should the rate of C recovery on eroded sites and in depositional sediments equal or exceed that eroded (see Basiden et al., these proceedings).

Use of catchment studies to calibrate physically based models for simulating erosion, transport, deposition and remineralisation of organic C in the landscape
Several studies of erosion-related C transfers and budgets in catchments that have well-constrained sediment budgets (Trustrum et al 1999) have been conducted to provide a basis to scale physically based models up to the national scale. Using the high resolution record of storm-induced erosion preserved in lake sediments in the 32-km^2 Lake Tutira catchment, North Island, we have constructed a C budget for the period of European pastoral settlement (Page et al., in prep.). Soil C losses from landslide and sheetwash erosion were derived from a catchment that represents the upper limit for landslide related soil C losses. Using measurements of C recovery on landslide scars of different age, and proportionate eroded areas from comparable erodible hill country (Trustrum et al., 1990), we also accounted for the amount of soil C that has been sequestered since landsliding occurred. Results indicate that although landsliding generates about 75% of the sediment entering the lake (and sheet erosion most of the remaining 25%) approximately similar amounts of C are delivered by both erosion processes. Importantly, only about one-quarter of C eroded by landslide and sheet erosion results in a net loss to the landscape, after taking into consideration C sequestered on eroded sites and deposited in terrestrial sediments (Page et al., in prep). This finding suggests that although C sequestration on previously eroded landslide scars regenerates about two-thirds of the eroded C, this catchment system does not reach a "dynamic equilibrium". However, more rigorous measurements of C sequestration rates, including C remineralisation (see Basiden et al., these proceedings), on a greater range of erosion processes and depositional sites, are still required to determine fully the mass balance of C transfers.

In the highly erodible Waipaoa River basin, where sediment yields are dominated by gully erosion supplemented by landsliding during extreme events, Gomez et al. (in review) have shown that the total Waipaoa POC yield is high both by world standards and by comparison with other turbid steepland rivers, and the yield of particulate organic C (POC) from the headwaters appears to be primarily from recalcitrant C. Gully erosion and deep-seated landslides proportionately erode greater quantities of weathered bedrock than the upper soil mantle, hence eroded sediment contains a greater proportion of recalcitrant C than labile C. Nevertheless, as shallow landsliding and sheet erosion processes still account for approximately 30% of the Waipaoa sediment budget (Page et al., 2000), labile C transfers in this highly erodible catchment and others like them, will be nationally significant.

Methodologies for national assessment of carbon losses from erosion
The NZ Land Resource Inventory and the NZ National Soils Data Base have been used to characterise erosion-C terrains throughout New Zealand, within which similar erosion and sedimentation processes operate. Integrated process models of sheet-wash, rill, channel, gully,

wind, and landslide erosion are being developed for each erosion-C terrain given a national NZ Digital Elevation Model (25x25 m pixel) and precipitation and hydrological data (Sidorchuk et al., these proceedings). Sediment delivery and storage is also modelled within river systems and calibrated using 4-10 catchments distributed nationally and constrained against national sediment yields of New Zealand's major rivers (Hicks 1996). Calculation of soil C loss uses the organic C content in topsoils and rocks within each of the erosion-C terrains obtained from the national soil C distribution (Scott et al., 2001). Overall mass balances calculated from these physically-based models will be validated by using data from the empirical measurement of total C export from rivers draining ~50% of New Zealand. Long term surrogates for C export (organic N export, 340 nm absorbance) collected by the NIWA water quality network (Smith et al., 1996, Hicks et al., 2001) are being calibrated against dissolved and particulate C collected for one year. Closest-to-ocean stations will assist in estimating C export to the ocean and multiple stations in rivers will help constrain storage of C in terrestrial sediments. Selected catchments such as the Waipaoa River basin will be used to determine the remineralisation of C and release of CO_2 to the atmosphere as carbon is transported in rivers and temporally stored in depositional sites.

Critical issues

Reducing the uncertainties associated with the preliminary national estimate of erosion-related C losses (Tate et al., 2000) will require:

- Improved inventories of the distribution of soil C component of erodible landscapes at catchments and national scales, to establish baselines for estimating net C losses from erosion
- Erosion models that will describe the proportion of sediment yields sourced from topsoils and rocks and the anthropogenic component of this erosion
- Well-calibrated physically based models that define the relationship between erosion processes and the transport and fate of sediment C
- Successful partitioning of eroded C between atmosphere, and temporary storage on land and ocean.

Conclusions

Preliminary mass balance assessments of C transfers in erodible catchment systems with well constrained sediment budgets suggest that erosion process lead to net C losses. However, C recovery on eroded sites and storage in depositional sites do significantly off-set the gross C losses that would otherwise occur. These results also suggest that C losses to the ocean, especially those related to anthropogenic disturbances, will be at the lower end of the 3-11 Mt C yr^{-1} range. The ability of soils and vegetation to regenerate C on eroded sites strongly supports the application of soil conservation practices that have always been traditionally applied to sustain the life supporting capacity of our terrestrial ecosystems. Globally, they now have an added value in enhancing the ability of our land systems to mitigate rising concentrations of atmospheric CO_2

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